DOE/MT/95008-4
Distribution Category UC-122

Hazardous Substance Report

Developing a Cost Effective Environmental Solution for Produced Water and Creating a "New" Water Resource

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May 2000

Work Performed Under Contract No DE-FC22-95MT95008

Prepared for
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ABSTRACT

The project goal is to convert a currently unusable by-product of oil production, produced water, into a valuable drinking water resource. The project was located at the Placerita Oil Field in Santa Clarita, California, approximately 25 miles north of Los Angeles. The project included a literature review of treatment technologies; preliminary bench-scale studies to refine a planning level cost estimate; and a 10-100 gpm pilot study to develop the conceptual design and cost estimate for a 44,000 bpd treatment facility. A reverse osmosis system was constructed, pilot tested, and the data used to develop a conceptual design and operational of four operational scenarios, two industrial waters levels and two irrigation/potable water. Generally, the pilot study demonstrated that by altering operating conditions, the treated water can meet industrial, irrigation, and drinking water quality standards. Cost estimates, with an accuracy of approximately -15 to +30 percent, were made for each option. For the high silica (<200 mg/L as SiO_2) industrial water scenario, the total project capital cost was \$3.1 million. The operation and maintenance (O&M) cost was estimated to be 4.5 - 7.4¢/bbl of water treated. For the low silica (<80 mg/L as SiO_2) industrial water scenario the total project capital cost was estimated at \$3.2 million. The O&M cost is estimated to be 5.7 - 10.1¢/bbl of water treated. The estimated total project capital cost was \$10.6 million for the blending water option. Total annual O&M cost is estimated to be \$4.5 million/yr which is equivalent to 16.6 - 23.6¢/bbl of water treated. The estimated total project capital cost for the flange-to-flange option was \$12.3 million. The O&M cost is estimated to be 16.5 - 23.4 ¢/bbl of produced water treated.

From a water utility perspective, when considering water resources alternatives, the total unit cost of the water resources is normally compared by the water utilities. For this study, total unit treatment cost includes total annual costs divided by the total amount of water reclaimed (e.g., \$/acre-ft). Total annual cost consists of annual O&M cost plus amortized capital costs. Capital costs were amortized over 20 years at an annual interest rate of 7 percent (typical for municipal projects), yielding a capital recovery factor of 0.0936 because many water utility projects are financed through bonds. For the upper silica industrial water goal, the unit treatment costs from \$490-\$720/acre-ft of water reclaimed for the best and base case assumptions,respectively. For the lower silica industrial reuse options ranged from \$600-\$940/acre-ft of water reclaimed for the best and base case assumptions, respectively. For the blending drinking water scenario, the unit treatment costs are estimated to range from \$2,400-\$3,200/acre-ft for the best and base case, respectively. For the flange- to-flange drinking water options the unit treatment costs were estimated to be \$2,500-\$3,300/acre-ft of water reclaimed, respectively. For perspective, a cost comparison of reclaimed water sources indicates that the industrial reuse costs in this study fall within the \$200 to \$2,000 per acre-ft. range for wastewater effluent disposal, while the blending and flange-to-flange options are greater than the \$300 to \$1,1000 per acre-ft. range for drinking water supply.

The conceptual design needs to be tested for at least 12 months with two objectives, 1) developing water quality data for the regulatory agencies; and 2) refining the conceptual design and explore ways to lower the estimated operating cost. To lower costs future studies should focus on three areas: 1) optimization of the chemicals used in warm softening; 2) reducing the cost of sludge disposal; and 3) membrane cleaning and flux recovery. These areas are listed in the relative order of their impact on reducing the annual costs.

EXECUTIVE SUMMARY

This report provides background information about the project goals, reviews treatment technologies applicable for produced water, discusses the advantages and disadvantages of various treatment options including planning level cost estimates, recommends a pilot treatment train, and presents results from bench-scale studies conducted for this project.

The goal of this project is to convert a currently unusable by-product of oil production, produced water, into a valuable water resource. The sponsors of the research include US Department of Energy; ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company (ARCO); Castaic Lake Water Agency; Electric Power Research Institute, Chemicals and Petroleum Office; Southern California Edison; and Kennedy/Jenks Consultants.

The diverse sources of funding for the project reflect the wide range of potential beneficiaries that have a stake in the success of the project, including:

1) water utilities that need additional water resources and are located near an oil production field,
2) oil producers that dispose of the produced water through costly underground injection at high pressures,
3) water users with projects such as housing developments and industrial manufacturing complexes that require additional potable water resources before they can be built;
4) oil refineries that may be able to use these technologies to recycle water at their facilities; and
5) industries that benefit from a healthy and growing regional economy.

Produced water requires treatment for a number of water quality constituents that vary depending on the intended water use. For this project, the major technical potable water quality concerns are the concentration of salinity, ammonia, boron, and organics. In addition, the concentration of hardness and silica presents well-known problems as a potential scaling problems for technologies that remove salinity.

The most promising treatment technologies considered for removing salinity from produced water were mechanical vapor compression (MVC) distillation and reverse osmosis (RO). For

the brackish water in this project, the RO process had an estimated capital and annual cost that was approximately half that of a MVC system. RO also enjoys wider acceptance and familiarity among municipal water suppliers. For these reasons, the pilot study was designed and constructed based on a reverse osmosis(RO) system.

In preparation for pilot scale tests, bench scale softening experiments were performed to optimize for boron and silica removal. Results from the bench scale tests indicate that warm precipitative softening with caustic soda at pH values between 9.5 and 10, with the addition of 400 to 800 mg/L of magnesium chloride, can simultaneously reduce both silica and boron levels. Under the high magnesium dose, two potential issues were identified, floc settleability and the greater production of sludge. The pilot study consisted of the following processes:

- Warm precipitative softening with caustic soda and magnesium chloride
- Cooling
- Fixed-Film Biological Organics Oxidation
- Pressure Filtration
- Ion-exchange softening
- Reverse Osmosis

The pilot study was conducted during the second and third quarters of 1997. The water quality goals were met for four potential use scenarios: 1) a high silica industrial water quality goal; 2) a low silica industrial water quality goal; 3) blended irrigation or drinking water; and 4) flange-to-flange drinking water. The data collected from operating the pilot plant were used to refine the cost estimates.

ESTIMATED CAPITAL AND O&M COST

Table ES-1 summarizes these water use scenarios, the required facilities, and the estimated capital and operations and maintenance (O&M) cost. The cost estimates are conceptual level estimates and assume a level site and have an accuracy of approximately -15 to +30 percent. The total project capital cost includes a 38 percent indirect capital cost that includes such expenses as engineering design and construction management, financial, legal, and administrative services, interest during construction, utility connection fees, environmental impact reports, and permits.

Table ES-1

Summary of Conceptual Design for 44,000 BPD Facility and Estimated Cost

Scenario	Key Water Quality Goals	Facilities	Total Project Capital Cost ($ million)	Base Case O&M (¢/bbl treated)	Best Case O&M (¢/bbl treated)
1	• <600 mg/L total hardness as $CaCO_3$ • <200 mg/L Si as SiO_2	• Warm precipitive softening at pH 7.7 • Sludge handling facilities	3.1	7.4	4.5
2	• <250 mg/L total hardness as $CaCO_3$ • <80 mg/L Si as SiO_2	• Warm precipitive softening at pH 8.6 • sludge handling facilities	3.2	10.1	5.7
3	• <500 mg/L of TDS • $\leq$ 1 mg/L of Ammonia • $\leq$1 mg/L of Boron • $\leq$2 mg/L of Total Organic Carbon	• Warm precipitive softening at pH 9.5 with magnesium • Pressure Filters • RO at pH 9.5	10.6	23.6	16.6
4	• $\leq$ 1 mg/L of Ammonia • $\leq$1 mg/L of Boron • $\leq$2 mg/L of Total Organic Carbon	• Warm precipitive softening at pH 9.5 • Pressure Filters • RO at pH 11 • Ammonia ion exchange removal	12.3	23.4	16.5

Four operational scenarios were identified and associated conceptual design and operational parameters were developed for each using the bench scale and pilot study results. The four scenarios were the following: 1) industrial water with a silica as SiO_2 goal of < 200 mg/L; 2) industrial water with a silica as SiO_2 goal of <80 mg/L; 3) blended irrigation/drinking water supply using 1 part treated water with 4 parts impaired water source with a treated water TDS goal of <150 mg/L, 5 mg/L of ammonia-N, and 5 mg/L of boron; and 4) flange-to-flange treated water with a TDS goal of < 150 mg/L, 1 mg/L of ammonia-N, 1 mg/L of boron, and a <2 mg/L of TOC.

A sensitivity analysis was performed to develop the best case using the following changes from the base case cost assumptions on the annual O&M costs and unit cost per barrel of produced water treated:

- Changing the labor rate from \$30/hour to \$25/hour
- Changing the electric rate from \$0.05/kw-hr to \$0.03/kw-hr
- Changing the dewatered sludge concentration from 20 percent to 50 percent
- Changing the NaOH cost from \$0.14/lb. to \$0.07/lb
- Combined impact of making all four changes simultaneously (best case)
-

Annual Costs - Water Utility Perspective

When considering water resources alternatives, the total unit cost of the water resources are normally compared by the water utilities. For this study, total unit treatment cost include total annual costs divided by the total amount of water reclaimed (e.g., \$/acre-ft). Total annual cost consist of annual O&M cost plus amortized capital costs. Capital costs were amortized over 20 years at an annual interest rate of 7 percent (typical for municipal projects), yielding a capital recovery factor of 0.0936 because many water utility projects are financed through bonds.

Base Case Scenarios

For the base case assumptions, the industrial reuse options ranged from \$ 720/acre-ft to \$940/acre-ft of water reclaimed for the upper and lower silica goal alternatives. In contrast, the unit treatment costs are estimated for the base case for the blending and the flange- to-flange options to be approximately \$3,200/acre-ft and \$3,300/acre-ft of water reclaimed, respectively.

Best Case Scenarios

The corresponding unit treatment costs for the best case assumptions ranged from \$490/acre-ft to \$600/acre-ft of water reclaimed for the upper and lower silica goal alternatives, and from approximately \$2,400/acre-ft and \$2,500 of water reclaimed for the blending and the flange-to-flange options, respectively.

A blending alternative with an impaired water supply was used to assess the cost of blending the treated water with TDS of approximately 145 mg/L and boron of 5 mg/L (as B) with a currently unusable water with high TDS (e.g., 1,200 mg/L) or a trace contaminant (e.g., 20 µg/L perchlorate [California DHS action limit for perchlorate is 18 µg/L]) with a cost of $100/ acre-ft. Assuming a blend of four parts of this water with the treated produced water, the resulting water resource would have a boron concentration of 1 mg/L and a TDS of 1,000 mg/L or a perchlorate concentration of 16 µg/L. The cost of the blended water would be from about $560/acre-ft. (best case) to $710/acre-ft (base case), which does not include additional infrastructure costs such as pipelines, pump station, or reservoir facilities to implement the blending option.

Sheikh et al. (1998) provided a cost comparison of reclaimed water sources indicating that the industrial reuse costs in this study fall within the $200 to $2,000 per acre-ft. range for wastewater effluent disposal, while the blending and flange-to-flange options are significantly greater than the $300 to $1,1000 per acre-ft. range for drinking water supply. The $560 - $710 per acre-ft. value of blending treated produced water with a marginal quality water, however, is within this water supply cost range. This comparison suggests that a subsidy would be required to use the irrigation blending or flange-to-flange water if an impaired water source is not available.

ADDITIONAL STUDIES

The conceptual design needs to be tested for at least 12 months. There would be two objectives of the 12 month testing program. The first objective would be to develop water quality data for the regulatory agencies. The second objective would be to refine the conceptual design and explore ways to lower the estimated operating cost.

Water Quality Data

In addition to providing additional operational data to refine the cost estimates, water quality data is needs to be collected to determine the potential impact on public health. The water quality data set generated by this study is insufficient to assist the regulatory agencies in determining the feasibility of the conceptual design to be used in the irrigation and potable water scenarios.

This evaluation indicates that the cost of treating produced water is heavily influenced by the chemicals used in warm softening. Future studies should focus on three areas: 1) optimization of the chemicals used in warm softening; 2) reducing the cost of sludge disposal; and 3) membrane cleaning and flux recovery. These areas are listed in the relative order of their impact on reducing the annual costs.

Optimization of Chemicals in Warm Softening

The use of magnesium hydroxide in place of magnesium chloride should be pilot tested to see if the warm softening costs can be further reduced. In addition to providing a magnesium source for silica removal, the magnesium hydroxide would also reduce the amount of caustic required (e.g., 58 mg/L of $Mg(OH)_2$ would reduce the NaOH requirement by 80 mg/L).

A larger cost saving may be realized if the waste caustic at ARCO's Los Angeles refinery can be used as the NaOH source. If technical and regulatory issues concerning the waste caustic can be addressed, the warm softening process should be pilot tested with treated waste caustic.

The high caustic dose requirements in part appear to be due to excess carbon dioxide in the produced water. Stripping some of the carbon dioxide (with nitrogen or methane gas or by vacuum deaeration) prior to warm precipitative softening should be investigated. This could reduce the caustic requirement by at least 200 mg/L, which would reduce O&M costs by about 1 ¢/bbl of produced water treated.

Reducing Sludge Disposal Cost

Preliminary dewatering tests of the softening sludge indicated that a 20 percent DS sludge could be produced with filter presses. Further testing with sludge dewatering should be performed to see if a dewatered sludge approaching 50 percent DS can be produced. This would help reduce the volume and costs of sludge disposal substantially. Specifically, this would reduce the disposal cost from $125/dry ton to $75/dry ton; the O&M cost reductions would range from 1.1 ¢/bbl of produced water treated for the upper silica industrial goal option to 2.4 ¢/bbl for the irrigation blending option.

The sludge could potentially be beneficially used as a constituent in soil amendments, cement mixtures, road paving, or ceramic bricks. The cost reduction could result from the sale of the sludge as a material rather than a waste for disposal. An evaluation of these should be conducted and then any promising alternatives tested on a pilot scale.

Membrane Cleaning and Flux Studies

Studies to reduce the SDI ahead of the RO unit process are needed. Reducing this parameter will require less cleaning and perhaps delay membrane replacement.

The impact of cleaning the membranes and flux recovery needs more study. This information is needed to determine whether the membrane is capable of removing both TOC and TDS under these relatively harsh conditions for an extended period.

ACKNOWLEDGEMENTS

The project team expresses its gratitude to the following organizations for providing additional funds to this DOE project. Without this additional financial support, the project would not have been possible.

- ARCO Western Energy
- Kennedy/Jenks Consultants
- Southern California Edison
- Electric Power Research Institute
- National Water Research Institute

Special thanks go to the following individuals and organizations for providing special resources to this project:

• Mr. Lory Larson	Southern California Edison
• Mr. Mazen Sadeq	Southern California Edison
• Dr. Harry Ridgway	Orange County Water District
• Dr. Yosif Karaka	US Geologic Survey
• Mr. C. Mike Rightmire	ARCO Exploration and Production Technology
• Dr. Michael Dubrovsky	Chevron Research and Technology Company

Our appreciation goes to Ms. Nancy C. Holt, the DOE technical project manager, the technical review panel, the technical advisory committee, and the California Department of Health Services and the California Regional Water Quality Control Board, Los Angeles Region. Our special appreciation goes to the field staff and contractors at AWE's Placerita Oil Field who made this project sail smoothly, even when there were rough waters.

The plan identified no each hazardous substance as defined under 40 CFR 261, subpart D anticipated to be purchased, utilized or generated in the performance of this Cooperative Agreement.

During the project two materials were purchased and utilized. The quantities are summarized in the table below.

Chemical	**CAS Number**	**Quantity bought**
Sodium hydroxide, 20 percent	1310-73-2	15,000 gallons
Sulfuric acid, 20 percent	7664-93-9	300 gallons

The caustic was used to adjust the pH of the inlet water of the DensaDeg warm softening treatment unit to as high as pH 9.8. This operating pH is less than the characteristic of corrosivity. If the aqueous pH is ≤ 2 or ≥ 12.5 the waste would exhibit the characteristic of corrosivity. The caustic was also used to adjust the pH of the inlet water to the reverse osmosis unit to pH as high as 11.0. This operating pH is less than the characteristic of corrosivity.

The sulfuric acid was used to adjust the reverse osmosis feed water from 9.5 to 7.8-8.5. The reverse osmosis concentrate and treated water were between pH 2 and 12.5. . This operating pH is less than the characteristic of corrosivity.

When raising the pH above pH 8, a DensaDeg sludge was generated. Testing summarized below indicated that this sludge was not a hazardous wastes by California or US EPA.

Summary of DensaDeg Sludge Waste Characteristics

Parameter	**California Limits**	**DensaDeg Sludge**
Flammability, °F	<140	>200
pH, 1:1 DI, units	≤ 2 or ≥ 12.5	10
Free Sulfide, H_2S, mg/Kg	~500*	<10
Free Cyanide, CN, mg/Kg	~10*	<1.0
Aquatic Toxicity, LC_{50} mg/L	< 500	>750

*when wastes exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment. Concentrations estimated based on confining conditions. There were no confining conditions for the sludge.

Summary of DensaDeg Sludge and Hazardous Waste Criteria

Substance	TTLC*, Wet Weight (mg/Kg)	mg/Kg	RCRA† Max Concentration (mg/L)	Extractable Concentration (mg/L)
Antimony and/or antimony compounds	500	<10	NA	NA
Arsenic and/or arsenic compounds	500	<0.25	5.0	<0.005
Barium and/or barium compounds (excluding barite)	10,000	63	100	0.75
Beryllium and/or beryllium compounds	75	<0.5	NA	NA
Cadmium and/or cadmium compounds	100	<0.5	1.0	<.01
Chromium and/or Chromium (III) compounds	2,500	<2.5	5.0	<0.05
Cobalt and/or cobalt compounds	8,000	<5.0	NA	NA
Copper and/or copper compounds	2,500	<2.5	NA	NA
Lead and/or lead compounds	1,000	<2.5	5.0	<0.05
Mercury and/or mercury compounds	20	<0.10	0.2	<0.002
Molybdenum and/or molybdenum compounds	3,500	<5.0	NA	NA
Nickel and/or nickel compounds	2,000	<2.5	NA	NA
Selenium and/or selenium compounds	100	<0.25	1.0	<0.005
Silver and/or silver compounds	500	<1.0	5.0	<.002
Thallium and/or thallium compounds	700	<10	NA	NA
Vanadium and/or vanadium compounds	2,400	<5.0	NA	NA
Zinc and/or zinc compounds	5,000	3.1	NA	NA

TTLC* = Total Threshold Limit Concentration, California EPA limits
RCRA† = Resource Conservation and Recovery Act

All the sodium hydroxide was consumed on site.

Approximately 25 gallons of sulfuric acid was left after the pilot study and was returned to the vendor, Argo Chemical.

All the DensaDeg sludge was air dried at the Placerita oil field and incorporated as road mix to resurface roads at the Placerita oil field in October 1997.

No hazardous waste was generated in the performance of this Cooperative Agreement as defined under California or EPA hazardous waste regulations.

Information Type	**Information**
Description of Substance/Chemical	None
EPA Hazardous Waste Number	None
EPA Hazard Code	None
Anticipated Quantity to be purchased, utilized or generated	None
Anticipated Hazardous Waste Transporter	None
Anticipated Hazardous Waste Disposal Facility	None
Participant and Location	Not Applicable
Anticipated Treatment Method	None

Chapter 1

Introduction

CHAPTER 1

INTRODUCTION

Oil production generates a significant by-product, commonly known as "produced water". As the oil is produced from an oil field, produced water can reach ≥ 90 percent of the fluids pumped from an oil well. In fact, heavy oil fields in California produce 10 to 15 barrels of water for every barrel of oil. In 1990 approximately 14.5 billion gallons per day of produced water were generated through hydrocarbon production in the US, including production within the three mile coastal water limits.

Methods of oil field produced water disposal include recycling and reuse for steam, deep well injection, discharge to a publicly owned treatment works (POTW), and surface discharge west of the 98th Meridian if it meets beneficial use water quality requirements.

PROJECT OBJECTIVE AND BENEFITS

The objective of this project was to demonstrate a treatment train that would treat excess produced water for export from the oil field and convert the water to a potable water resource for use by the public. If cost effective, a 1.8 mgd [~43,000 barrel per day (BPD)] full scale treatment facility would be constructed to treat produced water from the project site upon approval by the regulatory agencies. Possible applications for the treated effluent include irrigation, indirect potable use, engineered reuse, or direct potable use. The water quality goals and design of the treatment system depended on the intended application of the effluent. These goals are summarized later in this chapter.

The <u>social benefits</u> of treatment and removal of water from oil reservoirs include:

1. Add a new water resource to the shrinking number of water resources available in water short California.
2. Dramatically reduce the volume of oil field produced water injected into disposal wells.

3. Minimize the environmental impact of producing oil by dramatically reducing the total use of chemicals in the recovery and treating process.
4. Make better use of our natural and financial resources by lowering the cost of environmental compliance.
5. Reduce the demand for surface water resources by human and industrial users, which conflicts with the maintenance of endangered species and wild rivers.

The technical benefits of the removal of water from the oil reservoir will result in:

1. Improvement in the efficiency of thermal oil recovery by decreasing the amount of steam required to heat the water located with the oil in the reservoir.
2. Reduce all of the costs associated with the underground disposal of produced water including maintenance, acidizing, drilling new disposal wells, regulatory and administrative activities.
3. Reduce the potential for reservoir damage by disposal injection.
4. Reduce the recirculation of injected water into the oil producing horizons.
5. Lower the energy demand for oil field operations through reduced water production and handling.
6. Replace water being imported via the California State Water Project thereby lowering the overall energy demand.

TECHNICAL OBJECTIVES

The technical objectives of this project were to identify treatment processes that can meet potable or reuse "standards" at a competitive cost. The specific technical objectives for this project are presented below.

1. Identify current and anticipated water quality goals required for potable and reuse water.
2. Characterize the water quality of produced water and the concerns of the regulatory agencies that may impact the use of this water resource.
3. Identify candidate treatment alternatives, costs, operational barriers, and likelihood of success for meeting the identified water quality goals.

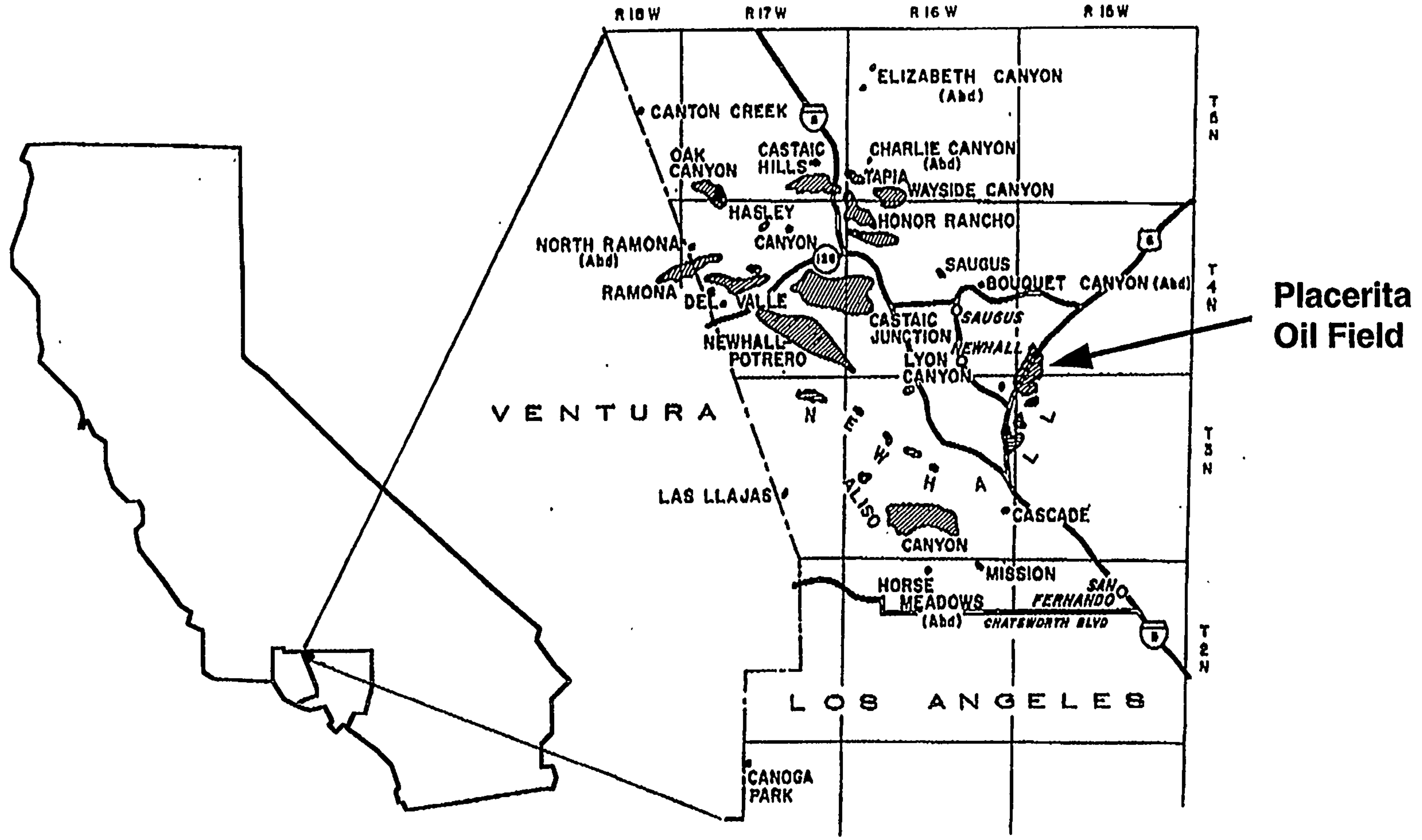
4. Characterize treatment alternatives using bench and pilot scale units to estimate costs, performance and feasibility to meet water quality goals using produced water from the Placerita Oil Field.
5. Establish design and operating criteria of produced water for potable and reuse applications.
6. Make recommendations regarding future research needs related to beneficial reuse of produced water.
7. Make this technology available to other potential sites.

INSTITUTIONAL OBJECTIVES

Besides the technical engineering and economic feasibility elements of this program, there were institutional considerations that had to be addressed. In California, the Department of Health Services (DHS) or Regional Water Quality Control Board must consent to a water's use or reuse. This project was structured to obtain agency approval to establish guidelines and design criteria that are applicable throughout California. Subsequent projects, if they follow the guidelines and design criteria will not need as much regulatory oversight.

PROJECT SITE

The project site was the Placerita Oil Field and it is located in Los Angeles County, California within the city limits of Santa Clarita. The field is adjacent to the Antelope Valley Freeway (Hwy 14) and is located on the northeast quarter of the northeast quarter of Section 31, Township 4 North, Range 15 West, San Bernardino Meridian, in the county of Los Angeles State of California. Figure 1-1 is a location map of the project site. The majority of the field is owned by ARCO Western Energy (AWE), a Unit of the Atlantic Richfield Company. There are three other small independent operators in the field, Caltico Oil Corporation, Hillside Oil Partners, and Placerita Oil Company, a subsidiary of AES, Inc. (AES). AES's primary activity is operating cogeneration facilities. One of these facilities is located adjacent to AWE's oil producing properties at Placerita. Figure 1-2 summarizes the current water balance of the ARCO Western Energy activities in the Placerita Field.



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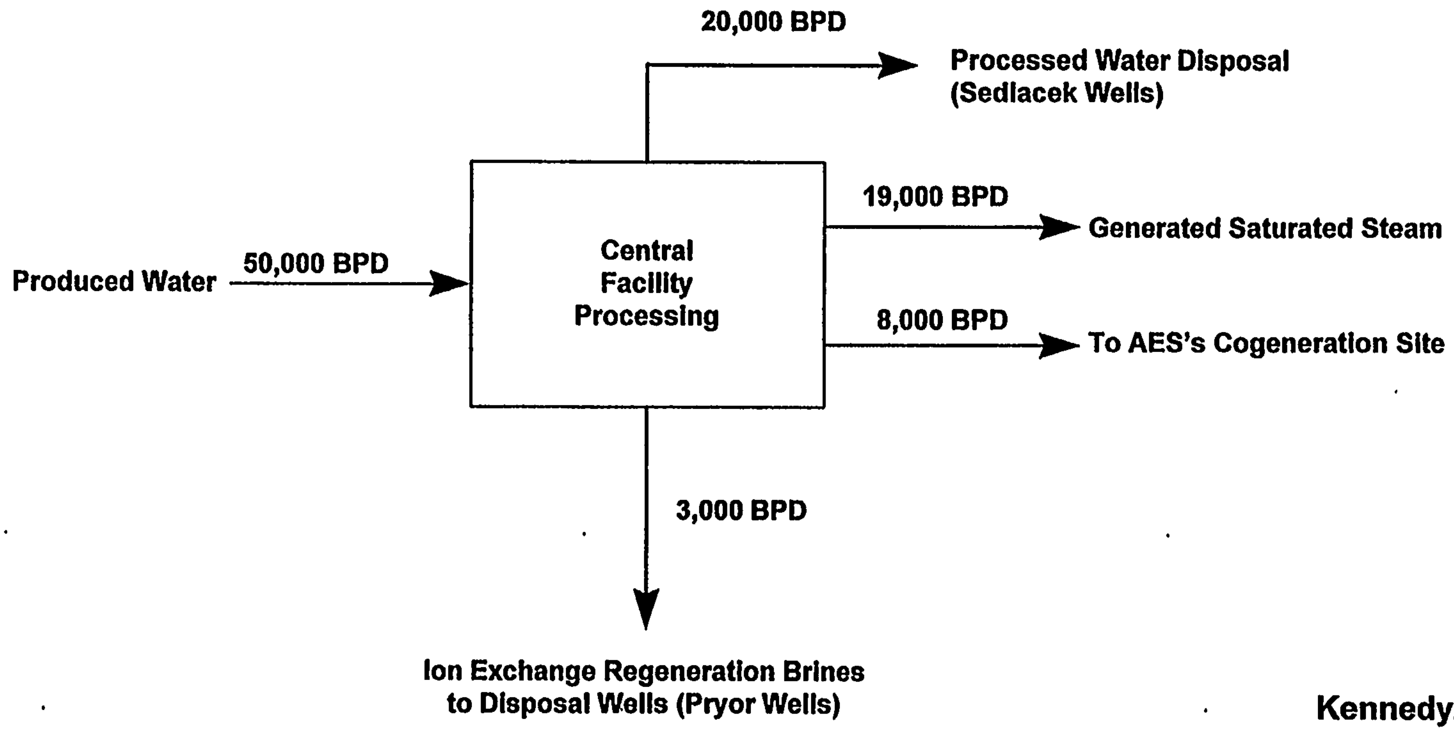
DOE Project # DE-FC22-95MT95008

Project Site Location

January 1998
K/J 964634.00

Figure 1-1



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DOE Project # DE-FC22-95MT95008

Current Placerita Oilfield
Water Balance

January 1998
K/J 964634.00

Figure 1-2

Project Tasks

This project was divided into two phases and this report is the deliverable for Phase II: Task 9. To provide a project perspective all the tasks for each phase are summarized below.

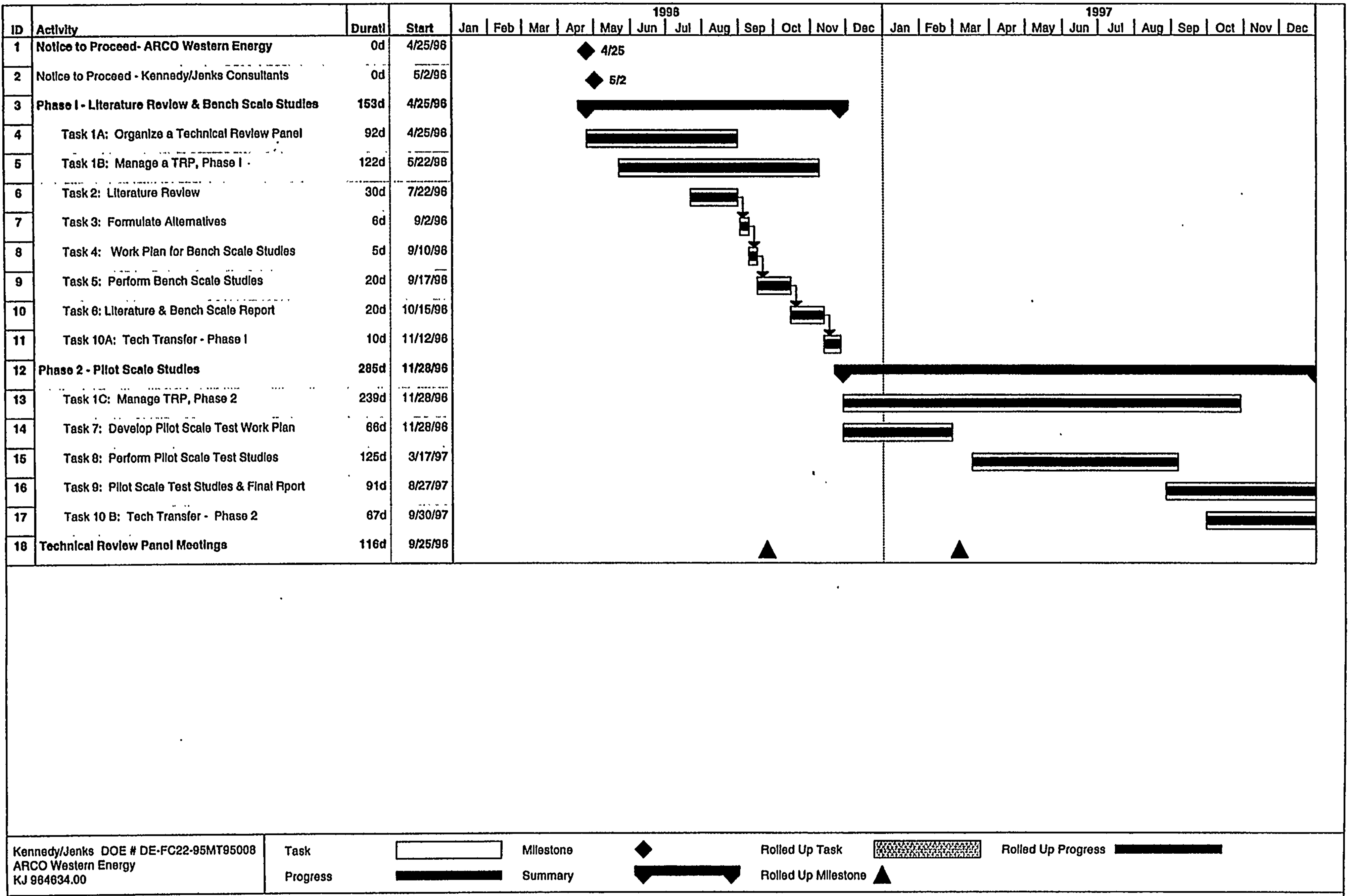
Phase I:	Literature Survey and Bench Scale Studies
Task 1.	Organize and Manage Technical Advisory Committee
Task 2.	Literature Review
Task 3.	Formulation of Treatment Options
Task 4.	Bench Scale Study Work Plan
Task 5.	Bench Scale Studies
Task 6.	Summary of Task 1-4
Task 10A.	Technology Transfer to the U.S. Professional Community, Phase I
Phase II:	Pilot Scale Demonstration
Task 7.	Work Plan
Task 8.	Experimental Demonstration.
Task 9.	Summary Report
Task 10 B.	Technology Transfer to the U.S. Professional Community, Phase II

Figure 1-3 is a project schedule of when the tasks were performed.

Project Entities

The project consisted of a team made up of the following participants:

- ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company (ARCO) who was the prime contractor with DOE.
- First tier subcontractor included Kennedy/Jenks Consultants, Inc. which is a privately owned, full service environmental engineering firm and currently serves as the Agency Engineer.
- Castaic Lake Water Agency was a second tier subcontractor providing technical support. Castaic Lake Water Agency is a public water agency responsible for the supplemental water supply to the households in the Santa Clarita Valley, located in Southern California.



ID	Activity	Durati	Start
1	**Notice to Proceed- ARCO Western Energy**	0d	4/25/96
2	Notice to Proceed - Kennedy/Jenks Consultants	0d	5/2/96
3	**Phase I - Literature Review & Bench Scale Studies**	153d	4/25/96
4	Task 1A: Organize a Technical Review Panel	92d	4/25/96
5	Task 1B: Manage a TRP, Phase I	122d	5/22/96
6	Task 2: Literature Review	30d	7/22/96
7	Task 3: Formulate Alternatives	6d	9/2/96
8	Task 4: Work Plan for Bench Scale Studies	5d	9/10/96
9	Task 5: Perform Bench Scale Studies	20d	9/17/96
10	Task 6: Literature & Bench Scale Report	20d	10/16/96
11	Task 10A: Tech Transfer - Phase I	10d	11/12/96
12	**Phase 2 - Pilot Scale Studies**	285d	11/28/96
13	Task 1C: Manage TRP, Phase 2	239d	11/28/96
14	Task 7: Develop Pilot Scale Test Work Plan	66d	11/28/96
15	Task 8: Perform Pilot Scale Test Studies	125d	3/17/97
16	Task 9: Pilot Scale Test Studies & Final Rport	91d	8/27/97
17	Task 10 B: Tech Transfer - Phase 2	67d	9/30/97
18	**Technical Review Panel Meetings**	116d	9/25/96

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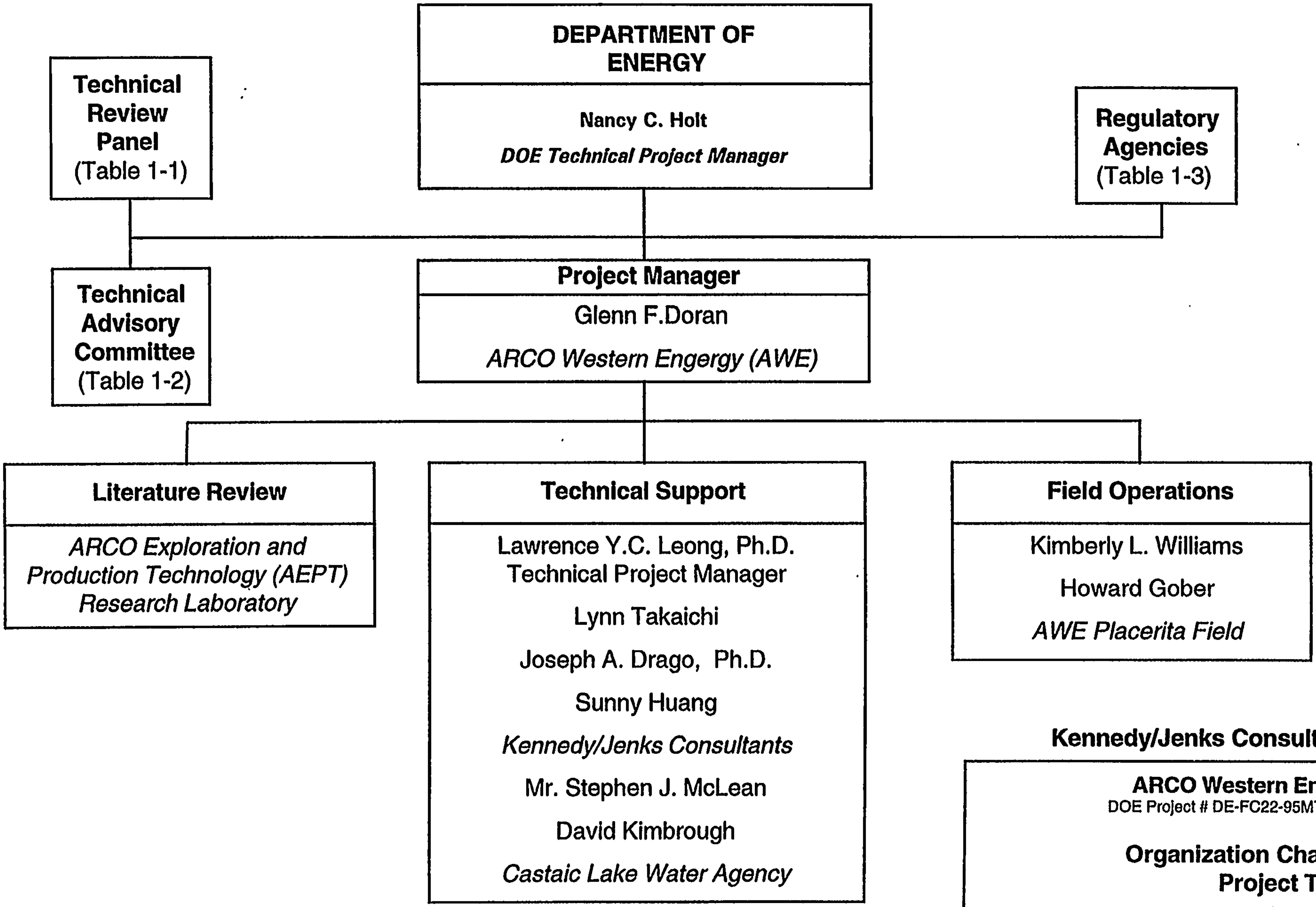
Figure 1-3 Project Schedule

Project Staff

The project team is presented in Figure 1-4. Mr. Glenn Doran of ARCO Western Energy was the Project Manager. Ms. Kimberly Williams, the facility engineer, and Mr. Howard Gober, the field supervisor, provided assistance at the Placerita Oil Field. The technical project team was led by Dr. Lawrence Y.C. Leong of Kennedy/Jenks Consultants. Key support staff include Mr. Lynn M. Takaichi, Dr. Joseph A Drago, Mr. Darrell A. Fruth and Mr. Sunny Huang of Kennedy/Jenks Consultants. From Castaic Lake Water Agency, project assistance was provided by Mr. Stephen McLean, Operations Engineer and Mr. David Kimbrough, Laboratory Supervisor.

Supporting this project was an independent technical review panel organized under the auspices of the Dr. Ronald Linsky, Executive Director of the National Water Research Institute. The responsibility of the panel was to provide a scientific critique of the work plans and products to assist the regulatory agencies in determining the scientific merits of the collected data. The members of the panel are identified in Table 1-1. In addition, there was a project advisory committee composed of interested parties. These members have contributed research funds, bring special expertise, or special experience to assist the conduct of this study and are identified in Table 1-2. The project team also invited staff from the regulatory agencies that are identified in Table 1-3 to participate in review meetings.



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Organization Chart of Project Team

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Figure 1-4

Table 1-1
Members of the Technical Review Panel

Name	Affiliation	Address
Ronald Linsky, Ph.D.	Executive Director	National Water Research Institute 10500 Ellis Avenue P.O. Box 20865 Fountain Valley, CA 92728-0865
Robert Carnahan, Ph.D.	Associate Dean for Research	College of Engineering University of South Florida 4202 E Fowler Ave, ENB 118 Tampa, FL 33620-5350
Harvey Collins, Ph.D.	California Department of Health Services, Retired	8685 River Road Sacramento, CA 95832
Mike Kavanaugh, Ph.D.	Vice President	Malcolm Pirnie, Inc. 180 Grand Ave., Ste 725 Oakland, CA 94612
Yosif Kharaka, Ph.D.	Research Hydrologeochemist	USGS, WRD 345 Middlefield Road, Mail Stop 427 Menlo Park, CA 94025
Stanley Ponce, Ph.D.	Director of Research	US Dept of Interior Bureau of Reclamation Sixth and Kipling, Bldg. 67, Rm 694 Denver Federal Center, D-6700 Denver, CO
Harry F. Ridgway, Ph.D.	Research Scientist	Biotechnology Research Department Orange County Water District 10500 Ellis Avenue P.O. Box 8300 Fountain Valley, CA
George Tchobanoglous, Ph.D.	Professor, UC, Davis Retired	662 Diego Place Davis, CA 95616
Walter J. Weber, Jr., Ph.D.	Professor	Dept. Civil and Environmental Engineering University of Michigan EWRE Bldg., Ste 181 1351 Beal Avenue Ann Arbor, MI 48109-2125

Table 1-2

Members of the Technical Advisory Committee

Name	Affiliation	Address
Lory Larson	Southern California Edison	Manager of Special Projects 6090 N. Irwindale Ave. Irwindale, CA 91702-3271
Michael Dubrovsky, Ph.D.	Chevron R & D Company	Staff Scientist P.O. Box 4054 Richmond, CA 94804-0054
Mike Rightmire	ARCO Exploration and Production Technology	Senior Engineer 2300 West Plano Parkway Plano, TX 75075
Dick Schmeal, Ph.D.	Electric Power Research Institute	Mgr, Chemicals & Petroleum Center 1800 St. James Place, Ste. 303 Houston, TX 77056

Table 1-3

Staff of the Regulatory Agencies

Name	Affiliation	Address
Robert Hultquist Chief, Drinking Water Technical Operations Section	California Dept of Health Services	Drinking Water Technical Program Branch 601 N. 7th Street, MS 92 PO Box 942732 Sacramento, CA 94234-7320
Magdy Baiady Associate Engineering Geologist	California EPA	Regional Water Quality Control Board Los Angeles Region 101 Centre Plaza Monterey Park, CA 91754

ORGANIZATION OF FINAL REPORT

The Final report is organized into three sections: Introduction, Results and Discussion, and Conclusions. The Introduction consists of two chapters. Chapter 1 describes the general background and goals of the project. Chapter 2 reviews potentially applicable treatment technologies for treating produced water to reusable quality, organized by water quality objective. The Results and Discussions is also presented in two chapters. Chapter 3 reviews the screening and selection of treatment processes, and outlines the selected pilot-scale treatment train. Chapter 4 presents the results of bench scale tests conducted for this project that demonstrated the use of precipitative softening to remove silica and boron from produced water. Chapter 5 describes the pilot plant unit processes, the analytical methods, and the operational plan. The results of the pilot plant study are presented in Chapter 6. The recommended full scale process train and the estimated cost are presented in Chapter 7. Conclusions are presented at the end of Chapter 8. The bench study work plan and pilot study results are presented in Appendixes A and B, respectively. Appendix C contains copies of the material that have been presented at DOE or national meetings to fulfill the technology transfer requirements of this project.

Chapter 2

Background

CHAPTER 2

BACKGROUND

WATER NEEDS IN CALIFORNIA

In the arid western United States, water shortages threaten both lifestyle and livelihood. In an average year California receives 1.49 trillion barrels (1 barrel = 42 gallons) of water. The largest single use (60 % of California's total average rainfall) is consumed by native vegetation and lost through evaporation. Of the remaining 40 percent, 12.8 percent flows as runoff to the rivers that is supplemented by another 11.6 percent that is dedicated to environmental protection through wild and scenic river designations and the Sacramento Delta water quality outflow requirements. Agriculture uses about 12.4 percent while city and industrial use accounts for 2.4 percent. The remaining 0.8 percent flows to Nevada.

For average rainfall conditions, the California state and federal systems can meet the current requirements for all sectors. However, the system is inadequate for prolong periods of drought. The most recent drought, 1987-1992, required wide spread mandatory rationing in agriculture and cities throughout California. In 1989 it was estimated that one third of the state's population was subject to mandatory water conservation or rationing and by 1991 it was three fourths of the population.

From a historical perspective the most recent drought was relatively short in duration. Tree ring analysis indicates that California had a prolong 60 year drought from 1760 to 1820, a 20 year dry spell from 1865 to 1885 in southern California, and a 7 year dry spell in 1928 through 1934.

Superimposed on the cycles of dry and wet spells of rainfall are the agricultural, population, and industrial growth patterns of California that increases the demand for water. The impact to agriculture in California is significant as it is one of the largest industries in California with annual sales of $18 billion. It was estimated that in 1990 194,000 acres were fallowed due to lack of water. The number of acres fallowed in 1991 was estimated to be between 500,000 and 600,000 by the California Farm Bureau Federation. The drought induced reduction in farm income for 1990 was estimated to be $455 million and the loss for 1991 was estimated to be $642 million by University of California, Davis agricultural economists.

In the urban environment both residential, commercial and industrial customers were able to conserve significant amounts of water. For example in northern California, the communities served by East Bay Municipal Utilities District (Oakland, Berkeley and surrounding communities) reduced use by 30.4 percent and in southern California the Los Angeles Department of Water and Power reported a 26.5 percent reduction. Many industries invested in recycling equipment and techniques to maintain productivity. If the drought had continued, it is unlikely that these customers could have further reduced their water consumption.

Estimates indicate that by the year 2010 California's need for water will outstrip its delivery system (Water Reuse 1993). The updated California Water Plan (DWR 1994) estimates that by the year 2020 annual reductions in total water supply for urban and agricultural uses could be in the range of 3.9-7.8 billion barrels (500,000 to 1 million AF) in average years and 15.5-23.3 billion barrels (2 to 3 million AF) in drought years. Accordingly, wastewater, including produced water, is beginning to be considered as a viable water resource. In the Water Recycling Act of 1991, the California legislature declared that reclaimed water is a valuable resource and encouraged its use in all appropriate applications.

PRODUCED WATER

Oil production generates a significant by-product, commonly known as "produced water". As the oil is produced from an oil field, produced water can reach ≥ 90 percent of the fluids pumped from an oil well. In fact, heavy oil fields in California produce 10 to 15 barrels (420 to 630 gallons) of water for every barrel of oil. In 1993 approximately 25.3 billion barrels, or 3.6 million acre-feet of produced water were generated through hydrocarbon production in the US, including production within the three mile coastal water limits. This represents a significant potential reclaimed water source in water short areas such as California. However, the feasibility of water reclamation is highly dependent on local conditions that include the chemical composition of the produced water, which is typically highly saline. The salinity can range from about 3,000 to more than 350,000 mg/L TDS, with sodium and chloride, generally, comprising

70 - 90 percent of the ions, and high concentrations of calcium, iron, manganese, boron, and dissolved organics (Kharaka et al. 1995).

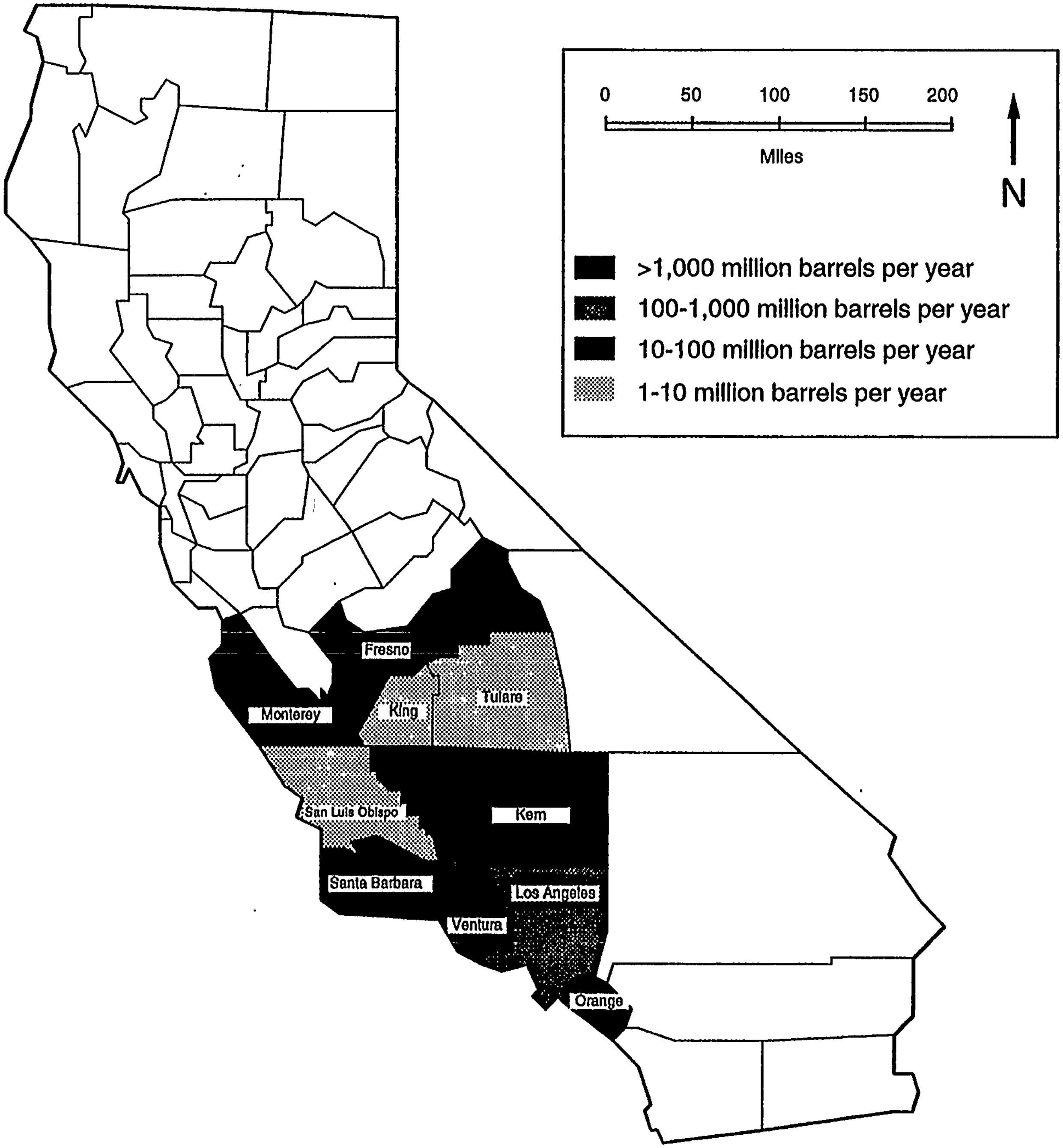
Current Disposal Practices and Beneficial Use Opportunities

The most prevalent method of handling oil field produced water is through underground injection, often at pressures exceeding 1,000 pounds per square inch gauge (psig). Over 65 percent of the produced water from onshore sources is currently re-injected into producing zones for enhanced oil recovery (water and steam flooding and subsidence control) and another 30 percent is injected into deep wells. The Clean Water Act only allows on-shore surface discharge west of the 98th Meridian (a north-south line approximately running just west of Minnesota and through Dallas, Texas) if the produced water is of acceptable quality for beneficial uses such as stream flow augmentation. Other potential beneficial uses of produced water include water source for cogeneration or cooling, agricultural irrigation, drinking water supply, and groundwater recharge.

Available Produced Water Resources in California

The California Division of Oil, Gas, and Geothermal Resources (DOGGR 1996) reports that about 1.9 billion barrels (250,000 acre-feet [AF]) of produced water were generated from oil and gas production in 1995. Table 2-1 summarizes the distribution of produced water for counties generating over 1 million barrels (130 AF) of produced water annually. About 50 percent of this produced water is likely to be unavailable due to offshore or reservoir reinjection and subsidence control or high salinity. Thus, over 4.2 million barrels (100,000 AF) are potentially available to augment water supplies.

As Figure 2-1 illustrates the produced water occurs primarily in 10 counties that are congregated along the southern and central coast and lower central valley areas of California, where there is significant interest in water reclamation.



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1995 Produced Water by County

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Figure 2-1

Table 2-1

Oil, Gas, and Produced Water Quantities in California for 1995

County Name	Oil Production (bbl)*	Nat. Gas Production (Mcf)†	Water Production (bbl)	Water Production (acre-ft)
Kern	207,606,727	105,424,313	1,085,398,711	139,880
Los Angeles	34,012,835	11,673,343	502,995,438	64,823
Fresno	10,409,518	27,699,375	95,146,538	12,262
Santa Barbara	4,723,804	3,033,534	76,597,412	9,823
Orange	6,729,990	3,225,742	74,886,944	9,651
Monterey	4,336,275	220,618	61,275,558	7,897
Ventura	10,163,569	10,796,438	50,726,087	6,537
San Luis Obispo	639,829	119,807	4,827,874	622
Tulare	30,638	31,976	2,576,648	332
Kings	175,409	939,086	1,090,505	140
Others	69,988	76,675,170	2,252,279	290
State Totals	278,898,582	239,839,402	1,957,773,994	252,305

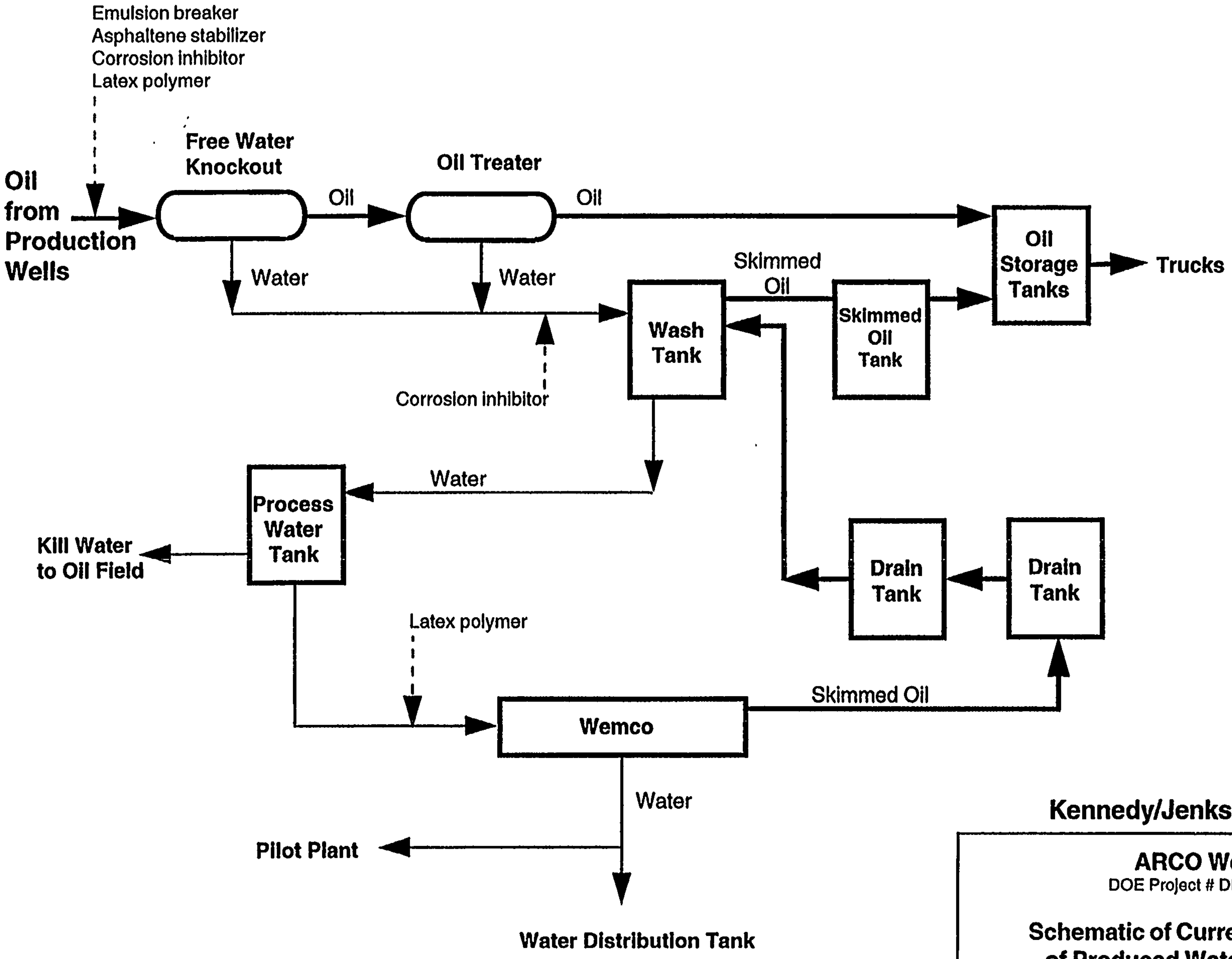
Source: California Div. Oil, Gas, & Geothermal Resources 1996
*bbl = barrel = 42 gallons
†Mcf = millions of standard cubic feet of gas
‡acre-ft = 325,900 gallons = 7,760 barrels

Quality

The DOGGR records from injection projects indicate that in the top ten producing counties, the majority of oil fields produce water with TDS concentrations between 15,000 and 35,000 mg/L. A number of large fields in these counties produce water with TDS levels below 10,000 mg/L, including Midway-Sunset, Kern River, Placerita, and Oak Ridge. The produced water from these lower salinity fields would be more amenable to treatments that are competitive with other new sources of water.

Produced Water at ARCO Placerita Oil Field

Figure 2-2 is a schematic of the current handling of the produced water at the Placerita Oil Field under the management of ARCO Western Energy. It is anticipated that within the next several



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Schematic of Current Treatment of Produced Water at Placerita

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Figure 2-2

years, due to increase development, the quantity of produced water will increase to 60,000 BPD. In addition, there are two other independent operators in the same field that generate another BPD. For planning purposes, the full scale plant under consideration would be designed to treat 44,000 BPD (1.8 mgd) generating ~33,000 BPD (1.4 mgd) of potable water. The finished water resource would be sufficient for approximately 3,100 homes.

WATER QUALITY GOALS

For planning and evaluating potential technologies, the most stringent water quality goals have been identified to provide the greatest flexibility for potential uses of the produced water. Drinking water standards, with few exceptions, are the most stringent and summarized in Table 2-2.

Besides these types of standards, regulatory agencies also have guidelines governing the physical layout of systems necessary to provide a physical separation between traditional potable and non-potable water. For this project the major concerns are the inorganic and organic parameters.

Due to the high temperature > 160 °F (> 70 °F) geological setting of produced water, microbial pathogens are not of concern. The primary concern from a microbial water quality perspective, is within a distribution system after treatment. The focus of the concern would be the biostability of the treated water. The remaining TOC and ammonia could create a significant biofilm or nitrification problem. Both conditions would significantly increase the chlorine demand and make it difficult to maintain a disinfectant residual throughout the distribution system.

Table 2-3 summarizes the water quality parameters of the produced water from the AWE production facilities. For the most part, produced water meets the majority of the primary drinking water maximum contaminant levels (MCLs). After treatment to meet secondary standards identified in Table 2-2 such as Total Dissolved Solids (TDS), the treated water should meet all but a few parameters. The primary parameters of concern would be the TDS, iron, boron, ammonia, sulfide, temperature, and organics.

Table 2-2

California Maximum Contaminant Levels and Action Limits

Constituent	Maximum Contaminant Level (MCL) (mg/L)	Action Level (AL) (mg/L)
<u>Microbial</u>		
Total Coliform	<1/100 ml	
<u>Inorganic Chemicals</u>		
Aluminum	1.	
Arsenic	0.05	
Barium	1.	
Cadmium	0.010	
Chromium	0.05	
Lead	0.05	
Mercury	0.002	
Nitrate (as NO_3)	45.	
Selenium	0.01	
Silver	0.05	
<u>Fluoride</u>		
≤53.7 Degrees Fahrenheit	2.4	
53.8 to 58.3	2.2	
58.4 to 63.8	2.0	
63.9 to 70.6	1.8	
70.7 to 79.2	1.6	
79.3 to 90.5	1.4	
<u>Radioactivity</u>		
Gross Alpha particle activity[1]	15 (pCi/l)[2]	
Gross Beta particle activity	50 (pCi/l)	
Combined Radium-226 and Radium-228	5 (pCi/l)	
Strontium-90	8 (pCi/l)	
Tritium	20,000 (pCi/l)	
Uranium	20 (pCi/l)	

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[1] Including Radium-226 but excluding Radon and Uranium

[2] pCi/l = pico Curies per liter

Table 2-2 (continued)

California Maximum Contaminant Levels and Action Limits

Constituent	Maximum Contaminant Level (MCL) (mg/L)	Action Level (AL) (mg/L)
Total Trihalomethanes (Sum of bromodichloromethane, dibromochloromethane, bromoform, and chloroform)	0.10	
Organic Chemicals[3]		
Alachlor (Alanex)	Unregulated (b)	0.0002
Aldicarb (Temik)	Unregulated (b)	0.010
Aldrin		0.00005
Atrazine (AAtrex)	0.003	
Baygon		0.090
Bentazon (Basagran)	0.018	
Benzene	0.001	
a-Benzene Hexachloride (a-BHC)		0.0007
b-Benzene Hexachloride (b-BHC)		0.0003
Bromobenzene (Monobromobenzene)	Unregulated (a)	
Bromochloromethane (Chlorobromomethane)	Unrelgulated (b)	
Bromacil (Hyvar X, Hyvar XL)	Unregulated (b)	
Bromodichloromethane (Dichlorobromomethane)	Unregulated (a)	
Bromoform (Tribromomethane)	Unregulated (a)	
Bromomethane (Methyl Bromide)	Unregulated (a)	
n-Butylbenzene (1-Butylpropane)	Unregulated (b)	
Sec-butylbenzene (2-Methyl-2-phenylpropane)	Unregulated (b)	
Tert-butylbenzene (2-Methyl-2-phenylpropane)	Unregulated (b)	
Captan		0.350
Carbaryl		0.060
Carbofuran (Furadan)	0.18	
Carbon Tetrachloride	0.0005	
Chlordane	0.0001	
Chloroethane (Ethyl Chloride)	Unregulated (a)	

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[3] Not Regulated: monitoring not required. No MCL or Action Level established.
Unregulated (a): monitoring required for all community and non-transient, non-community water systems.
Unregulated (b): monitoring required for all community and non-transient, non-community water systems if determined vulnerable.

Table 2-2 (continued)

California Maximum Contaminant Levels and Action Limits

Constituent	Maximum Contaminant Level (MCL) (mg/L)	Action Level (AL) (mg/L)
2-Chloroethylvinyl Ether	Non Regulated	
Chloroform (Trichloromethane)	Unregulated (a)	
Chloromethane (Methyl Chloride)	Unregulated (a)	
Chloropicrin		0.050 (0.037)[4]
Chlorothalonil (Bravo, Daconil)	Unregulated (b)	
2-Chlorotoluene (o-Chlorotoluene)	Unregulated (a)	
4-Chlorotoluene (p-Chlorotoluene)	Unregulated (a)	
2, 4-D	0.1	
Diazinon (Basudin, Neocidol)	Unregulated (b)	0.014
Dibromochloromethane (Chlorodibromomethane)	Unregulated (a)	
1,2-Dibromo-3-chloropropane (DBCP)	0.0002	
Dibromomethane (Methylene Bromide)	Unregulated (a)	
1,2-Dichlorobenzene (o-Dichlorobenzene)	Unregulated (a)	0.130 (0.010)[5]
1,3-Dichlorobenzene (m-Diclorobenzene)	Unregulated (a)	0.130 (0.020)[5]
1,4-Dichlorobenzene (p-DCB)	0.005	
Dichlorodifluoromethane (Difluorodichloromethane)	Unregulated (a)	
1,1-Dichloroethane (1,1-DCA)	0.005	
1,2-Dichloroethane (1,2-DCA)	0.0005	
1,1-Dichloroethylene (1,1-DCE)	0.006	
cis-1,2-Dichloroethylene	0.006	
trans-1,2-Dichloroethylene	0.01	
1,2-Dichloropropane (Propylene Dichloride)	0.005	
1,3-Dichloropropane	Unregulated (a)	
2,2-Dichloropropane	Unregulated (a)	
1,1-Dichloropropene	Unregulated (a)	
1,3-Dichloropropene	0.0005	
Dieldrin		0.00005
Di(2-ethylhexyl)phthalate (DEHP)	0.004	
Dimethoate (Cygon)	Unregulated (b)	0.140
2,4-Dimethylphenol		0.40[6]
Diphenamide		0.040

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[4] Taste and Odor Threshold

[5] Taste and Odor Threshold - Action level for 1,2-Dichlorobenzene and 1,3-Dichlorobenzene is either for a single isomer or for the sum of the 2 isomers.

[6] Taste and Odor Threshold

Table 2-2 (continued)

California Maximum Contaminant Levels and Action Limits

Constituent	Maximum Contaminant Level (MCL) (mg/L)	Action Level (AL) (mg/L)
Diuron (Karmex, Krovar)	Unregulated (b)	
Endrin	0.0002	
Ethion		0.035
Ethylene Dibromide (EDB)	0.00002	
Formaldehyde		0.030
Glyphosate	0.7	
Heptachlor	0.00001	
Heptachlor Epoxide	0.00001	
Hexachlorobutadiene (Perchlorobutadiene)	Unregulated (b)	
Isopropyl N (3-chlorophenyl) carbamate (CIPC)		0.350
Isopropylbenzene (Cumene)	Unregulated (b)	
p-Isopropytoluene (p-Cymene)	Unregulated (b)	
Lindane (gamma-BHC)	0.004	
Malathion		0.160
Methoxychlor	0.1	
Methyl Ethyl Ketone (MEK, Butanone)	Not Regulated	
Methyl Isobutyl Ketone (MIBK)	Not Regulated	
Methyl Parathion		0.030
Methylene Chloride (Dichloromethane)	Unregulated (a)	0.040
Molinate (Ordram)	0.02	
Monochlorobenzene (Chlorobenzene)	0.030	
Naphthalene (Naphthalin)	Unregulated (b)	
Parathion		0.030
Pentachloronitrobenzene (Terrachlor)		0.0009
Pentachlorophenol		0.030
Phenol		0.0050[7]
n-Propylbenzene (1-Phenylpropane)	Unregulated (b)	
Prometryn (Caparol)		
Simazine (Princep)	0.01	
Styrene (Vinylbenzene)	Unregulated (a)	
2, 4, 5-TP (Silvex)	0.01	
1,1,2,2-Tetrachloroethane	0.001	
1,1,1,2-Tetrachloroethane	Unregulated (a)	
Tetrachloroethylene (PCE)	0.005	
Thiobencarb (Bolero)[8]	0.07	

---

[7] Taste and Odor Threshold - for chlorinated systems

[8] Also listed as a Secondary Drinking Water Standard with MCL of 0.001 mg/l.

Table 2-2 (continued)

California Maximum Contaminant Levels and Action Limits

Constituent	Maximum Contaminant Level (MCL) (mg/L)	Action Level (AL) (mg/L)
Toluene (Methylbenzene)	Unregulated (a)	0.10
Toxaphene	0.005	
1,2,3-Trichlorobenzene	Unregulated (b)	
1,2,4-Trichlorobenzene (Unsym-trichlorobenzene)	Unregulated (b)	
1,1,1-Trichloroethane (1,1,1-TCA)	0.200	
1,1,2-Trichloroethane (1,1,2-TCA)	0.032	
Trichloroethylene (TCE)	0.005	
Trichlorofluoromethane (Freon 11)	0.15	
1,2,3-Trichloropropane (Allyl Trichloride)	Unregulated (a)	
1,1,2-Trichloro-1,2,2-Trifluoroethane (Freon 113)	1.2	
1,2,4-Trimethylbenzene (Pseudocumene)	Unregulated (b)	
1,3,5-trimethylbenzene (Mesitylene)	Unregulated (b)	
Trithion		0.0070
Vinyl Chloride (VC)	0.0005	
Xylenes (single isomer or sum or isomers)	1,750	
<u>Secondary Drinking Water Standards</u>		
Chloride	250-500-600[9]	
Color	15 units	
Copper	1.0	
Corrosivity	Relatively Low	
Foaming Agents (MBAS)	0.5	
Iron	0.3	
Manganese	0.05	
Odor—Threshold	3 units	
Specific Conductance (micromhos)	900-1600-2200[9]	
Sulfate	250-500-600[9]	
Thiobencarb (Bolero)[10]	0.001	
Total Dissolved Solids	500-1000-1500[9]	
Turbidity	5 units	
Zinc	5.0	

---

[9] Recommended-Upper-Short Term

[10] Also listed as a Primary Drinking Water Standard with MCL of 0.07 mg/l.

Table 2-3
Summary of Historical Water Quality Data
ARCO Produced Water

Parameter	As	Unit	Representative Model	Model in meq	Min	Median	Average	Max
Sodium	Na	mg/L	1,400	60.9	710	1,368	1,247	1492
Calcium	Ca	mg/L	240	12.0	140	179	247	490
Magnesium	Mg	mg/L	70	5.8	49.5	68	72	110.4
Ammonium	NH4	mg/L	15	0.8	11.6	13	13	16.5
Strontium	Sr	mg/L	5	0.1	1	5	5	11.5
Potassium	K	mg/L	100	2.6	60.9	67	94	190
Cation Subtotal		meq	1830.0	82.1				
Hydroxide	OH	mg/L	0	0.0	0	0	0	0
Carbonate	CO3	mg/L	0	0.0	0	0	0	<2.6
Bicarbonate *	HCO3	mg/L	800	13.1	616.1	641	722	981
Chloride	Cl	mg/L	2,400	67.7	1945	2,411	2,399	3093
Sulfate	SO4	mg/L	30	0.6	5	30	32	70
Borate	B2O5	mg/L	50	0.7	0	40	42	58.2
Nitrate	NO3	mg/L	5	0.1	5	5		5
Dissolved Sulfide	S		10	0.6	10.4	10		10.4
Anion Subtotal		meq	3295.0	82.8				
Total Sulfide	S2	mg/L	12		10.2	10.8	11	12.5
Silica	SiO2	mg/L	200		95.4	168.2	179	295.8
Boron	B	mg/L	20		0.9	7.26	15	66
Salinity as NaCl	NaCl	mg/L	3900		3,200	3,894	3,739	3,969
Hardness as CaCO3	CaCO3	mg/L	915		563.9	775	912	1,570
Dissolved Solids (measured)		mg/L	5000		4,573	5,138	5,068	5,492
Calculated TDS**		mg/L	5282					
Conductivity		umhos.	8200		5,800	7,895	7,633	8,910
pH		—	7.2		6.56	7.3	7	7.79
Temp.		F			—			—
Specific Gravity		—			0.996	1.002	1.006	1.039
Color		units	60		5	63	63	120
Odor		T.O.N.	20		3	17	17	30
Turbidity		N.T.U.	5		1.4	4.7	4.7	8
Total Solids		mg/L	5,000		4,300	4,873	4,856	5,306
Suspended Solids		mg/L	10		6.6	8.9	8.9	11.2
Foaming Agents		mg/L	1		0.4	0.8	0.8	1.1
Aluminum		ug/L	<50		<5			<50
Arsenic		ug/L	<5		<5			0
Barium		ug/L	2,070		996	1,850	1,635	2,300
Cadmium		ug/L	14.4		<5	11	11	16
Chromium		ug/L	9.9		6	9	9	11
Copper		ug/L	<50		<50			<50
Fluoride		ug/L	1,980		<100	2,200	2,200	2,200
Iron		ug/L	10,000		800	1,840	4,509	18,600
Lead		ug/L	39.6		<5	29	29	44
Manganese		ug/L	398.7		170	307	307	443
Mercury		ug/L	<1		<0.2			<1
Selenium		ug/L	<2		<2			<2
Silver		ug/L	36		5	23	23	40
Zinc		ug/L	225		<10	172	172	250
TOC		mg/L			—			—
Tot. O&G		mg/L	5		1.7		24	48.2
Benzene		ug/L	10		3.1	7.85	7.9	12.6
Toluene		ug/L	10		1.4		5.0	8.6
Chlorobenzene		ug/L	60		63.8		63.8	63.8
Ethyl Benzene		ug/L	50		24.7		44.3	63.8
m+p Xylene		ug/L	10		5.4		9.0	12.5
o Xylene		ug/L	10		4		7.1	10.1
1,2-Dichlorobenzene		ug/L	15		14.7		14.7	14.7
1,3-Dichlorobenzene		ug/L	25		24.6		24.6	24.6
1,4-Dichlorobenzene		ug/L	15		6.7		12.7	18.7

* Measured by titration, which would include organic acids. The one acids measurement reported accounted for < 10 % of tot

** Calculated by summing of all ions, including B2O5, SiO2, Iron, Barium, and accounting for CO2 that would be lost in evaporati

Regulatory Requirements for Produced Water as a Water Resource

In California, there are no current drinking water regulations covering the use of treated produced water. There are reclamation standards and design criteria for treatment of domestic wastewater for a direct beneficial use or a controlled use that would not otherwise occur. There are extensive federal and state regulations for drinking water. All suppliers of domestic water to the public are regulated by the federal EPA under the federal Safe Drinking Water Act and by the California Department of Health Services. California has been granted primary authority to enforce the federal Act under certain conditions which include adoption of regulations no less stringent than the EPA standards regarding water quality, treatment, monitoring, and public notification of violation. The California Code of Regulations, Title 22, Division 4, and subsequent Chapters define the current requirements for potable water and reclaimed domestic wastewater that include direct reuse, irrigation, groundwater recharge, or non-engineered (indirect) potable use. There are no reclamation regulations for treated produced water to be used in the same manner. Recycling of treated produced water for groundwater recharge or surface water discharge would be regulated by the California EPA under the auspices of the State and Regional Water Quality Control Board. Table 2-4 summarizes the specific requirements or the most appropriate portion of the regulations. There are no current DHS regulations that address produced water as a potable water resource. The most appropriate portions of the regulation have been identified because they would likely serve as a preliminary guideline for the standards and design criteria to be required by DHS for produced water treatment facilities.

Table 2-4

Water Usage and Applicable California Code of Regulation

Use	Applicable Chapter	Comments
Potable, flange to flange	Chapter 15 (Domestic Water Quality and Monitoring), Chapter 16 (California Waterworks Standards)	May require significant reliability elements. Creates the highest economic value. The pricing for reclamation water is typically less than 50 percent of potable water.
Potable, not flange to flange		Would require less reliability elements, but would require similar evaluation as in Groundwater Recharge
Irrigation of Food Crops; Irrigation of Fodder, Fiber, and Seed Crops; Landscape Irrigation; and Recreational Impoundments	Chapter 3 (Reclamation Criteria), Article 2-5, and 6	Regulations only address microbial water quality. Requires turbidity to be continuously monitored. Includes by inference that if the chemical parameters in produced water are similar to a domestic wastewater that is adequately disinfected, oxidized, coagulated, clarified, and filtered and meets the groundwater basin plan, it would be acceptable.
Groundwater Recharge	Ch 3, Article 5.1 and 6	Reclaimed water used for groundwater recharge of domestic water by surface spreading shall be at all times of a quality that fully protects public health. The DHS will recommend to the Regional Water Quality Control Board on a case by case basis including the following factors: effluent quality and quantity; spreading area operations; soil characteristics; hydrogeology; residence time; and distance to withdrawal. Requires domestic wastewater reclamation plant to have continuous turbidity monitoring.

Pending Federal Regulations

Table 2-5 identifies the pending water regulations which can impact this project from an organics perspective. Some of the rules identified below address microbial pathogens. These portions of the rules have not been addressed because the Placerita Oil Field is a steam flood and the operating temperatures of 100-175 °F would inactivate any potential pathogens. In addition, this produced water is from an non-vulnerable source and is not expected to have any pathogens.

Table 2-5

Summary of Potential Federal Drinking Water Rules

Potential Rule	Impact
Stage I Disinfection byproduct Rule	Regulates total trihalomethanes (THMs) to 80 µg/L and the total of five haloacetic acids (HAA5) 60 µg/L. Only the THMs are currently regulated at 100 µg/L. It is estimated that this regulation will become effective within five years. These compounds are formed when disinfecting waters with chlorine.
Stage II Disinfection byproduct Rule	Regulates THMs to 40 µg/L and HAA5 to 30 µg/L. It is estimated that this regulation may become effective within the next 10 years.
Information Collection Rule	Groundwaters with an annual average of >2.0 mg/L of TOC are required to perform GAC or membrane pilot studies. This information may lead to regulate drinking water TOC in the Enhanced Surface Water Treatment Rule. This rule became effective in June 14, 1996.
Enhanced Surface Water Treatment Rule	Drinking water may be regulated to 2 mg/L of TOC. It is estimated that this new regulation will become effective in the next 10 years
Groundwater Disinfection Rule	Requires groundwaters to be disinfected and meet the THM and HAA5 regulations. It is estimated that this new regulation will become effective in the next 5 years.

Basin Plan Impacts

The ground water basin plan for this area which is under the jurisdiction of the California EPA, Regional Water Quality Control Board, LA Region, requires any surface discharge meet specific water quality objectives. Table 2-6 summarizes these water quality regulatory limits.

Table 2-6

Summary of Water Quality Limits for Surface Discharge at Project Site

Parameter	Limit (mg/L)
Total Dissolved Solids	800
Sulfate	140
Chloride	100
Boron	1
Nitrogen	5
Sodium Adsorption Ratio	5

POTENTIAL WATER USE SCENARIOS

This developed water resource can be used for industrial, agricultural, and domestic supply. The following sections highlight the important constraints or features for using this water in this way.

It should be pointed out that in the water resources area there is a lack of institutional structure for the use of this water resource. For example, there are no regulatory standards for the beneficial use of this water. Once a water resource has been privately developed for irrigation or industrial use that replaces current potable uses, there are no institutional mechanisms that allow one to accumulate, sell, or trade "water credits" as there is in the air pollution arena.

Industrial Water

A distinguishing feature of industrial use of water, in contrast to domestic use, is the extreme variability in water usage from one industry to another. Each industry will have to continue to treat water in accord with its own needs for process water. Generally, the siting of a new plant is governed more by the quality of return water that industry is permitted to discharge than by the quality of the water at its intakes.

Generally, as long as the TDS meets the current supply, there would not be an added treatment cost for a given industry, all things being equal. In some instances, however, some component of the TDS may create a particular problem for a particular industry. For example, if there was an increase in total hardness without a change in TDS, an industrial boiler user would experience an incremental increase in softening cost. Similarly, if chlorides become higher in the water supply, the pretreatment costs to remove it by ion exchange for black and white photographic processing would increase proportionately. In both these instances, for some other industries, there would be no change in their operational costs associated with these changes in water quality.

In the case of Placerita, the largest immediate industrial use is for steam generation in the steam flood operation of oil production and electrical generation by the neighboring AES facility. The industrial water quality goals for this project are the following:

Total hardness as $CaCO_3$ silica	≤ 600 mg/L
Silica as SiO_2	80 - 200 mg/L

Agriculture/Irrigation Water

The factors that limit the usefulness of a water for agriculture have been developed on the basis of salinity, sodium, boron, and bicarbonate concentrations.

Salinity

Table 2-7 presents data from the US Department of Agriculture (Bernstein, 1964) summarizing the effect of salinity on plants.

Table 2-7
Effect of Salinity on Crop Response

Salinity (mmhos/cm)	TDS (mg/L)	Crop Response
0-2	0-1,300	Salinity effects mostly negligible
2-4	1,300-2,500	Yields of very sensitive crops may be restricted
4-8	2,500-5,000	Yields of many crops restricted
8-16	5,000-10,000	Only tolerant crops yield satisfactorily
>16	>10,000	Only a few very tolerant crops yield satisfactorily

Plants have difficulty in obtaining water from saline solutions and affects their growth. Both interference with plant nutrition and acute injury to the plant may be involved in the salinity effect.

The characteristics of soils are not adversely affected by high concentrations of salts, if sodium is low in comparison with calcium and magnesium. Sodium renders soils impermeable to air and water. When water is applied to these soils, they become plastic and sticky reducing the ability of plants to grow. The effect of sodium on the soil is measured by the sodium absorption ratio (SAR) which expresses its effect by the relative portion, not the total concentrations.

$$SAR = Na^{+}/((Ca^{+2} + Mg^{+2})/2)^{1/2}$$

Boron

Boron is toxic to plants in certain concentrations but varies with species and climate factors. Table 2-8 summarizes the effect of boron (McKee and Wolf, 1963).

Table 2-8

Effect of Boron on Crops

Boron (mg/L)	Type of Crop
0.33-1.25	Sensitive (fruits, nuts, beans)
0.67-2.50	Semitolerant (cereals, vegetables, cotton)
1.00-3.75	Tolerant (alfalfa, sugar beets, asparagus)

The water that is used for agriculture must also comply with the California EPA Regional Water Quality Control Board discharge limits established for each ground water basin (Ground Water Basin Plan). The Placerita Oil Field is located in a ground water basin that has a discharge limit of 1 mg B/L.

Bicarbonates

Bicarbonates in irrigation water tend to make calcium more soluble. When calcium bicarbonate enters the soil an increase in temperature or evaporation may precipitate the calcium as CaCO3 which tends to hold the calcium in the soil. The reduction of calcium in the drainage water results in an increase in the SAR.

High residual sodium carbonate (sum of the equivalents of carbonate and bicarbonate minus the sum of the equivalents of calcium and magnesium) is not suitable for agriculture. Waters containing less than 66 mg/L residual sodium carbonate can be safely used in irrigation, between 66 and 132 mg/L is marginal and above 132 mg/L is not suitable.

Drinking Water

Domestic raw water supplies must, at a minimum, be of such quality that the EPA and California Drinking Water Standards are reliably achievable. These standards are summarized in Table 2-2.

The treated water can be used directly as a potable water supply (flange to flange). The flange to flange option could have more stringent water quality criteria as well as operational constraints to ensure the reliability of the treatment train.

Alternatively, the treated water can be used to augment a raw water supply reservoir that would receive additional treatment providing more safeguards. To satisfy this option, the treated water would have to meet the recreation and aquatic life water quality criteria. From an administrative perspective, the owner would probably be required to obtain a National Permit Discharge Elimination System (NPDES) permit from California EPA, Regional Water Quality Control Board, Los Angeles Region.

ENERGY SAVINGS

An energy analysis was performed to determine the energy savings. This analysis is summarized in Table 2-9. Because the water treated by this project would not have to be pumped into southern California via the State Water Project or treated by Castaic Lake Water District, there would be a savings of 3,807 kWh/AF. The energy savings from avoiding disposal of produced water by deep well injection is 648 kWh/AF. The combined saving would be 4,455 kWh/AF.

Table 2-9

Summary of Energy Analysis, Assuming a Flange to Flange Project

Element	kWH per Acre-Foot	
State Water Project Pumping	(4,322)	
Hydroelectric Generation	744	
Castaic Lake Water Treatment	(229)	
SWP Savings		3,807
43,000 BPD Produce Water *Water Treatment Plant*	3,114	
Avoided Injection	(3,760)	
Local Project Savings		648
Project Savings Overall		4,455

Chapter 3

Treatment Selection and Bench Studies

CHAPTER 3

LITERATURE REVIEW

The following sections review treatment technologies potentially applicable to this project based on the water quality concerns described in Chapter 2.

REMOVAL OF TOTAL DISSOLVED SOLIDS

High levels of dissolved salts are detrimental to both potable and agricultural uses. EPA recommends that the total dissolved solids (TDS) should be less than 500 mg/L. Above this level the TDS will affect the taste of the water and may start to become a problem to salt sensitive plants.

Desalting technologies separates the feedwater into two streams: one with a low concentration of dissolved salts (product water) and the other containing the remaining dissolved salts (the concentrate). These technologies require energy to operate and are based on different principals for the separation. This section briefly describes the various desalting processes commonly used to desalt saline or brackish water. The general technology descriptions have been adapted from The Desalting ABC's (Buros 1990).

EVAPORATIVE TECHNOLOGIES

Over 60 percent of the world's desalted water is based on thermal processes to distill fresh water from sea water. The distillation process mimics the natural water cycle in that feedwater is heated, producing water vapor that is in turn condensed to form fresh water. In a laboratory or industrial plant, water is heated to the boiling point to produce the maximum amount of water vapor.

For this to be done economically in a desalination plant, the boiling point is controlled by adjusting the atmospheric pressure of the water being boiled. The temperature required to boil water decreases as one moves from sea level to a higher elevation because of the reduced atmospheric pressure on the water. Thus, water can be boiled on top of Mt. McKinley in

Alaska, elevation 6,200 meters (20,300 feet) at a temperature of about 16 °C (28 °F) less than boiling it at sea level. The reduction of the boiling point is important in the desalination process for two major reasons: multiple stage boiling and scale control.

To boil, water needs two important conditions: the proper temperature relative to its ambient pressure and enough energy for vaporization. When water is heated to its boiling point and then the heat is turned off, the water will continue to boil only for a short time because the water needs additional energy (the heat of vaporization) to permit boiling. Once the water stops boiling, boiling can be renewed by either adding more heat or by reducing the ambient pressure above the water. If the ambient pressure is reduced, then the water would be at a temperature above its boiling point (because of the reduced pressure) and will boil with the extra heat from the higher temperature to supply the heat of vaporization needed. As the heat of vaporization is applied, the temperature of the water will fall to the new boiling point.

To significantly reduce the amount of energy needed for vaporization, the distillation desalting process usually uses multiple stages of boiling in successive vessels, each operating at a lower temperature and pressure. This process of reducing the ambient pressure to promote boiling can continue downward and, if carried to the extreme with the pressure reduced enough, the point at which water would be boiling and freezing at the same time would be reached.

Aside from multiple boiling, the other important factor is scale control. Although most substances dissolve more readily in warmer water, some dissolve more readily in cooler water. Unfortunately, some of these substances like carbonates and sulfates are found in sea water. One of the most important is gypsum ($CaSO_4$), which begins to precipitate when water approaches about 95° C (203° F). This material forms a hard scale that coats any tubes or containers present. Scale creates thermal and mechanical problems and, once formed, is difficult to remove. One way to avoid the formation of this scale is to keep the temperature and boiling point of the water below the scaling temperature of gypsum. These two concepts of lowering temperature and pressure have made various forms of distillation successful in locations around the world.

Multi-stage Flash Distillation

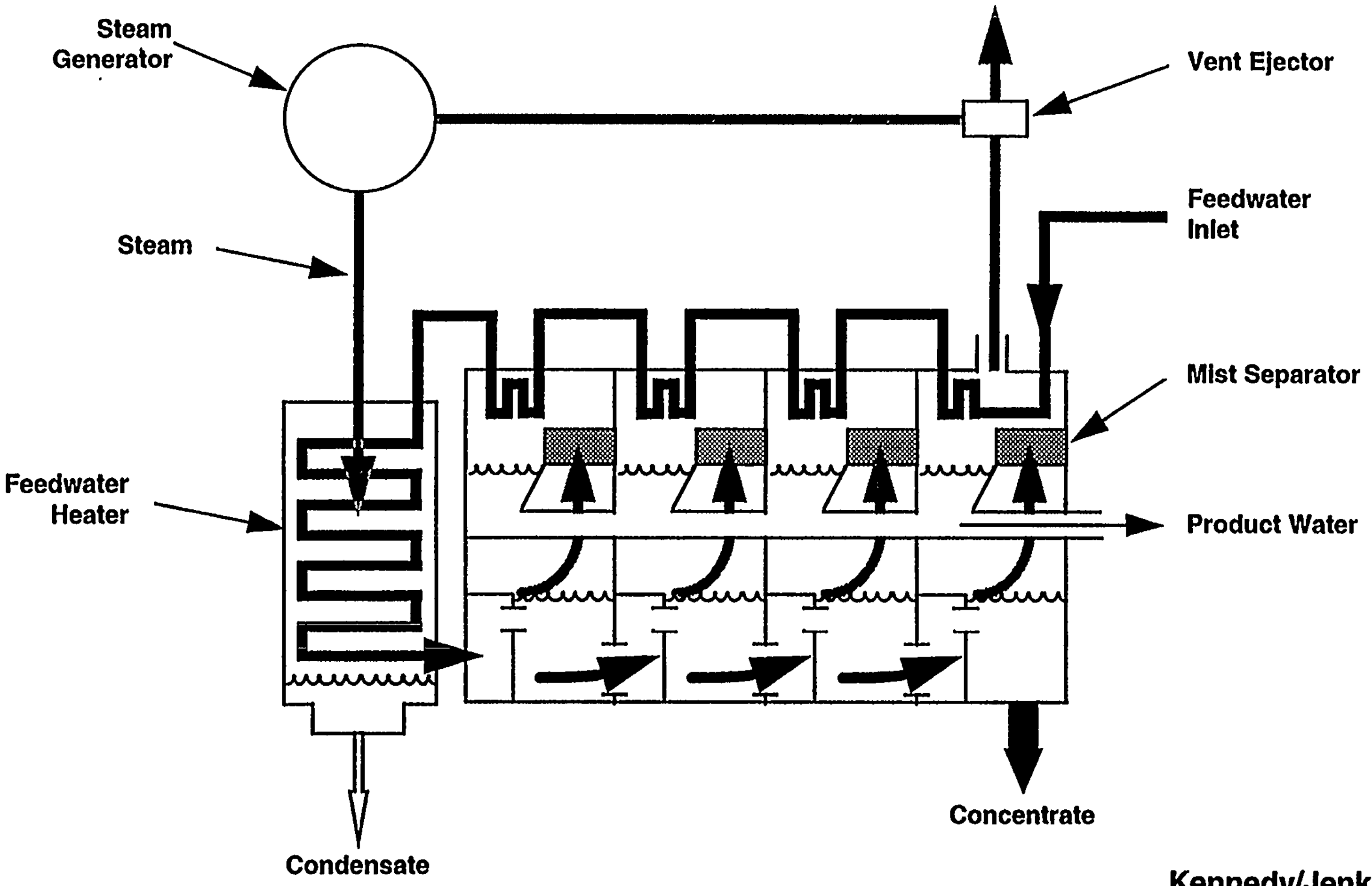
The process which accounts for the most desalting capacity is multi-stage flash distillation, commonly referred to as the MSF process and schematically shown in Figure 3-1. The concept of distilling water with a vessel operating at a reduced pressure is not new and has been used for well over a century. In the 1950s, a unit that used a series of stages set at increasingly lower atmospheric pressures was developed. In this unit, the feed water could pass from one stage to another and be boiled repeatedly without adding more heat. Typically, an MSF plant can contain from 4 to about 40 stages.

The steam generated by flashing is converted to fresh water by being condensed on tubes of heat exchangers that run through each stage. The tubes are cooled by the incoming feed water going to the brine heater. This, in turn, warms up the feed water so that the amount of thermal energy needed in the brine heater to raise the temperature of the sea water is reduced.

Multi-stage flash plants have been built commercially since the 1950s. They are generally built in units of about 1 to 8 mgd (4,000 to 30,000 m^3/d). The MSF plants usually operate at the top feed temperatures (after the brine heater) of 194 - 249 °F (90 - 120 °C). One of the factors that affects the thermal efficiency of the plant is the difference in temperature from the brine heater to the condenser on the cold end of the plant. Operating a plant at the higher temperature limits of 248 °F (120 °C) tends to increase the efficiency, but it also increases the potential for detrimental scale formation and accelerated corrosion of metal surfaces.

Multiple Effect Distillation

The multiple effect distillation (MED) process has been used for industrial distillation for a long time and is presented schematically in Figure 3-2. One popular use for this process is the evaporation of juice from sugar cane in the production of sugar or the production of salt with the evaporative process. Some of the early water distillation plants used the MED process, but this process was displaced by the MSF units because of cost factors and MSF's apparent higher efficiency. However, in the past decade, interest in the MED process has renewed, and a number of new designs have been built around the concept of operating on lower temperatures.



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Schematic of Once Through Multi-Stage Flash Distillation

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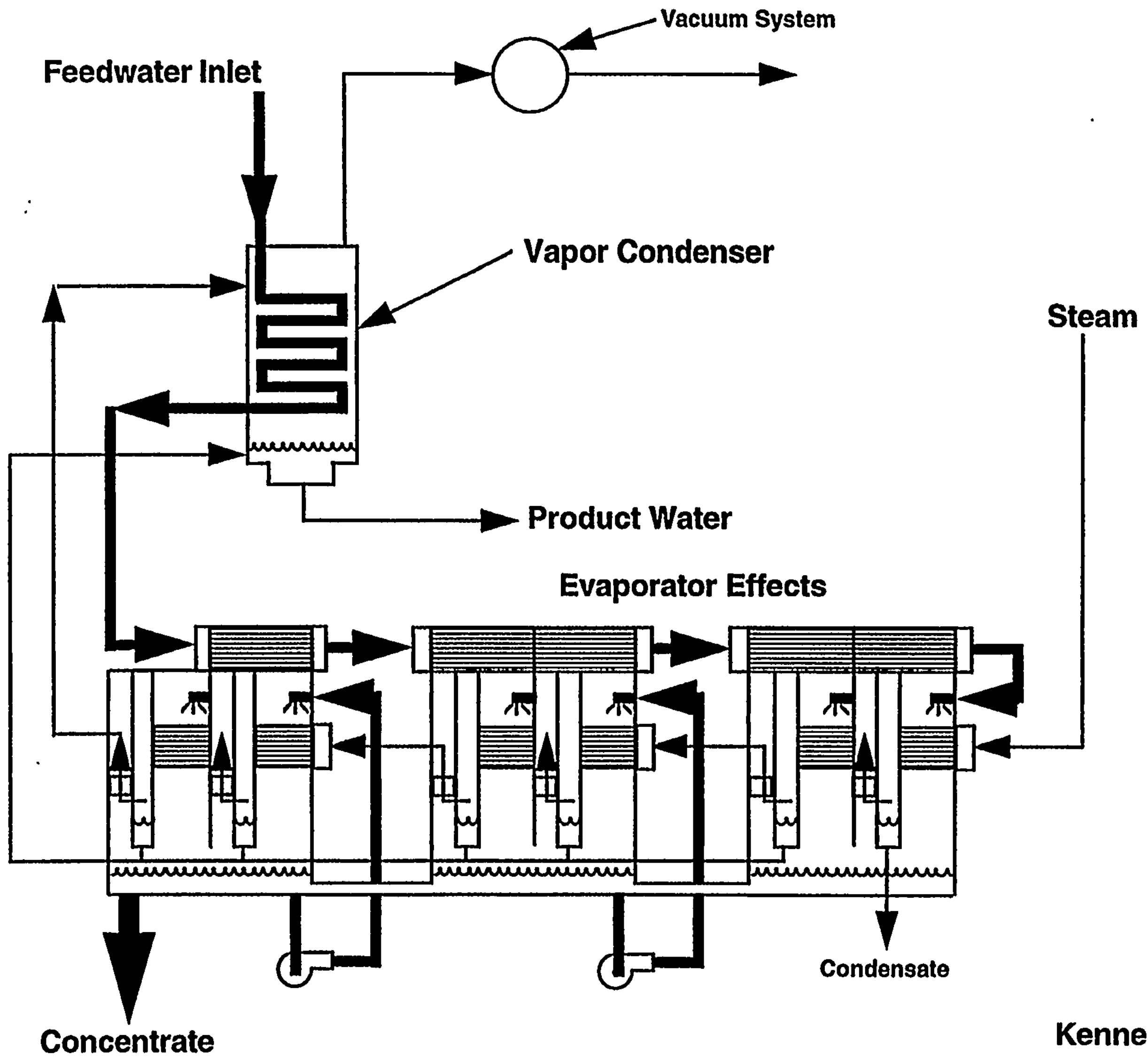
Figure 3-1



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Schematic of
Multiple Effect Distillation

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Figure 3-2

MED, like the MSF process, takes place in a series of vessels (effects) and uses the principle of reducing the ambient pressure in the various effects. This permits the sea water feed to undergo multiple boiling without supplying additional heat after the first effect. In an MED plant, the sea water enters the first effect and is raised to the boiling pint after being preheated in tubes. The sea water is either sprayed or otherwise distributed onto the surface of evaporator tubes in a thin film to promote rapid boiling and evaporation. The tubes are heated by steam from a boiler, or another source, which is condensed on the opposite side of the tubes. The condensate from the boiler steam is recycled to the boiler for reuse.

Only a portion of the sea water applied to the tubes in the first effect is evaporated. The remaining fed water is fed to the second effect, where it is again applied to a tube bundle. These tubes are in turn being heated by the vapors created in the first effect. This vapor is condensed to fresh water product, while giving up heat to evaporate a portion of the remaining sea water feed in the next effect. This continues for several effects, with 8 or 16 effects being found in a typical large plant.

Usually, the remaining sea water in each effect must be pumped to the next effect so as to apply it to the next tube bundle. Additional condensation takes place in each effect on tubes that bring the feed water from its source through the plant to the first effect. This warms the feed water before it is evaporated in the first effect.

MED plants are typically built in units of 0.5 to 2.5 mgd (2,000 to 10, 000 m^3/d). Some of the more recent plants have been built to operate with a top temperature (in the first effect) of about 158 °F (70 °C), which reduces the potential for scaling of sea water within the plant but in turn increases the need for additional heat transfer area in the form of more tubes. Most of the more recent applications for the MED plants have been in some of the Caribbean areas. Although the number of MED plants is still relatively small compared to MSF plants, their numbers have been increasing.

Vapor Compression

The vapor compression (VC) distillation process is generally used for small-and medium-scale sea water desalting units. The heat for evaporating the water comes from the compression of vapor rather than the direct exchange of heat from steam produced in a boiler.

The plants which use this process are generally designed to take advantage of the principle of reducing the boiling point temperature by reducing the pressure. Two primary methods are used to condense vapor so as to produce enough heat to evaporate incoming sea water: a mechanical compressor or a steam jet. The mechanical compressor is usually electrically driven, allowing the sole use of electrical power to produce water by distillation.

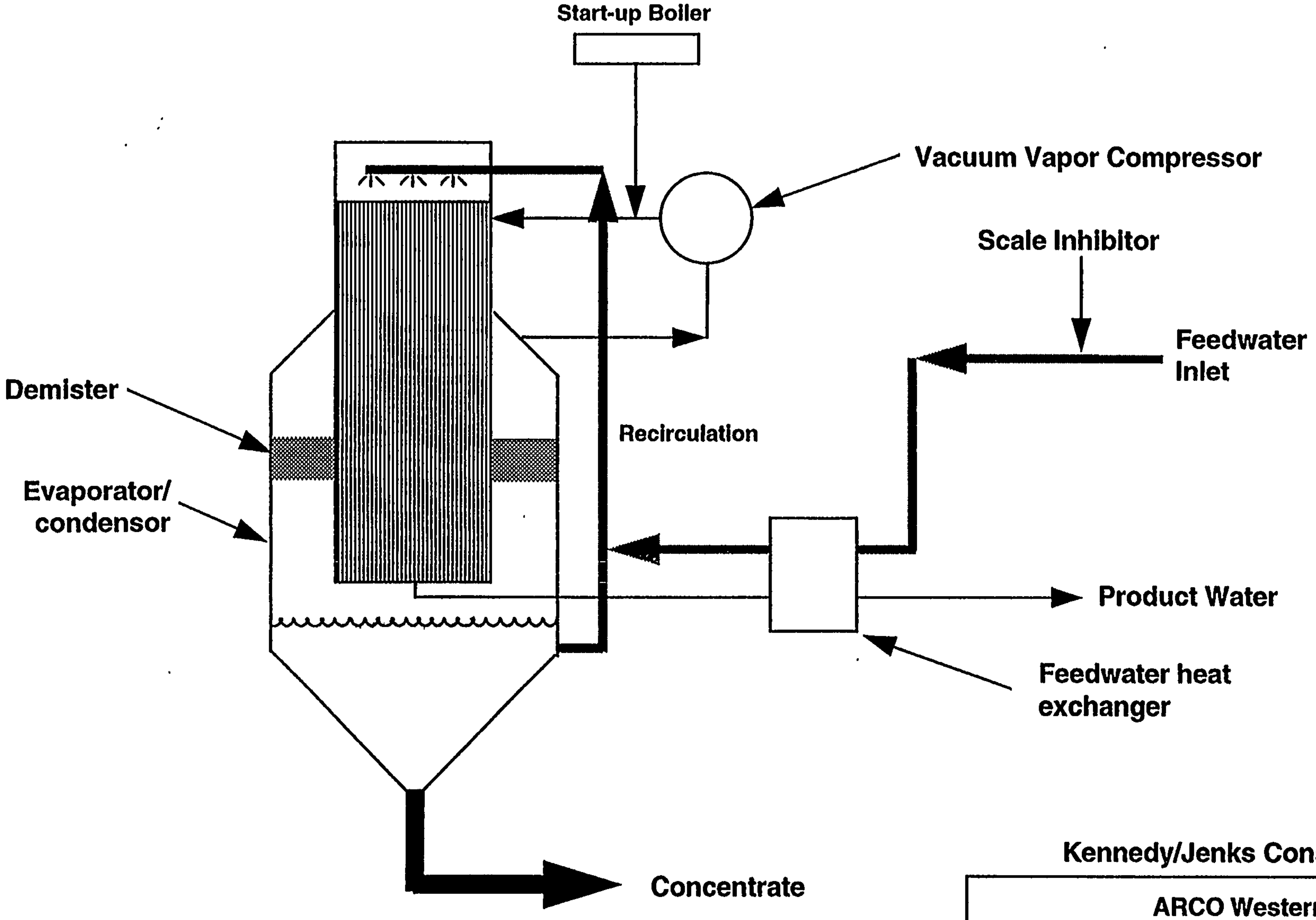
VC units have been built in a variety of configurations to promote the exchange of heat to evaporate the sea water. Figure 3-3 illustrates a simplified method in which a mechanical compressor is used to generate the heat for evaporation. The compressor creates a vacuum in the vessel and then compresses the vapor taken from the vessel and condenses it inside of a tube bundle also in the same vessel. Feed water is sprayed on the outside of the heated tube bundle where it boils and partially evaporates, producing more water.

With the steam jet-type VC unit, also called a thermocompressor, a venturi orifice at the steam jet creates and extracts water vapor from the main vessel, creating a lower ambient pressure in the main vessel. The extracted water vapor is compressed by the steam jet. This mixture is condensed on the tube walls to provide the thermal energy (heat of condensation) to evaporate the sea water being applied on the other side of the tube walls in the vessel.

VC units are usually built in the 0.005 to 0.5 mgd (20 to 2000 m^3/d) range. They are often used for resorts, industries, and drilling sites where fresh water is not readily available.

Installed Applications

Seeded-slurry vapor compression systems, or brine concentrators, are well-suited for produced water applications. The technology can be used to concentrate brine from RO processes to increase water recovery and minimize quantities of brine requiring disposal. The VC brine



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Schematic of
Vacuum Vapor Compression

January 1998
K/J 964634.00

Figure 3-3

concentrators require little or no pretreatment and yield water recoveries up to 98 percent. The systems can also accommodate changes in feed composition and upsets as well.

Seeded-slurry VC are designed to combine pretreatment and evaporation in a single step by constantly recycling brine that has been seeded with calcium sulfate. Silica and other potentially scaling compounds precipitate onto the calcium sulfate seed crystals in the brine slurry rather than onto the heat transfer surfaces. The concentrators can be chemically cleaned in place. Cleaning cycles for these units range from several days to no cleaning at all, with typical systems cleaned annually (Solomon 1990).

Emerging Applications

The Metropolitan Water Agency began a demonstration project in 1990 to develop a lower-cost MED plant for saltwater desalination. Using aluminum evaporators and a concrete shell are the two primary cost saving features of a the project, which is currently in the pilot testing phase (Dean 1996).

Membrane Technologies

Membranes are used in a number of commercially important desalting processes, including reverse osmosis(RO), nanofiltration, electrodialysis, and electrodialysis reversal. Each process uses the ability of the membranes to differentiate and selectively separate salts and water. However, membranes are used differently in each of these processes.

Reverse Osmosis

RO is a membrane separation process in which the water from a pressurized saline solution is separated from the solutes (the dissolved material) by flowing through a membrane. No heating or phase change is necessary for this separation. The major energy required for desalting is for pressurizing the feed water.

In practice, the saline feed water is pumped into a closed vessel where it is pressurized against the membrane. As a portion of the water passes through the membrane, the remaining feed water increases in salt content. At the same time, a portion of this feed water is discharged without passing through the membrane.

Without this controlled discharge, the pressurized feed water would continue to increase in salt concentration, creating such problems as precipitation of supersaturated salts and increased osmotic pressure across the membranes. The amount of the feed water discharged to waste in this brine stream for brackish water varies from 10 to 40 percent of the feed flow, depending on the salt content of the feed water.

An RO system is made up of the following basic components:

- Pretreatment
- High-pressure pump
- Membrane assembly
- Post-treatment

Pretreatment is important in RO because the feed water must pass through very narrow spacings throughout the process. Therefore, suspended solids must be removed and the water pre-treated so that salt precipitation or microorganism growth does not occur on the membranes. Usually the pretreatment consists of fine filtration and the addition of acid or other chemicals to inhibit precipitation.

The high-pressure pump supplies the pressure needed to enable the water to pass through the membrane and have the salts rejected. This pressure ranges from 17 to 27 bar (250 to 400 psi) for brackish water and from 54 to 80 bar (800 to 1,180 psi) for sea water.

The membrane assembly consists of a pressure vessel and a membrane that permits the feed water to be pressurized against the membrane. The membrane must be able to withstand the drop of the entire pressure across it. The semi-permeable membranes are fragile and vary in their ability to pass fresh water and reject the passage of salts. No membrane is perfect rejecting salts, so a small amount of the influent salt passes through the membrane and appears in the product water.

RO membranes are made in a variety of configurations. Two of the most commercially successful are spiral-wound and hollow fine fiber. Both of these configurations are used to desalt both brackish and sea water, although the construction of the membrane and pressure vessel will vary depending on the manufacturer and expected salt content of the feed water.

Post-treatment consists of stabilizing the water and preparing it for distribution. This post-treatment might consist of the removing gases such as carbon dioxide and hydrogen sulfide and adjusting the pH.

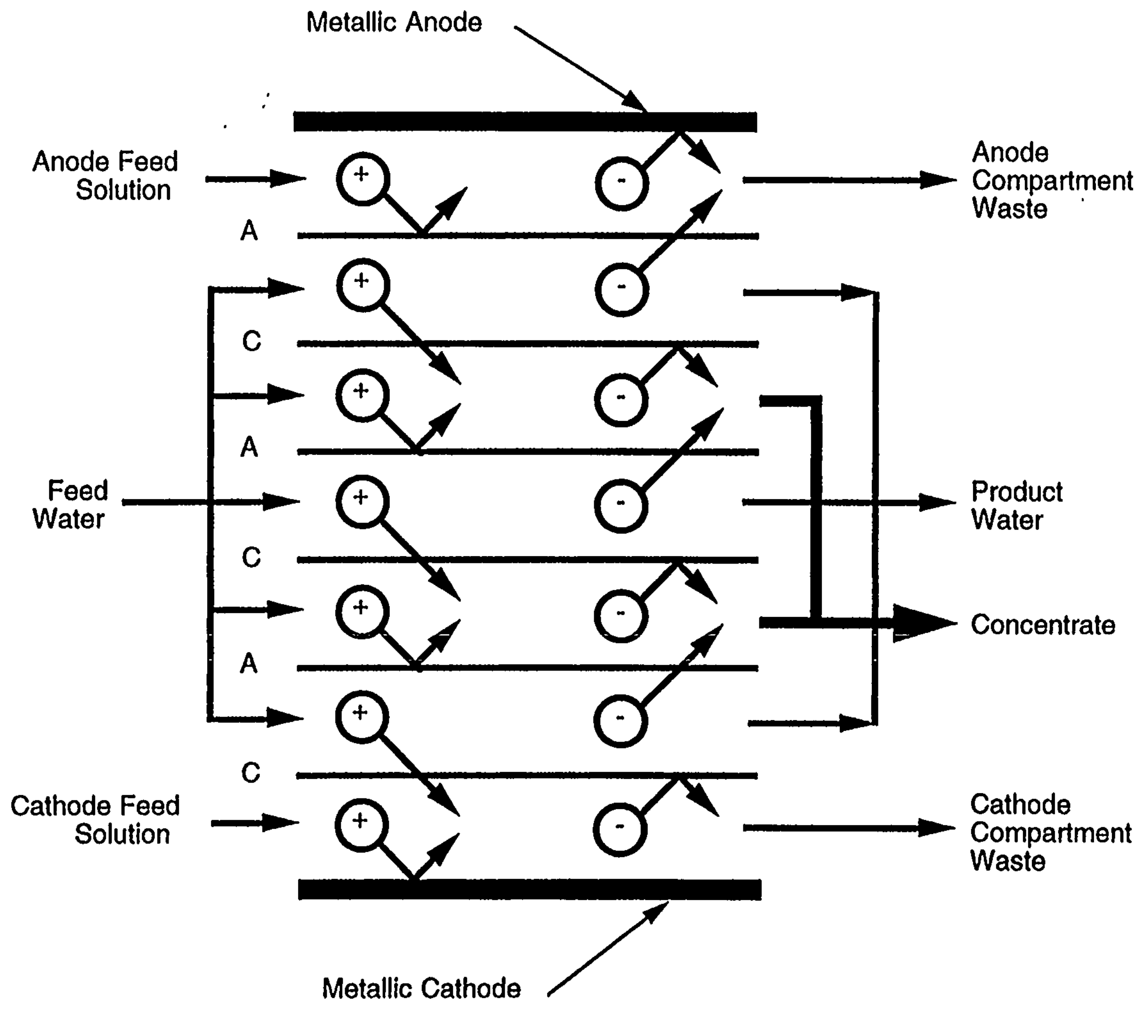
Two developments have helped to reduce the operating cost of RO plants during the past decade: the development of membranes that can operate efficiently with lower pressures and the use of energy recovery devices. The low-pressure membranes are being widely used to desalt brackish water. The energy recovery devices are connected to the concentrate stream as it leaves the pressure vessel. The water in the concentrate stream loses only about 1 to 4 bar (15 to 60 psi) relative to the applied pressure from the high-pressure pump. These energy recovery devices are mechanical and generally consist of turbines or pumps of some type that can convert pressure drop to rotating energy.

Nanofiltration

Nanofiltration (NF) membranes remove dissolved solids from the influent raw water and are similar to RO membranes. Like RO, nanofiltration is a pressure driven membrane process in which water is forced to flow from the high ion concentration side of the membrane to the low ion concentration side of the membrane. The NF membranes permit the passage of water molecules but prevent most of the ions in the water from passing through. NF membranes have a larger nominal pore size than the RO membranes, and as a result, they require a lower pressure to produce the same volume of product water. However, the larger pores also permit more dissolved solids including monovalent salts and lower molecular weight organics to pass through the membrane to the product water side.

Electrodialysis / Electrodialysis Reversal

Electrodialysis was commercially introduced in the early 1960s, about 10 years before RO. The development of electrodialysis provided a cost-effective way to desalt brackish water and spurred considerable interest in this area. Figure 3-4 is a schematic of this process.



LEGEND

C = Membrane permeable to positive ions only
A = Membrane permeable to negative ions only
+ = Any positive ion, e.g. Na
- = Any negative ion, e.g. Cl

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Schematic of Electrodialysis Stack System

January 1998
K/J 964634.00

Figure 3-4

Electrodialysis depends on the following general principles:

- Most salts dissolved in water are ionic, with positive (cationic) or negative (anionic) charge.
- These ions are attracted to electrodes with an opposite electric charge.
- Membranes can be constructed to permit selective passage of either anions or cations.

The dissolved ionic constituents in a saline solution such as sodium (+), calcium (++), chloride (-), and bi-carbonate (-) are dispersed in water, effectively neutralizing their individual charges. When electrodes connected to an outside source of direct current like a battery are placed in a container of saline water, electrical current is carried through the solution, with the ions tending to migrate to the electrode with the opposite charge.

For these phenomena to desalinate water, membranes that will allow either cations or anions (but not both) to pass are placed between a pair of electrodes. These membranes are arranged alternately with an anion-selective membrane followed by a cation-selective membrane. A spacer sheet that permits water to flow along the face of the membrane is placed between each pair of membranes.

One spacer provides a channel that carries feed (and product) water, while the next carries brine. As the electrodes are charged and saline feed water flows along the product water spacer at right angles to the electrodes, the anions in the water are attracted and diverted towards the positive electrode. This dilutes the salt content of the water in the product water channel. The anions pass through the anion-selective membrane, but cannot pass any farther than the cation-selective membrane, which blocks its path and traps the anion in the brine. Similarly, cations under the influence of the negative electrode move in the opposite direction through the cation-selective membrane to the concentrate channel on the other side. Here, the cations are trapped because the next membrane is anion-selective and prevents further movement towards the electrode.

By this arrangement, concentrated and diluted solutions are created in the spaces between the alternating membranes. These spaces, bounded by two membranes (one anionic and the other cationic) are called cells. The cell pair consists of two cells, one from which the ions migrated (the dilute cell for the product water) and the other in which the ions concentrate (the concentrate cell for the brine stream).

The basic electrodialysis unit consists of several hundred cell pairs bound together with electrodes on the outside and is referred to as a membrane stack. Feed water passes simultaneously in parallel paths through all of the cells to provide a continuous flow of desalted water and brine to emerge from the stack. Depending on the design of the system, chemicals may be added to the streams in the stack to reduce the potential for scaling.

An electrodialysis unit is made up of the following basic components:

- Pretreatment train
- Membrane stack
- Low-pressure circulating pump
- Power supply for direct current (a rectifier)
- Post-treatment

The raw feed water must be pre-treated to prevent materials that could harm the membranes or clog the narrow channels in the cells from entering the membrane stack. The feed water is circulated through the stack with a low-pressure pump with enough power to overcome the resistance of the water as it passes through the narrow passages. A rectifier is generally used to transform alternating current to the direct current supplied to the electrodes on the outside of the membrane stacks.

Post-treatment consists of stabilizing the water and preparing it for distribution. This post-treatment might consist of removing gases such as hydrogen sulfide and adjusting the pH.

Electrodialysis Reversal Process (EDR)

In the early 1970s, an American company commercially introduced the EDR process for electrodialysis. An EDR unit operates on the same general principle as a standard electrodialysis plant except that both the product and the brine channels are identical in construction. At intervals of several times an hour, the polarity of the electrodes is reversed, and the flows are simultaneously switched so that the brine channel becomes the product water channel, and the product water channel becomes the brine channel.

The result is that the ions are attracted in the opposite direction across the membrane stack. Immediately following the reversal of polarity and flow, enough of the product water is dumped until the stack and lines are flushed out, and the desired water quality is restored. This flush takes about 1 or 2 minutes, and then the unit can resume producing water. The reversal process is useful in breaking up and flushing out scales, slimes and other deposits in the cells before they can build up and create a problem. Flushing allows the unit to operate with fewer pretreatment chemicals minimizes membrane fouling.

Application

Electrodialysis has the following characteristics that lend it to various applications:

- Capability for high recovery (more product and less brine)
- Energy usage that is proportional to the salts removed
- Ability to treat water with a higher level of suspended solids than RO
- Lack of effect by non-ionic substances such as silica
- Low chemical usage for pretreatment

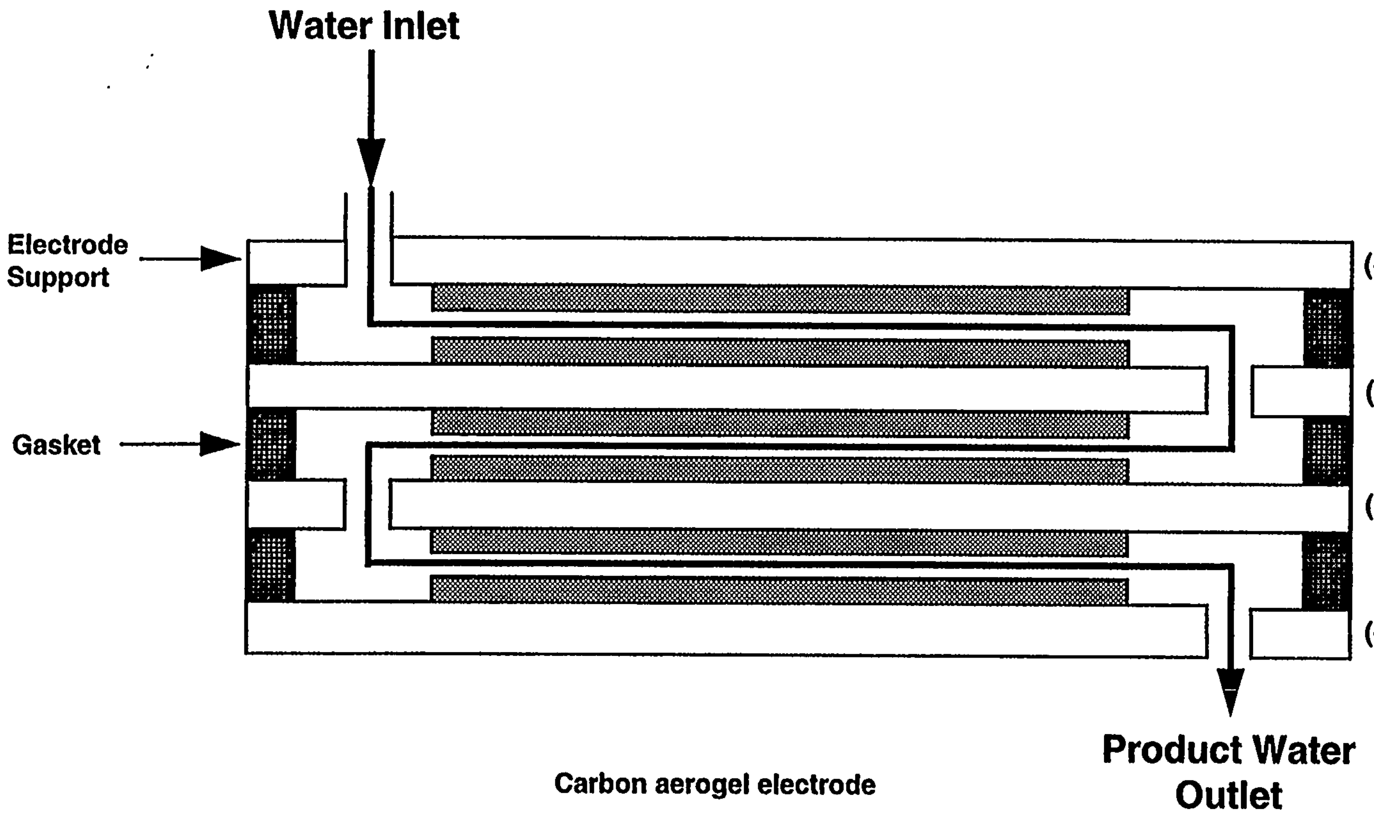
Electrodialysis units are normally used to desalinate brackish water. The major energy requirement is the direct current used to separate the ionic substances in the membrane stack.

OTHER TECHNOLOGIES

There are a number of other technologies in different states of development that are described below. Some are emerging while others are case specific.

Capacitive Deionization

Capacitive deionization (CDI) is an emerging technology that involves the use of porous carbon aerogel electrodes to remove dissolved ions through application of an electrostatic field. A bench-scale prototype for the capacitive deionization of water with a stack of carbon aerogel electrodes has been developed at Lawrence Livermore National Laboratory (LLNL). Figure 3-5 is a schematic of the prototype. As yet, the prototype does not necessarily represent the optimal geometric configuration from a reaction or hydraulic perspective. Aqueous solutions of NaCl or $NaNO_3$ have been passed through a stack of carbon aerogel electrodes, each having a



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DOE Project # DE-FC22-95MT95008

Schematic of Aerogel Technology

January 1998
K/J 964634.00

Figure 3-5

very high specific surface area (400 to 1,100 m^2/g). After polarization, non-reducible and non-oxidizable ions are removed from the electrolyte by the imposed electric field and held in electric double layers formed at the surfaces of electrodes producing a purified water. To regenerate the capacity of the aerogel a smaller amount of water is passed through the apparatus while reversing the applied charge to release the ions. In addition to charged species, compounds removed by carbon adsorption could potentially be removed from the feedwater with this process, but this application has not yet been tested. It is unclear how a large dissolved organic content in the feed water would affect the performance of this process.

CDI technology has been shown to successfully remove ionic species in bench-scale tests. LLNL plans to test a pilot-scale unit at various sites over the next year. This emerging technology was not considered for this project because it has not been tested under field conditions.

Freeze Thaw

Extensive work was done in the 1950s and 1960s to develop freezing desalination. During the process of freezing, dissolved salts are naturally excluded during the formation of ice crystals. Sea water can be desalinated by cooling the water to form crystals under controlled conditions. Before the entire mass of water has been frozen, the mixture is usually washed and rinsed to remove the salts in the remaining water or adhering to the ice crystals. The ice is then melted to produce fresh water.

Theoretically, freezing has some advantages over distillation, the predominant desalting process at the time the freezing process was developed. These advantages include a lower theoretical energy requirement, minimal potential for corrosion, and little scaling or precipitation. The disadvantage is that it involves handling ice and water mixtures that are mechanically complex to move and process.

A small number of plants have been built over the past 40 years, but the process has not been a commercial success in the production of fresh water for municipal purposes. The most recent significant example of freezing desalting was an experimental solar-powered unit constructed in Saudi Arabia in the late 1980s. The experimental work has been concluded, and the plant disassembled. At this stage, freezing desalting technology probably has a better application in the treatment of industrial wastes rather than the production of municipal drinking water.

Cogeneration

In some situations, it is possible to use energy so that more than one use can be obtained from it as the energy moves from a high level to an ambient level. This occurs with cogeneration where a single energy source can perform several different functions.

Certain types of desalination processes, especially the distillation process, can be structured to take advantage of a cogeneration situation. Most of the distillation plants installed in the Middle East and North Africa operate under this principle. These units are built as part of a facility that produces both electric power and desalted sea water for use in the particular country.

The electricity is produced with high-pressure steam to run turbines which in turn power electric generators. In a typical case, boilers produce high-pressure steam at about 540 °C (1,000 °F). As this steam expands in the turbine, its temperature and energy level is reduced. Distillation plants need steam whose temperature is about 120 °C (248 °F) or below, and this can be obtained by extracting the lower temperature steam at the low pressure end of the turbine after much of its energy has been used to generate electricity. This steam is then run through the distillation plant's brine heater, where it is condensed in the tubes, thereby increasing the temperature of the incoming sea water. The condensate from the steam is then returned to the boiler to be reheated for use in the turbine.

The main advantage of a cogeneration system is that it can significantly reduce the consumption of fuel when compared with the fuel needed if two separate plants were required. Since energy is a major operating cost in any desalination process, this can be an important economic benefit. One of the disadvantages is that the units are permanently connected together and, for the desalination plant to operate efficiently, the steam turbine must be operating. This can create a problem with water production when the turbine or generator is down for repairs.

This type of power and water production installation is commonly referred to as a dual-purpose plant. Since many of the oil producing countries of the Middle East and North Africa were engaged in building up their total infrastructure, these types of installations fit in well with the overall development program in these countries.

Other types of cogeneration facilities, such as industrial processes or incinerators, can reduce the cost of desalination by providing lower-cost sources of steam.

REMOVAL OF SCALE-CAUSING HARDNESS AND SILICA

As discussed previously, both membrane and thermal desalting processes require pretreatment to prevent inorganic scaling. Inorganic scaling occurs when the concentration of inorganic compounds such as calcite exceed their solubility product in the concentrated brine. Calcium and magnesium hardness, as well as silica, are the primary compounds of concern for inorganic scaling.

Seeded-slurry vapor compression systems are designed to combine pretreatment and evaporation in a single step by constantly recycling brine that has been seeded with calcium sulfate. If designed and operated correctly, they do not require pretreatment.

The most prevalent approach to address scaling in RO and thermal processes is to decrease the pH of the feed water to less than 7 and add an anti-scalant. The solubility of calcium and magnesium increases at a lower pH, and the anti-scalant helps prevent silica and other compounds from precipitating as solids.

Reverse osmosis also requires treatment to avoid organic fouling that occurs when dissolved organics are adsorbed and provide nutrients for biological activity within the pores of the RO membrane or on the membrane surface as a biofilm. Experience treating produced water with RO has shown that reducing feed water pH is not a practical operating strategy because it increases organic fouling (Dyke et al. 1992). The efficiency of boron removal also decreases with a lower pH because boron exists primarily in an unionized form of boric acid at pH below 9.5. Thus hardness and silica are usually removed from source water prior to treatment with either an RO membrane or thermal process. The most common processes used to remove hardness and silica are precipitative softening and/or ion exchange.

Precipitative Softening

In precipitative softening, hydrated lime ($Ca(OH)_2$) or caustic soda (NaOH) is added to the feed water to raise the pH and convert bicarbonate alkalinity into carbonate and hydroxide alkalinity. Soda ash, Na_2CO_3 may also be added as a source of carbonate. Calcium then precipitates with carbonate and magnesium precipitates with hydroxide. Silica precipitates directly with magnesium or co-precipitates with magnesium hydroxide, so additional magnesium is sometimes added to increase silica removal.

Produced water is typically warm when extracted, and precipitative processes are usually operated at either warm (90° to 170° F) or hot (215° to 230° F) temperatures rather than ambient temperatures (40° to 90°F). At the hot temperatures, the solubility of calcium carbonate is lower, the solubility of magnesium salts is higher, chemical kinetics are faster, and precipitates settle more quickly.

The primary difference between a hot process and the colder processes is that hot softening process operates in closed vessels under pressure, while warm and ambient softening processes operate at atmospheric pressure. In hot processes, carbon dioxide is generally flashed off prior to chemical addition as the water is heated above boiling, which reduces the doses of lime or caustic soda required.

Table 3-1 compares reported removal effectiveness of hot and warm lime softening processes at pilot-scale or full-scale produced water installations. The data indicate that both warm and hot lime processes are capable of removing up to 85 percent of influent silica to levels below 30 mg/L SiO_2. Bench studies, including those reported in Chapter 4 and described below, indicate that effluent silica concentrations can be reduced to less than 10 mg/L SiO_2 (VandeVenter et al. 1989).

Table 3-1

Comparison of Reported Silica Removal from Produced Water Using Warm-Lime and Hot-Lime Softening

Source (Size) Warm/Hot	Temperature (°C) / (°F)	SiO2 Influent	SiO2 Effluent	SiO2 Perc. Removal	Operating pH
Bridle 1986 (5,824 gpm) Hot	80 - 90 / 176-194	203	28	86	9.5
Tao et al. 1992 (5 gpm) Warm	up to 78 / up to 172	250	<30	88	11.0
VandeVeeter et al. 1989 (1,200 gpm) Warm	38 / 100	63	23	63.5	11.2
Zalewski et al. 1991 (6,900 gpm) Warm	60-75 / 140-167	290	45	85	9.1 - 9.4

Effluent hardness concentration is controlled by the availability of carbonate for precipitation and the solubility of calcium and magnesium at the operating pH and temperature. At warm temperatures, effluent hardness concentrations can be reduced to less than 20 mg/L $CaCO_3$ by adding excess soda ash to react with hardness (DeSilva 1996). Hot processes with excess soda ash can reduce hardness to less than 12 mg/L $CaCO_3$ (Powell 1966). For complete softening, a subsequent polishing ion exchange step is necessary for both hot or cold softening processes.

Silica Removal Mechanisms

Silica removal in precipitative softening is often characterized in the literature as adsorption to or co-precipitation with magnesium hydroxide. Mujeriego (1976) suggests that silica is also removed by forming metal silicates, such as magnesium silicate shown in the following reaction:

$$2Mg^{2+} + 3SiO_2(aq) + 5.5\ H_2O = Mg_2Si_3O_8(H_2O)_{3.5}\ (s) + 4H^+$$

Mujeriego's research indicated that silica removal by magnesium is controlled by the $H_3SiO_2^-$ while silica removal by calcium is controlled by $H_2SiO_2^{2-}$. He found that silica removal was optimized at pH levels that corresponded to the maximums of the controlling species. For example, silica removal with magnesium was greatest at a pH where $H_3SiO_2^-$ dominates: $(p^*K_1 + p^*K_2)\ /2$ where p^*K_1 and p^*K_2 represent the first and second dissociation constants for orthosilicic acid. The temperature-dependent equation for these constants are given below, for T in Kelvin:

$$p^*K_1 = 3405.9\ /\ T - 6.368 + 0.016346 \times T$$

$$p^*K_2 = 8949.2\ /\ T - 33.11 + 0.049581 \times T$$

Table 3-2 provides values for these dissociation constants at room temperature and at temperatures indicative of produced water.

Table 3-2

Dissociation Constants for Orthosilicic Acid *

T (°C / °F)	p^*K_1	p^*K_2	$(p^*K_1 + p^*K_2) /2$
25 / 77	9.93	11.69	10.81
50 / 122	9.45	10.61	10.03
60 / 140	9.30	10.27	9.78
65 / 149	9.25	10.15	9.70
70 / 158	9.17	9.98	9.58

*For the reactions:

$H_4SiO_2 = H_3SiO_2^- + H^+$

$H_3SiO_2^- = H_2SiO_2^{2-} + H^+$

$p^*K_1 = [H_3SiO_2^-] / [H_4SiO_2]$

$p^*K_2 = [H_2SiO_2^{2-}] / [H_3SiO_2^-]$

The amount of sludge produced by a precipitative softening process depends on the amount of hardness removed and the amount of lime added, if any. For silica removal, sludge is often recycled or allowed to form a sludge blanket (Powell 1966).

Ion Exchange

Hardness and silica can also be removed through a series of ion-exchange resins. Ion exchange is a process in which ions from a bed of synthetic resin are exchanged for ions in water that passes through the bed. The resins exchange different ions with different affinities, based on thermodynamic characteristics of the ions and the resins. In general ions with higher charge densities, defined as charge per ion size, are exchanged for ions with lower charge densities. The resins are initially saturated with ions that are absorbed with less affinity than the ion to be removed from the influent water. Source water is then passed through the column until the bed becomes exhausted, when undesirable levels of ions from the source water break-through the column. Resins are then regenerated with high concentrations of salts, bases, or acids to elute the undesirable ions from the resins.

Cationic exchange resins used for softening release sodium to preferentially remove calcium, magnesium, and other multivalent cations. Since calcium and magnesium are selected preferentially over sodium, source waters with high salinity can be softened.

Anionic exchange resins used for silica removal replace hydroxide with silicate. However, with chloride concentrations much higher than silicate concentrations, silica removal from high chloride produced water is impractical due to early exhaustion. Figure 3-6 provides a schematic of cation and anion exchange system for complete demineralization.

Combined Precipitative and Ion Exchange Softening System

A combination of precipitative softening and ion exchange can be used to economically remove hardness and silica from source waters. In this case, precipitative softening without the addition of soda ash reduces effluent silica concentrations to less than 10 mg/L while leaving between 50 to 150 mg/L of the hardness in the effluent. When no soda ash is supplied, less calcium is removed as sludge, and silica is removed more efficiently because magnesium hydroxide accounts for a larger share of the precipitation product. Cation exchange would then used to remove the residual calcium hardness to less than 1 mg/L.

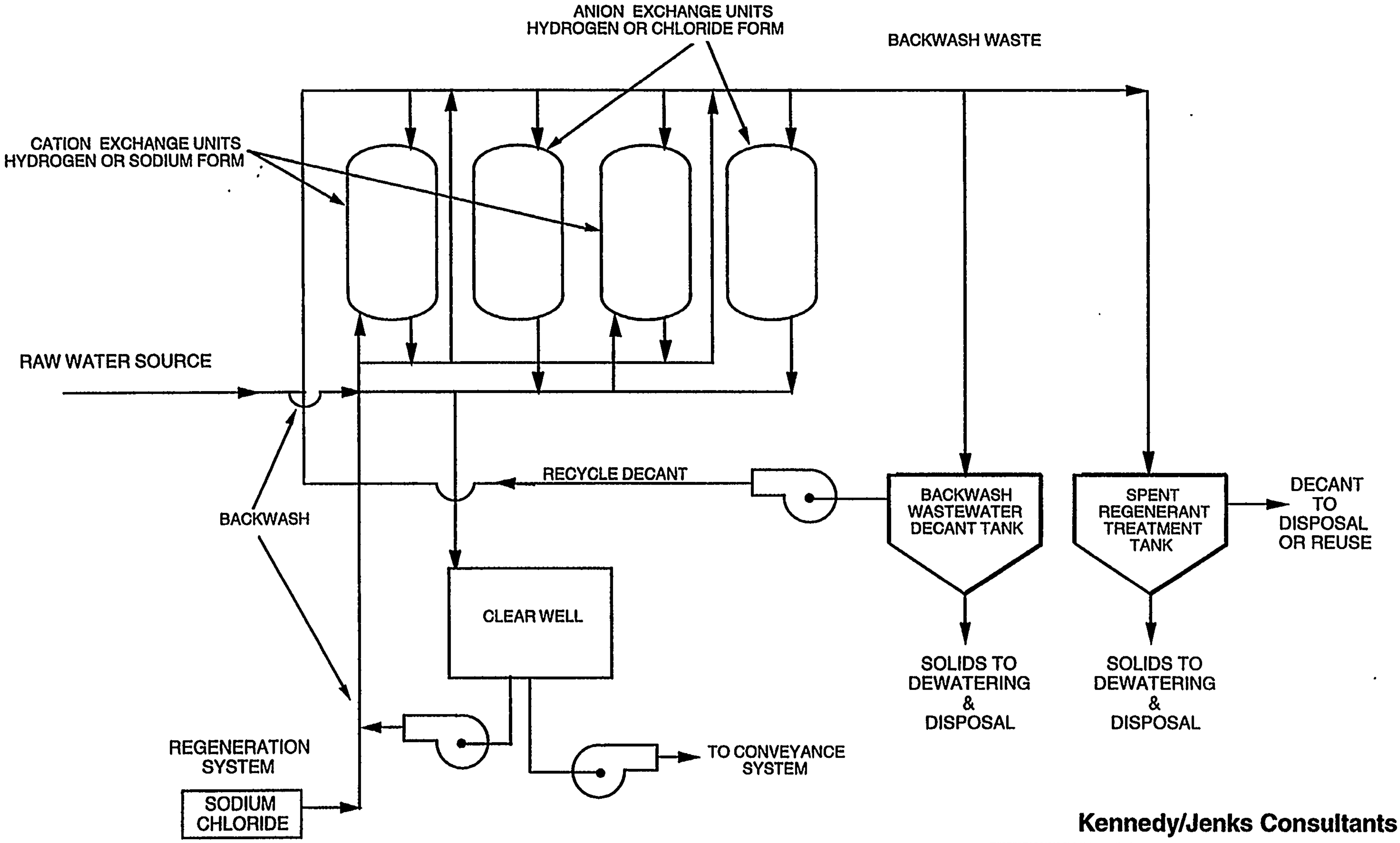
REMOVAL OF BORON

Boron, often found in produced waters as borate, must be removed from water that will be used for agricultural irrigation, especially for citrus crops. Boron is often found at levels over 20 mg/L B in produced water, while irrigation goals are between 0.7 and 0.5 mg/L B, thus necessitating more than 95 percent removal.

Boron is difficult to remove as an unionized form of boric acid at pH below 9.5. At higher pH, boron can be removed from produced water with precipitation, boron-selective ion exchange resins or reverse osmosis.

Precipitative Softening

Boron is removed during precipitative softening in a process similar to silica removal. Results from a bench scale study, discussed below, indicate that influent boron concentrations of 18 to



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ARCO Western Energy
DOE Project # DE-FC22-95MT95008

Schematic of
Two Bed Ion Exchange System

January 1998
K/J 964634.00

Figure 3-6

20 mg/L can be reduced to 5 to 10 mg/L in precipitative softening effluent by adjusting pH and adding magnesium chloride. The chemical precipitation behavior of boron is similar to silica, as Table 3-3 indicates.

Table 3-3

Dissociation Constants for Boron*

T (°C / °F)	pK_1	pK_2	$(pK_1 + pK_2)/2$
25 / 77	9.2	12.74	10.97
50 / 122	8.48	11.74	10.11
60 / 140	8.23	11.39	9.81
65 / 149	8.11	11.21	9.66
70 / 158	7.99	11.05	9.52

*For the reactions:
$H_3BO_3 = H_2BO_3^- + H^+$
$H_2BO_3^- = HBO_3^{2-} + H^+$
$pK_1 = [H_2BO_3^-] / [H_3BO_3]$
$pK_2 = [HBO_3^{2-}] / [H_2BO_3^-]$

This table shows that the average between first and second dissociation constants of boric acid is similar to values for orthosilicic acid. If boron is removed through a mechanism similar to silica, removal for both metals should be optimized at the same pH.

Ion Exchange

The Rohm and Haas Company sells an ion exchange resin Amberlite IRA-743 that selectively removes borate and boric acid. A variety of solutions containing boron have been tested under laboratory conditions using a cross-linked polymer resin to remove boron. In one experiment, a solution of 500 mg/L sodium chloride and 10 mg/L boron was passed through a bed of the Amberlite IRA-743 resin. Effluent boron concentrations were less than 1 mg/L. At a flow rate of 2 gallons per minute per cubic foot of resin (gpm/ft^3), the resin absorbed 2.0 ounces per ft^3, equivalent to 1,500 gallons of water per ft^3 of resin (Rohm and Haas 1993.)

While the boron removal results are promising for ion exchange, costs for this technology are high. Extrapolation of these and other similar results, approximately 800 ft^3 of resin would be required to treat 1.2 mgd of water from reverse osmosis or thermal process from an average boron concentration of 10 mg/L to less than 1 mg/L. At approximately $1,000 per ft^3 of resin, a planning level capital cost estimate for a boron-selective ion exchange system is $1.6 to $2.3 million including installation (Crossen 1996).

Reverse Osmosis

When operated at a pH where boron is present as borate (disassociated boric acid), reverse osmosis (RO) removes a significant fraction of boron in produced water. At pH between 10.6 and 11.0, greater than 99 percent boron rejection has been reported (Dyke et al. 1992). At a lower pH, the RO process was less successful in removing boron.

CHARACTERIZATION OF ORGANICS

The majority of organic material found in the produced water, unlike surface and uncontaminated shallow groundwaters, can often be totally identified from a mass balance perspective, within analytical accuracy. Reported values of dissolved organics in produced waters range from 10,000 mg/L to 1,000 mg/L (Somerville 1987, Giordano and Kharaka 1994).

The organic species that have been reported in produced waters as organic acids, and aromatic and aliphatic hydrocarbons. More than 80 percent of the dissolved organics are monocarboxylic (e.g., acetate, proprionate, and butyrate) and dicarboxylic (e.g., oxalate, malonate, and succinate) acid anions (Somerville 1987, Giordano and Kharaka 1994). Kharaka et. al. have hypothesized that the origin of these organic acids are from the thermal alteration of kerogen in source rocks. Approximately 15 percent are organic acids containing more than four carbons. The remaining organics, approximately 5 percent, can be identified by conventional EPA Priority Pollutant Organics Analysis as phenols and single ring aromatics e.g., benzene, toluene, xylene, ethylene benzene.

From Table 3-4 the dissolved organics of produced water as measured by Total Organic Carbon (TOC) is approximately 50 mg/L. The aromatic compounds are all in the µg/L range. The chlorinated benzene compounds are not native to the formation. ARCO Western Energy is performing an audit to determine the source of these chemicals. A review of the Material Safety Data Sheets of the feed chemicals does not indicate that these chlorinated benzenes are components, but it is likely that the source is from some of the feed chemicals or operational procedure.

ORGANICS REMOVAL

Without pretreatment, the primary desalting technologies, RO and thermal distillation, are expected to remove approximately 90 percent of influent dissolved organics from produced water. However, the remaining level of TOC, approximately 5 mg/L for the Placerita produced water is likely to be regulated to a lower level for the proposed Disinfection Byproduct Rule for drinking water. In the recently negotiated EPA Disinfection/Disinfection Byproducts Rule for drinking water, groundwater systems with TOC concentrations greater than 2 mg/L must conduct precursor removal studies (Pontius 1993). Depending on the results of a national survey that will be completed in 1998, the TOC levels in drinking water may be limited to less than 2 mg/L. In view of this potential regulatory requirement, additional organics removal would likely be necessary prior to using the treated water as a potable water source.

Except for the chlorinated benzenes, more than 99 percent of the dissolved organics can be biodegraded. Additional engineered processes such as stripping, adsorption, and membrane technologies can be used to get the TOC below 2 mg/L and specific targeted organics below EPA MCLs or the State of California action limits identified in Table 2-2.

Adsorption

Granular activated carbon (GAC) has been demonstrated to remove TOC to low levels (Roberts and Summers 1992). Unfortunately, the character, particularly the isotherm characteristics, of organics, remaining in produced water after RO or thermal distillation has not has not been determined. In general, the less soluble an organic compound is in water, the better it is adsorbed with GAC (JMM 1985). The majority of organics in produced water are polar organic acids that are highly soluble in water, so required empty bed contact times for GAC adsorption may be longer than systems that treat other types of water.

For TOC removal GAC is a well established technology and is generally used as one of the last treatment steps. In the treatment of produced water, this would occur after RO or distillation and at this location, would minimize carbon usage.

Air Stripping

Air stripping has been used to remove hydrogen sulfide, carbon dioxide, and volatile organics (e.g., the aromatics found in produced water) from water (AWWA 1990). Since the majority of organics in produced water are organic acids and not volatile or semi-volatile, air stripping would not effectively remove them under most practical design and operating conditions. This process is a proven technology for removing the aromatic organics to below EPA MCLs or the State of California action limits.

Biological Treatment

Biological treatment has been used extensively for the treatment of municipal and industrial wastewaters (Eckenfelder 1966). Several research studies have demonstrated that biological treatment can degrade a wide range of trace organic compounds (Manen and Rittman 1992; Krasner et al. 1993). Generally, biological treatment is accomplished in either suspended growth or fixed-film arrangements. In suspended growth systems, biological activity occurs as free-floating microbes consume nutrients and utilize electron acceptors (usually oxygen) that are typically mixed vigorously. In fixed-film systems, biological activity occurs when nutrients and electron acceptors are absorbed into a film of attached microbes. For wastewaters, activated sludge is a common example of a suspended growth system while trickling filters are a common fixed-film process. Additional fixed-film processes include rotating biological contactors and fluidized or packed-bed reactors (Kinner 1988).

For treating drinking water, fixed-film approaches are generally employed. Biologically active sand filters or biologically active carbon filters are two examples. These reactors combine physio-chemical adsorption with biological activity to increase the effectiveness of organic removal and decrease the frequency of GAC reactivation.

The Gas Research Institute (GRI) has sponsored research using biological granular activated carbon-fluidized bed reactors (GAC-FBR) to treat fluids from gas production and exploration. The fluidized bed reactor tested is an ultra-high rate, biological fixed film treatment process that has proven effective at removing benzene, toluene, ethylbenzene and xylenes (BTEX) compounds (Hickey et al. 1994).

Fixed film processes have not been extensively used for produced water treatment. The suspended growth technology has been installed at many full scale sites at petroleum refineries where the organics are similar in nature to produced water, but in much higher concentrations.

Ammonia Removal

While not specifically regulated in water quality standards, ammonia presents a number of operational problems, including increased corrosion in copper and copper alloys, additional chlorine disinfectant demand, and increased biological activity in potable distribution systems that includes nitrification and enhanced biofilm formation.

Possible ammonia treatment technologies include air stripping, ion exchange, and break point chlorination. Generally, these technologies have been listed in order of preference. Except for break point chlorination, which is used extensively in Europe, these are considered proven technologies in the US for drinking water applications. The major water quality concerns for using the break point chlorination process include elevated levels of disinfection by-products (DBPs), taste and odor compounds associated with this treatment approach, and the increase of chlorides.

RO is not generally used when ammonia is the only parameter for removal, but this process is effective when operating at a pH where ammonia is in the form of NH_4^+. Ammonia is generally removed by RO with efficiencies exceeding 85 percent when operating below pH 8.5. Similar pH conditions are required for ammonia removal with ion exchange. However, when operated at a high pH, RO rejects less than 15 percent of ammonia in the feedwater (Dyke et al. 1992). Air stripping of ammonia generally requires a pH above 10 to ensure that the majority of it is in the strippable form of NH_3. Break point chlorination is not as dramatically affected by the operational pH, but chlorine requirements increase outside of the optimal range of pH 6 - 7.

Cooling

The temperature of produced water, typically between 100 and 170 °F (38 and 77 °C) when extracted, must be reduced to less than 100 °F before the water can be treated with reverse osmosis membranes. Assuming a water temperature of 160 °F (71.1 °C) after lime softening and a target temperature of 90°F (32 °C) for RO membranes, the produced water must be cooled 70 °F (39 °C). This cooling translates into approximately 11.3 M kilo-calories per hour of heat transfer for a 1.8 mgd flow. The cooling required can also be expressed as 240 tons of refrigeration, where each ton equals 12,000 BTU per hour. The produced water may also require additional cooling before it is discharged to receiving water bodies such as drinking water reservoirs or irrigation channels.

A cooling tower is one common industrial cooling device in which hot water is passed in direct contact with a large volume of air. Towers are designed with natural or mechanically induced flow of air that can be directed counter-current or cross-current with respect to the downward flow of water. The choice of design depends on the required transfer efficiency and prevailing weather patterns at the site (Nalco 1988). The effective area of heat transfer between the water and air can be maximized by spraying the water into fine droplets or directing the water through a bed of randomly packed materials. Heat is transferred from the water to the air though conductive transfer and evaporation. The cooling tower requires periodic blow-down to remove fouling and solids that concentrate and build-up within the tower. Depending on atmospheric conditions and water stability, approximately 5 to 15 percent of the water applied to the cooling tower will be lost to evaporation and blowdown, although in principle evaporated water may be recovered.

Heat can be transferred away from produced water though direct transfer into the atmosphere or through an indirect heat exchange system. Since most cooling towers cannot operate above 130 °F, direct cooling systems often pre-cool with radiators or recycle cooled water to reduce the temperature of water applied to the cooling tower. The potential for ammonia stripping is one advantage of direct cooling.

An indirect cooling system utilizes a heat exchanger with a separate cooling loop. One arrangement is a heat exchanger with produced water on the hot side changing temperature from 160 to 90 °F (71 to 32 °C) and a recycled flow twice as large on the cool side changing temperature from 80 to 120 °F (27 to 49 °C). The recycled cooling loop would include a cooling tower or other cooling system to reduce the temperature of the cooling water to from 120 to 80

°F (49 to 27 °C). The primary advantage of indirect cooling is that the produced water is not applied directly to a cooling tower, which reduces the potential for fouling.

TECHNOLOGY SCREENING AND SELECTION DESCRIPTION

Table 3-1 presents the treatment steps recommended for treating produced water to drinking water standards. The table also lists anticipated concentration levels for constituents of concern throughout the process.

Table 3-4

Concentrations of Constituents of Concern Anticipated in Proposed Treatment System

Process	Temp (°F)	pH	Ammonia (mg/L)	TOC (mg/L)	Total Hardness (mg/L $CaCO_3$)	TDS (mg/L)	Silica (mg/L SiO_2)	Boron (mg/L B)
Influent	160	7	15	120	1,500	6,000	200	20
Warm Precipitative Softening	150	9.7	15	110	100	5,500	10	10
Cooling	90	8 - 8.5	15	110	100	5,500	10	10
Fixed-Film Organic Removal	90	8 - 8.5	2	30	100	5,500	10	10
Sand Filtration*	90	8 - 8.5	2	20	100	5,500	10	10
Ion Exchange Softening	90	8 - 8.5	2	20	10	5,500	10	10
Reverse Osmosis	85	10 - 11	2	2	0	300	< 1	< 0.5
Stabilization	85	7.5	2	2	70	350	< 1	< 0.5
Disinfection	85	7.5	< 1	2	70	350	< 1	< 0.5
Effluent	80	7.5	< 1	2	70	350	< 1	< 0.5

* Sand filters are included primarily to remove suspended solids sloughed from the biological process. Cartridge filters will also be included to protect the ion exchange resin and RO membranes from fouling.

The following sections explain the rationale behind the selection of warm versus hot precipitative softening and reverse osmosis over thermal evaporative treatment trains.

Warm Lime Versus Hot Lime

A warm precipitative softening process was selected as a pretreatment to remove a majority of potential scale-forming silica, as well as a portion of influent hardness, oil and grease, and boron.

As discussed above, hardness and silica can be removed through either warm (90° to 175° F; 32 to 80 °C) or hot (215° to 230° F; 102 to 110 °C) precipitative softening processes. Warm and hot processes remove silica to comparable effluent qualities while hot processes remove hardness to slightly lower levels when operated with excess soda ash.

To minimize the quantity of sludge produced from the precipitative softening process, partial softening without soda ash would likely be used for the Placerita produced water. In this operating scenario, the potential advantage of a lower effluent hardness concentration from a hot process operated with excess soda ash would not be utilized.

From an operational perspective, the warm process offers several advantages (Zalewski et al. 1991). Since a warm process softener is operated at atmospheric pressure, it is easier to operate and monitor. A warm process is also less energy intensive because it does not require an external heat source. Furthermore, the effluent from a warm process requires less cooling before being treated with RO membranes or being used to regenerate ion exchange resins.

Reverse Osmosis Versus Thermal Technologies

Treatment technologies to remove dissolved salt from water include thermal distillation and membrane processes, as discussed above. Within the desalination industry, membrane technologies such as reverse osmosis (RO) are generally the technology of choice for brackish applications, while both distillation and membrane processes are considered competitive for higher salinity waters such as sea water. Selecting the appropriate desalting technology for a particular project depends to a large extent on specific conditions and requirements of the project. In the case of brackish produced water, the high influent temperature and the need for extensive treatment prior to treatment with membranes suggest that thermal processes should be considered.

The two desalting processes considered for this project are mechanical vapor compression (a distillation process) and reverse osmosis. The following discussion describes the two processes and compares their capital cost, operation and maintenance (O&M) cost, total annual cost, defined as the sum of amortized capital and operational costs. The suitability of the processes for the proposed produced water treatment plant is also evaluated.

Mechanical Vapor Compression

Mechanical vapor compression (MVC) is the most energy efficient distillation processes for desalting brackish water. The desalting equipment consists of a vessel with a tube bundle, mechanical compressor, heat exchanger, and pumps.

Incoming filtered produced water is dosed with a scale inhibitor and preheated if necessary in the heat exchanger by the exiting product and brine. The preheated produced water mixes with recirculating brine inside the shell and is sprayed onto the outside of the tubes. Vacuum created on the suction side of the compressor lowers the boiling point of the salt water mixture allowing vapor to evaporate from the produced water. This vapor is compressed and returned inside the tubes where it condenses. The latent heat released is transferred to the influent assisting in the evaporation process. Additional vacuum is provided by a vacuum pump, which draws off non-condensable gases, and vents outside the system.

For most applications "low-temperature" MVC operates with an internal temperature of less than 150 °F (65 °C). This relatively low operating temperature, approximately the same as the influent produced water, together with the scale control additive, reduces the scaling problems associated with higher temperature processes, and, because scale control additives generally are effective at lower temperatures, acid is not required. This feature allows a wider choice of materials for the heat transfer surfaces. However, acid is required for routine cleanings.

MVC systems have been installed in the United States and abroad, with the majority designed as zero-discharge brine concentrators and treatment systems for steam-water makeup. A popular evaporator for recovery of produced waters is the vertical tube, falling film evaporator, operated with seeded slurry to reduce or eliminate pretreatment requirements. Extensive pretreatment, including silica removal, is required for evaporators to treat produced water operated in the un-seeded mode. The amount of treatment is similar to pretreatment required for RO systems.

Companies offering MVC processes in the U.S. include Aqua-Chem Inc, Milwaukee, WI (414) 577-2723; IDE Technologies Limited, distributed through Ambient Technologies, North Miami Beach Florida (305) 937-0610; and Resources Conservation Company, owned by Ionics, Bellevue, Washington (206) 828-2400.

Reverse Osmosis

The reverse osmosis (RO) process uses hydraulic pressure to force pure water from the feedwater through a membrane. The energy required to overcome natural osmotic forces depends on the quantity of salts to be removed, but not in direct proportion.

RO has been the desalination technology of choice for small single-purpose plants for the last fifteen years. Both capital and operating costs for well-designed systems are below those for competing processes, especially up to about 20 MGD. The critical factor is pretreatment of the feedwater, as pretreatment costs vary depending on the water source.

A typical RO membrane is a modified film under pressure in the 150 - 600 psi range. The membrane acts like a filter to retain ions such as sodium and chloride on the brackish water side, while permitting pure or nearly pure water to pass through the membrane. Commercial RO units utilize the RO principle in several different process designs and membrane configurations. There are two major types of membrane systems which have been used in operating plants: 1) spiral wound, and 2) hollow fine fiber.

The recovery (hydraulic recovery) of RO and other desalting processes is the ratio of the product water to the feedwater. In general, most brackish water RO systems operate at recoveries between 65 and 90 percent depending upon the composition of the feedwater and the size of the system. A recovery of 90 percent means that for every 100 gallons of feedwater 90 gallons of product water and 10 gallons of concentrate are produced.

The recovery, or level of concentration in the brine, in part determines the amount of pretreatment necessary to prevent fouling of inorganic constituents. When compounds such as silica and calcite are concentrated in the brine, they may exceed their respective solubility concentrations.

COMPARISON OF COSTS

Costs for the two treatment systems were obtained by requesting planning-level costs estimates from vendors and cost-estimating computer models. Costs were compared based on capital cost, operation and maintenance (O&M) cost, and total annual cost, defined as the sum of amortized capital and operational costs. Capital costs were amortized over 20 years at an interest rate of 7 percent per year, yielding a capital recovery factor of 0.0936. These amortization rates are typical for municipal water utilities that often finance capital expenses through bonds.

Table 3-5 presents planning level cost comparison of the treatment options, reverse osmosis with pretreatment, VC with pretreatment, and seeded-slurry VC that does not require extensive pretreatment. The cost estimates have an accuracy of approximately -30 to + 50 percent.

Total capital costs listed include equipment and direct construction costs (50 percent of equipment) such as installation costs, as well as indirect costs (38 percent of equipment and construction costs) such as bonding, permits, legal fees and administration. Operating costs include chemicals, sludge disposal, energy, and labor. Operating costs do not include concentrate disposal or maintenance. Annual costs and unit costs include amortized capital and operations and maintenance costs.

Table 3-6 through 3-8 list the components of capital and annual costs for the three treatment trains evaluated and presents rounded totals that correspond to Table 3-5. Table 3-9 lists generic cost assumptions and Table 3-10 presents technology-specific design parameters used to estimate treatment costs.

Table 3-5

Planning Level Cost Estimates for

1.8 MGD Reverse Osmosis and Vapor Compression Systems

Desalting Technology	Treated Water Recovery (Percent of 1.8 MGD)	Total Capital Cost (Million 1996 Dollars)	Annual Operating Costs (Million 1996 Dollars/yr)	Total Annual Cost (Million 1996 Dollars/yr)	Total Unit Cost (1996 Dollars/AF of water produced)	Total Annual Cost (1996 cents/barrel of water treated)
Reverse Osmosis, including pretreatment	80	11	2.1 - 2.9	3.1 - 3.9	2,000 - 2,500	21 - 27
Mechanical Vapor Compression, including pretreatment	90	29	6.1	8.8	5,800	61
Mechanical Vapor Compression, Seeded Slurry	98	28	7.7	10.3	5,400	71

Table 3-6

Cost Breakdown for Reverse Osmosis System

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Cost (Thousand 1996 $)	Total Unit Cost (1996 $/AF of water produced)	Total Unit Cost (1996 cents/ barrel of water treated)
Warm Softening*	2.3	1,000 - 1,800	1,200 -2,000	800 - 1,300	8 - 14
Cooling	0.6	60	120	75	1
Fixed-Film Organics Removal	1.0	50	150	100	1
Sand Filtration	1.3	130	250	150	2
Ion Exchange Softening	1.3	150	280	160	2
Reverse Osmosis	4.1	600	1,000	700	7
Stabilization	0.1	20	30	20	<1
Disinfection	0.1	40	50	30	<1
Total	**11**	**2,100 - 2,900**	**3,100 - 3,900**	**2,000 - 2,500**	**21 - 27**

* Operating costs depend on operational strategy.

Table 3-7

Cost Breakdown for Vapor Compression System with Pretreatment

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Cost (Thousand 1996 $)	Total Unit Cost (1996 $/AF of water produced)	Total Unit Cost (1996 cents/ barrel of water treated)
Warm Softening	2.3	1,000	1,200	700	8
Sand Filtration	1.3	125	250	240	2
Vapor Compression	23.6	4,800	7,000	4,200	48
Cooling and Stripping	0.5	50	110	60	1
Carbon Filtration	1.3	100	200	250	1
Stabilization	0.1	20	30	20	<1
Disinfection	0.1	40	50	30	<1
Total	**29**	**6,100**	**8,800**	**5,800**	**61**

Table 3-8

Cost Breakdown for Seeded-Slurry Vapor Compression System Without Pretreatment

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Cost (Thousand 1996 $)	Total Unit Cost (1996 $/AF of water produced)	Total Unit Cost (1996 cents/ barrel of water treated)
Vapor Compression	25.7	7,500	10,000	5,200	68
Cooling and Ammonia Stripping	0.6	60	120	60	1
Carbon Filtration	1.4	100	120	130	2
Stabilization	0.1	20	30	20	<1
Disinfection	0.1	40	50	30	<1
Total	**28**	**7,700**	**10,300**	**5,400**	**71**

Table 3-9

Values Assigned to Generic Cost Factor

Parameter	Value	Unit
Capital		
Dollar	1996	index year
Mobilization and Bonding, Site Preparation, Contractor's Overhead and Profit, and Contingencies	50	percent of facilities costs
Indirect Costs, including Legal and Administrative	38	percent of construction bid costs
Interest Rate	7	percent/annum
Capital Recovery Period	20	years
O&M		
Electricity Rate	0.05	$ per kW hr
Labor Rate	30	$ per hr

Table 3-10

Design Parameters Assumed for Cost Estimation

Technology	Design Assumptions
Warm Precipitative Softening	NaOH dosage 700 - 1000 mg/L $MgCl_2$ 40 - 400 mg/L NaOH \$0.2 / lb; $MgCl_2$\$0.26 / lb Sludge Disposal \$50/ton (dry)
Cooling	Based on Packed tower with A/W = 50:1
Carbon Filtration	EBCT = 15 min Carbon replacement every 3 years
Fixed-Film Organics Removal	BOD loading = 50 lbs/day / 1000 ft^3 media 2- 40' diameter x 20' deep trickling filters
Sand Filtration	Hydraulic Loading Rate = 5 gpm/ft^2
Ion Exchange	EBCT = 3 min
R/O	Membrane replacement every 18 months 500- 8" x 40" elements at \$800/element 4 kWh/1000 gallon treated
MVC	140 kWh/1000 gallon treated

Capital Costs

Capital costs for VC systems are approximately 2.5 times larger than capital costs for RO systems. Costs for storage, including disinfection contact time, were not included in capital cost estimates because the storage costs will vary considerably depending on the use of the water.

Operating Costs

The major operating cost for RO and a large cost for VC is precipitative softening pretreatment. Sludge disposal and chemical costs for caustic soda and magnesium chloride account for roughly 90 percent of these costs. Costs were estimated for precipitative softening based on two operational strategies. As pretreatment for silica removal only, costs were based on a sodium hydroxide dosage of 700 mg/L and a magnesium chloride dosage of 40 mg/L. These silica removal costs were used for VC with pretreatment and as a lower bound for RO. As pretreatment for silica and boron removal, costs were based on a caustic dosage of 1,000 mg/L NaOH and 400 mg/L $MgCl_2$. These costs were used as an upper bound for RO, which may over-estimate costs because additional boron removal in softening could allow more flexible operation of the RO membranes and reduce the frequency of membrane replacement.

Electricity is the primary operating cost for VC and a major operating costs for RO. For brackish water applications, RO is much more energy efficient than VC. Typical energy usage rates are 1 to 10 KWh/1000 gallons for RO compared to 35 to 150 Kwh/1000 gallons for VC. Treating 1.8 mgd with an electricity cost of 5¢ per kWh, an RO process that requires 4 KWh/1000 gallons uses $0.15 million per year of electricity, while a VC process that requires 140 KWh/1000 gallons uses $4.6 million per year of electricity.

Membrane replacement costs are also significant for RO. Assuming an eighteen month membrane life, approximately 30 to 50 percent of the expected life in brackish municipal applications where organic loadings are much lower, the membrane replacement costs represents approximately half of RO annual operating costs.

Total Annual Costs

Total annual costs for vapor compression are approximately 2.3 to 3.3 times larger than total annual costs for reverse osmosis. In terms of cost per acre-ft of treated water produced, vapor compression is approximately 2.2 to 2.9 times more expensive. Costs measured this way reflect the water recovery of the treatment process. For example, RO produces 1.4 mgd of treated water from 1.8 mgd of feed water, while MVC produces in excess of 1.6 mgd from 1.8 mgd of feed water. On the other hand, total unit costs in terms of cents per barrel of produced water treated only account for the total volume of water treated, 1.8 mgd in either case. In these terms, total annual costs for vapor compression are 2.3 to 3.4 times larger than RO costs.

Chapter 4

Pilot Plant Description

CHAPTER 4

BENCH SCALE STUDIES

Bench-scale tests were conducted to provide information about the treatability of produced water from the Placerita site. These tests focused on precipitative softening because it is a key pretreatment step that may influence the selection and effectiveness of other processes in the treatment train, and also has a major impact on operations and maintenance costs. A series of jar tests was used to evaluate the effectiveness of warm precipitative softening in removing hardness, silica, boron, and organics.

GOALS

There were two goals of the bench scale testing phase of this project.

1) What combination of chemical additions, dosages, and pH values removes the highest amount of silica, organics, and borate?

2) How does the performance of hot-lime processes compare with warm-lime processes in terms of silica and organics removal?

TESTING PROCEDURE

Standard jar tests were performed to measure softening efficiency at a variety of chemical combinations and pH values by varying dosages of calcium hydroxide, sodium hydroxide, ferric chloride, and magnesium chloride. Experiments were conducted in 2 liter square jars using a standard Phipps and Bird jar testing apparatus. After chemicals were added, the jars were mixed at 150 rpm for two minutes, then mixed at 20 rpm for 20 minutes for flocculation, and allowed to settle quiessently for 30 minutes. Details of the experimental set-up are provided in Appendix A.

For each experiment initial and residual concentrations of total hardness, calcium hardness, alkalinity, silica, and boron were measured. Magnesium hardness was estimated as the difference between total hardness and calcium hardness. Chemical oxygen demand (COD) and biochemical oxygen demand (BOD) were also measured for optimization experiments.

Most jar tests were performed at warm temperatures of approximately 140 - 155 °F (60 - 68°C). The jars were placed in a water bath to regulate the temperature of their contents, with the water bath temperature regulated by coil-immersion heaters. Comparisons of silica, organics, and borate removal between warm lime and hot lime processes were made by testing a few combinations at higher temperatures and by reviewing literature results from hot-lime processes.

EXPERIMENT DESIGN AND RESULTS

Experiments were conducted to test whether the removal mechanisms for silica and boron predicted above were effective in the Placerita produced water.

The precipitation experiments were divided into three phases: preliminary, screening, and optimization. Data for all of the experiments are provided in Table 4-1.

Preliminary

During the preliminary phase titration curves with lime and sodium hydroxide were developed for the produced water at the desired temperature. The physical effects of adding lime and sodium hydroxide were also observed to determine when the produced water will generate precipitate with calcium and magnesium hardness naturally present in the produced water.

Preliminary tests indicated that relatively high dosages of lime and sodium hydroxide were required to raise the pH of the produced water. For example, over 1,000 mg/L of sodium hydroxide or lime was required to raise the pH to 11.0.

Screening

During the screening phase, a range of concentrations of lime, sodium hydroxide, magnesium, and iron was examined to determine the appropriate range to be tested for optimization. Lime dosages and sodium hydroxide concentrations were selected to provide a range of pH. Magnesium dosages were selected based on a molar ratio of silica in the influent, ranging from 2 to 16:1 $Mg:SiO_2$ on a molar basis. Sodium di-phosphate was also tested as a potential precipitation aid.

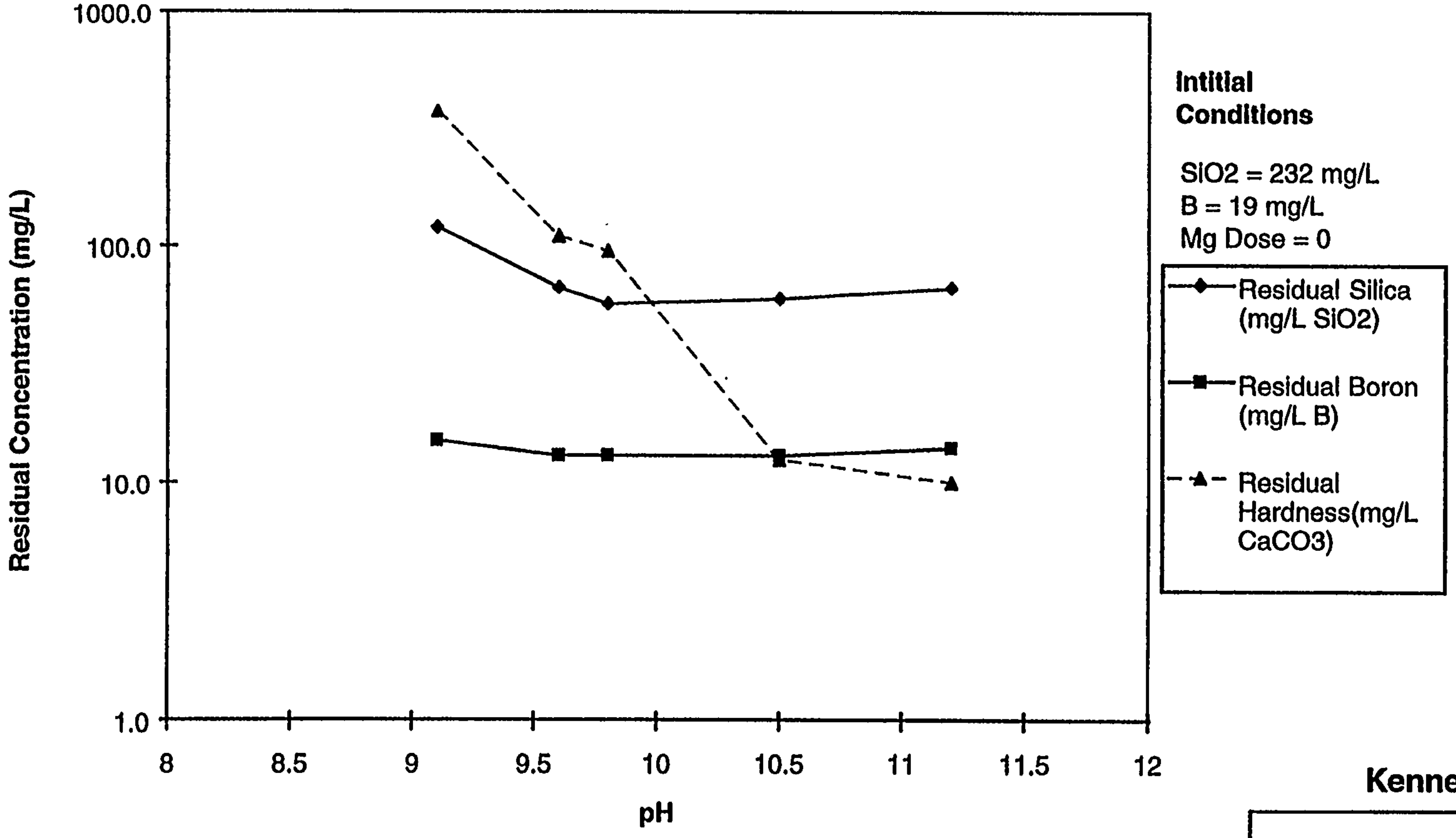
In the first experiment, increasing dosages of sodium hydroxide were added to each of the five jars. The residual concentrations of silica, boron, and hardness are presented in Figure 4-1. The minimum silica residual of 57 mg/L on this figure occurs near pH = 9.7, which agrees with

Table 4-1
Results of Bench-Scale Softening Experiments

Sample ID				Chemical Addition					Analytical results													
				NaOH	Lime	MgCl2 6 H2O	FeCl3 6 H2O	Na2PO4 7 H2O	pH		Temp (C)		Sludge Depth	Tot. Alk. (CaCO3)	Tot Hard. (CaCO3)	Ca (Ca) titr	Mg (Mg) titr	Silica (SiO2)	Boron (B)	COD	TOC	BOD
Date	Test	Sample		mg/L	mg/L	mg/L	mg/L	mg/L	Warm	Cool	Initial	Final	(mm)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10/14	1	Raw Unfilt	R							7.3				482	1200	320	96	232	19			
10/14	1	1	T	400					9.1	8.6	64	55		240	375	51	12.3	120	15			
10/14	1	2	T	600					9.6	9.3	64	55		232	110	18	15.8	67	13			
10/14	1	3	T	750					9.8	9.4	64	55		254	95	12	15.6	57	13			
10/14	1	4	T	875					10.5	10.5	64	55		392	12.5	2	1.8	60	13			
10/14	1	5	T	1,000					11.2	11.4	64	55		628	10	2	1.4	67	14			
10/15	2	Raw Filt	R											480	1240	316	108	202	19			
10/15	2	1	T		425				8.2	8.6	64	59.5	2	124	800	196	74	127	15			
10/15	2	2	T		650				9.1	9.2	64	59.5	5	132	850	140	60	118	15			
10/15	2	3	T		900				10.2	10.1	64	59.5	7	156	840	324	7	27	13			
10/15	2	4	T		1,050				11.1	11.2	63.5	59	11	304	940	358	11	23	13			
10/15	2	5	T		2,000				11.9	11.9	63	58.5	25	1130	1680	604	41	9.2	13			
10/15	2	6	T		900				10.7	10.9	85	75		264	960	372	7	35.3	13			
10/17	3	Raw Filt	R							7.8					1180			200	19	324	109	
10/17	3	Raw Unfilt	R											468		292	108				113	
10/17	3	1	T	400		800			8.8	8.4	65	58	14	252	800	84	142	99	14	356	171	
10/17	3	2	T	600		800			8.9	8.7	65	58	22	204	510	42	97	32	13	356	117	
10/17	3	3	T	750		800			9	8.9	65	57	25	208	390	34	73	19	12	356	109	
10/17	3	4	T	875		800			9.3	9.2	64	54.5	30	216	240	16	48	15	11	344	119	
10/17	3	5	T	1,000		800			9.7	9.6	64	54.5	34	238	105	7	21	10	8	348	111	
10/18	4	Raw Filt	R											408	1160	280	110	194	19	328	104	
10/18	4	Raw Unfilt	R							7.9					1170	280	113	226	19	348	94	
10/18	4	1	T	1,000					11.2	11.5	68	58.5	25	544	18		4	58	14	324	107	
10/18	4	2	T	960	37				11.3	11.6	68	58	24	516	14		3	55	14	342	105	
10/18	4	3	T	920	74				11.3	11.7	68	58	23	512	12	2	2	61	14	344	101	
10/18	4	4	T	840	148				11.3	11.6	66	55	21	380	30	8	2	54	13	352	102	
10/18	4	5	T	680	296				11.1	11.4	66	55	20	408	173	66	2	40	13	280	100	
10/22	5	Raw Filt	R											474	1210	180	122	174	17	312	92	14
10/22	5	Raw Unfilt	R							7.2				368	1240	268	139	188	18			12
10/22	5	1	T	700					9.7	9.6	68	59	21	156	80	14	11	23	12	312		10
10/22	5	2	T	800		400			9.7	9.5	68	59	28	152	108	18	15	13	10	328	96	10
10/22	5	3	T	1,000		800			9.8	9.8	68	59	35	152	100	8	19	6	8	320	103	8
10/22	5	4	T	940		1,200			9.7	10	68	60.5	40	172	150	6	33	6	7	328	99	11
10/22	5	5	T	1,100		1,600			9.7	10	68	62	45	164	160	6	35	6	5	324	98	7
10/23	6	Raw Filt	R											480	1290	340	106	142	18	348	95	19
10/23	6	Raw Unfilt	R												1290	348	100	123		348		13
10/23	6	1	T	750					9.7	9.5	66	59	22	225	130	14	23	31	12	308	95	9
10/23	6	2	T	775				526	9.7	9.6	66	59	27	426	120	18	12	48	11	308	85	8
10/23	6	3	T	800				1,052	9.8	9.8	66	58	27	506	72	6	14	58	13	284	82	8
10/23	6	4	T	825				2,105	9.7	9.6	66	60	30	706	22	5	2	83	14	280	92	8

Table 4-1
Results of Bench-Scale Softening Experiments

Sample ID				Chemical Addition					Analytical results													
				NaOH	Lime	MgCl2 6 H2O	FeCl3 6 H2O	Na2PO4 7 H2O	pH		Temp (C)		Sludge Depth	Tot. Alk. (CaCO3)	Tot Hard. (CaCO3)	Ca (Ca) titr	Mg (Mg) titr	Silica (SiO2)	Boron (B)	COD	TOC	BOD
Date	Test	Sample		mg/L	mg/L	mg/L	mg/L	mg/L	Warm	Cool	Initial	Final	(mm)	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10/23	6	5	T	850				3,157	9.7	9.7	66	60	30	904	16	4	1	17	14	364	88	17
10/24	7	Raw Filt	R							8.1				416	1160	392	103	111	17	320	95	20
10/24	7	Raw Unfilt	R												1180	300	103	124	18	348	92	
10/24	7	1	T	750					10	10	68	61		252	16	3	2	36	12	332	105	18
10/24	7	2	T		900				10.7	11	68	60		186	855	329	8	22	12	192	101	22
10/29	8	Raw Filt	R											352	1110	288	69	180	20	388	116	25
10/29	8	Raw Unfilt	R											484	1150			174	18	388		24
10/29	8	1	T	600					9.5	9.3	78	70.5	18	168	80	18	4	51	14	348	129	25
10/29	8	2	T	870		800			9.5	9.6	78	72	38	156	90	15	4	7	9	340	141	23
10/29	8	3	T	1,200		1,600			9.5	9.8	78	74	47	148	190	13	38	6	6	368	152	24
10/30	9	Raw Filt	R						7.8	7.3				420	1140	288	101		17		145	26
10/30	9	Raw Unfilt	R											484	1140			176	17	432		
10/30	9	1	T	850		800			9.7		64	61	17	228	255	16	52	10	9	420	151	22
10/30	9	2	T	1,060			1,080		9.7		64	61	17	248	155	12	30	14	14	428	164	21
10/30	9	3	T	1,450			2,160		9.7		64	61	19	186	245	14	50	18	15	398	142	21
10/30	9	4	T	700			1,080		8.6		64	61	11	184	565	67	95	73	17	392	168	25
10/30	9	5	T	1,150			2,160		8.6		64	61	12	120	635	112	85	37	17	416	150	23
10/31	10	Raw Filt	R																		133	
10/31	10	Raw Unfilt	R											480	1150	112	209	115	18	424		14
10/31	10	1	T	750					10.9		18	18	16	624	100	34	3	28	13	360	132	17
10/31	10	2	T	1,000		800			10.9		18	18	37	444	288	45	42	16	13	400	137	11
10/31	10	3	T	1,000		1,600			10.9		18	18	60	540	378	35	70	8	10	400	138	11
10/31	10	4	T	1,230			1,080		10.9		18	18	30	536	232	40	32	13	14	380	136	16
10/31	10	5	T	850			1,080		9.5		18	18	28	360	556	88	81	20	14	392	130	25
10/31	10	6	T	1,000	444				11.9		18	18	25	632	52	6	9	49	13	388	113	22
11/1	11	Raw Filt	R												1200	326	93	110	17	412	130	13
11/1	11	Raw Unfilt	R											500	1210	272	127	112	17	444		25
11/1	11	1	T	750					9.7		69	59	21	224	40	9	4	29	11	432	135	9
11/1	11	2	T	880		800			9.7		69	60	27	212	156	8	32	8	8	420	125	8
11/1	11	3	T	985		1,600			9.7		69	61	27	204	420	10	95	4	6	440	121	6
11/1	11	4	T	1,010			570		9.7		69	55	24	236	76	11	11	16	12	426	114	7
11/1	11	5	T	1,240			1,080		9.7		69	55	26	240	84	8	15	5	14	396	137	7



Kennedy/Jenks Consultants

ARCO Western Energy
DOE Project # DE-FC22-95MT95008

Results of Bench Tests with Caustic Soda Addition

January 1998
K/J 964634.00

Figure 4-1

the predicted value for a temperature of approximately 140 °F (60 °C). The jars were initially 147 °F (64 °C) and had cooled to 131°F (55 °C) by the end of quiescent settling. Boron removal was also highest in this range with a constant residual value of 13 mg/L for pH values between 9.1 and 10.5.

A second experiment was conducted using only lime. As shown in Figure 4-2, residual silica concentrations decreased as pH increased, with silica concentrations below 40 mg/L for all pH values above 10. Residual boron concentrations were constant for all pH values above 10.

Several tests were also conducted adding ferric chloride at a variety of pH values and iron dosages. Iron removed silica slightly less effectively as magnesium on a molar basis, and removed boron much less effectively.

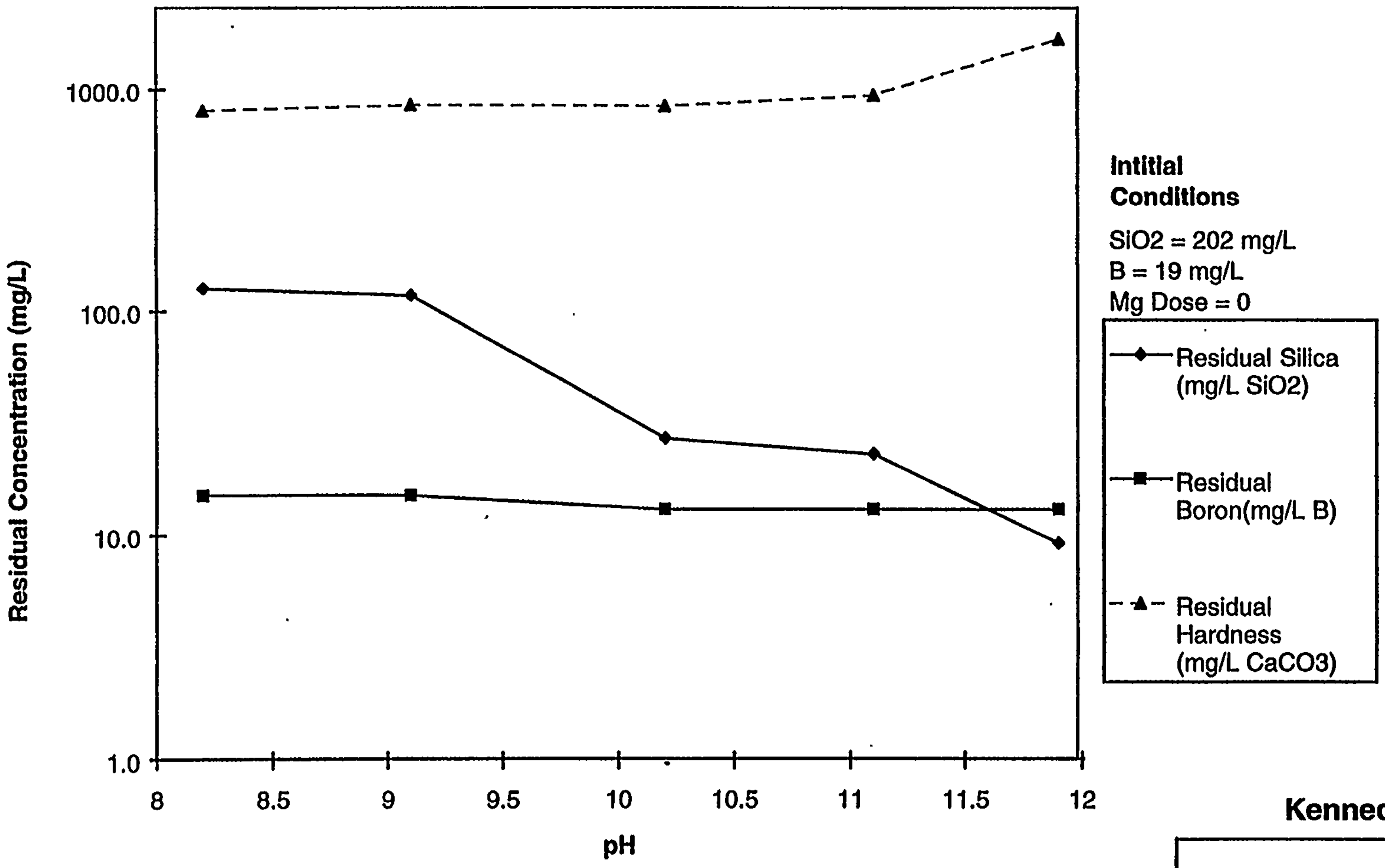
Sodium di-phosphate was also tested. Results from these tests indicate that phosphate did not remove silica or boron as effectively as magnesium. Additionally, the dosage of Na_2HPO_4 that corresponded to the minimum silica residual was not the same as the dosage that yielded the lowest boron concentration. No further experiments were conducted with phosphates.

Optimization

Promising combinations of lime, caustic soda and magnesium were further tested in the optimization phase. The experiments focused on two pH ranges: 11-12 for removal with calcium, and 9.5 to 10 for removal with magnesium. These ranges were based on theoretical removal mechanisms and results from screening tests.

In addition to measuring residual silica and boron concentrations, sludge depths were recorded for these tests to estimate the production of sludge.

To determine the optimal level of magnesium addition for simultaneous removal of boron and magnesium, several tests were conducted with various dosages of magnesium at a constant pH of approximately 9.7. Figure 4-3 shows the results of this experiment. Residual silica concentrations were constant at 6 mg/L for magnesium chloride dosages between 400 and 1600 mg/L, while boron concentrations continued to decrease in this range, from 10 mg/L to 5 mg/L. Sludge depth and residual hardness increased with increasing magnesium dosages.



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Results of Bench Tests with Lime Addition

January 1998
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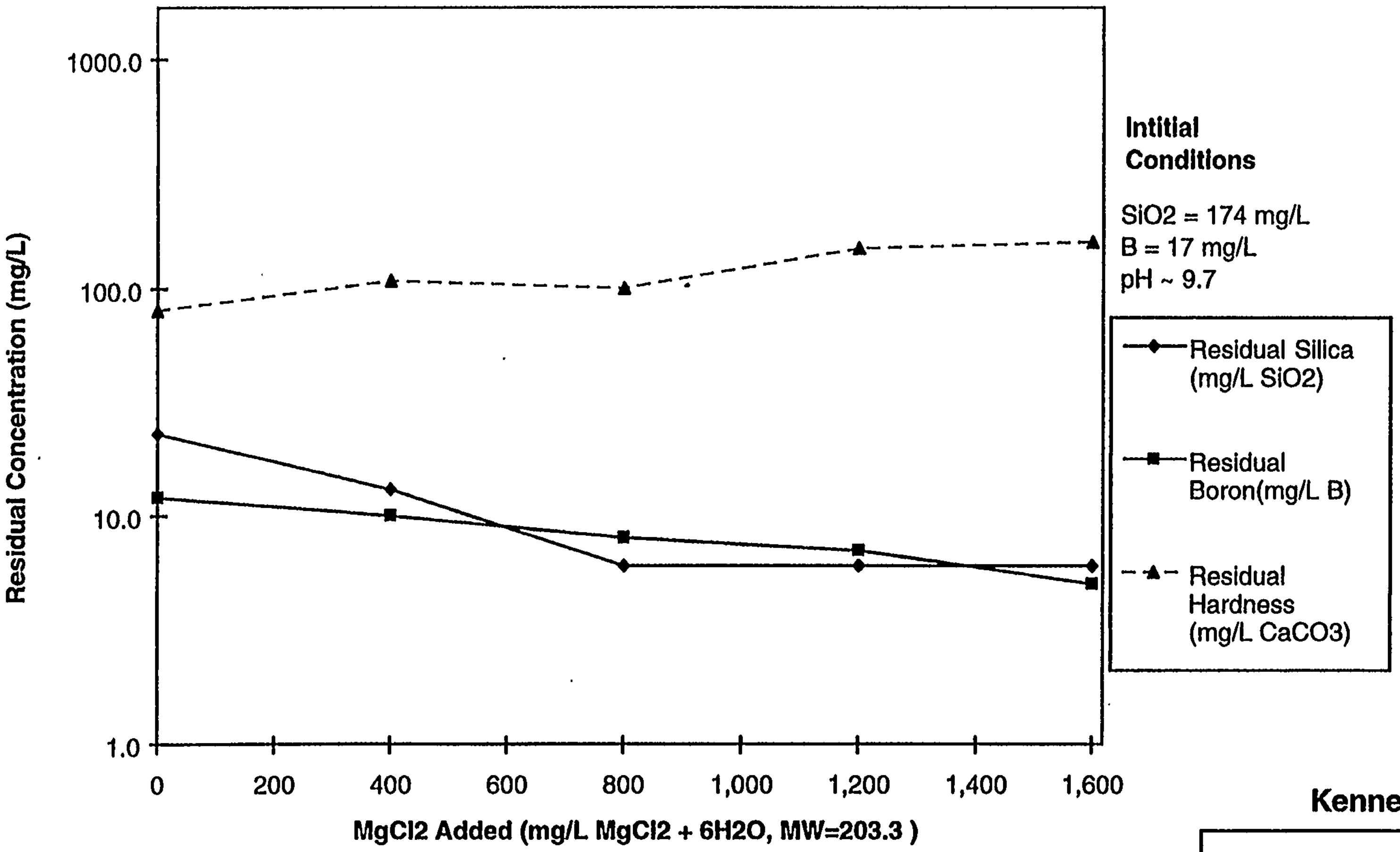
Figure 4-2



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DOE Project # DE-FC22-95MT95008

Results of Bench Tests with Various Dosages of $MgCl_2$ Added

January 1998
K/J 964634.00

Figure 4-3

Throughout the remainder of the experiments, jars with magnesium addition at pH of 9.7 were tested to provide duplicate values and as a control. When residual silica values are plotted against pH and magnesium removed (since raw water magnesium concentrations varied), a definite pattern emerges. Figures 4-4 through 4-6 present the results of these tests with isoconcentration contours. Figure 4-4 shows that for a given amount of magnesium removed, the lowest concentrations of residual silica occur between pH values of 9.4 and 10. This presents further evidence for the magnesium silicate removal mechanism. Within this range, residual silica concentrations decrease with increasing magnesium removal until approximately 15 meq of magnesium have been removed. This point corresponds to a magnesium chloride dosage of approximately 800 mg/L. With further magnesium dosages and removals, silica concentrations remain between 4 and 6 mg/L, with one exception of 10 mg/L.

Figure 4-5 presents a similar plot for residual boron, while Figure 4-6 presents results for residual hardness. Both figures indicate local minimums at pH ~ 9.7 and 15 meqs of magnesium removal. At this pH, the concentration of boron appears to decrease as magnesium removal increases, while residual hardness begins to increase as magnesium removal increases beyond 15 to 20 meqs.

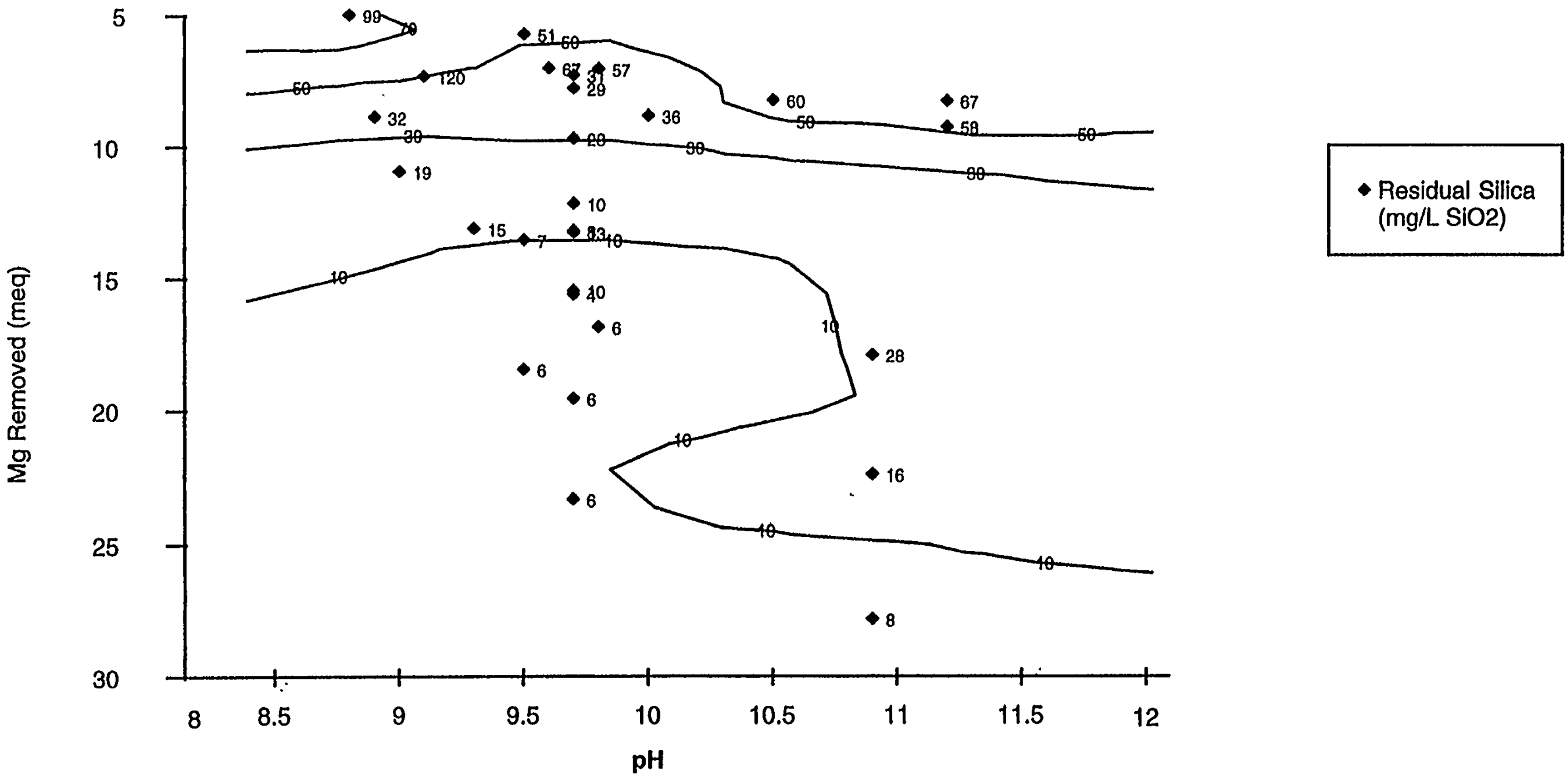
Additional Experiments

Throughout the testing, a number of experiments were conducted to evaluate the effects of changing temperature and sample aging on test results. Experiments conducted at 158 - 172 °F (70 - 78 °C) did not produce significantly different results.

CONCLUSIONS FOR BENCH SCALE STUDIES

Results from the bench scale tests indicate that warm precipitative softening with caustic soda at pH values between 9.5 and 10, with the addition of magnesium chloride, can simultaneously reduce both silica and boron levels. Results indicate that increasing magnesium chloride dosages between 0 and 800 mg/L provide higher removal percentages for boron and silica. For magnesium chloride dosages above 800 mg/L, residual boron concentrations decrease, residual silica concentrations remain constant, and residual hardness levels increase.

Softening with lime was also shown to be effective at a higher pH range of 11 to 12. Precipitation using iron was shown to be less effective than magnesium at removing silica and was not shown to effectively remove boron.



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Residual Silica Concentration Contours for Tests Adding $MgCl_2$

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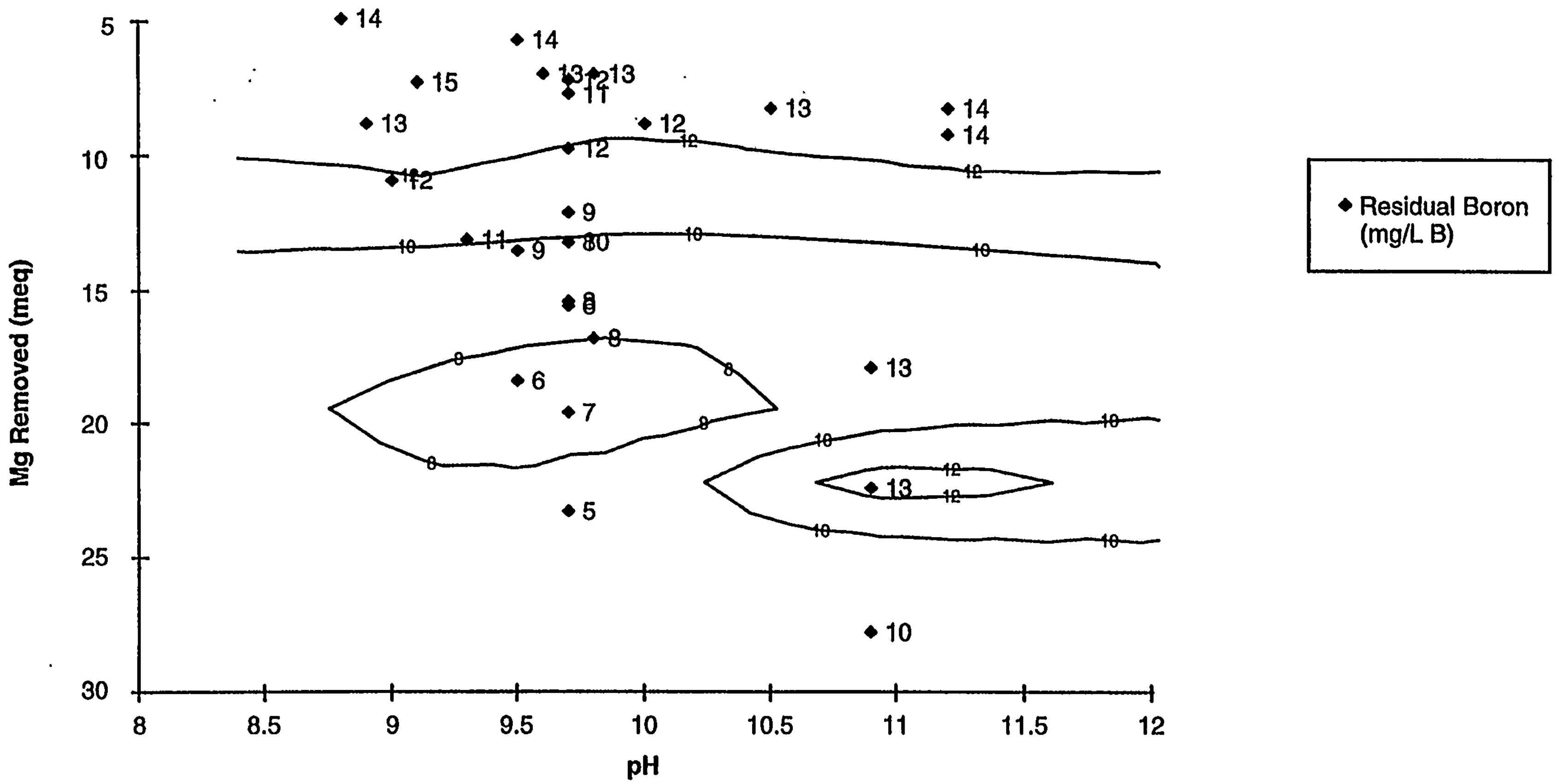
K/J 964634.00

Figure 4-4



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Residual Boron Concentration Contours for Tests Adding $MgCl_2$

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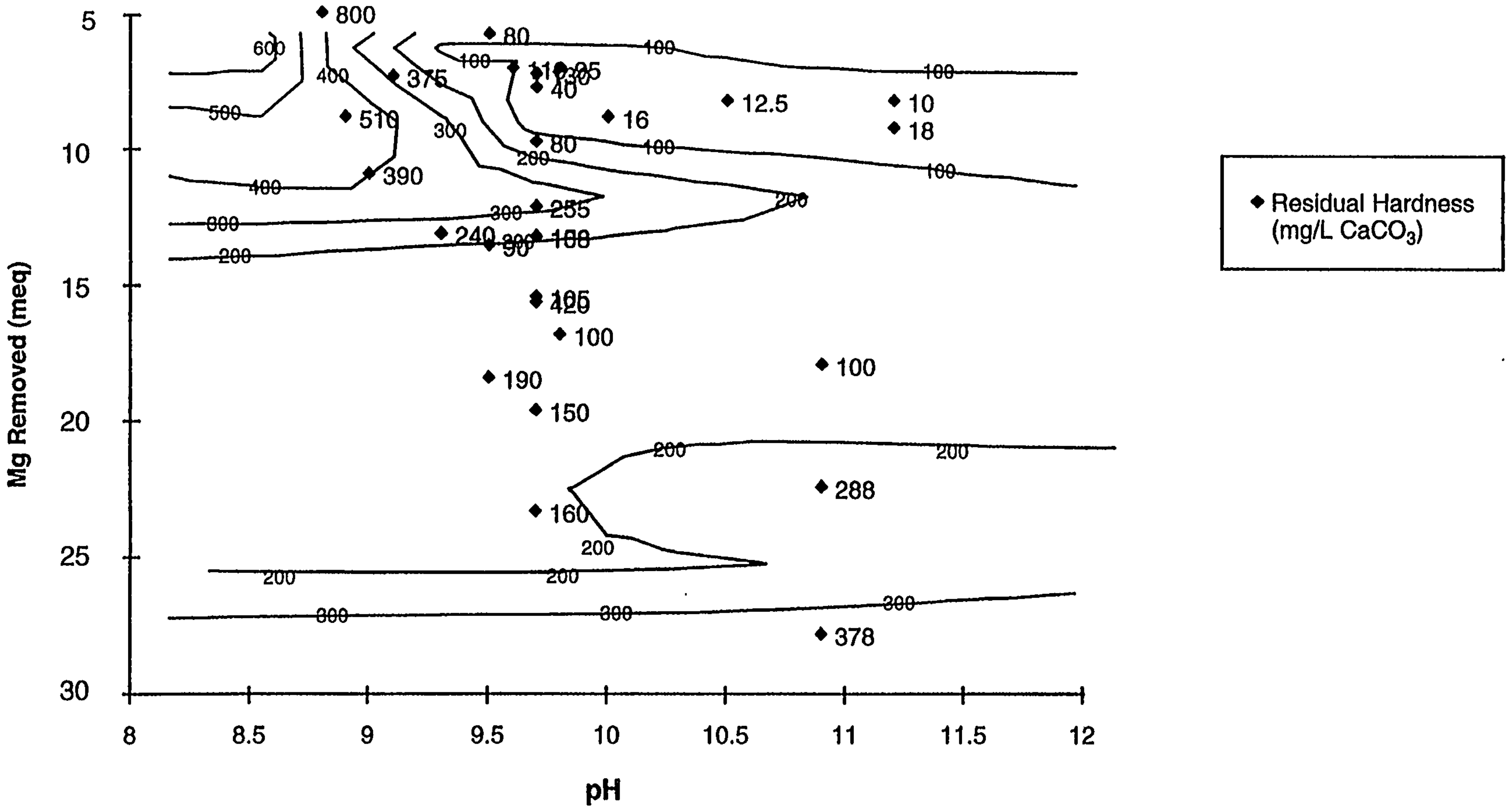
Figure 4-5



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DOE Project # DE-FC22-95MT95008

Residual Hardness Concentrations Contours for Tests Adding MgCl$_2$

January 1998
K/J 964634.00

Figure 4-6

Results from the jar test indicated that precipitative softening with magnesium or iron at the pH values tested above 8 does not effectively remove organics when measured as BOD or COD.

Recommended Strategy for Pilot Tests

Controlling pH between 9.6 and 9.8 with caustic soda and adding approximately 400-600 mg/L of magnesium chloride appears to be the most promising strategy to operate a pilot precipitative softening process to remove silica and boron. In jar tests, this combination consistently led to residual silica concentrations of 20 mg/L or lower and boron concentrations of 10 mg/L or lower. Higher dosages of magnesium reduce residual boron concentrations but also require higher dosages of caustic soda, produce more sludge, and increase magnesium hardness levels of the effluent.

Dosages may require adjustment if the softening occurs in a reactor with a sludge blanket, or improved silica and boron removal may occur at the same doses studied here. A range of dosages will be tested to evaluate the tradeoff between chemical use and sludge production versus silica and boron removal.

Selected Treatment Train and Rationale

Warm precipitative softening was selected over hot precipitative softening for the following reasons:

- Warm softening has lower anticipated capital costs than hot softening
- Warm softening is less energy intensive than hot softening
- Warm softening is easier to operate than hot softening

RO was selected as the process to desalt produced water for this project for the following reasons:

- RO capital costs are less than 40 percent of the VC costs
- RO operating costs are less than 45 percent of VC costs
- RO has greater acceptance in U.S., especially for drinking water applications.

Chapter 5

Pilot Plant Description

CHAPTER 5

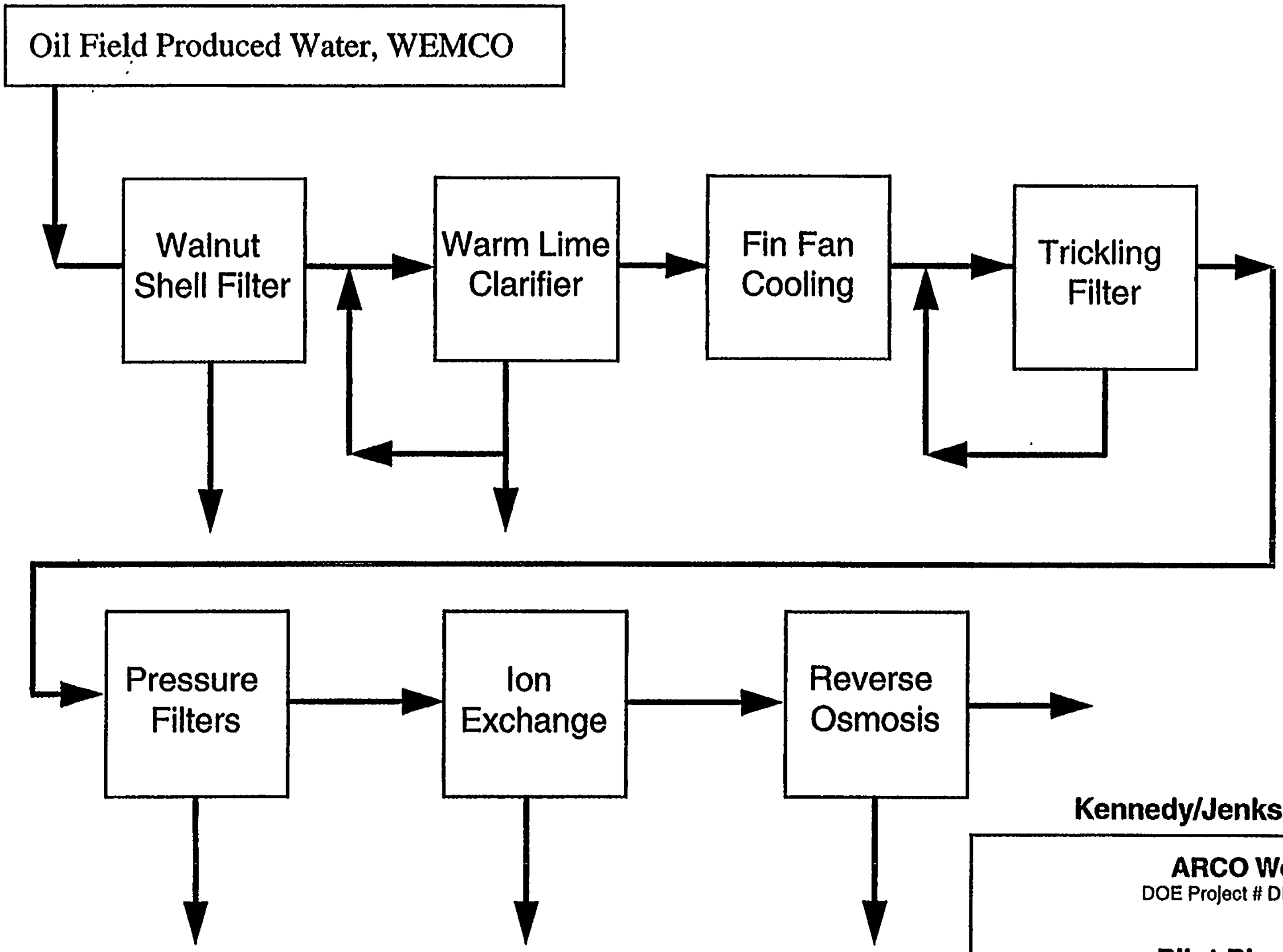
DESCRIPTION OF PILOT PLANT STUDY

This chapter describes the methods and approach used in the pilot plant study. First the unit processes are described, followed by the analytical methods, and the pilot testing approach and schedule.

UNIT PROCESS DESCRIPTIONS

A general schematic of the pilot plant treatment train is shown in Figure 5-1. A plot plan showing the layout of the various units is shown in Drawing 5-1. The water treated in this project was taken from ARCO's WEMCO induced gas flotation cell WF-2 that is in the lower left hand corner of the drawing. ARCO Western Energy with assistance from Kennedy/Jenks developed the piping and instrumentation diagrams (Drawings 5-2 to 5-6) that were used to construct the pilot facilities. Figure 5-2 is a photograph of the pilot plant site during construction.

The following is a description of the pilot plant units (see Drawing 5-2). The raw water (also referred to as inlet or influent water) was passed through a booster pump to achieve the target flow rate through the system and then was sent to the DensaDeg warm precipitative softener. After the DensaDeg, the process water was sent to a 2,000 gallon constant head tank that provided water for the downstream pumps. Excess flow was sent to an overflow line connected to the system drain and was returned to ARCO's water handling system. From the constant head tank, the process water was pumped into a fin-fan type heat exchanger to cool the water from 150+°F to just above ambient air temperature. Such cooling was needed since the units downstream of the DensaDeg were susceptible to damage at temperatures above 100°F. After the heat exchanger, the water proceeded to the trickling filter for biological oxidation of organics. Biological oxidation was followed by a booster pump to increase the system pressure to 80-100 psig and the water was then sent to the multi-media filters to remove solids including any biological solids that may have sloughed from the trickling filter. During most stages of testing, the trickling filter was bypassed to allow the microbes produced to acclimate to the water organics. When bypassing the trickling filter, the water was sent directly from the heat



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DOE Project # DE-FC22-95MT95008

Pilot Plant Schematic

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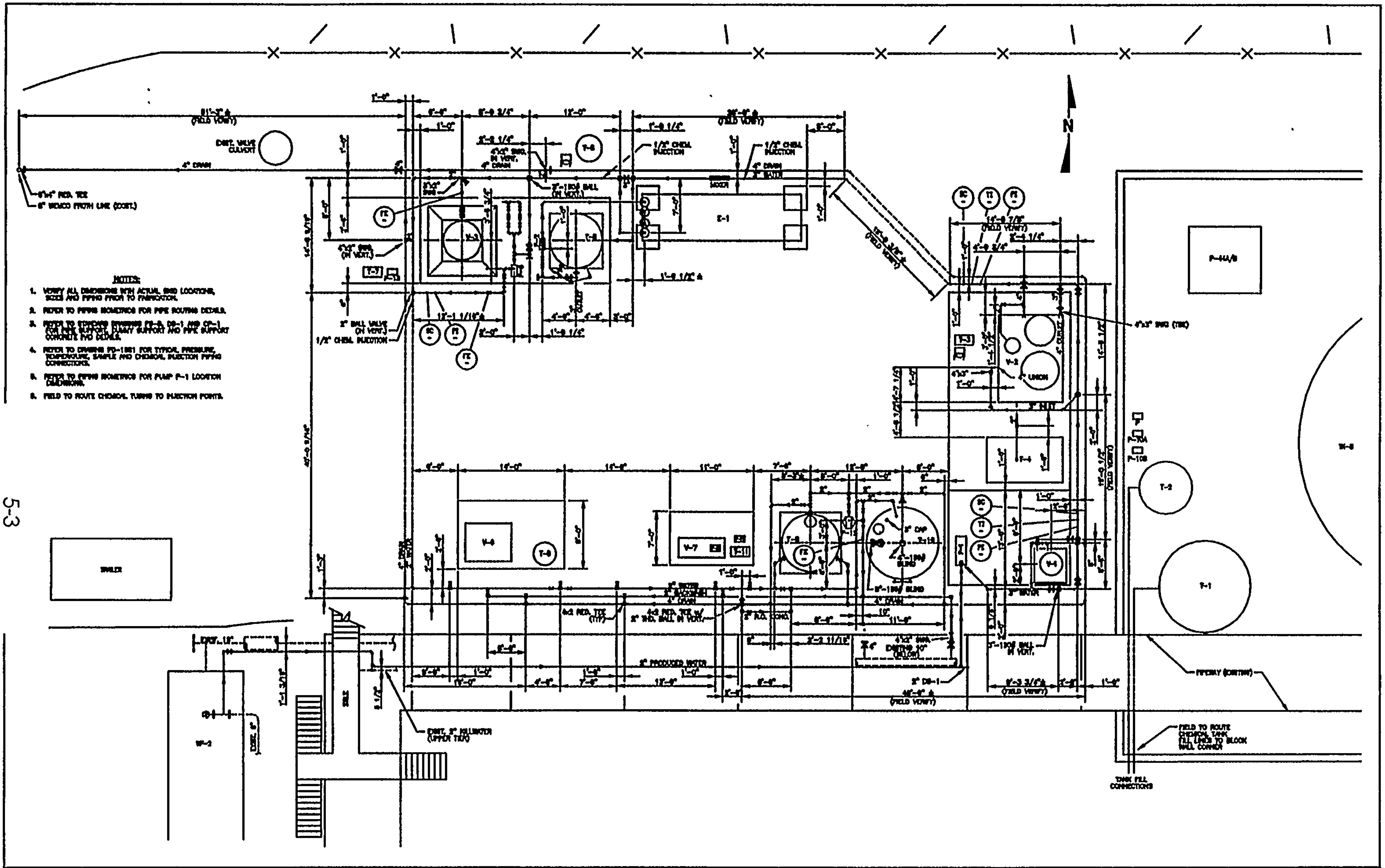
Figure 5-1



NOTES:

1. VERIFY ALL DIMENSIONS WITH ACTUAL SKID LOCATIONS, SIZES AND PIPING PRIOR TO FABRICATION.
2. REFER TO PIPING ISOMETRICS FOR PIPE ROUTING DETAILS.
3. REFER TO STANDARD DRAWINGS PS-2, DS-1 AND CP-1 FOR PIPE SUPPORT, DUMMY SUPPORT AND PIPE SUPPORT CONCRETE PAD DETAILS.
4. REFER TO DRAWING PD-1551 FOR TYPICAL PRESSURE, TEMPERATURE, SAMPLE AND CHEMICAL INJECTION PIPING CONNECTIONS.
5. REFER TO PIPING ISOMETRICS FOR PUMP P-1 LOCATION DIMENSIONS.
6. FIELD TO ROUTE CHEMICAL TUBING TO INJECTION POINTS.

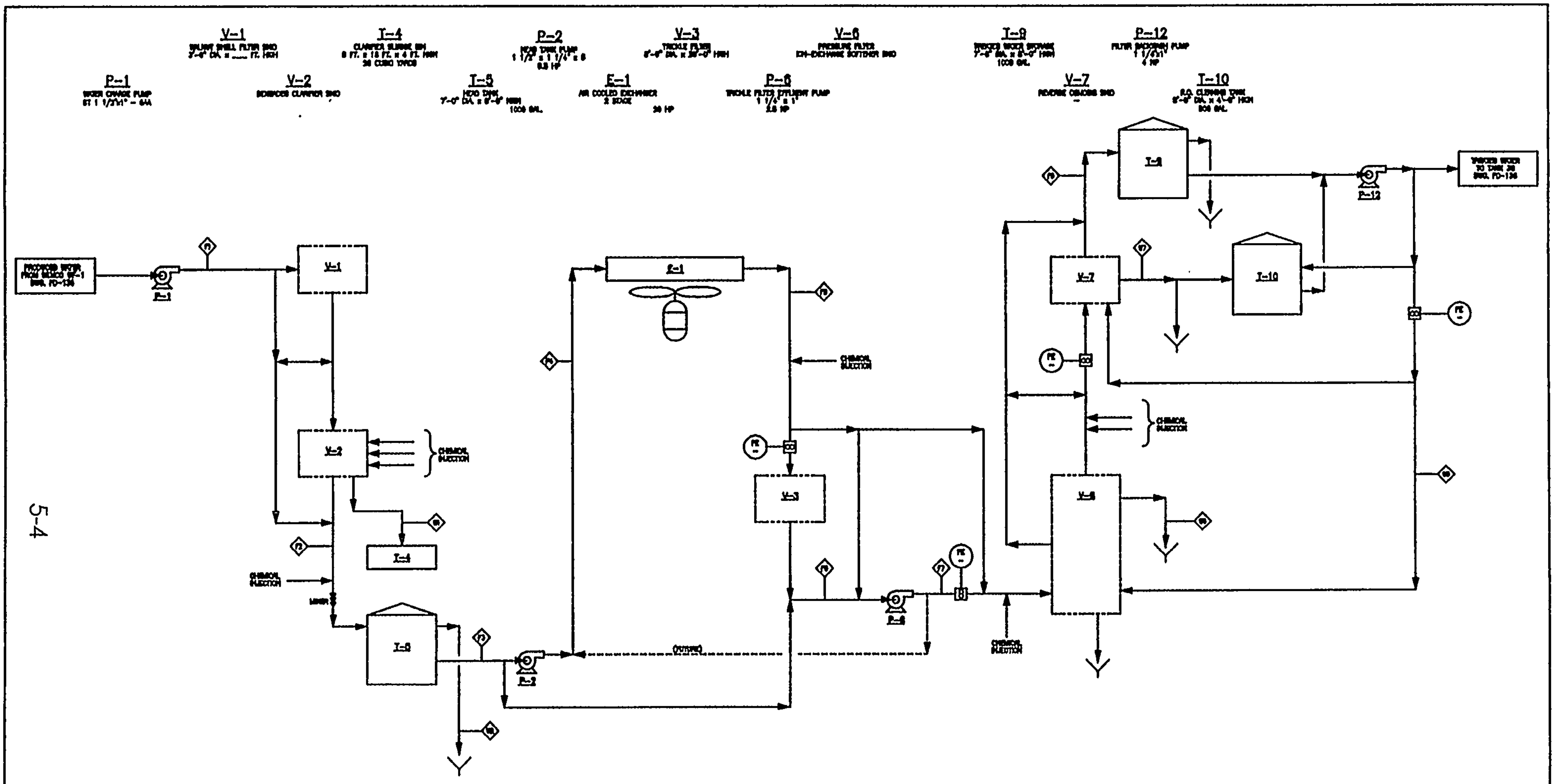
PIPING PLAN
D.O.E. PILOT PLANT
PRODUCED WATER RECLAMATION SYSTEM
PLACERITA CANYON PRODUCTION FACILITY
LOS ANGELES COUNTY, CALIFORNIA

ARCO Western Energy

Rev	Date	Description	By	App'd
4	4/14/97	ADDED T-9/10 AND P-12 PIPING	TR	
3	4/8/97	ADDED P-1 PIPING	TR	KW
2	4/7/97	EXTENDED CONCRETE PAD / ADDED P-1 / MOVED TANKS	TR	KW
1	4/1/97	ISSUED FOR APPROVAL AND CONSTRUCTION	TR	KW
0	3/25/97	ISSUED FOR APPROVAL AND CONSTRUCTION	TR	KW

Drawn By	TAR	3/13/97	Design	GFD
Check			Cad No.	PD-1550
Approved			Scale	3/16" = 1'-0"
Engineer	GFD	3/13/97	Dwg. No.	6-1

D



STEAM FLOW SUMMARIES

STREAM No. / DESCRIPTION	F1 PRODUCED WATER	F2 CLARIFIER EFFLUENT	W1 CLARIFIER BLOWDOWN	F3 ACIDIFIED WATER	W2 WASTE WATER	F4 PUMPED WATER	F5 COOLED WATER	W3	W4	F6 CLARIFIER EFFLUENT	F7 R.O. PRETREAT	W5 FILTER BACKWASH	W6 SPENT REGENERANT	W7 R.O. CON-CENTRATE	F8 R.O. PERMEATE	◇	◇	◇	◇	◇
MAX. FLOW (GPM)	100	100	20	50	90	50	50			15	15	40	2	5	10					
AVERAGE FLOW (GPM)	80	80	0	10	40	10	10			10	10	40	2	3	7					
TEMPERATURE (°F)	180	180	180	100	180	100	90			90	90	90	90	90	90					
PRESSURE (PSIG)	45	10	10	10	10	25	25			5	70	5	5	0	5					
pH	7.0-8.0	8.5-10.0	8.5-10.0	6.0-8.5	8.5-10.0	6.0-8.5	6.0-8.5			6.0-8.5	6.0-8.5	6.0-11.0	6.0-8.0	8.0-11.0	8.0-11.0					

PROCESS FLOW DIAGRAM
D.O.E. PILOT PLANT
PRODUCED WATER RECLAMATION SYSTEM
PLACERITA CANYON PRODUCTION FACILITY
LOS ANGELES COUNTY, CALIFORNIA

ARCO Western Energy

Rev	Date	Description	By	App'd
1	4/11/87	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	
0	3/26/87	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	

Drawn By	TAR	3/3/87	Design	KENNEDY/JENKS	2/10/87
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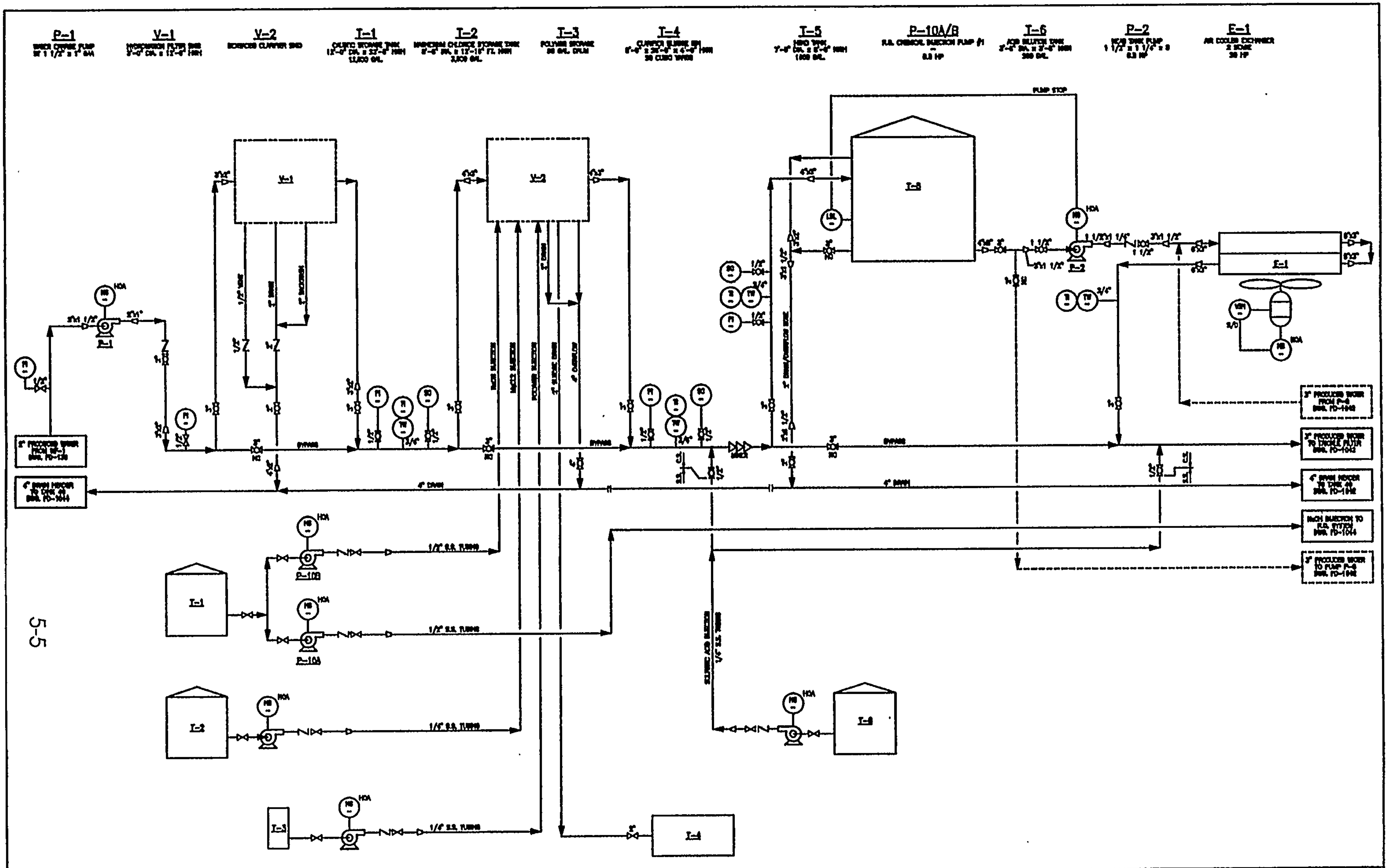
Approved			Scale	NONE	
Engineer	GFD	3/3/87	Dwg. No.	5-2	



PIPING AND INSTRUMENTATION DIAGRAM
D.O.E. PILOT PLANT
PRODUCED WATER RECLAMATION SYSTEM
PLACERITA CANYON PRODUCTION FACILITY
LOS ANGELES COUNTY, CALIFORNIA

ARCO Western Energy

Rev	Date	Description	By	App'd
2	4/11/97	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	
1	3/25/97	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	
0	3/25/97	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	

Drawn By	TAR	2/26/97	Design	KENNEDY/JENKS	2/10/97
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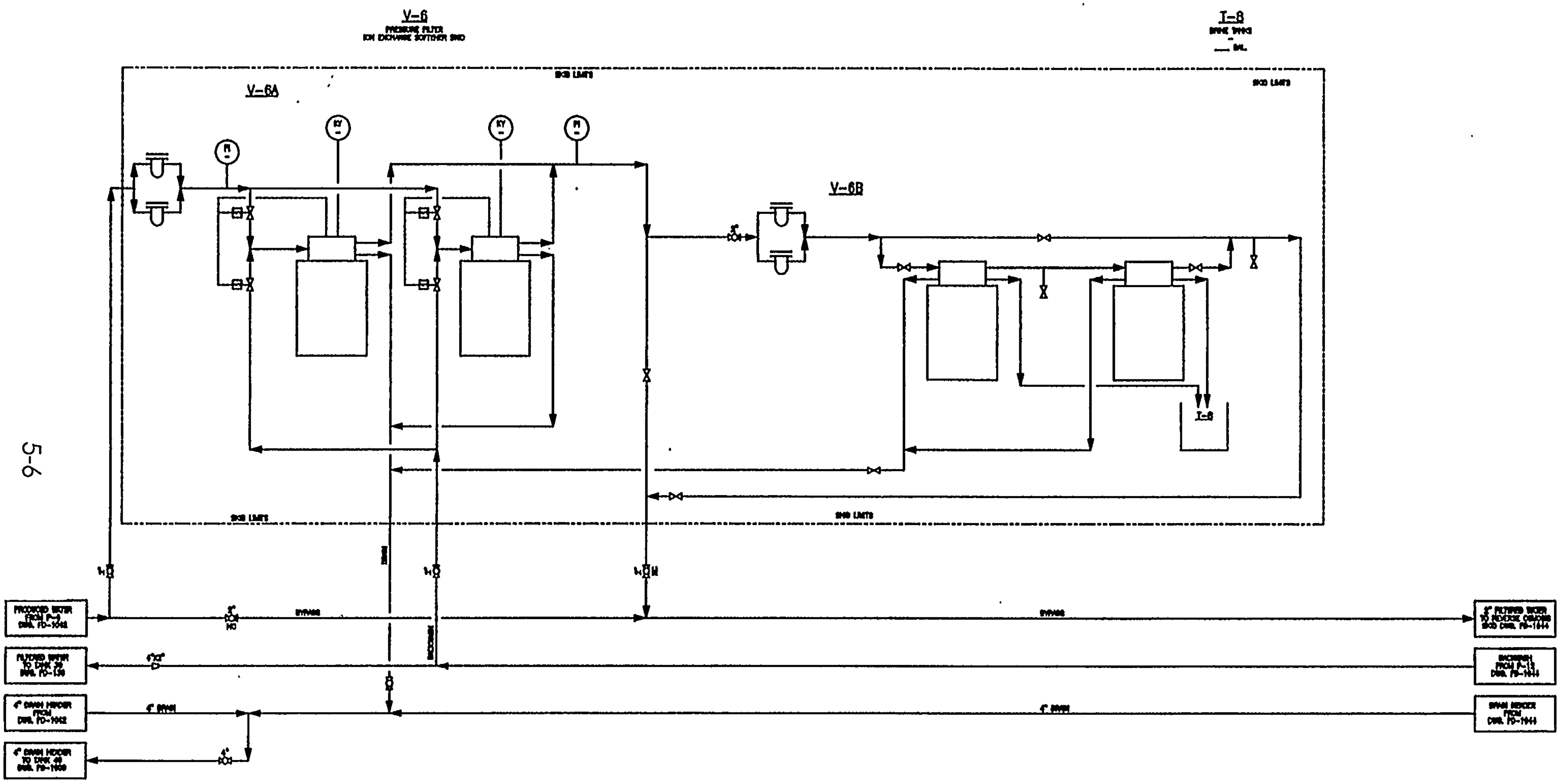

PIPING AND INSTRUMENTATION DIAGRAM
D.O.E. PILOT PLANT
PRODUCED WATER RECLAMATION SYSTEM
PLACERITA CANYON PRODUCTION FACILITY
LOS ANGELES COUNTY, CALIFORNIA

ARCO Western Energy

Rev	Date	Description	By	App'd
1	5/21/97	[illegible]	TY	[illegible]
0	3/26/97	[illegible]	TR	

Drawn By	TAR	2/20/97	Design KENNEDY/JENKS	2/10/97
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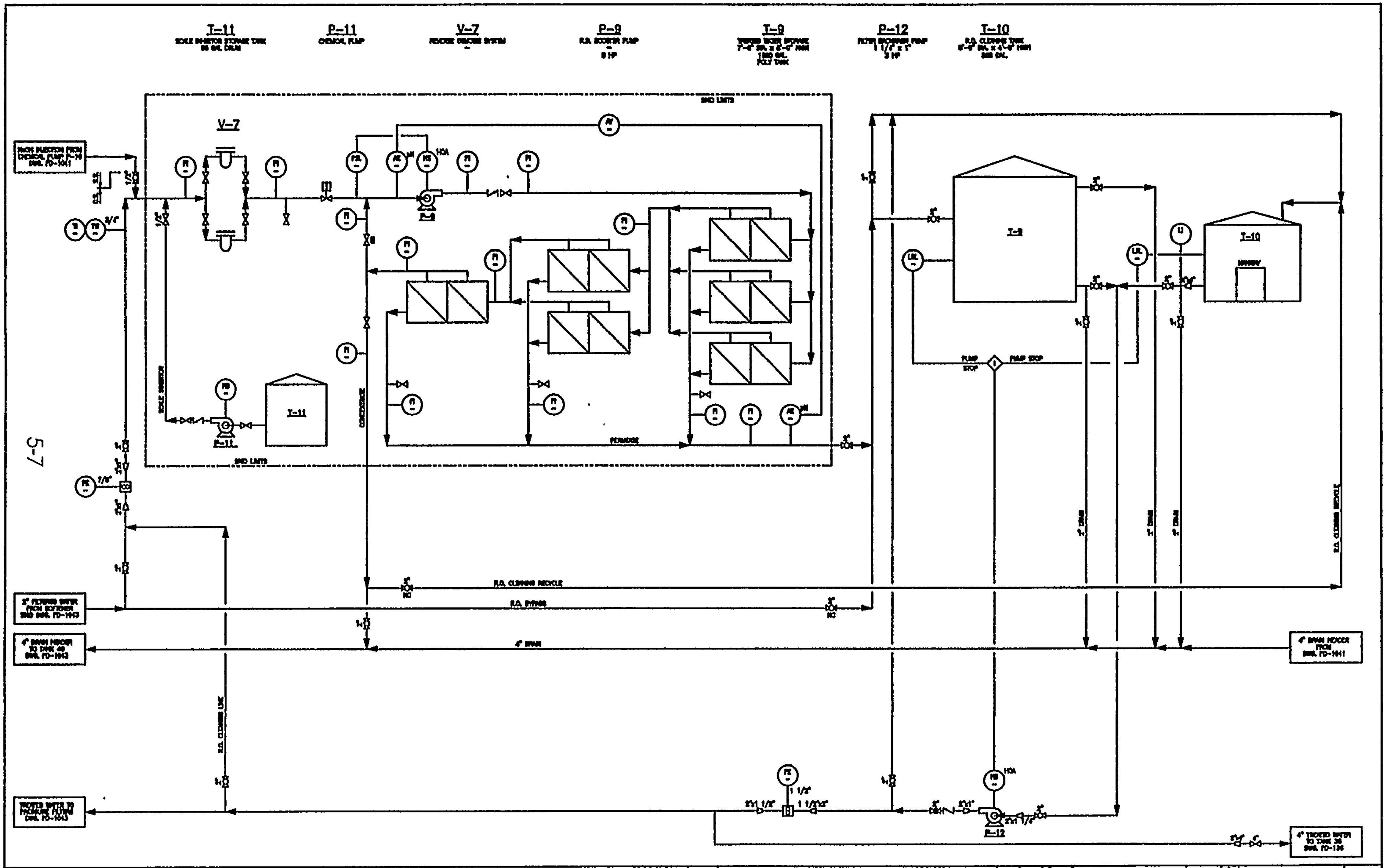
Approved			Scale NONE	
Engineer	GFD	2/20/97	Dwg. No. 5-4	



PIPING AND INSTRUMENTATION DIAGRAM
D.O.E. PILOT PLANT
PRODUCED WATER RECLAMATION SYSTEM
PLACERITA CANYON PRODUCTION FACILITY
LOS ANGELES COUNTY, CALIFORNIA

ARCO Western Energy

Rev	Date	Description	By	App'd
1	5/21/97	REVISED PER GENERAL REVISIONS	TF	KW
0	3/26/97	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	

Drawn By	TAR	2/27/97	Design KENNEDY/JENKS	2/10/97
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Approved			Scale NONE	
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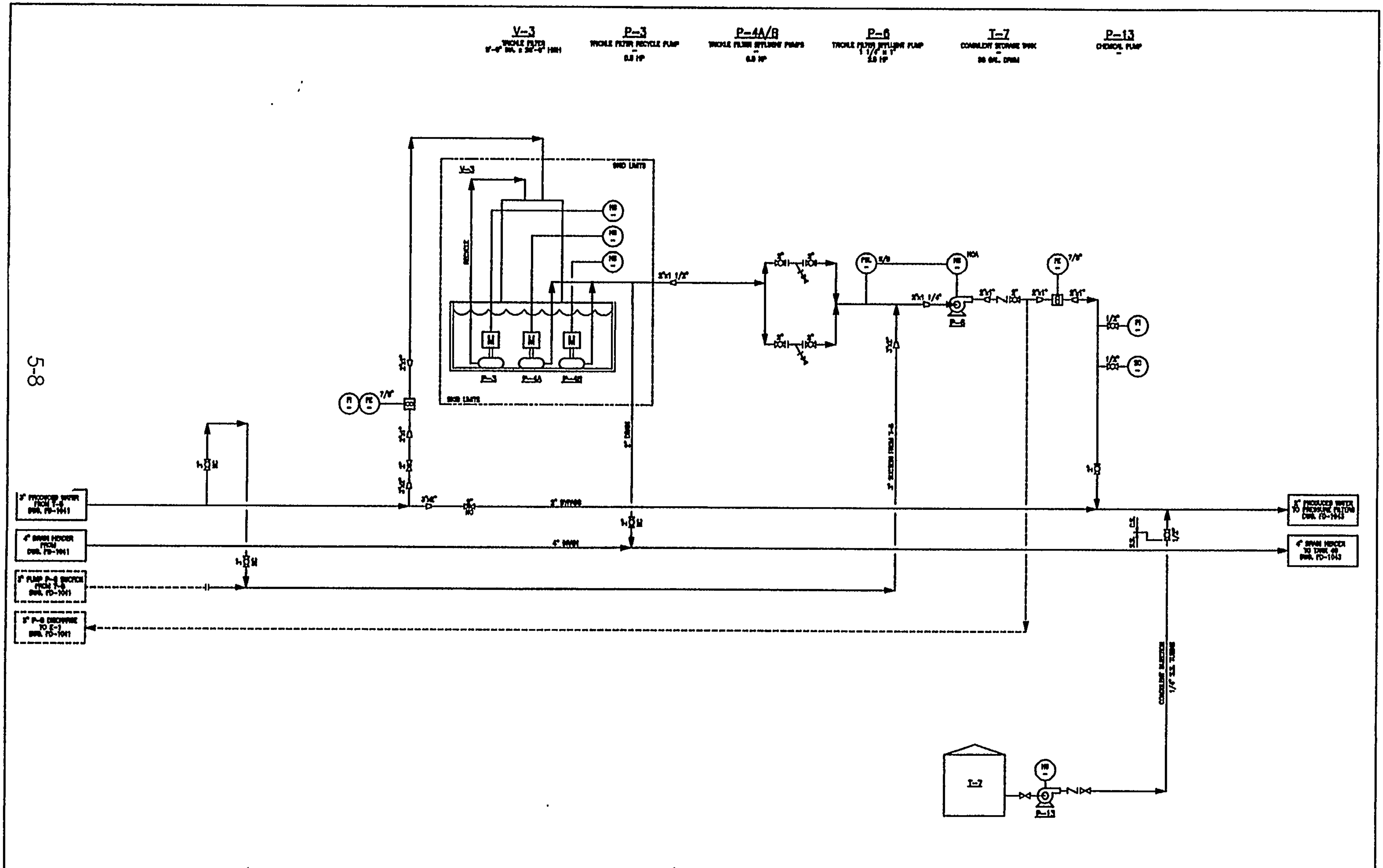

PIPING AND INSTRUMENTATION DIAGRAM
D.O.E. PILOT PLANT
PRODUCED WATER RECLAMATION SYSTEM
PLACERITA CANYON PRODUCTION FACILITY
LOS ANGELES COUNTY, CALIFORNIA

ARCO Western Energy

Rev	Date	Description	By	App'd
2	4/15/97	REMOVED V-3 AND ISSUED FOR FINAL APPROVAL	TR	
1	3/26/97	ADDED P-6 SUCTION STRAINER	TR	
0	3/20/97	ISSUED FOR FINAL APPROVAL AND CONSTRUCTION	TR	

Drawn By	TAR	2/28/97	Design	KENNEDY/JENKS	2/10/97
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Approved			Scale	NONE	
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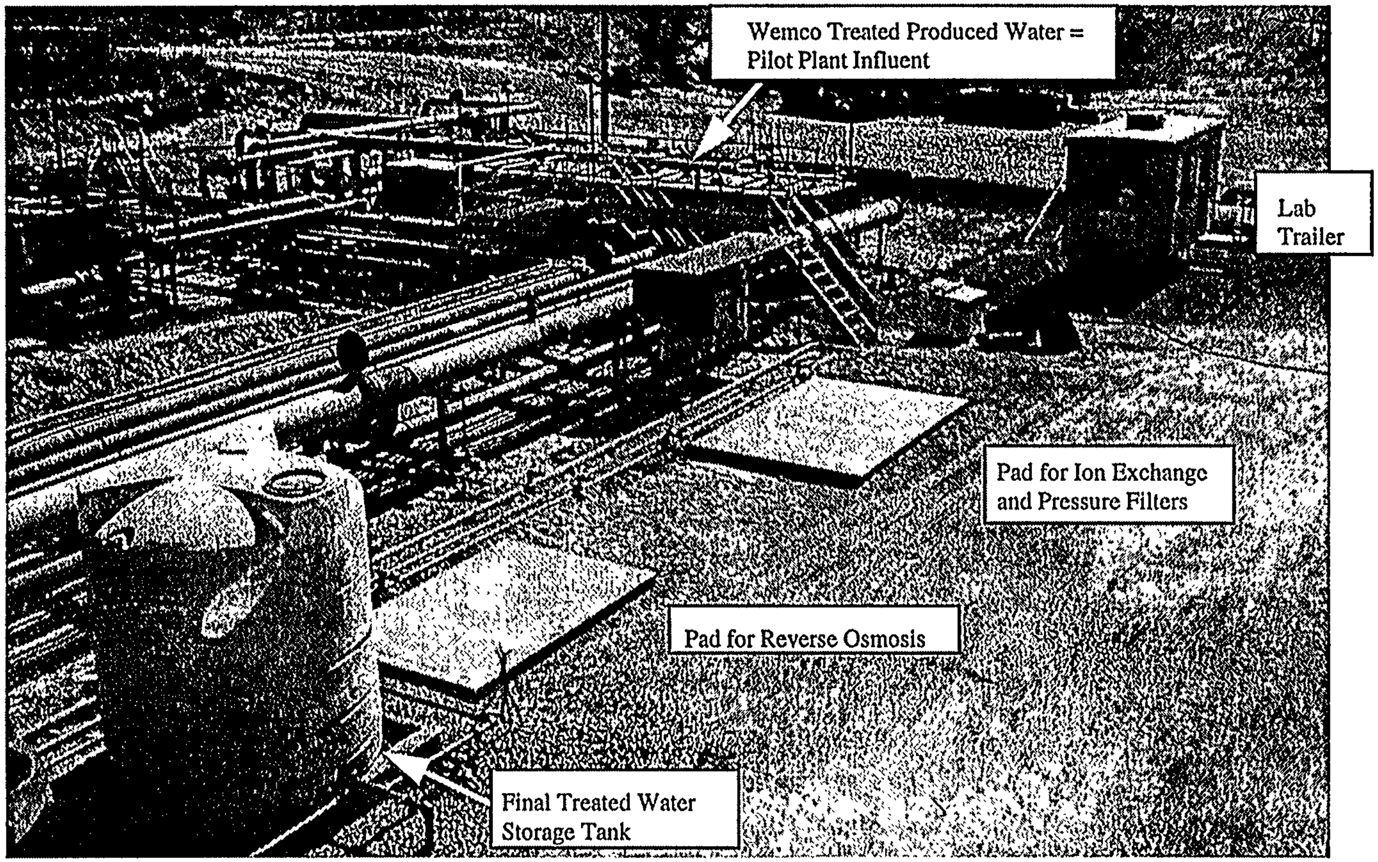

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DOE Project # DE-FC22-95MT95008

Pilot Plant Construction and Laboratory Trailer

January 1998
K/J 964634.00

Figure 5-2

exchanger to the booster pump. The process water was next sent through the pressure filters, then the ion exchange softeners to remove any residual hardness. This was followed by the RO to remove the TDS, boron and additional organics. The RO permeate was sent to a 2,000 gallon polyethylene tank for storage. The concentrated reject stream was sent to the system drain.

Table 5-1 summarizes the design parameters for each process and is followed by a more detailed description of the individual unit processes. The walnut shell filter was evaluated separately as a pretreatment unit to minimize the impact of suspended oil caused by WEMCO WF-2 upsets.

Table 5-1

Summary of Pilot Plant Design Criteria

Pilot Unit	Element	Characteristic
Walnut Shell Filter	Hydraulic Loading Rate	15 gpm/ft^2
	Media Size	1.17 to 1.40 mm
	Media Area	7 ft^2
	Media Depth	36 inches
DensaDeg	Vessel Volume	
	Rapid Mix Chamber	400 gal
	Reaction Tank	1100 gal
	Thickener/Clarifier	2100 gal
	Total	3600 gal
	Hydraulic Loading Rate	9.2 gpm/ft^2 at lamellar tube settlers
	Flow Rate	100 gpm
Fin Fan Cooling	Flow Rate	10 gpm
	4 Fans	3 HP each
	Heat Exchanger	2 Banks, each contains 4 rows of 13 20 foot long brass tubes

Table 5-1 (continued)

Summary of Pilot Plant Design Criteria

Pilot Unit	Element	Characteristic
	Cooling Design Criteria	160°F to +10°F of ambient air
Trickling Filter	Packing Media Type	Q-PAC by Lantec Products
	Packing Media Depth	20 ft
	Trickling Filter Diameter	5 ft
	Wettable Area	30 ft^2/ft^3
	Voids Fraction	0.975
	Organic Loading Rate	
	Lower	6 lbs/1000 ft^3
	Upper	300 lbs/1000 ft^3
	Hydraulic Loading Rate	
	Lower	0.5 gpm/ft^2
	Upper	2.5 gpm/ft^2
Multi-Media Filters	Hydraulic Loading Rate	5 gpm/ft^2
	Filtration Rating	30 micron
	Media Area (per filter)	2.6 ft^2
	Media Depths	
	Anthracite #1	3.5 inches
	Silica Sand #20	5 inches
	Garnet (30 x 40 mesh screen)	12.5 inches
	Garnet (8 x 12 mesh screen)	21.5 inches
	Gravel Underdrain	7 inches
	Total Depth	49.5 inches
	Media Particle Diameters	
	Anthracite #1	1.0 to 1.2 mm
	Silica Sand #20	0.45 to 0.55 mm

Table 5-1 (continued)

Summary of Pilot Plant Design Criteria

Pilot Unit	Element	Characteristic
	Garnet (30 x 40 mesh screen)	0.37 to 0.53 mm
	Garnet (8 x 12 mesh screen)	1.4 to 2.4 mm
	Gravel Underdrain	3.2 to 6.4 mm
Ion Exchange Columns	Hydraulic Loading Rate	33 gpm (cont.); 45 gpm (peak)
	Exchange Resin	Ionac C-249
	Resin Type	Cationic
	Bed Volume (per Column)	4 ft^3
	Resin Capacity (Rated)	25 to 30 kilo-grains/ft^3
	Resin Capacity (Expected)	20 kilo-grains/ft^3
Reverse Osmosis	Cartridge Filters	
	Filtration Rating	5 micron
	Size	2.5 inch x 20 inch
	Quantity (per bank)	5
	No. Banks	2
	Membrane Elements	
	Type	Fluid Systems "XR" Polyamide TFC
	Size	4 inch x 40 inch
	Quantity	12
	Membrane Surface Area	72 ft^2 per element
	Unit Configuration	Single Array, 3 Stage 2 x 1 x 1
	No. Elements per Tube	3
	Max Feed Pressure	600 psi

Walnut Shell Filter

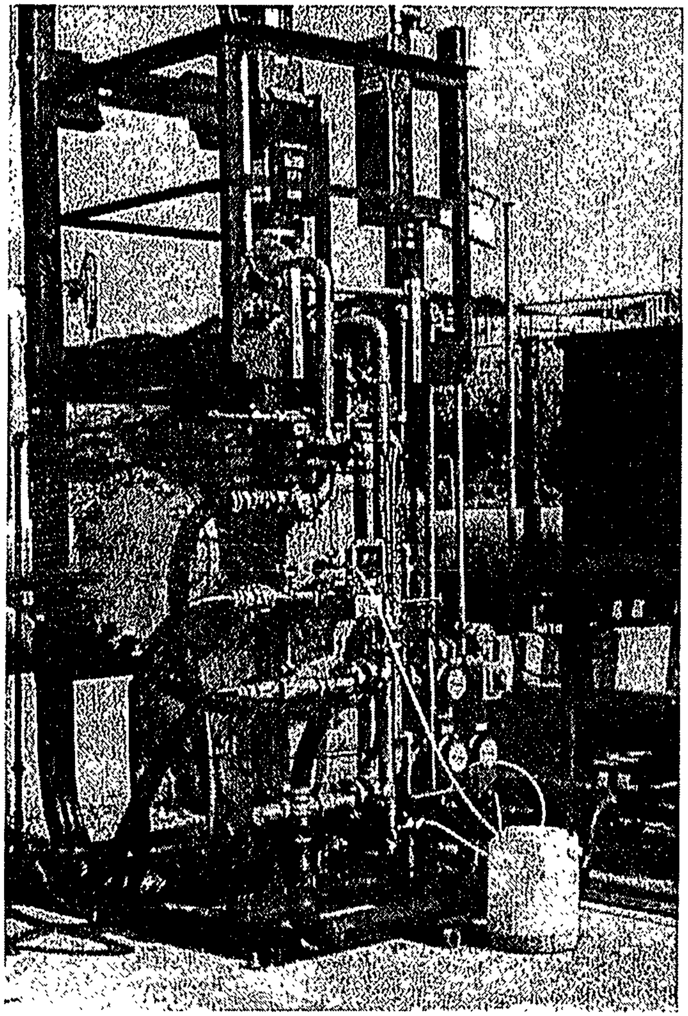
A walnut shell filter was tested for use as the first treatment process to remove additional oil and grease and to provide protection of the downstream membranes from episodic upsets of the existing water handling system. The unit tested, as shown in Figure 5-3 was a Hydromation model FDP-7P Deep Bed Filter with 7.0 ft^2 of filter area and a bed depth of 36 inches. The media was crushed black walnut shells between 12 and 20 mesh. The unit was designed for a maximum loading rate of 15 gpm/ft^2 that is equivalent to a flow rate of 105 gpm. Backwash was accomplished with the assistance of a mechanical mixing.

The unit was tested at loading rates from 2 to 15 gpm/ft^2 and for run lengths from 15 to 65 hours. The unit was backwashed at 70 gpm with raw water until the backwash effluent appeared relatively clear of oil and grease. Although the manufacturer recommends 8 minutes of backwash time, 15 - 20 minutes were required to thoroughly clean out the unit each time.

DensaDeg

Warm precipitative softening was accomplished using a DensaDeg unit provided by Infilco Degremont, Inc. The unit, as shown in Figure 5-4, consists of 3 components: a rapid mix chamber, a reaction tank, and a thickener/clarifier. The rapid mix chamber is composed of a 2 ft. diameter by 17 ft. high cylindrical tank and a Lightnin' model XJQ-117 mixer powered by a 1.17 hp 1,800 rpm Duramix motor. The mixer imparts approximately 1,200/sec of velocity gradient. The reaction tank is made up of a 3½ ft. diameter by 17 ft. high outer tank, a 1.5 ft. diameter by 15 ft. high inner cylinder, a 3 ft. 3 inch by 15 ft. baffle plate, and a Lightnin' model V5 6Q150 mixer powered by a 2 hp variable speed motor. The thickener/clarifier consists of a 2,100 gallon tank separated into a downflow thickener section and an upflow clarifier section, lamellar tube settlers at the top of the clarifier, and a 0.5 rpm sludge scraper powered by a 0.5 hp Sew Eurodrive motor. The DensaDeg also has a sludge recirculation pump to return a portion of the developed solids from the thickener section of the thickener/clarifier back to the inner cylinder of the reaction tank. The sludge recirculation pump is a Moyno Progressing Cavity pump powered by a Sterling 3 hp variable speed motor.

The unit is a 20-100 gpm prototype with a design upper loading rate of 9.2 gpm/ft^2 as measured at the tube settlers of the clarifier. Sodium hydroxide (caustic soda) and magnesium chlorides were added to the influent process water to induce precipitation in the reaction tank. Chemtreat P-813E, a 35% by weight anionic polyacryamide polymer in a water-in-oil emulsion was also added to the reaction tank to aid in flocculation. Polymer dosages during testing ranged from 3 to 6 ppm (liquid volume basis). The unit was operated 24 hours per day and the thickened



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**Hydromation Walnut Shell Filter
Pilot Unit**

January 1998
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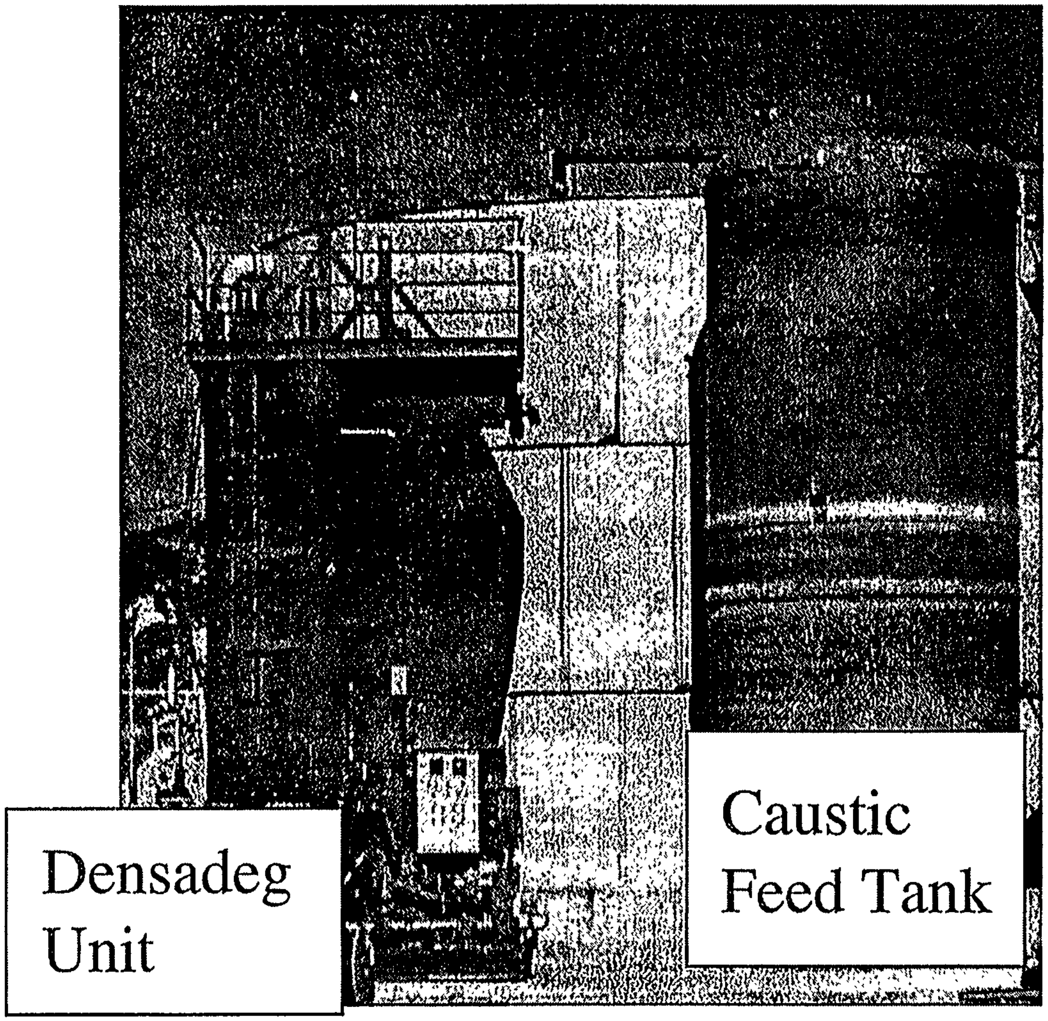
Figure 5-3



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DOE Project # DE-FC22-95MT95008

DensaDeg Warm Softening Unit

January 1998
K/J 964634.00

Figure 5-4

sludge was manually blown-down from the unit twice per 24 hour period. Typically, the sludge was blown-down in the morning and in the afternoon.

Fin Fan Heat Exchanger

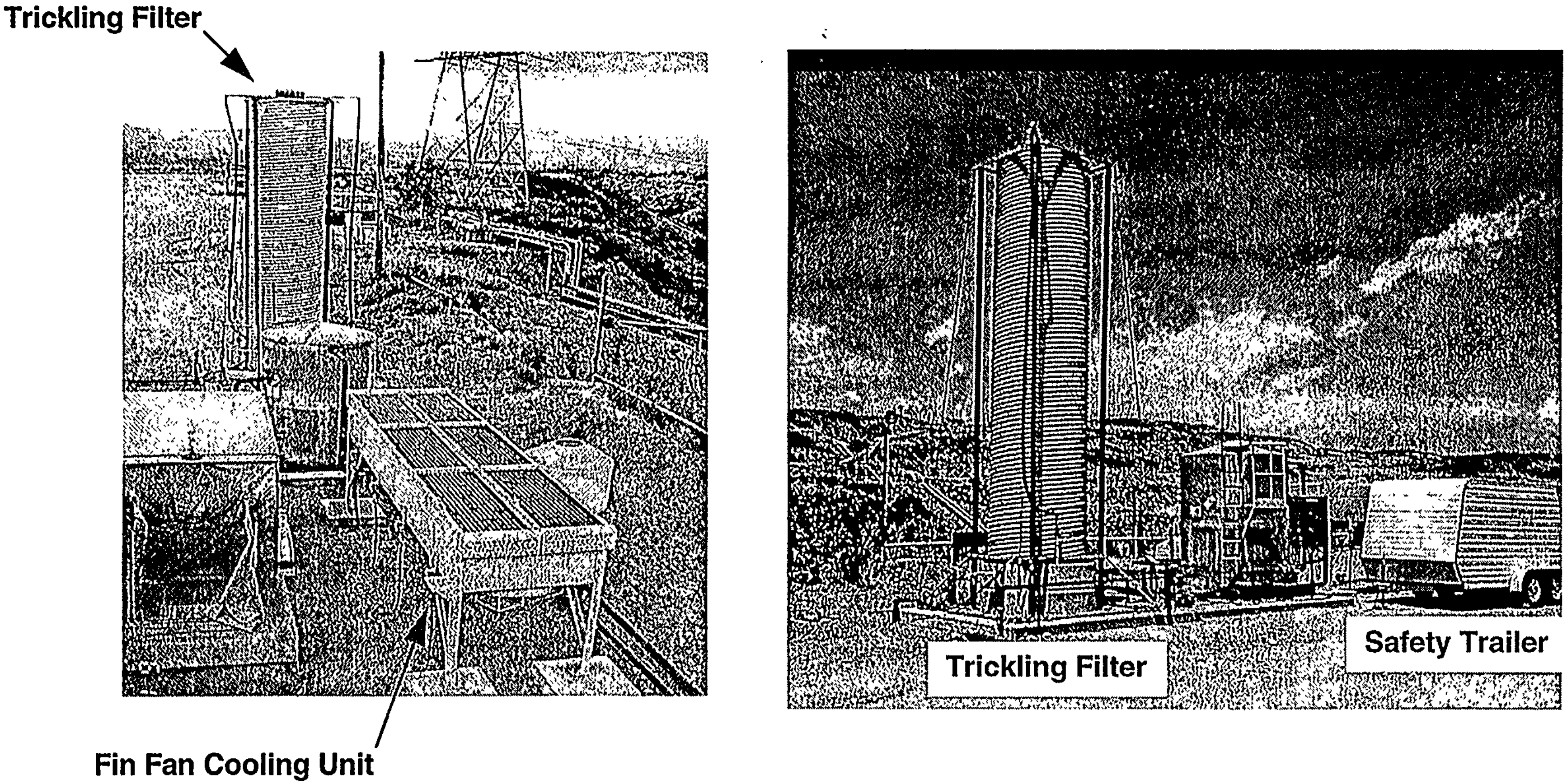
The pilot study utilized a fin-fan type heat exchanger to reduce the temperature of the process water (See Figure 5-5). Cooling was necessary to protect the biological growth on the trickling filter and thin-film composite RO membranes from the $\geq$ 150 °F temperature of the effluent from the warm softening process.

The heat exchanger utilizes fans to drive air at ambient temperature across a series of parallel tubes containing the process water. Attached to the exterior of the tubes are spiral wound metal fins designed to increase available surface area in contact with the passing air. This increased area allows for a greater rate of heat transfer per unit volume of air passing across the tubes. The unit used on this project utilized four 3 HP fans to drive air through two banks of 20 foot long brass tubes. Each bank contained 4 rows of 13 tubes arranged in a staggered formation. The unit could reduce the process water temperature from 160°F to within 10°F above ambient air at a flow rate of 10 gpm.

Trickling Filter

The trickling filter, as shown in Figure 5-5, was 5 feet in diameter and 25 feet tall. There was 20 feet of random packed media that totaled approximately 400 cubic feet. Q-PAC, manufactured by Lantec, was the media, and it provided 30 square feet of surface area per cubic foot with a voids fraction of 97.5 percent. Q-PAC is made of polypropylene and each unit had a nominal diameter of seven inches. Hydraulic and organic loadings could vary between 0.5 - 2.5 gpm/ft^2 and 6 to 300 lbs BOD/1000 ft^3 of media per day. For this study, the trickling filter was operated at a hydraulic loading rate of 2.5 gpm/ft^2 and an organic loading rate of 20 lbs/1000 ft3 of media per day.

In the first two phases, this unit process was bypassed to acclimate the bacteria to the produced water substrate. During this phase, the unit was operated separately in a semi-batch mode. Effluent from the warm precipitative softener was fed to the unit in a separate slip



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Fin Fan and Trickling Filter Pilot Units

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Figure 5-5

stream on a daily basis. In the third phase, the unit was operated in a continuous flow through mode.

Pressure Filtration

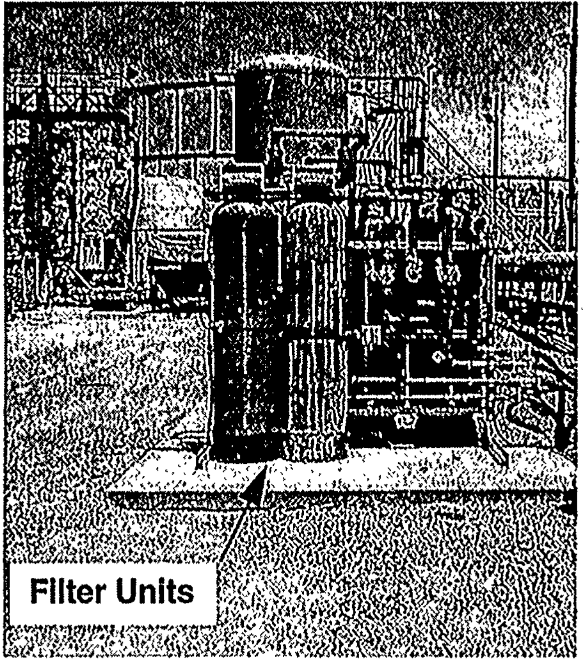
Two multimedia pressure filters were operated in parallel immediately downstream of the trickling filter to remove biological solids that could potentially slough from the trickling filter into the process stream. These filters are shown in Figure 5-6. Each filter, a model MMF180-F28 filter manufactured by U.S. Filter, is 22 inches in diameter and contains approximately 3.3 feet of multimedia filter material consisting of anthracite, sand, and garnet. With approximately 2.6 ft^2 of area per filter, the design maximum hydraulic loading rate for the filters is approximately 5 gpm/ft^2. For this study, the units were operated at loading rates of 1.3 and 1.8 gpm/ft^2. Chemtreat P-822L, a cationic polyamine polymer filter aid manufactured by ChemTreat, was added to the filter influent during the later stages of phase three testing. Dosing rates for the filter aid ranged from 1.5 to 8.6 ppm (volume/volume basis). The filters were manually backwashed at periodic intervals with reverse osmosis permeate. During the backwash period, the ion exchange and reverse osmosis units were taken off-line. Backwashes were performed when the filter effluent turbidity entered the 1.0 - 1.5 NTU range.

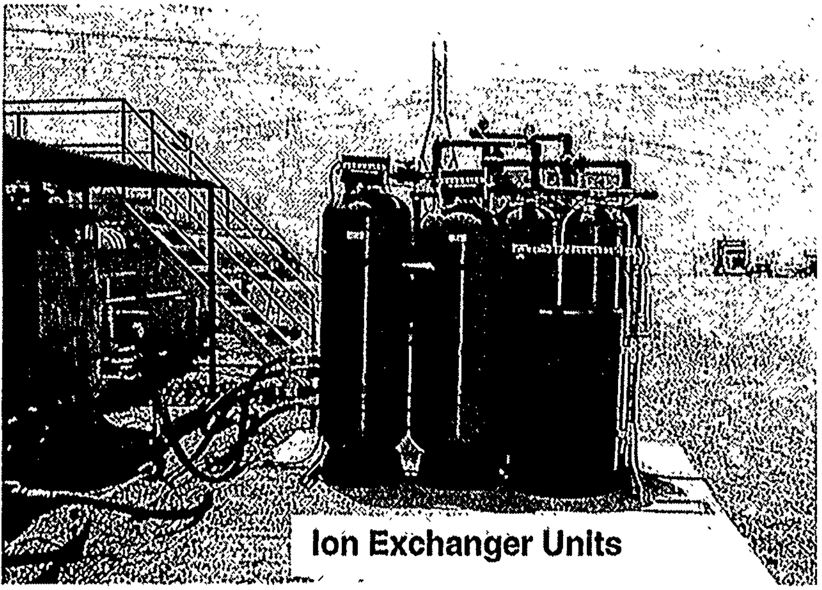
Ion Exchange

Two cation exchange columns were operated in parallel to remove residual divalent cations from the process water and are shown in Figure 5-6. Each column, model MCF-1120-1.5 water conditioner manufactured by U.S. Filter, is 16 inches in diameter and contained approximately 4 ft^3 of Ionac C-249 resin with a rated capacity approximately 25-30 kilo-grains per ft^3. The high TDS of the water was expected to reduce the capacity of the resins by approximately 20 percent, resulting in an operating capacity of approximately 20 kilo-grains per ft^3. Periodic regeneration was performed manually using the DensaDeg softened and pressure filtered water for backwashing and brine solution make up. During regeneration, the reverse osmosis unit was taken off line.

Reverse Osmosis

Reverse osmosis (RO) was the final unit in the treatment process as shown in Figure 5-7. It consisted of the following components: twelve 4" x 40" brackish water spiral wound membrane





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Filtration and Ion Exchange Pilot Units

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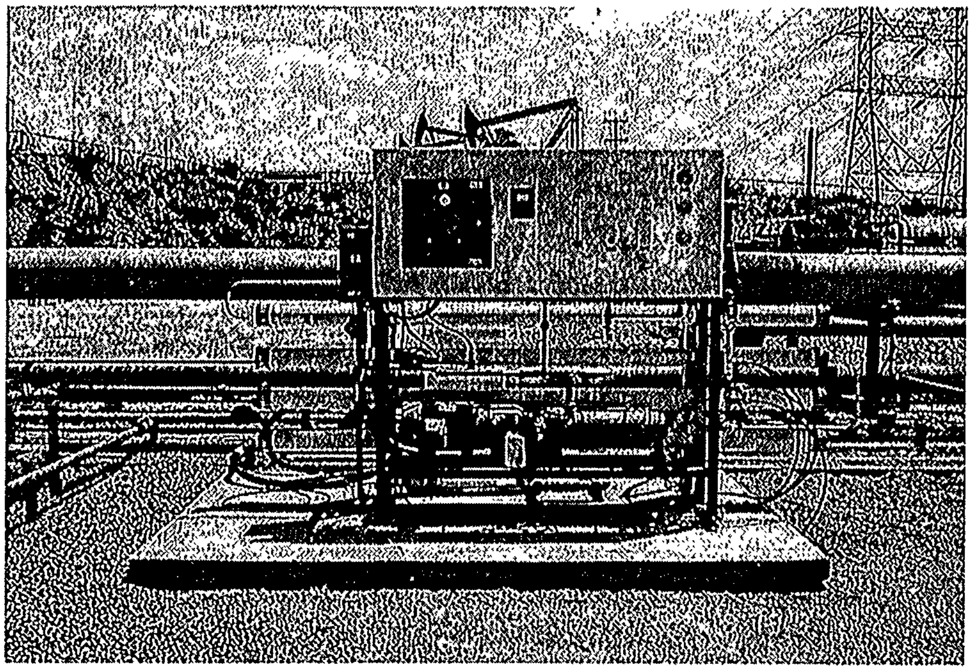
Figure 5-6



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Reverse Osmosis Pilot Unit

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Figure 5-7

elements housed in 4 pressure vessels that were arranged in a 3-stage (2 *x* 1 *x* 1) array; two interchangeable banks of 5-micron filters that preceded the membrane elements; a high pressure pump; and a recycle line that returned a portion of the reject stream to the incoming feed. The membranes were Fluid Systems XR "extra-high rejection" polyamide elements. The flow configuration was set and maintained at a permeate recovery of 75 percent. The unit typically operated at feed pressures from 380 to 450 psig, but experienced feed pressures as high as 600 psig.

During its operation, the RO was tested at several feed water pH conditions ranging from pH 8.2 up to pH 10.8. The elevated pH range was intended to examine the rejection of boron that was reported by Dyke *et al* (1992). The low pH range was intended to examine the membranes' ability to reject organics and ammonia. Adjustment of the pH was accomplished through the addition of caustic or sulfuric acid as required.

PreTreat Plus 0100, an inorganic scale inhibitor/antifoulant manufactured by King Lee Technologies, was added to the RO feed water during all test runs at a rate of 1 mg dry powder/L feed water to reduce the prospect for inorganic fouling. During pH < 9.6 and all following trials, Protec RO, an organic antifoulant manufactured by King Lee Technologies, was also added to the RO feed water at a rate of 5 mg dry powder/L feed water to minimize potential hydrocarbon fouling. Cleaning was performed using DIAMITE AFT manufactured by King Lee Technologies when either a pressure drop of 20 percent was observed between stages or a 20% pressure increase was observed across the membrane at the inlet to the first stage. Fifty gallons of cleaner was made by diluting 1 part concentrated cleaning solution to 40 parts water. For each cleaning, the solution was circulated through the RO unit at 7 gpm and 60 psi for 1 hour.

ANALYTICAL METHODS SUMMARY

The field analyses were performed by Kennedy/Jenks staff. The testing methods are summarized in Table 5-2. Field oil and grease concentrations were determined with a method used by the Nalco representative at the Placerita oil field. The procedure used to perform field analyses for oil and grease was provided by Hydromation as well as the Nalco representative at the Placerita oil field. The method consisted of taking a known volume and extracting the oil and grease using a 500 ml separatory funnel for 2 minutes with 50 ml of TCE. The TCE extract is then read at 420 nm using a 13 mm cuvette. The standard curves generated by Nalco were then used to convert the percent transmission to ppm of oil and grease.

The laboratory analyses were performed by Castaic Lake Water Agency (CLWA), Truesdail Laboratories, Inc., or Zalco Laboratories, Inc. The methods and the laboratories used for each analysis are summarized in Table 5-3. All laboratories are approved by the California Department of Health Services to perform all the assigned analyses. The approval requires that each laboratory maintain an extensive quality assurance and quality control system to ensure the reliability of the reportable laboratory findings.

Table 5-2

Field Analytical Methods

Parameter	Method/Description
pH	Standard Methods 4500 H+
Temp (°F)	Standard Methods 2550 B
Turbidity (NTU)	Standard Methods 2130
Conductivity (µmho)	Standard Methods 2510 B
UV Abs.	Shimadzu UV-1601 Spectrophotometric at 254 nm
Alkalinity (mg/L as CaCO3)	Standard Methods 2320 B
Total Hardness (mg/L as CaCO3)	Hach Method 8226
Ca (mg/L as CaCO3)	Hach Method 8222
SiO2	Hach Method 8185 Colorimetric at 420 nm
Oil and Grease	Nalco, Spectrophotometeric at 420 nm

Table 5-3

Summary of Laboratory Analytical Methods

Parameter	Method/Description	Laboratory
pH	Standard Methods 4500 H+	CLWA
Temp (°F)	Standard Methods 2550 B	CLWA
Alkalinity (mg/L as CaCO3)	Standard Methods 2320	CLWA
Total Hardness (mg/L as CaCO3)	Calculated, Ca and Mg from ICP-AES USEPA Method 200.7	CLWA
Ca (mg/L as CaCO3)	ICP-AES USEPA Method 200.7	CLWA
Mg (mg/L as CaCO3)	ICP-AES USEPA Method 200.7	CLWA
B	ICP-AES USEPA Method 200.7	CLWA
Fe	ICP-AES USEPA Method 200.7	CLWA
Si	ICP-AES USEPA Method 200.7	CLWA
K	ICP-AES USEPA Method 200.7	CLWA
Na	ICP-AES USEPA Method 200.7	CLWA
Ba	ICP-AES USEPA Method 200.7	CLWA
Sr	ICP-AES USEPA Method 200.7	CLWA
Cl	IC USEPA Method 300.0	CLWA
SO4	IC USEPA Method 300.0	CLWA
Br	IC USEPA Method 300.0	CLWA
NO3	IC USEPA Method 300.0	CLWA
TOC	USEPA Method 415.1	CLWA
NH3	Selective Ion Probe 4500 NH3 D	CLWA
TSS	Standard Methods 2540 D	CLWA
TDS	Standard Methods 2540 C	CLWA
Heterotrophic Plate Count	Standard Methods 9223	CLWA
Sludge Solids Analysis	USEPA Methods 3050 B (Aqua Regia) and 6010 B	CLWA
Oil and Grease	USEPA Method 1664 or 413.1	Truesdail
Base Neutral Acid Extractables	USEPA Method 8270	Truesdail
Purgeable Organics (Volatiles)	USEPA Method 624	Truesdail
BOD	USEPA Method 405.1	Truesdail
COD	USEPA Method 410.4	Truesdail
CAM Solids	USEPA Methods 7.3H2S, 7.3CN, 418.1, 1010, 1311A, 6010A, 7061A, 7471A, 7741A, and 9045. CA Dept. of Fish and Game LC50	Zalco

PILOT PLANT OPERATIONAL PLAN

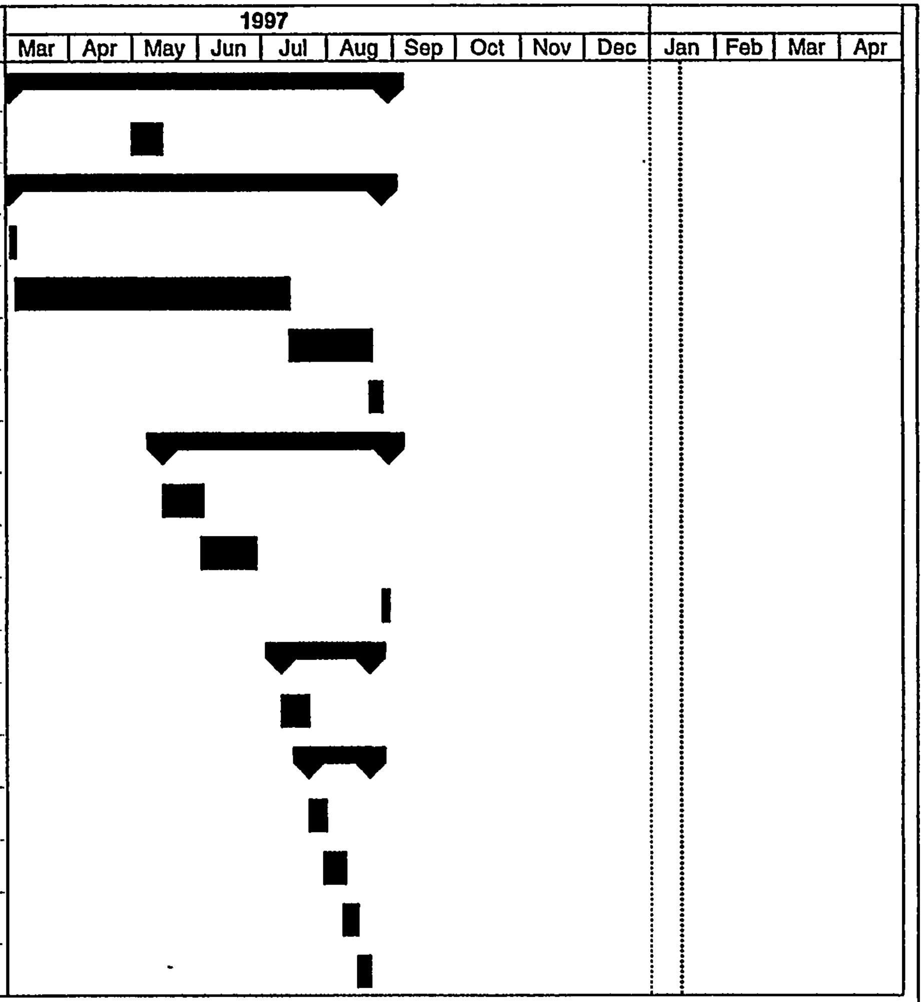
There were six operational phases for the pilot study. Figure 5-8 is a timeline of these phases of the pilot study. The operational plan was developed around the equipment delivery schedule as follows:

1. The trickling filter was constructed and operated in a batch mode to develop an acclimated microbial population, which was estimated to take 3 months.
2. The walnut shell filter was tested to determine if it would help remove suspended oil and grease from potential WEMCO upsets.
3. The DensaDeg was operated at different hydraulic loading rates and pH to determine hardness, silica, boron, and TOC removals.
4. After a long delay due to the membrane delivery schedule, the RO was operated at different pH's to determine boron removal.
5. The trickling filter was added to the process train to determine the additional organics removal.
6. The last phase involved operating the DensaDeg with a high magnesium dose in combination with the RO at a DensaDeg target pH of 9.6.

WALNUT SHELL FILTER

Kennedy/Jenks and ARCO Western Energy conducted a pilot-scale study between 28 April 1997 and 14 May 1997 to evaluate the performance of a Hydromation Walnut Shell filter (WSF) for removing suspended solids and oil and grease. Three conditions were tested in four tests as summarized in Table 5-4. For the DOE pilot study, this unit is being considered for removing additional oil and grease under normal operating conditions and for handling upset conditions of the WEMCO gas flotation unit.

ID	Task Name	Duration	Start	Finish
1	**Task 8: Perform Pilot Scale Test Studies**	**130d**	**3/3/97**	**8/29/97**
2	***Walnut Shell Filter Testing***	10d	5/1/97	5/14/97
3	***Trickling Filter Organics Removal***	**127d**	**3/3/97**	**8/26/97**
4	Install Trickling Filter	3d	3/3/97	3/5/97
5	Operate In Batch Mode	92d	3/6/97	7/13/97
6	Operate In 5 Days Per Week Mode	29d	7/14/97	8/21/97
7	Place In Pilot Plant Treatment Train	4d	8/21/97	8/26/97
8	***Warm Softening***	**77d**	**5/15/97**	**8/29/97**
9	DensaDeg Startup	13d	5/15/97	6/2/97
10	Silica/Hardness Removal -Optimize DensaDeg pH	20d	6/2/97	6/27/97
11	High Magnesium Studies	3d	8/27/97	8/29/97
12	***RO Pilot Unit***	**30d**	**7/10/97**	**8/20/97**
13	Startup RO	9d	7/10/97	7/22/97
14	**Boron Removal Studies - Alter RO feed pH**	**21d**	**7/23/97**	**8/20/97**
15	Operating Target pH 9.6	6d	7/23/97	7/30/97
16	Operating Targe pH 10	8d	7/30/97	8/8/97
17	Operating Target pH 10.7	5d	8/8/97	8/14/97
18	Operating Target pH 8.2	4d	8/15/97	8/20/97



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Task	□	Summary	▬	Rolled Up Progress	▬
Progress	▬	Rolled Up Task	■		
Milestone	◆	Rolled Up Milestone	◇		

Figure 5-8 Pilot Plant Operational Schedule

Table 5-4

Test Parameters and Methods

WSF Test No.	Loading Rate (gpm/ft2)	Flow (gpm)	Run Length (hours)
1	15	105	21
2	12.5	87.7	47
3	12.5	87.6	65
4	2	14	15

Test 1 was stopped when the influent pump was no longer able to maintain the desired flow rate. Test 2 was stopped when a downstream flow blockage disturbed pressure within the vessel. During these first two tests, engineers from K/J monitored water quality and AWE monitored flow rate 24 hours per day. Test 3 was run at an average rate of 87.6 gpm (12.5 gpm/ft^2) for 65 hours, and Test 4 was run at 14 gpm (2 gpm/ft^2) for approximately 15 hours, with pressure and flow rate reading recorded every two hours and water quality samples collected at the beginning and end of the tests. The accuracy of the WSF flowmeter was checked by measuring the time required to fill a known tank volume. The flowmeter read approximately 20 percent higher than the measured flow rate.

The filter backwash was only characterized for suspended solids. Influent and effluent grab samples were analyzed for turbidity and oil and grease. Three grab samples were also analyzed for total organic carbon (TOC). Composite influent, effluent, and backwash samples were analyzed for total suspended solids (TSS). Readings of flow rate and inlet and outlet pressures were also recorded.

PILOT SAMPLING PLAN

A sampling plan, summarized in Table 5-5, was formulated to provide guidance for the rest of the pilot units that were operated as a treatment train. The sampling plan was intended to provide information to assist in making operational decisions. It was not intended to provide

Table 5-5
Sampling Plan for Process Characterization and Optimization

Sample		Field Readings					Parameters Analyzed in Field										Parameter Analyzed in the Lab															
Location	Description	Flow	Tot. Flow	Flow Calib.	Pres.	Temp	pH	Cond	Turb	SDI	Alk	TH	Ca	UV	SIO2	O&G	pH	Alk	CO2	B	Fe	SIO 2	TOC	NH3	TSS	TDS	O&G	Heavy Metals	Cations	Anions	Settleability	% Solids
S1	Influent				D		D	D	D		D	D		D	D	D	3XC		C	D	3XC	D	D	D				C	3XC	3XC		
S3	Warm Lime Effluent	D	D	D		D*	D		D		D	D	D	D	D		3XC			D	3XC	D	D	D	D			C	3XC	3XC		
S4	Trickling Filter Effluent	D				D	D							D									D	D							C	C
S5	Booster Pump Effluent	D	D	D	D		D																									
S6	Pressure Filter Effluent				D		D	D	D	D	D	D		D		D																
S7	Ion Exchange Effluent				D		D	D	D	D	D	D	D										3XC			3XC						
S8-cf	Cartridge Filter Effluent	D			D				D							D																
S8-I	RO Influent (after CF)				D	D	D	D		D																						
S8-1p	Stage 1 Permeate	D			D			D																								
S8-2p	Stage 2 Permeate	D			D			D																								
S8-3p	Stage 3 Permeate	D			D			D																								
S8-sp	System Permeate	D		D	D	D	D	D						D	D					D			D	D		3XC		C				
S8-sc	System Concentrate			D	D		D	D			3XC	3XC	3XC		3XC		3XC	3XC		3XC		3XC				3XC		C				
S8-wc	Waste Concentrate	D																														
S8-rc	Recycle Concentrate	D																														
	Residuals																															
S2W	Warm Lime															3XC	3XC	3XC	3XC	3XC		3XC						3XC	3XC	3XC		3XC
S3W	Trickling Filter																														3XC	3XC
S5W	Filtration																															
S6W	Ion Exchange						3XC	3XC				3XC	3XC												3XC			C				
S7W	RO (see system concentrate)																															

Notes
* In and out of heat exchanger
D= Two Samples per day
C= One sample per operating condition
3XC = Three samples per operating condition

rigorous scientific data to defend or develop theoretical mechanisms of performance or removals of the unit processes within the treatment train.

ADDITIONAL STUDIES

Several members of the Technical Review Panel, Dr. Yosif Kharaka of the USGS, Dr. Harry Ridgway of Orange County Water District, and Mr. Lory Larson of Southern California Edison, provided assistance to the project. Dr. Yosif Kharaka attempted to identify the organic components of the Placerita produced water after treatment with the WEMCO WF-2. Dr. Harry Ridgway performed a series of test to determine the biogradability of the organics in raw water and warm soften produced water. Mr. Lory Larson arranged assistance from Southern California Edison and the Electric Power Research Institute to test two membrane systems using their mobile membrane test trailer. The results from these studies are included in Appendix B. Where appropriate, the results are incorporated in Chapter 6.

Chapter 6

Pilot Plant Results and Discussion

CHAPTER 6

PILOT PLANT RESULTS AND DISCUSSION

This chapter is organized in the same manner as Chapter 2, by water quality parameter. The discussion focuses on the performance of the units to meet the water quality goals and their implication rather than a theoretical based explanation of the results. The chapter discusses the removal of inorganics in the processed water, the organics in the process water, the sludge from the DensaDeg, the concentrate from the reverse osmosis (RO), and then operational findings of importance by unit process.

REMOVAL OF INORGANICS

The following section of this chapter discusses the results related to the removal of the important inorganic parameters by the pilot plant, total dissolved solids (TDS), Hardness, Silica, Boron, and Ammonia.

TDS Removal

The main unit process that addresses TDS removal is the RO. The DensaDeg unit increases the TDS slightly and depending on the pH adjustments, the TDS is not substantially changed until the RO unit. The TDS removal is summarized in Table 6-1.

Table 6-1

Average Removal of TDS by RO

Unit Process	Samples	Average TDS Concentration (mg/L)	Standard Deviation (mg/L)	Cumulative Removal (%)
Raw Water	5	5428	663	NA
RO Feed	24	5,825	308	107
RO Product	45	143	31	97.4
RO Concentrate	41	24,447	1444	450

Components of RO Effluent

The average TDS of the water after treatment with all the pilot plant unit processes was 143 mg/L. The TDS would increase slightly in the conceptual design when stabilizing the water with respect to corrosion control and final disinfection. A TDS by addition and ion balance was attempted to check on the data presented in Table 6-2. The pH of the RO water was assumed to be 9.5.

Table 6- 2

Summary of Average Cation, Anions, and TDS Components in RO Effluent

Cations	Average (mg/L)	Anions	Average (mg/L)	TDS Component	Average (mg/L)
Na	55	Alkalinity*	53	TOC	2.2
K	1.5	Cl	24.5	SiO_2	1
Ca	0.4	BO_3 (B^{+5})	29		
Mg	0.1				
Total TDS	57		70		3

*Alkalinity is as $CaCO_3$

The major cation was sodium and the major anions were chloride, bicarbonate, and boron. The ammonia concentration is expected to vary between 1-11 mg/L but does not appear in the Table 6-2 because it will evaporate off when performing a TDS measurement. The alkalinity concentration has been adjusted by assuming that 1/2 of the BO_3 titrates as alkalinity (subtract 0.25 meq/L from 0.53 meq/L of alkalinity equals 0.28 meq/L of carbonate) so that the 53 mg/L of CaCO3 alkalinity converts to 17 mg/L of TDS. The estimated TDS by addition using these adjustments is 130 mg/L which is within 10 percent of the average gravimetric TDS, which is very good closure.

Assuming the alkalinity is as carbonate/borate as previously described, the milliequivalents (meq) for the cation calculates out to 2.46 meq/L and 2.38 meq/L for the anions which is within the acceptable limits according to *Standard Methods.* The TDS by addition and the meq/L balance are quality assurance checks on the reported average values. Both of these checks indicate that these estimates are consistent.

Hardness Removal by Precipitive Softening and Ion Exchange

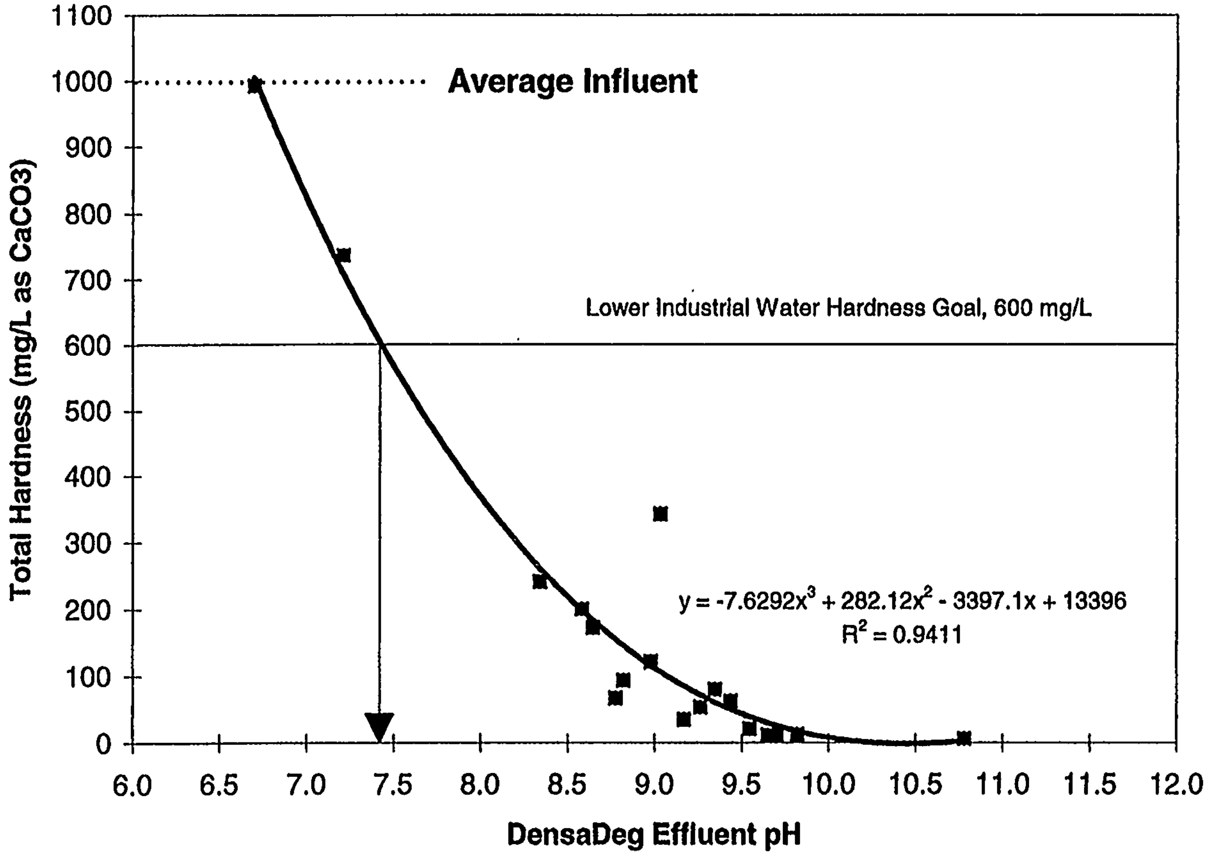
The hardness goals can be met by operating the DensaDeg at a designated pH. This relationship can be seen in Figure 6-1 and is summarized in Table 6-3. For an industrial water that only has a hardness water quality goal of 600 mg/L as $CaCO_3$, the operational pH would be ~ 7.7. The produced water for oil field has a high silica content and to meet the silica water quality goal requires operating the DensaDeg at a high pH. These data are discussed in the silica removal section of this chapter.

Table 6-3

Residual Total Hardness as $CaCO_3$ at Varying Operating pHs of DensaDeg or Ion Exchange Softening

Operating pH of DensaDeg	7.5-8.5	8.5-9.0	9.1-8-9.5	9.6-10.0	>10	Ion Exchange
Average	221	112	64	15	6.1	15
Max	242	172	260	35	6.1	41
Min	200	37	10	8	6.1	3
Samples	2	7	24	14	1	7

It should be noted that the ion exchange was placed in service when operating the RO at pH >9.5 to remove boron to protect the membranes from scaling. For the majority of the time, the ion exchange units were off line because the DensaDeg was capable of producing an residual total hardness that could be handled by the antiscalant chemicals. Table 6-3 also summarizes the data from the ion exchange unit while it was in operation for comparison. The average hardness from the effluent of the ion exchange was 15 mg/L as $CaCO_3$ which is comparable to the effluent of the DensaDeg in the conceptual design ~ pH 9.6. The total hardness from the DensaDeg spikes that occur as indicated by the high maximum values are primarily due to the floc carryover. If the DensaDeg or filters can reliably remove this floc, then the ion exchange units would not be needed. Warm softening with the DensaDeg unit followed by reliable turbidity removal can probably produce an effluent of $\leq$ 25 mg/L of total hardness as $CaCO_3$.



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Residual Hardness Verses Operating pH of DensaDeg

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Figure 6-1

Residual Calcium

To examine the major components of the hardness, Table 6-4 summarizes the operational pH of the DensaDeg and the residual calcium in the effluent as determined by laboratory analyses. The residual calcium drops in accordance with its decreasing solubility as the pH increases as can be seen in Figure 6-2. There is more variation as indicated by the wide range of the maxima and minima due to floc carryover. These DensaDeg upsets were primarily caused by the inability to maintain the target operational pH due to the poor performance of a caustic metering pump. Better performance would be expected in a full scale facility.

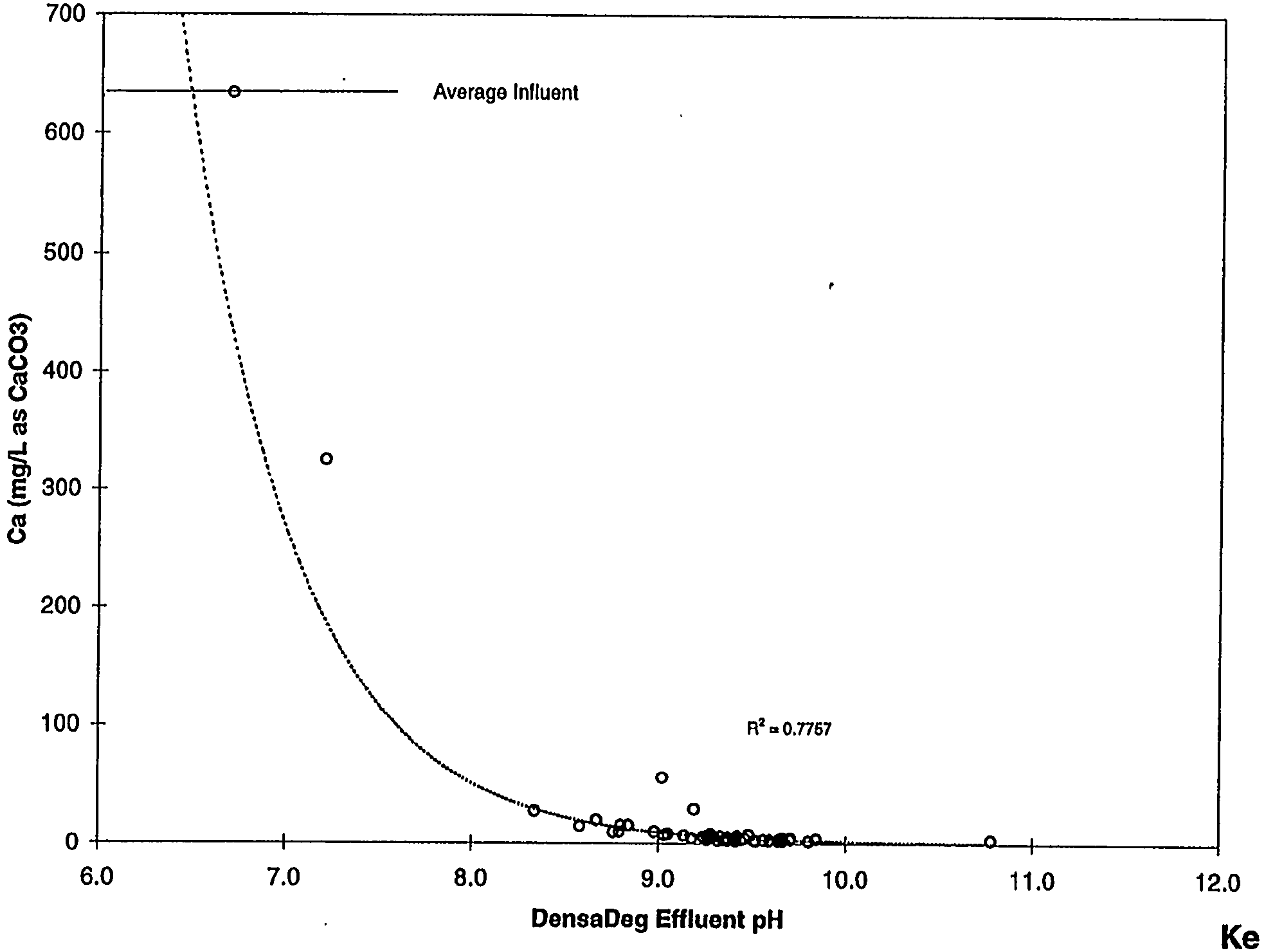
Table 6-4

Residual Calcium as $CaCO_3$ in DensaDeg Effluent at Varying Operating pHs

Operating pH of DensaDeg	**7.5-8.5**	**8.5-9.0**	**9.1-8-9.5**	**9.6-10.0**	**>10**
Average	21	14	8	3	3.2
Max	27	2.4	56	4.8	3.2
Min	15	0.8	2.5	2	3.2
Samples	2	12	25	14	1

Residual Magnesium

The residual magnesium component of the hardness is summarized in Table 6-5. It shows that with increasing pH, the magnesium hardness drops following the decreased in theoretical solubility of magnesium silicate and hydroxide with increasing pH.



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Residual Calcium Verses
Operating DensaDeg pH

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Figure 6-2

Table 6-5

Residual Magnesium as $CaCO_3$ in DensaDeg Effluent at Varying Operating pHs

Operating pH of DensaDeg	7.5-8.5	8.5-9.0	9.1-8-9.5	9.6-10.0	>10
Average	200	87	58	13	3
Max	214	152	254	32	3
Min	185	26	5	5	3
Samples	2	6	24	14	1

Turbidity with Operational pH of DensaDeg

Table 6-6 summarizes the effluent turbidity as the operational pH of the DensaDeg was varied. Although the averages do not increase with pH the maximum values increase. In some cases the maximum is dramatically higher which is reflective of periodic floc carryover. These data are supportive of the conclusion that the variation in total hardness, calcium and magnesium as represented by the maximum and minimum concentrations was due to periodic floc carryover.

Table 6-6

Effluent DensaDeg Turbidity at Varying Operating pHs

Operating pH of DensaDeg	7.5-8.5	8.5-9.0	9.1-8-9.5	9.6-10.0	>10
Average	1.025	1.3	3.9	1.3	20
Max	1.3	1.7	36	3.3	20
Min	0.75	0.66	0.6	0.6	20
Samples	2	6	28	15	1

Silica Removal

From the bench scale results it appeared that silica removal was based on a precipitive process. The minimum seen in Figure 6-3 could be explained by the pK's that are similar to the bench scale findings. The minimum for the laboratory measurements was at pH 9.6-9.7, the same for the pilot scale results, pH 9.6. The measured silica in the field trial had an average value lower than the bench scale (19 ppm versus 72 ppm). The lower result is probably due to the intrinsic design of the DensaDeg that has a sludge recirculation feature that facilitates additional removal by adsorption.

For the RO effluent, as the operational pH increased, the silica in the effluent increased. At the higher pH of 10.8 one would expect the opposite since more of the silica would be ionized. Perhaps, the membranes "leak" more molecules due to the higher pH.

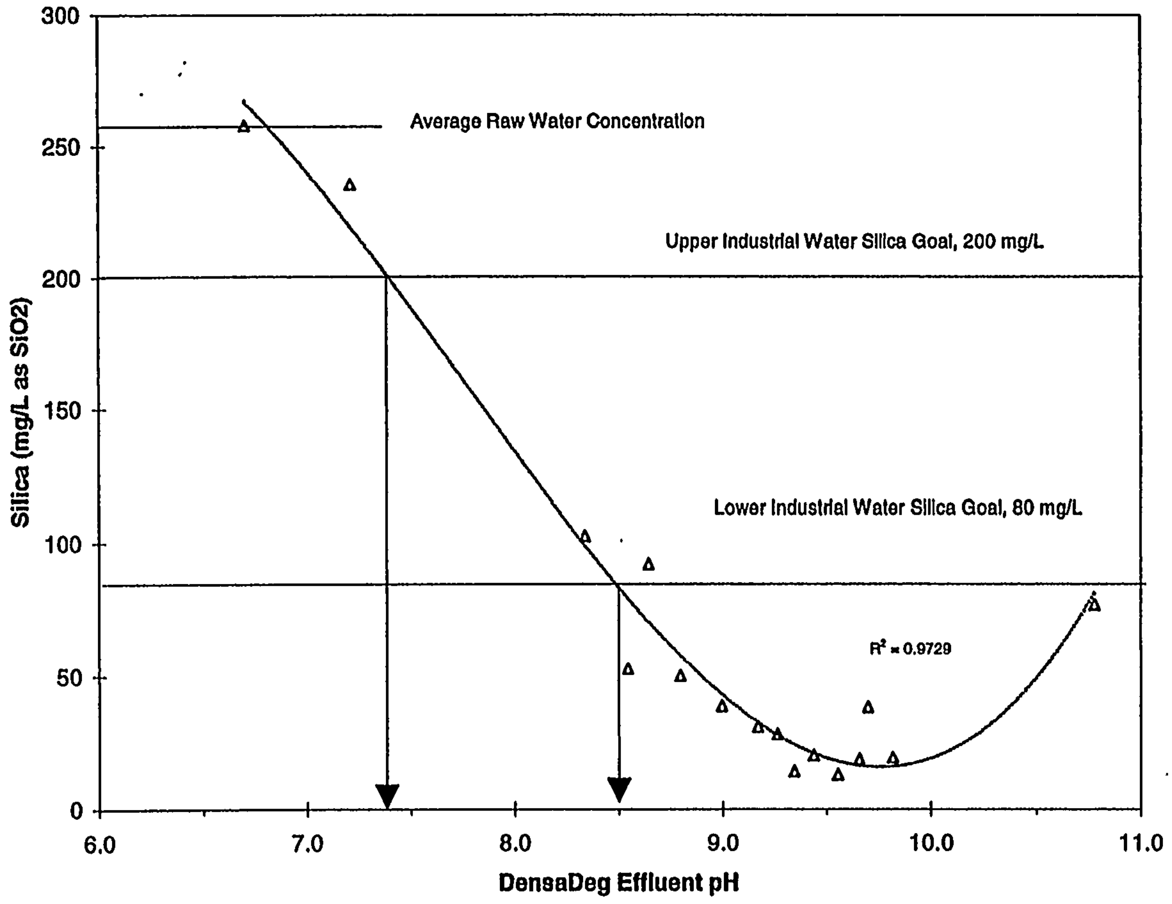
Table 6-7

Summary of Silica as SiO_2 by Warm Softening and RO Treatment

Unit Process	Condition	Samples	Average Silica Concentration, mg/L	%Cumulative Removal
Influent	NA	55	255	NA
DensaDeg	pH 9.5-9.8	14	20	92
DensaDeg	Mg, 400-800 mg/L	3	3.8	98.5
RO Effluent	Influent pH 8.7	14	0.8	99.7
RO Effluent	Influent, pH 9.5	13	1.7	99.3
RO Effluent	Influent, pH 10	5	2.6	99
RO Effluent	Influent, pH 10.8	1	5.7	97.8

BORON REMOVAL

Boron removal was evaluated using two different unit processes. The first was to vary the magnesium dose being fed to the DensaDeg so that it was removed either through a



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Residual Silica Verses Operating pH of DensaDeg

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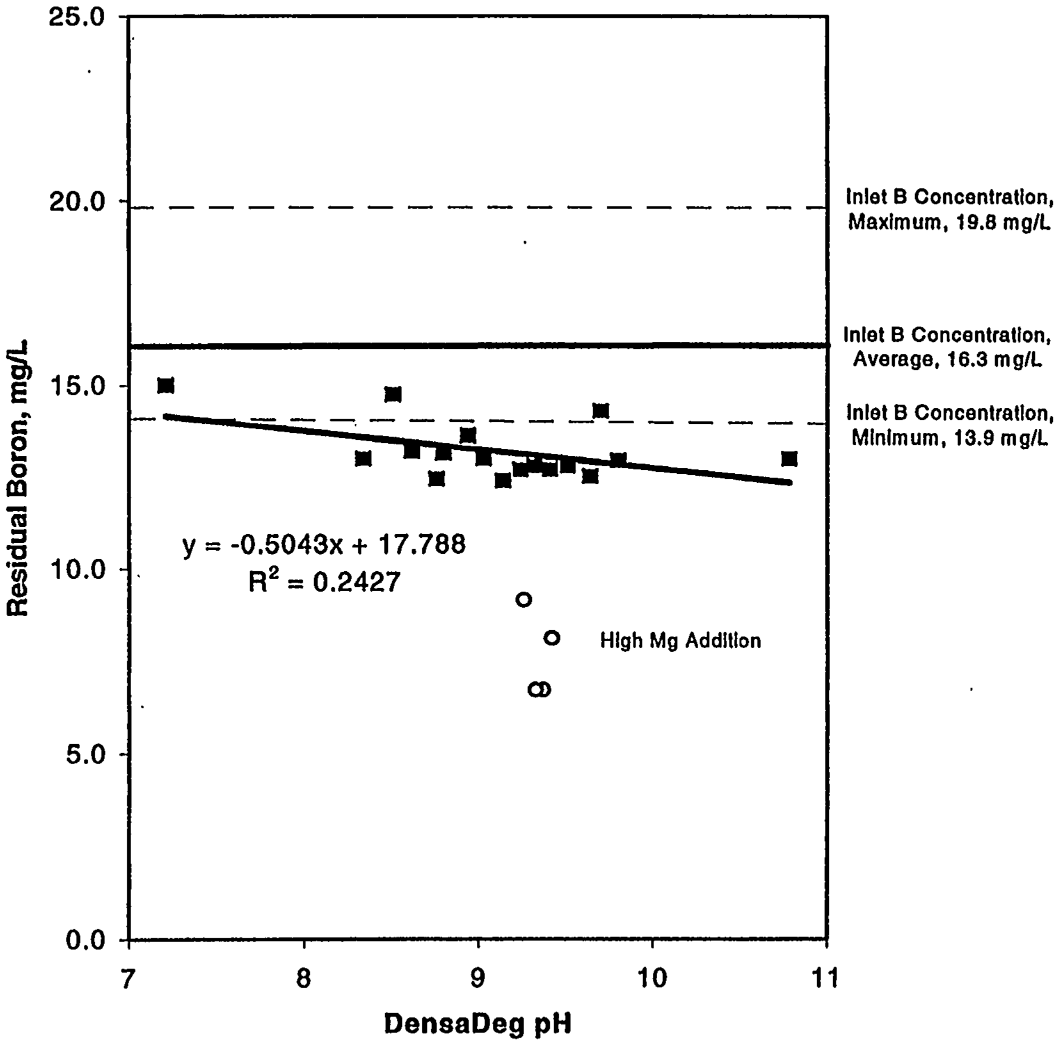
Figure 6-3

precipitation or sorption mechanism. The second approach was to increase the pH ahead of the RO to create an ionic form of boron so that it could be rejected by the membrane.

The first approach evaluated was to increase the softening pH to approximately 9.7. Unlike silica, boron removal did not improve very much with higher pH operating conditions (See Figure 6-4). During these trials, the magnesium was kept constant at 25 mg/L. At this level of addition, the magnesium was in slight excess of the stoichiometric amounts, assuming a magnesium silica/boron precipitation product. The boron concentrations dropped by only 10-25 percent although a removal rate of > 93 percent is necessary to meet the boron goal of 1 mg/L. To achieve the higher removals, the DensaDeg must operate at a magnesium dose more than 10 times stoichiometry. These operating conditions would generate a lot of sludge and a magnesium floc that is difficult to settle and remove as a sludge. The high magnesium dose result indicates that sorption is the likely major mechanism (~30 percent removal) for the boron removal in the softening process.

We were not able to keep a suitable sludge blanket in the DensaDeg with the dose of 800 mg/L of $MgCl_2$, so the dose was dropped back to 400 mg/L. Performance of the DensaDeg was similar for these two doses, although not enough data was collected to make a statistical comment. The data were grouped and summarized in Table 6-8 as high magnesium. This operational scenario reduced the boron by 55 percent to approximately 7 mg/L. The residual boron levels were slightly lower than the bench scale results indicating that the sorption in the sludge blanket of the DensaDeg was more efficient that straight precipitation for removing boron.

The second approach was to increase the pH of the RO feed water to ionize the boron. Table 6-8 summarizes the removal of boron by the DensaDeg and RO processes under the different operating conditions described above. Figure 6-5 shows that raising the pH of the RO feed water decreases the boron concentration in the RO effluent. As the pH increases a larger faction of the boron becomes ionized and rejected by the RO membrane. Using the graph to extrapolate the removal of boron to the 1 mg/L treatment goal, the pH would have to be adjusted to approximately 11.4 which is beyond the long term operational criteria of most polymeric membranes.



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Residual Boron Versus Operational pH of DensaDeg

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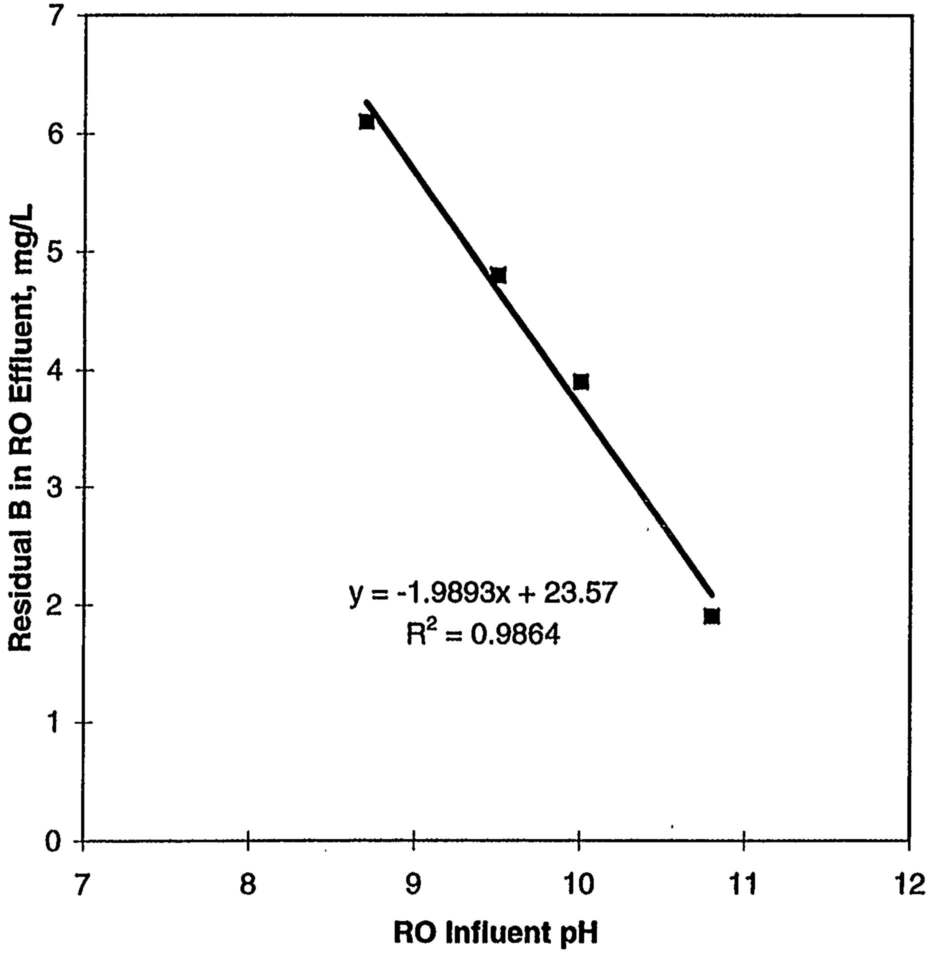
Figure 6-4



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Residual Boron Versus
pH of RO Feed Water

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Figure 6-5

Table 6-8

Summary of Boron Removal by Warm Softening and RO Treatment

Unit Process	Condition	Samples	Average Boron Concentration (mg/L)	Cumulative Removal (%)
Influent	NA	59	16.5	NA
DensaDeg	Mg, 30 mg/L	72	13.2	20
DensaDeg	Mg, 400-800 mg/L	4	7.4	55
RO Effluent	Influent pH 8.7	16	6.1	63
RO Effluent	Influent, pH 9.5	12	4.8	71
RO Effluent	Influent, pH 10	6	3.9	76
RO Effluent	Influent, pH 10.8	7	1.9	88

AMMONIA REMOVAL

Table 6-9 provides a summary of the behavior of ammonia through the pilot treatment process. The pKa for ammonia at 30 C is approximately 9.2. These data reflect the rejection of the ionized form. As pH increases to near pH 11, more than 90 percent of the ammonia is un-ionized and not removed by the RO membrane. At pH 8.7 approximately 30 percent of the ammonia is un-ionized. These data indicate that there was a little higher removal, 84 verses 70 percent, than indicated by the pKa ionization.

Table 6-9

Summary of Ammonia Removal by Pilot Treatment Units

Unit Process	Condition	Samples	Average Ammonia Concentration (mg/L)	Cumulative Removal (%)
Influent	NA	45	9.3	NA
DensaDeg	pH 9.5-9.8	47	8.6	7.5
Trickling Filter	pH 9.5	8	7.7	20
RO Effluent	Influent pH 8.7	16	1.8	81
RO Effluent	Influent, pH 9.5	16	5.7	39
RO Effluent	Influent, pH 10	8	5.2	44
RO Effluent	Influent, pH 10.8	7	11	-18

ORGANICS

There have been a number of different organics measurements made on the inlet water. They include gross measurements such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), total organic carbon (TOC),and oil and grease as well as compound specific scans such as EPA Organic Priority Pollutants. In addition several special studies have been performed by Drs. Yosif Kharaka and Harry Ridgway that have provided additional characterization.

Organics Characterization

Table 6-10 summarizes the different measurements made during the course of this investigation. The emphasis of the pilot study was on the behavior of the TOC through the treatment train.

Table 6-10

Organic Content of Produced Water at Placerita

Organic Measurement	Samples	Average	Max	Min
TOC	60	107	178	47
BOD	7	19	26	14
COD	7	406	432	334
Oil & Grease, SM 5520 B (gavimetric)	10	42	59	14
Nalco, % transmission Oil & Grease	37	16.4	22.7	10.7

Identification of Organic Composition of Placerita Produced Water

Dr. Yosif Kharaka performed a speciation of the produced water according to his protocol (ref). A copy of Dr. Yosif Kharaka's report on the speciation of organics in the inlet water is in Appendix B and Table 6-11 and is a summary of these results. Unlike some of the other reports in the literature (refs), more than 90 percent of the TOC can not be identified. The percentage of unidentified carbon in this produced water is very similar to other reports of naturally occurring organics in drinking water (refs).

Table 6-11

Summary of Organic Composition of Placerita Produced Water

Chemical Class	µg/L C	% of TOC
Base Neutral Extractables	2,662	2.4
Benzene, Toluene, Xylene, Ethylbenzene	100	0.1
Short Chain Organic Acids (Acetate, Formate, Succinate, Propionate)	5,402	4.9
Phenol	497	0.45
Ketones	864	0.87
Total Identified Carbon	9,537	8.7
Unidentified Carbon	100,463	91.3
Total Organic Carbon	110,000	100

Organic Biodegradability

There were three experimental conditions. One was operating the trickling filter as a batch reactor. The second was operating the trickling filter in a continuous flow. The third was a bench scale study performed by Orange County Water District.

Orange County Water District Microcosm Study

Dr. Harry Ridgway provided the project with bench scale testing to determine the potential conversion of the TOC to CO_2. Water samples were sealed in 100 mL vials with a headspace of 50 mL to provide oxygen. The vials were shaken using an orbital shaker for 19 days at room temperature supplemented in the following manner:

- Appropriate controls with $HgCl_2$ (Killed Controls)
- No Additions (Neat)
- Diluted 1:10 and N and P nutrients with trace elements
- Microbes from Orange County Sanitation Districts Plant No. 1 activated sludge
- N and P nutrients with trace elements
- N and P nutrients with trace elements and microbes

The amount of CO_2 was measured in the headspace and the net amount of CO_2 evolved from the TOC was calculated.

The results are present in Table 6-12 and indicate that there appears to be a toxic effect. These results indicate that when the toxic effect is removed the total potential TOC that can be expected to be mineralized is approximately 25 percent. These results are similar to the trickling filter findings (14 percent removal) summarized in Table 6-13 where the TOC removal was estimated to be when operated in the batch mode.

Table 6-12

Summary of Microbial Utilization of TOC Potential of Placerita Produced Water

Source of Water	Treatment	% TOC-C Mineralized
AWE-1	Neat	11.3
	1:10, Neat	27
	+ Cells	15.7
	+ Cells + Nutrients	26
	+ Nutrients	16
AES	1:10, Neat	24
	Neat	8.5
	+ Cells	6
	+ Cells + Nutrients	9.3
	+ Nutrients	4.8

Trickling Filter Batch Reactor Study

The trickling filter was seeded with pure oxygen waste activate sludge for LACSD which treats wastewater from 6 oil refineries within the Los Angeles area. Eight ounces of 30 percent phosphate fertilizer was added to ensure that this element was not limiting growth. The unit was operated from March 6 to July 14 in a batch mode. During this time influent water was periodically added to make up evaporative lost. The conductivity changed from 8,961 to 27,300 μmhos/cm^2 resulting in a concentration factor of ~3. Making the appropriate adjustments to the organic measurements, the estimated removals are summarized in Table 6-13. These would be maximum expected removals from an acclimated biomass due to the long detention time.

The results are similar to the OCWD results summarized in Table 6-12 and are closer to the neat sample. Although the microbes were acclimatized for ~90 days, these results indicate that there may have been some residual toxicity that reduced the overall removal of the organics due to the concentrating effect of the organics by evaporation. The COD results indicate that there was little or no removal of the carbon as defined by this test. The BOD results indicate that most of the TOC that was removed was the easily biodegradable BOD portion. If they are equal, 50 % of TOC was removed as BOD.

Table 6-13

Maximum Organics Removal by Batch Loading Trickling Filter

Parameter	Location	Concentration (mg/L)	Max Expected % Removal
COD	Average Influent	406	NA
COD	TF Effluent	440*	-10†
TOC	Average Influent	107	NA
TOC	TF Effluent	92*	14
BOD	Average Influent	20	NA
BOD	TF Effluent	12*	40

* Laboratory results divided by 3.05 to correct for evaporative concentration.

† No removal

Continuous Trickling Filter Operation

The trickling filter was operated 5 days a week between 8 to 16 hours a day from July 14 until August 26. During this operational period several samples were taken to determine the ability of the trickling filter to reduce the organics and these results are summarized in Table 6-14. When the trickling filter was used in line, there was a 30 percent reduction of the BOD. The reduction was almost as high as the observed in the batch mode, but the BOD level was twice as high, i.e., 26 verses 12 mg/L. The TOC removal was about the same when operated in the batch mode, considering that we are comparing pilot plant and bench scale results. The COD dropped slightly, whereas it increased in the batch mode. This probably indicates little or no change of the carbon by this measurement.

Table 6-14

Summary of Organic Removal by the Trickling Filter Unit

Parameter	Location	Samples	Average (mg/L)	Removal (%)
COD	Influent	1	526	NA
COD	TF Effluent	1	493	6.3
TOC	Influent	14	95	NA
TOC	TF Effluent	15	87	8.4
BOD	Influent	1	38	NA
BOD	TF Effluent	1	26	31.5

Bacteria Loading from Trickling Filter to RO

With the trickling filter off line, 3 out of the four samples for heterotrophic plate counts (HPC) were <1CFU/mL and one sample had 2 CFU/mL indicating a very low microbial load to the membranes. This would be expected since the temperature of the produced water is relatively high 150 - 180 °F (66-82 °C, which does not permit much microbial growth), although it is cooled by the pilot fin fan coolers to ~90 °F (~32 °C, which does accelerate microbial growth). After cooling, the retention times in the pilot reaction vessels are short, lowering the microbial growth potential.

The bacterial load to the RO membranes when placing the tricking filter on line ranged from 1.3 - 31.2 $x\,10^6$ CFU/mL. Without optimizing the pressure filters, this loading onto the membranes would create a significant biofouling problem with a marginal gain in organics removal by the trickling filter.

Oil and Grease Removal by Walnut Shell Filter

The raw data from the walnut shell filter (WSF) pilot testing are presented in Appendix C. The performance of the walnut shell filter for the key parameters is summarized in Table 6-15. It should be noted that both the TOC and the oil and grease data reported in this table are for total oil and grease, most of which is soluble. Results from 10 un-matched gravimetric measurements of total oil and grease ranged from 44 to 59 in the inlet and 45 to 62 in the outlet. Hydromation submitted a separate report also in Appendix C (Kozar and Henry, 1997) that indicated this unit had an average suspended oil removal of 97.4 percent. Hydromation also reported that the removal of suspended solids averaged 94.0 percent over the entire test period.

Table 6-15

Summary of Walnut Shell Removal

Parameter	Location	Samples	Average	Max	Min	Average Removal (%)
Turbidity, NTU	Inlet	38	3.9	6.3	2.5	NA
Turbidity, NTU	Outlet	38	1.45	4.5	0.9	65
Oil & Grease, mg/L	Inlet	37	16.4	22.7	10.7	NA
Oil & Grease, mg/L	Outlet	52	9.5	18.4	6.5	39
TOC, mg/L	Inlet	3	99	99	98	NA
TOC, mg/L	Outlet	3	108	110	85	109

TOC Removal by Unit Processes

The DensaDeg removed very little of the TOC. It appears that most of the organics are soluble and smaller than the larger disinfection byproduct (DBP) precursors such as humic and fulvic fractions that have been reported to be removed by enhanced softening. The combined precipitative softening and trickling filter removed about 12 percent. The majority of the organics were removed by the RO process as can be seen in Table 6-16. The trickling filter provided some small additional removal at the RO, but the numbers of tests were not enough to demonstrate that this difference is statistically significant.

Table 6-16

Summary of TOC Removal by Pilot Unit Processes

Unit Process	Condition	Samples	Average TOC Concentration (mg/L)	Cumulative Removal (%)
Influent	NA	60	107	NA
DensaDeg	Mg, 30 mg/L	50	97	9.3
RO Effluent	Influent pH 8.7	13	2.1	98
RO Effluent	Influent, pH 9.5	12	2.1	98
RO Effluent	Influent, pH 10	7	3.7	96.5
RO Effluent	Influent, pH 10.8	7	2.8	97.4
With Trickling Filter	Influent pH 8.9-9.9	8	1.8	98.3

Figure 6-6 is a plot of the TOC against RO influent pH that was adjusted with NaOH or H_2SO_4 as appropriate. More TOC was expected to be rejected as the pH is lowered. The trend line indicates some additional removal as the pH is lowered (98 % removal at pH 9 versus 96 % removal at pH 10.8).

Identification of Organics in the RO Effluent

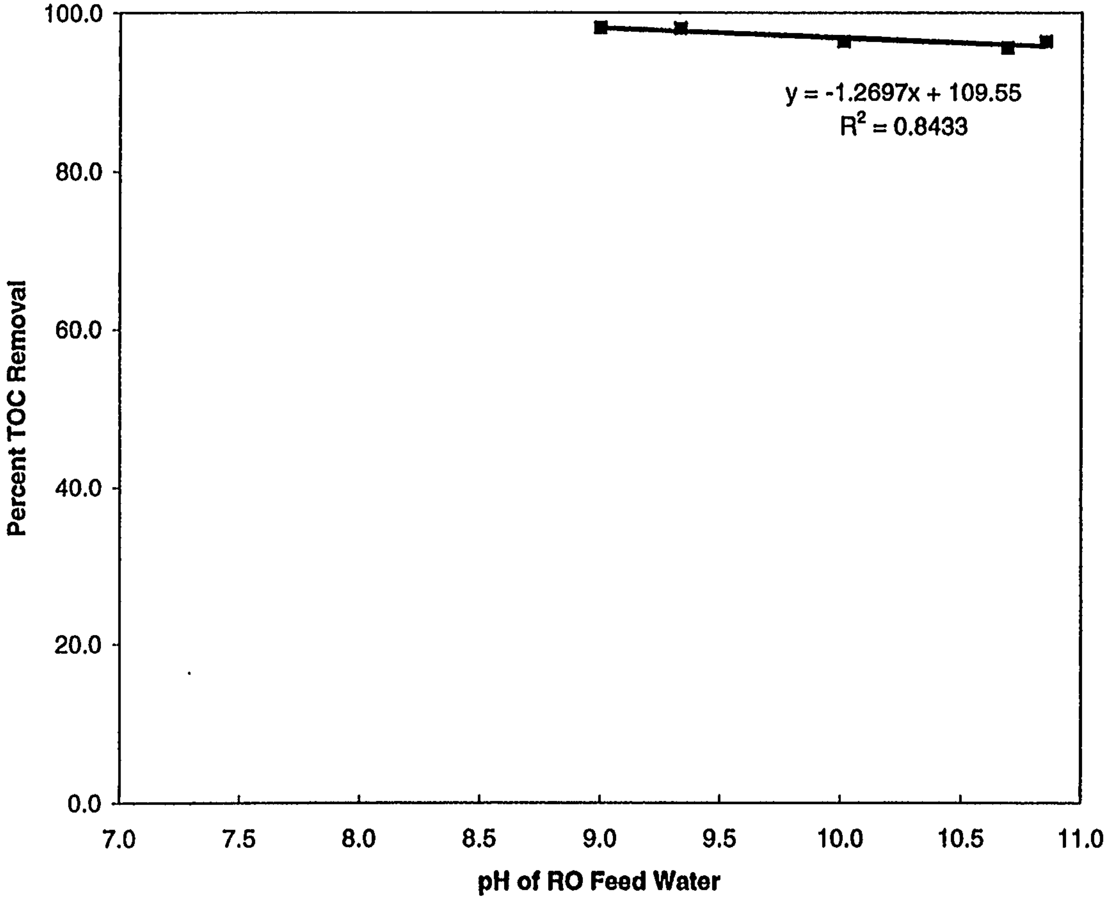
EPA priority pollutant analysis detected two volatile compounds, 2-butanone and ethyl benzene. There was one extractable organic detected, naphthalene. These results are summarized in Table 6-17. Less than 3 percent of the TOC has been identified with these tests.

Table 6-17

Organic Compounds Detected in the RO Effluent

Compound	Type	Concentration (µg/L)
2-Butanone	VOA*	53.1
Ethylbenzene	VOA	4.85
Naphthalene	BNA‡	11.6

* Volatile Organic Analysis
‡ Base Neutral Acid



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TOC Removal Verses
Operational pH of RO

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Figure 6-6

An important finding is that phenol was removed to below detection of 10 µg/L. Chlorinated phenols form as a byproduct of chlorination that have a low taste and odor threshold (2-210 µg/L). The 2-butanone and naphthalene findings are a potential problem from a taste and odor perspective.

Disinfection Byproduct (DBP) Formation Potential

Although there was DBP formation potential testing performed, the plan would be to use chloramines to maintain a distribution disinfection residual to take advantage of the residual ammonia in the RO effluent. It has been extensively reported in the literature that chloramines inhibit the formation of DBPs. The use of this residual maintenance is estimated to be below 20 µg/L for the trihalomethanes (THM), well below the proposed Stage 2 THM MCL of 40 µg/L. The haloacetic acids are estimated to be < 20 µg/L, below the proposed Stage 2 HAA5 of 30 µg/L.

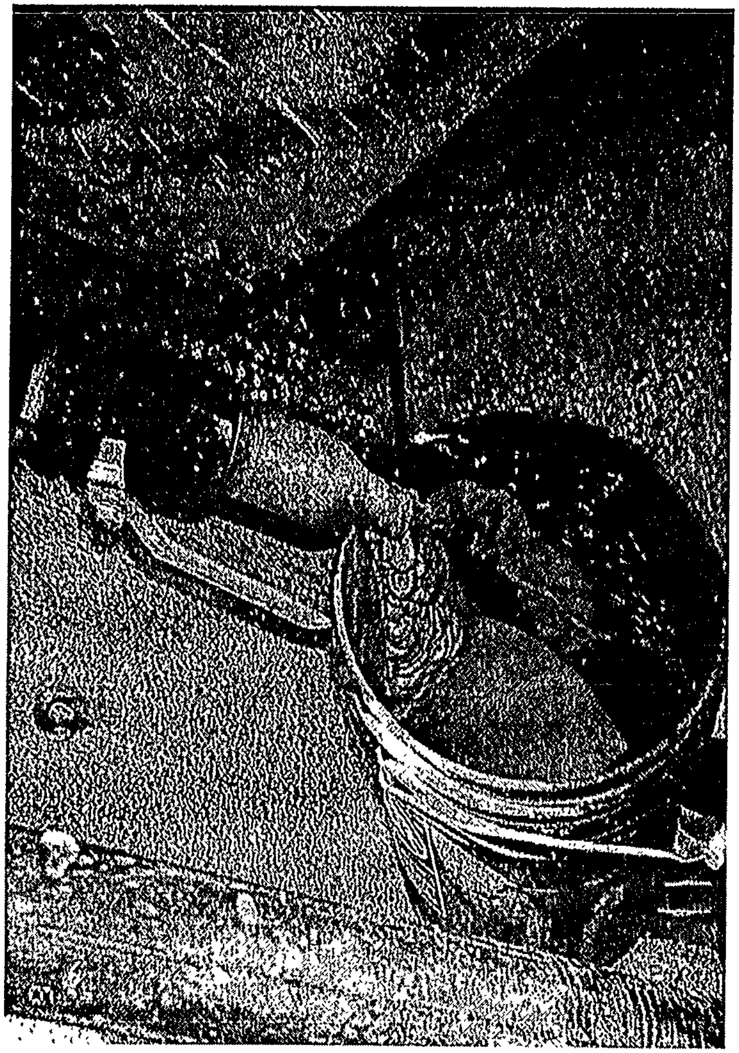
WASTE STREAMS

The proposed system would have three relative large waste streams: 1) DensaDeg sludge; 2) Pressure filter backwash; and 3) RO concentrate. A relatively small waste stream would be generated when cleaning the RO membranes. This would include the spent cleaning solution and wash water that is needed before placing the RO back on line. The following is a characterization of these waste streams.

DensaDeg Sludge

During the study, there were three operational flow rates used when testing the pilot treatment train. The records indicate that the volume of sludge production as a percentage of flow decreases with increasing flow rate and when operating with the high magnesium dose. The sludge production with the high magnesium dose was expected and was due to the poor settleability of the magnesium floc. The reduction in the percent solids for this operational mode supports the observations that there was difficulty in removing the magnesium floc.

The trend of sludge production with flow and the associated percent solids varied. Figure 6-7 is a picture of the sludge representing approximately 10 percent solids which represents the upper



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DensaDeg Sludge

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Figure 6-7

boundary, i.e., the most concentrated sludge. These results are influenced by operator experience, level of staffing, and hydraulic loading.

It would appear that the highest percent solids and lowest sludge volume were generated between 27 and 40 gpm. However, it should be noted that there was insufficient pilot plant staff until the latter part of August and record keeping for the sludge blow down may not have been adequate during this study. Also, the lower flow rates coincided with better operations due to increased staff experience with the pilot equipment, but the 19 gpm was tested only once for the percent solids. Table 6-18 summarizes the sludge volume and percent solids data.

Table 6-18

Summary of Sludge Production from the DensaDeg

Flow Rate	Date	$MgCl_2$ Addition (mg/L)	Average Sludge Volume (% of Flow)	Average Percent Solids
40 gpm	7/15 to 7/23	100	1	6
27 gpm	7/24 to 8/19	100	2	8
19 gpm	8/20 to 8/26	100	4	3.5*
19 gpm	8/28 to 8/29	400-800	12	2.4

*Based on one trial.

An analysis of the DensaDeg solids indicates that the sludge is primarily a calcium carbonate, magnesium hydroxide, and magnesium silicate sludge (See Table 6-19). There were high concentrations of sodium and boron which may restrict the beneficial use of the sludge as a soil amendment. Boron and sodium can potentially leach out causing problems for plant or soils with a high clay content.

Table 6-19

Summary of DensaDeg Sludge Primary Components

Parameter (mg/L)	Samples	Average	Max	Min
Calcium	11	27,400	33,000	17,000
Magnesium	7	11,700	16,000	8,100
Sodium	6	2,450	3,700	2,000
Potassium	6	90	137	61
Boron	10	376	650	270
Silica	6	1,350	3,400	800
Iron	11	252	650	6
Barium	11	114	150	81
Strontium	3	805	842	783

DensaDeg Sludge Hazardous Waste Determination

All testing on the sludge indicated that it would not be considered a hazardous waste by EPA's Resource Conservation and Recovery Act (RCRA) or similar California regulations. The sludge was tested in accordance with California EPA rules as described in the California Code of Regulations, Title 22, Article 2, Section 66261.24(a)(2). When a waste exhibits a waste characteristic or contains substances which equal or exceeds the threshold level, it must be handled as a hazardous waste. Table 6-20 summarizes the results of the waste characterization indicating that its non-hazardous waste by California regulations. Table 6-21 is a comparison of the total threshold concentration limits (TTLC) and the concentration found in one sample of the DensaDeg sludge and provides information that makes the sludge a non-hazardous waste by California regulations. Generally, California has stricter standards implying that if the sludge was classified as non-hazardous by these regulations, it would also have the same classification by US EPA regulations.

Table 6-20

Summary of DensaDeg Sludge Waste Characteristics

Parameter	California Limits	DensaDeg Sludge
Flammability, °F	<140	>200
pH, 1:1 DI, units	≤ 2 or ≥ 12.5	10
Free Sulfide, H_2S, mg/Kg	~500*	<10
Free Cyanide, CN, mg/Kg	~10*	<1.0
Aquatic Toxicity, LC_{50} mg/L	< 500	>750

*..when wastes exposed to pH conditions between 2 and 12.5, can generate toxic gases, vapors, or fumes in a quantity sufficient to present a danger to human health or the environment. Concentrations estimated based on confining conditions. There were no confining conditions for the sludge.

Table 6-21

Summary of Sludge and Hazardous Waste Criteria

Substance	TTLC*, Wet Weight (mg/Kg)	mg/Kg	RCRA† Max Concentration (mg/L)	Extractable Concentration (mg/L)
Antimony and/or antimony compounds	500	<10	NA	NA
Arsenic and/or arsenic compounds	500	<0.25	5.0	<0.005
Barium and/or barium compounds (excluding barite)	10,000	63	100	0.75
Beryllium and/or beryllium compounds	75	<0.5	NA	NA
Cadmium and/or cadmium compounds	100	<0.5	1.0	<.01
Chromium and/or Chromium (III) compounds	2,500	<2.5	5.0	<0.05
Cobalt and/or cobalt compounds	8,000	<5.0	NA	NA
Copper and/or copper compounds	2,500	<2.5	NA	NA
Lead and/or lead compounds	1,000	<2.5	5.0	<0.05
Mercury and/or mercury compounds	20	<0.10	0.2	<0.002
Molybdenum and/or molybdenum compounds	3,500	<5.0	NA	NA
Nickel and/or nickel compounds	2,000	<2.5	NA	NA
Selenium and/or selenium compounds	100	<0.25	1.0	<0.005
Silver and/or silver compounds	500	<1.0	5.0	<.002
Thallium and/or thallium compounds	700	<10	NA	NA
Vanadium and/or vanadium compounds	2,400	<5.0	NA	NA
Zinc and/or zinc compounds	5,000	3.1	NA	NA

TTLC* = Total Threshold Limit Concentration
RCRA† = Resource Conservation and Recovery Act

Filter Backwash

The filters were operated only when the RO was in operation, typically 15 hours per day, five days per week. The filters were backwashed when elevated effluent turbidities were noted. The frequency of backwash was approximately once per week. Based on this operational scenario, the volume of the filter backwash from the pilot study would not be characteristic of a full scale operation. Kennedy/Jenks' water treatment experience with pressure filters will be used to determine the backwash volume.

For the full scale plant the filter backwash would be recycled to the DensaDeg. Based on this assumption, the filter backwash was not characterized during this phase of the study. However, based on water treatment experience, the suspended solids is estimated to range between 0.5 to 1.5 percent. The estimate was based on the range and average turbidities of the DensaDeg effluent. The average DensaDeg effluent was 1.6 NTU with a range of 0.5 to 5 NTU.

During the pilot study, filtration was not optimized by using a coagulant or filter aid. The solids content of the backwash water might increase by another 0.5 percent when optimized.

RO Concentrate

The concentrate consisted of approximately 25 percent of the treated flow. For the full scale treatment plant, the concentrate would be deep well injected.

A major anion and cation analysis was not performed, so a similar analysis for the ion balance and calculated TDS can not be performed. A mass balance of TDS which has been developed and described in the next section demonstrates that the results are within 5.7 percent of closure. The available data are summarized in Table 6-22. The average TDS of 24,447 mg/L is approximately four times the TDS of the currently injected produced water. However, when comparing the measured dissolved ions in the RO concentrate with the produced water currently injected at the Placerita field, the only potential problem that can be identified is the high pH. The hardness and silica are well below the current injected levels. The turbidities are low although there were only two measurements. The pH of the concentrate can be appropriately adjusted by acid or carbon dioxide addition, which would create a RO concentrate that would pose few problems to the current practice of deep well injection disposal.

Table 6-22

Summary of Water Quality Parameter for the RO Concentrate

Parameter	Samples	Average	Max	Min
pH, units	30	9.0	10.2	7.65
Turbidity, NTU	2	0.65	0.9	0.4
Conductivity, µmhos/cm^2	46	36,370	42,600	16,000
TDS, mg/L	41	24,447	28,700	21,800
Sodium, mg/L	25	10,068	11,200	8,960
Magnesium, mg/L	25	40	207	2.5
Calcium, mg/L	25	14	47	2.5
Si, mg/L	35	28	88	0.8
Iron, mg/L	36	0.43	3.65	<0.01

RO TDS Mass Balance

The inlet flow to the RO was set at 9.3 gpm with 7 gpm of RO product water and 2.3 gpm of RO concentrate. Using the flow and the TDS information in Table 6-1 the following information is calculated and summarized in Table 6-23.

Table 6-23

TDS Mass Balance of RO

Source of Salt	Average TDS (mg/L)	Flow Rate Conversion	Average Salt Loading Rate (mg/L per min)
RO Feed Water	5,826	9.3 gpm X 3.785 L/gal	205,078
RO Product	143	7 gpm X 3.785 L/gal	3,788
RO Concentrate	24,447	2.3 gpm X 3.785 L/gal	212,823

205,078 mg/liter mins - 216,611 mg/liter mins out = 11,533 mg/liter per min

The RO salt balance closure is within 5.6 percent of closure which is acceptable. It should be noted that the percent standard deviations for the RO feed is 5.3 percent and for the RO concentrate, it is 5.9 percent so the mass balance is within the standard deviations of the numbers used in the calculation.

Membrane Cleaning Solution

The membrane cleaning solution volume is the smallest waste liquid stream. The membranes were cleaned three times over the course of the study using a total volume of 200 gallons. This frequency did not provide enough operational time to estimate the volume that might be used for a full scale operation. The spent cleaning solution was not characterized during the pilot study to determine whether it would be classified as a hazardous waste. Assuming that the solution is not a hazardous waste according to California EPA criteria, this solution would be added to the RO concentrate and deep well injected in the full scale plant.

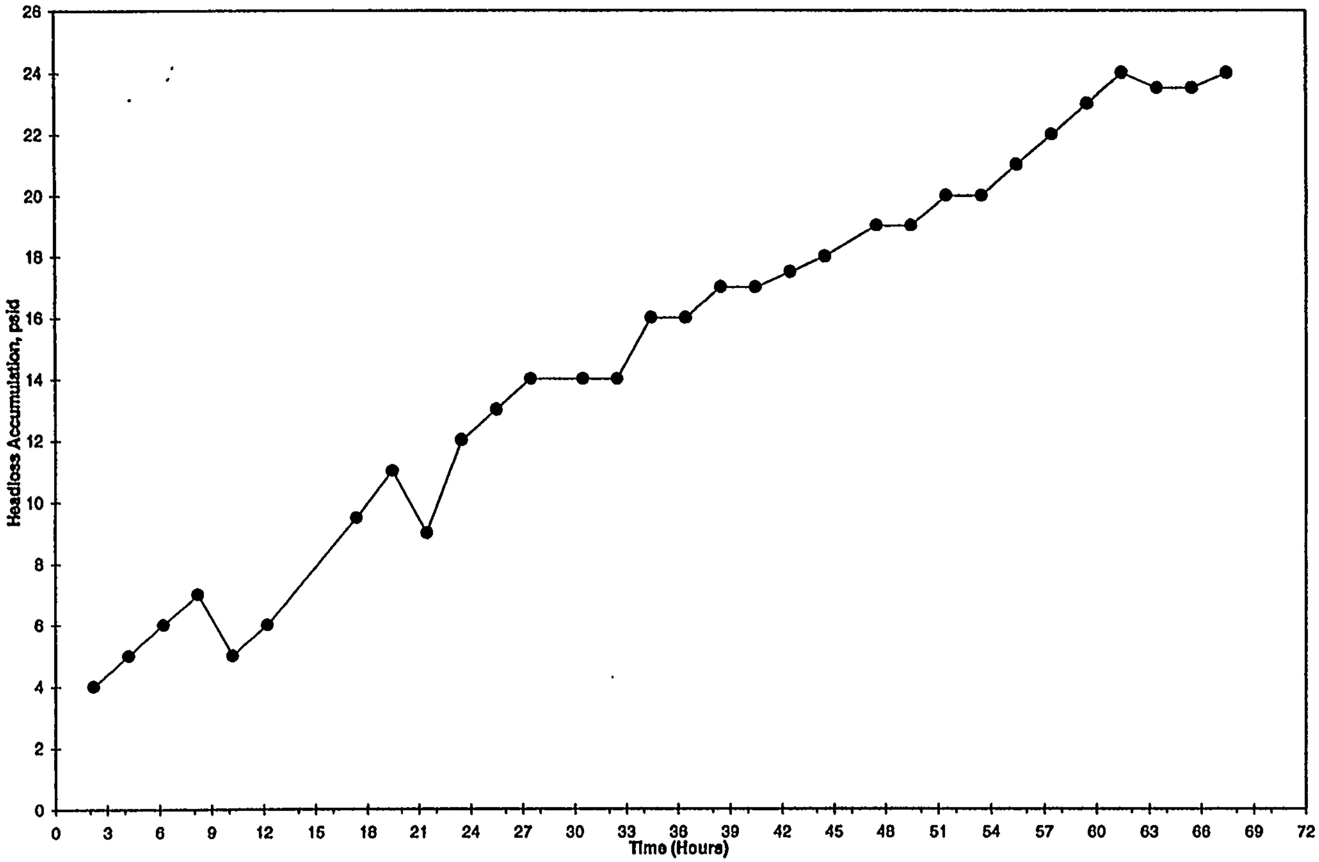
ENGINEERING ASPECTS OF THE UNIT PROCESSES

This section summarizes the important engineering parameters that may impact the full scale design. The trickling filter and ion exchange units are not part of the final conceptual design. As a result, the discussion that is presented in this report is very limited. Also, the mode of operation of the pressure filters did not generate the type of engineering data required for an engineering analysis.

Walnut Shell Filter

Figures 6-8 to 6-10 illustrate the typical performance of the walnut shell filter. The walnut shell filter behaves similarly to other types of deep bed filters as reflected in a gradual build up of headloss (Figure 6-8). For both the turbidity (Figure 6-9) and oil and grease (Figure 6-10), the filter unit behaves as a conventional granular media filtration unit. There is an initial poor removal for turbidity and oil and grease as the filter "matures" and then performance improves, leveling off to "normal" operating performance. The maturation time for turbidity is about 3-4 hours. For oil and grease as measured by the TCE extraction technique, the maturation process is approximately 2 hours.

It would appear breakthrough for turbidity and oil and grease is beyond 65 hours at the tested loading rates. The headloss criterion of 20 psid appears to occur first, and would be the operational parameter governing backwash when operating the unit at 15-12.5 gpm/ft^2.



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Walnut Shell Filter
Headloss Accumulation, 87.5 gpm

January 1998
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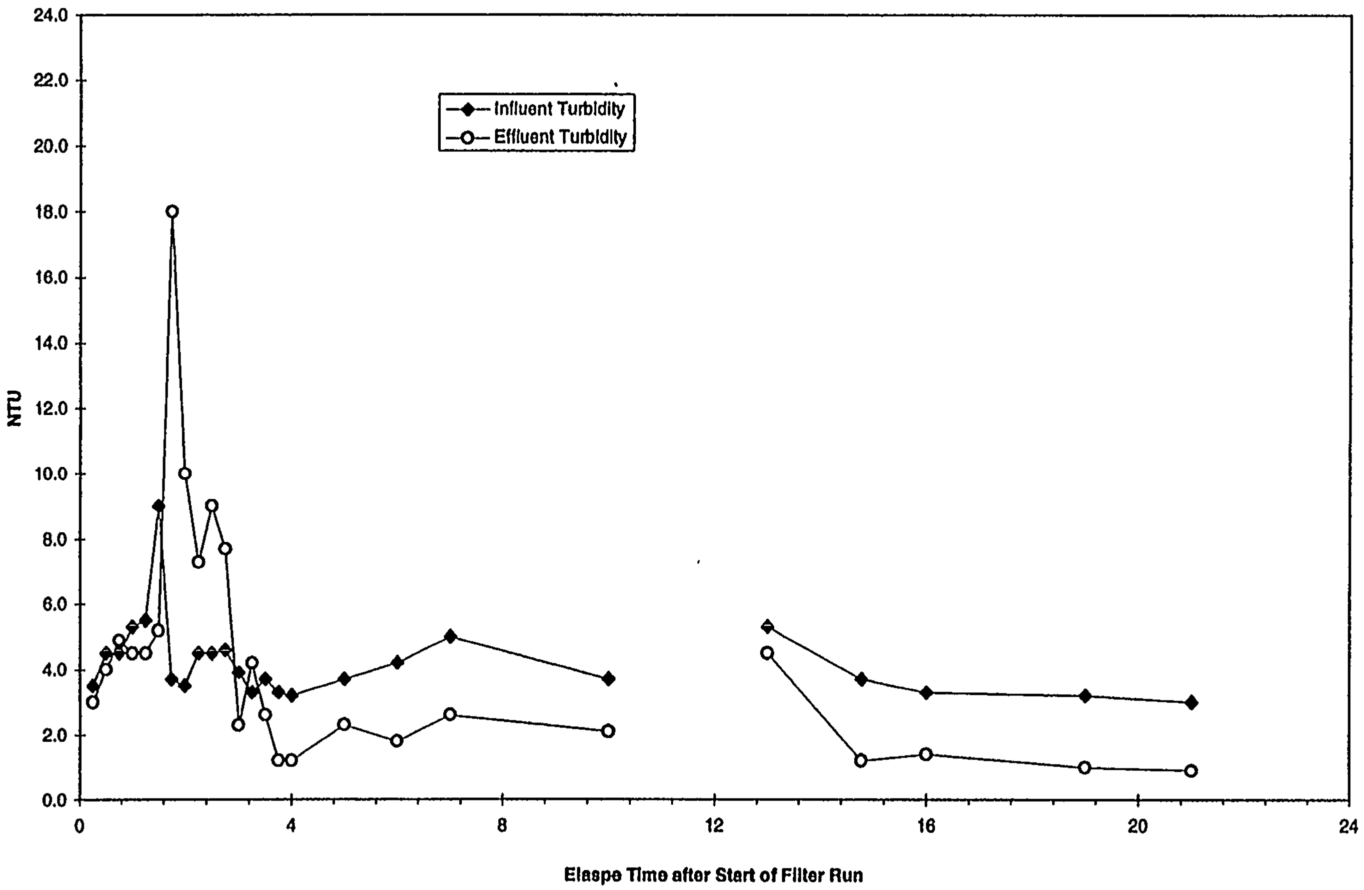
Figure 6-8



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Turbidity Break Through Curve

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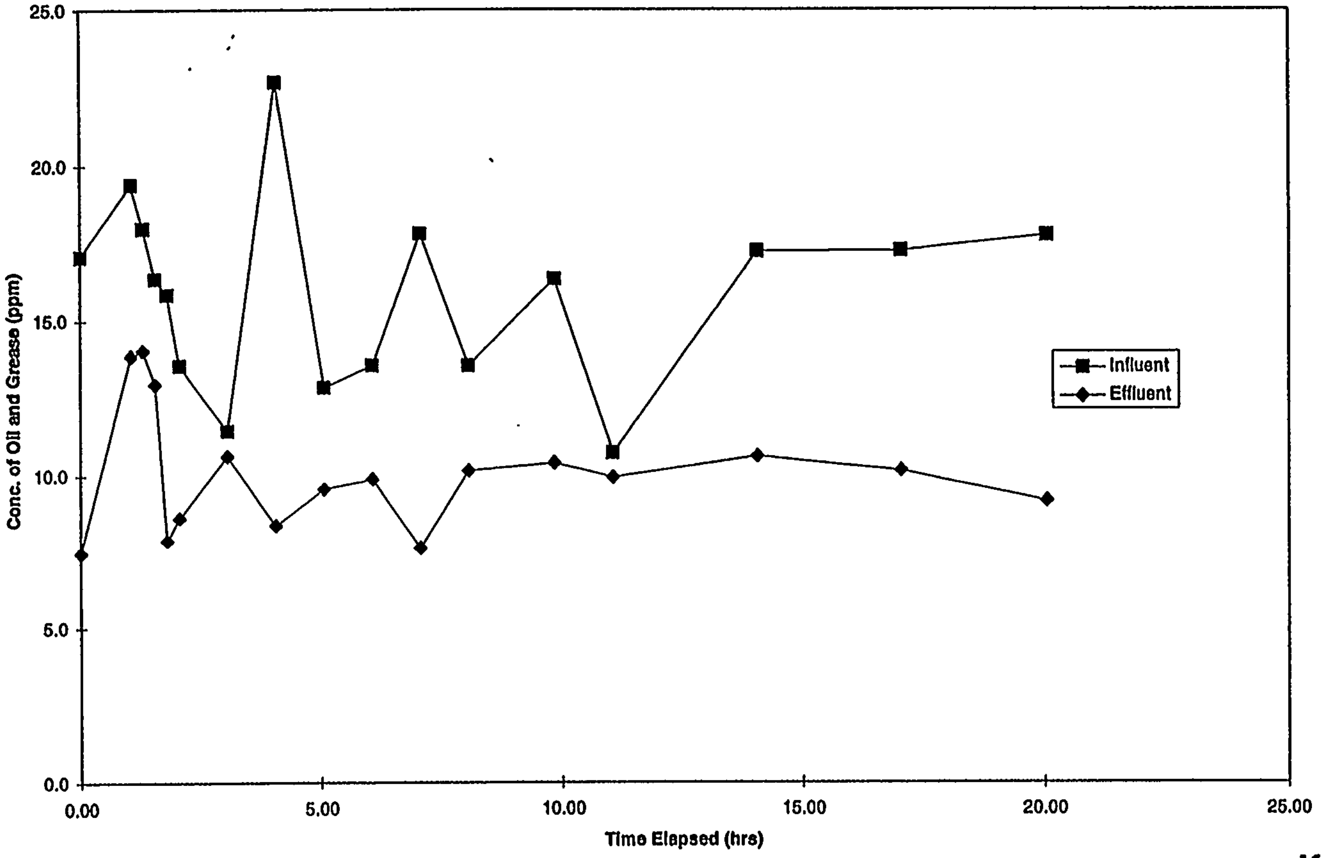
Figure 6-9



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Oil and Grease (Nalco Method)
Break Through Curve

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Figure 6-10

Composite samples from the backwash had total suspended solids (TSS) concentrations on the average of approximately 200 times more concentrated than the average TSS removal of the filter. If the backwash cleans the WSF of all collected solids, the concentrations would suggest that the backwash water accounts for approximately 0.5 percent of the volume of water filtered prior to backwash. Actual backwash volumes measured by the WSF flowmeter ranged from 0.5 to 1.0 percent.

Hydromation recommended a backwash flow rate of 70 gpm for 8 minutes with a 3 minute filter to waste rinse. This backwash regime would require approximately 800 gallons of produced water. During the testing, the filter was backwashed at 70 gpm until the backwash water looked visibly clean, usually after 10 to 20 minutes of backwash and a 3 minute rinse. This procedure required approximately 1,600 gallons of produced water.

Based on these two backwash conditions, the effective filtration rate (R_e) was calculated and compared with conventional water treatment filters. The formula for this calculation is the following (JMM, 1985):

$$R_e = \frac{(UFRV - USWV)}{(t_f + t_b)}$$

where UFRV (Unit Filter Volume)= V_f/A

USWV = V_b/A

V_f = volume of filter run

V_f = volume of backwash

A = area of filter

t_f = duration of filter run

t_b = duration of filter backwash

Neglecting the time required to backwash, the ratio of the effective filtration rate to the maximum design filtration rate (R_d) is given by:

$$\frac{R_e}{R_d} = \frac{(UFRV - UBWV)}{UFRV}$$

To achieve a production efficiency greater than 95 percent the UFRV of 5,000 gal/ft^2 is required. Typical water treatment filters production criteria are set at 10,000 gal/ft^2. To determine whether the walnut shell filter provided a similar performance criterion, the psid headloss for the calculation was set at 10 feet or 4.2 psid, the same as most water treatment filter headloss backwash criteria.

The resulting calculation using the low and high backwash volumes (800 and 1,600 gallons) indicates that the production efficiency is 98-99 percent and the UFRV is 12,542 to 12,335 gal/ft^2. These numbers are slight better than most water filtration goals, but water filters have a much better effluent turbidity, typically <0.5 NTU. It is our opinion that setting a turbidity goal of <1 NTU would significantly alter the production efficiency of the walnut shell filter. In our experience a turbidity goal of <1 NTU would also significantly reduce the number of 1-10 micron particle in the treated water.

WSF Verses Sand Filters

Additional data were collected on the performance of current treatment to use as a baseline for comparing the performance of the walnut shell filter and are presented in Appendix C. Table 6-24 summarizes data that were obtained from AWE's chemical representative, Nalco, for sand filters currently used at the Placerita site to treat produced water. Nalco measurements of oil and grease in the inlet and outlet were approximately 5 to 10 mg/L lower than observed during the pilot testing, with some results below the detection limit of 0.5 mg/L.

Table 6-24

Summary of Sand Filter Performance

Parameter	Location	Samples	Average	Max	Min	Average % Removal
Total Suspended Solids, mg/L	Inlet	21	11.1	28.1	5.6	NA
Total Suspended Solids, mg/L	Outlet	21	2.0	23.2	0.3	83
Oil & Grease, mg/L	Inlet	22	1.15	10	<0.5	NA
Oil & Grease, mg/L	Outlet	22	0.75	4	<0.5	78

Kennedy/Jenks also measured turbidity and oil and grease in the inlet and outlet of the sand filters on June 10, 1997. Measured turbidity values for this sampling event were 3.5 and 0.9 NTU, which represents a 74 percent removal and is above the median removal of the walnut shell filters. Total oil and grease concentrations obtained by spectrophometric absorption were 18 mg/L and 8.7 mg/L, which represents a 52 percent removal, also higher than the average removal of the walnut shell filter.

Based on the results of this study and historic data obtained from Nalco, the walnut shell filter performs at a level similar to the pressure filters currently used at the Placerita oilfield in terms of turbidity and total oil and grease removal. The walnut shell filter appears to remove higher percentages of suspended solids than the sand filters.

Based on the average TOC removals, the DensaDeg can achieve similar results to the walnut shell filter for oil and grease removal (see Tables 6-21 and 6-22). However, under upset WEMCO conditions, the oil and grease (i.e., pilot plant observations of oil or an oily sheen at the top of the clarifier portion of the DensaDeg) was not all removed. The residual oil and grease could potentially cause significant RO membrane fouling. The conceptual design needs to address the handling of the influent during upset WEMCO conditions.

DensaDeg

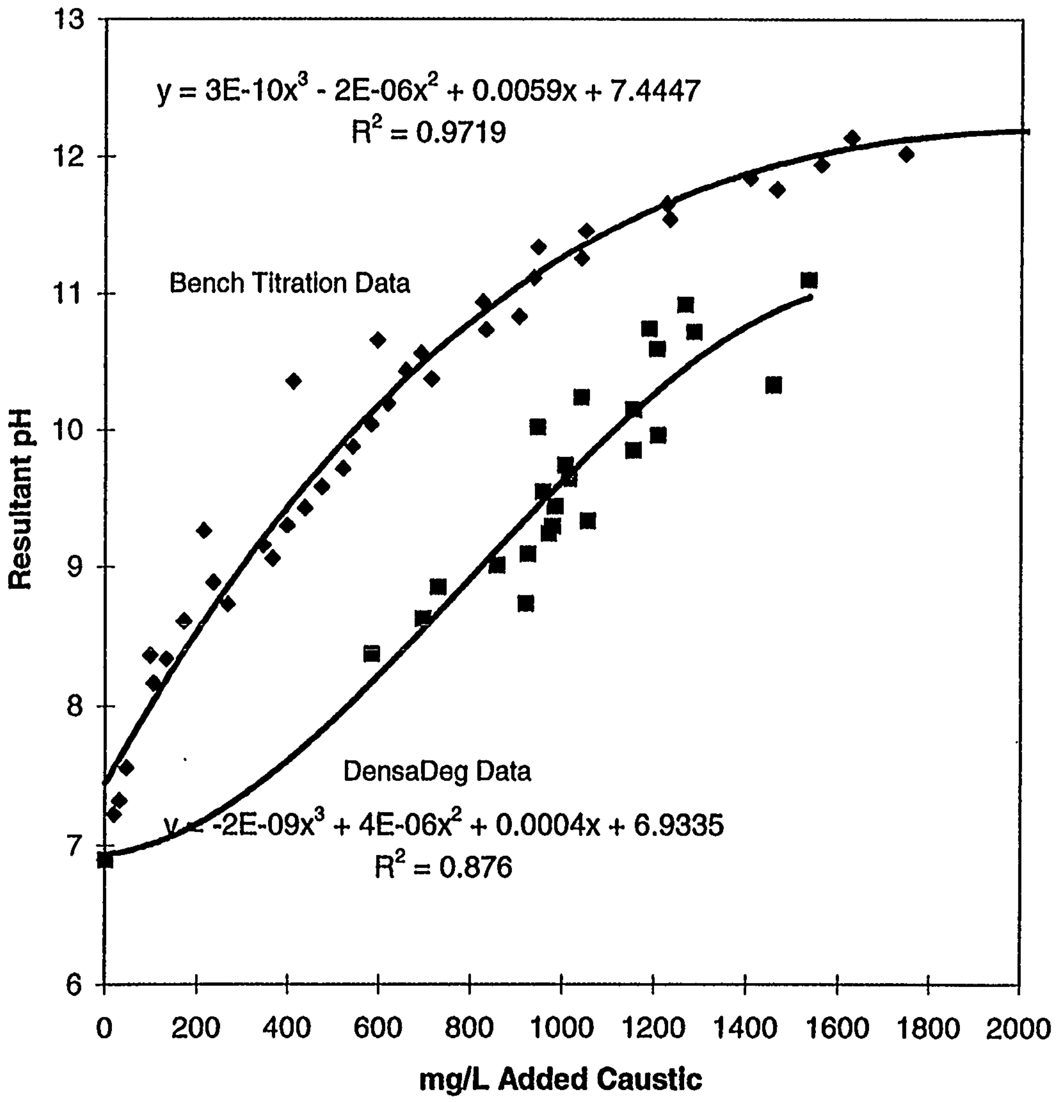
During the pilot study there were several operational findings that affected the conceptual design. The first finding was that the amount of caustic required to reach a target pH under bench scale conditions was very different than with the DensaDeg. Figure 6-11 illustrates the differences in pH obtained when adding the same amount of caustic. The most likely explanation for the difference is the loss of carbon dioxide when doing the bench scale titration. Under the pilot plant conditions, the carbon dioxide does not get a chance to degas and therefore, reacts with the caustic. Stripping the carbon dioxide from the produced water would lower the caustic required to attain a target pH, but this reduces the required alkalinity to precipitate the total hardness (there is about a milliequivalence difference between the total alkalinity and total hardness).

A summary of the water quality parameters from this treatment unit, operational pH and required caustic from this treatment unit are presented in Table 6-25. Figure 6-12 combines the results of the hardness and silica when operating the DensaDeg at different pHs along with the target water quality goals. The operational pH of the DensaDeg to achieve the total hardness and silica effluent levels was determined from the best fit line equations shown in Figures 6-1 and 6-3, respectively. The required caustic was calculated using the best fit equation shown in Figure 6-11.

Table 6-25

Summary of DensaDeg Water Quality, Operation pH, and Require Caustic

Water Type	Water Quality Parameter	DensaDeg Effluent (mg/L)	Operational pH	Required Caustic (mg/L)
Industrial Water	Lower Total Hardness Limit	600	7.5	360
	Upper Silica Limit as SiO_2	200	7.7	440
	Lower Silica Limit as SiO_2	80	8.6	770
Irrigation and Drinking Water	Silica as SiO_2	25	9.5	1,100
	Boron	13.2	9.7	1025
	Boron, $\geq$ 400 mg/L $MgCl_2$	7	9.4	900



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Caustic Requirements to Raise pH

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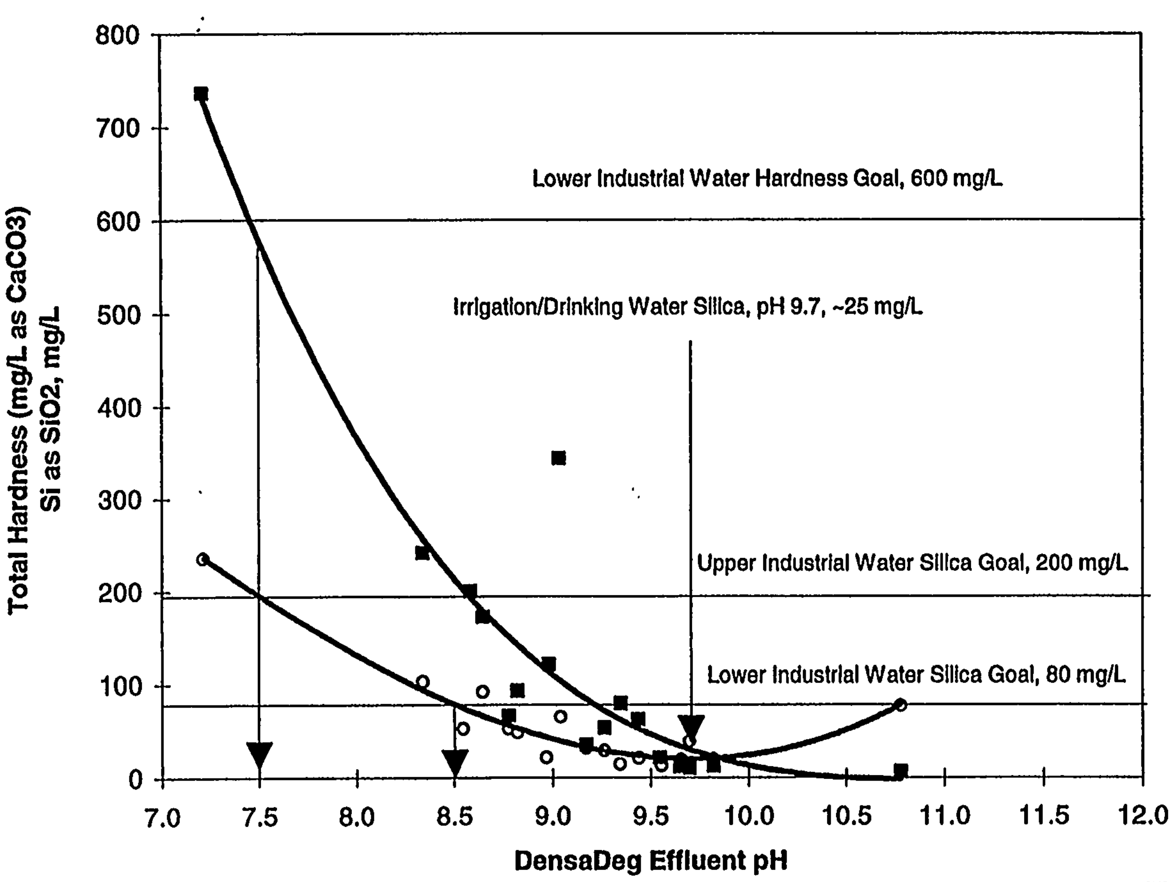
Figure 6-11



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Target Operating pH for DensaDeg

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Figure 6-12

DensaDeg Sludge

As previously described the sludge volume ranged between 1-4 percent of the treated flow with a range of 2.4 to 8 percent solids. Three percent of the treated flow and a 7 percent dry solids were used for the sludge parameters in the conceptual design.

A sludge sample was sent to Komline-Sanderson in Peapack, NJ to evaluate potential dewatering technologies to reduce disposal volumes and associated costs. A belt filter press and a membrane filter press were the tested technologies and the results are summarized in Table 6-26. A copy of their report is included in Appendix C. In both cases, there will be on-site solids storage required to optimize the sizing of the solids handling equipment. The belt filter press technology will require the use of a polymer while the press would not. The cycle time for the press has been estimated at 1.5 hours per batch while the belt filter press is continuous when in operation.

Table 6-26

Results from Potential Sludge Dewatering Technologies

Technology	% Dry Solids	Predicted Solids Capture (%)	Estimated Operational Hours	Type of Operation
Belt Filter Press	17-22	≥ 98	8-16	Continuous
Filter Press	20	≥ 99	16	Batch

There are several potential uses for the sludge that include the following:

- cement manufacturing (method used by West Basin Municipal Water District, $27/wet ton)
- road mix (method used by the neighboring AES facility using a similar softening process, $25/wet ton)
- agricultural soil amendment
- boron manufacturing

It has been estimated by Christensen (1997) that about one-third of the vineyards in Fresno County have a potential for a boron deficiency. Within the San Joaquin Valley of California, affected areas are primarily soils of granitic origin on the east side, running from northern Tulare County to San Joaquin County. The deficiency is particularly common on soils associated with the original flood plains of alluvial fans of the Kings, Merced and Stanislaus rivers. These would be potential areas for the DensaDeg sludge that averaged 376 mg/L boron. It is not clear whether the other components of the sludge would become a problem with this use.

Trickling Filter

The trickling filter did not remove a significant amount of TOC even after providing a long period for acclimation of the microbial community. The plate counts were high indicting a sufficient number of bacteria, but very little if any biological floc was observed. This process will not be included in the final conceptual design. No additional analyses will be presented as part of this report.

Ion Exchange

Because the ion exchange units are not being recommended as part of the final design concept, additional analyses are not presented. Based on the pilot plant data for the removal of hardness, the residual hardness from the DensaDeg can be handled by the appropriate antiscalant thereby eliminating the need for additional hardness removal. However, if the DensaDeg is operated with a high magnesium dose scenario, i.e., > 400 mg/L, then the ion exchange unit would be required to protect the RO membranes. When operating the DensaDeg in the high magnesium scenario, the floc was not easily removed. The ion exchange unit served to reduce the magnesium to minimize the potential for magnesium precipitation to occur on the RO concentrate side of the membrane.

Pressure Filters

The operational period for the filters was the same for the RO. Typically, the filters and RO units were operated 5 days per week and 8 to 16 hours per day. This non-continuous mode of operation does not lend itself to generate meaningful engineering data that can be used for the conceptual design. In addition, rapid build up of headloss in the filters was due high turbidity events caused by upsets in the DensaDeg. The upsets were caused by a poorly regulated caustic feed pump that caused wide changes in the operational pH. This caused a break down of the sludge blanket as indicated by the large maximum values (36 NTU) summarized in Table 6.6. The conceptual design assumes proper pH control and sludge blanket management which would be associated with low turbidities, < 4 NTU, as indicated in Table 6-6. The conceptual design will have to rely on engineering judgment.

Reverse Osmosis

The operational data from the RO pilot unit provided some insights on how the full scale plant may function. One of the more critical concerns for the RO process is the membrane replacement frequency. The membrane cleaning frequency, Silt Density Index (SDI) and the RO inlet pressure analysis are the most helpful data that were collected to assist in making an engineering judgment on membrane fouling.

Silt Density Index

To prevent fouling of the RO membranes, the membrane manufacturer recommended that the SDI be ≤ 5. During the pilot study, SDI measurements were performed at three locations: after the pressure filters, after the ion exchangers, and after the cartridge filters which preceded the RO membranes. Table 6-27 summarizes the average SDI after each process. These averages were not significantly different using a Student's "t" test ($t \leq 0.78$) and are slightly higher than the manufacturer's recommendation and may contribute to a rather short period between membrane cleaning.

Table 6-27

Summary of SDI Measurements by Location

Location	Samples	Average	Max	Min
Pressure Filter Effluent	19	6.11	6.56	4.66
Ion Exchange Effluent	8	6.19	6.44	5.79
RO Pretreatment Cartridge Filter	19	6.06	6.55	4.58

There were not enough data collected to determine whether there were SDI differences between operational scenarios for the DensaDeg. The SDI needs to be reduced and further optimization of the filtration process would appear to be the most logical approach.

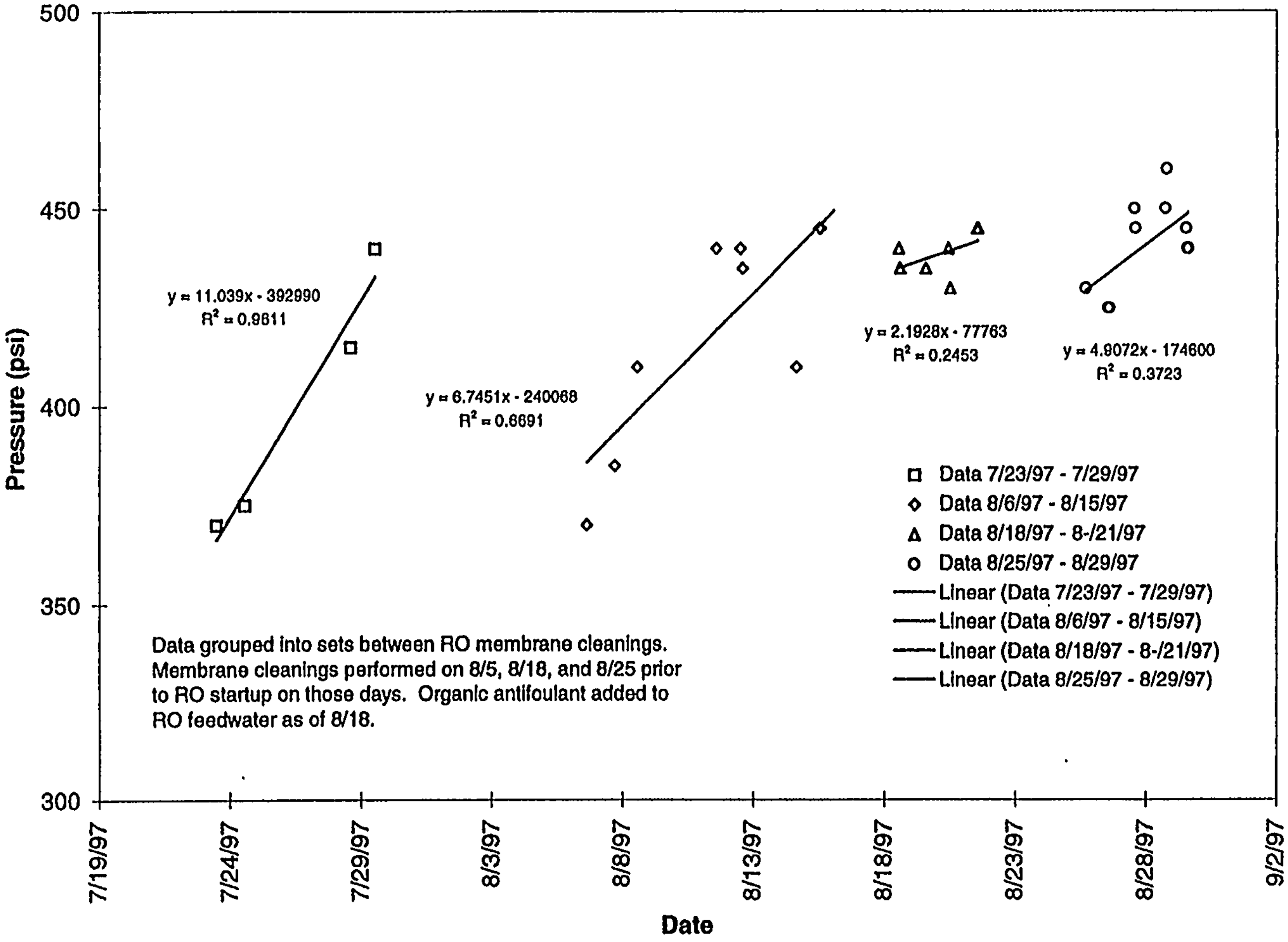
Head Loss Across the RO Membranes

The RO pilot unit was operated 5 days per week for 8 to 16 hours per day. Due to this mode of operation, typical headloss build up and cleaning curves can not be generated. However, the data were grouped to estimate the headloss build up and cleaning curves. The first step was to group the data by cleaning period, i.e., 0, first, second, and third. The next step was to select the pressure reading for each day after 5 to 7 hours of operations (JMM, 1985). The assumption is that the headloss build up is incremental after each start up. Figure 6-13 is a graph of the data that were selected in this manner. One can see that the "headloss accumulation curves" look similar to the traditional headloss curves for continuous operations. There appears to be a faster build up of headloss after a new membrane is cleaned. These curves suggest that frequent cleaning may be required due to the rapid loss of head across the membranes. Alternatively, the cleaning process used during the pilot tests was not the most effective. Some optimization of cleaning may be required. Observations made of the cleaning solution indicates that a lot of the material fouling the membrane was organic in nature as confirmed by the large reduction of TOC (Table 6-22).

Membrane Cleaning Frequency

The membranes were cleaned three times over the seven week test period. This cleaning frequency is higher than many potable or reclamation water systems that require a cleaning every 4-14 weeks.

Initially, the criterion for cleaning was a 15 percent increase in headloss. After the second cleaning the criterion was increased to 20 percent. The West Basin Municipal Water District's Reclamation Facility in El Segundo, California is using a 25 percent increase in pressure as its cleaning criterion. If a 25 percent increase in pressure build up was used as the criteriion for cleaning, less cleaning would have been required during the operations of the pilot RO unit. Croue and Leenheer have reported that 100 percent of the natural organics were eluted from membranes using a 0.1 N NaOH solution. This would indicate that repeated cleaning using a cleaning solution at pH 13 may be capable of removing the bulk of the organic fouling material. Perhaps a short soak at pH 13 using 0.1 N NaOH followed by normal cleaning may lower the headloss build up that was accumulating after successive cleanings (See Figure 6-13 and discussion of head loss). However, it is not clear until there is further pilot testing that the membrane rejection performance can also be maintained using this cleaning approach.



Data grouped into sets between RO membrane cleanings. Membrane cleanings performed on 8/5, 8/18, and 8/25 prior to RO startup on those days. Organic antifoulant added to RO feedwater as of 8/18.

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Headloss Accumulation after Cleanings

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Figure 6-13

For the cost estimate used in this report, an 18 month membrane life was used which is one half to one third of the useful life in many potable or reclamation projects, i.e., 24 to 36 months. More testing is required to determine whether the shorter membrane life adjustment is appropriate for the more frequent cleaning required.

Membrane Flux

The RO was not operated using a decline in flux as an operational parameter. Membrane cleaning was initiated when exceeding the membrane headloss criteria that occurred before observing a drop in flux. It would be interesting to operate the RO unit using flux as the cleaning criteriion to determine whether different operational problems can be identified.

ELECTRIC POWER RESEARCH INSTITUTE (ERPI)/SOUTHERN CALIFORNIA EDISON MEMBRANE TRIALS

Prior to operating the pilot RO facility, 4 barrels of produced water were tested using EPRI's mobile membrane trailer that was on temporary location in Irwindale, California. Testing of two membrane processes was performed under the direction of Dr. Jatal Mannapperuma. One test system consisted of conventional RO, similar to the RO pilot unit. The conductivity and chemical oxygen demand (COD) for this trial was significantly higher than the pilot study as reported in this chapter. This was probably because there was only a single stage in the EPRI set up while the pilot RO unit was a three stage membrane system. Dr. Mannapperuma reports that cleaning with a caustic solution restored the thin film composite membrane to the original conditions. This would support the cleaning estimate presented above.

The other system was treated by seeded reverse osmosis. The seeded reverse osmosis system had higher fluxes and higher rejection of TDS and COD. The seed was created by adding magnesium oxide that is capable of removing the hardness and silica. Membrane fouling is minimized by tangential flow of the retentate that contains the seed. This particular process should be examined in a pilot scale to determine its feasibility.

Chapter 7

Recommended Design Criteria and Estimated Cost

CHAPTER 7

RECOMMENDED DESIGN CRITERIA AND ESTIMATED COST

This Chapter presents the preliminary design criteria and cost estimates for conceptual 44,000 barrel per day (1,280 gpm) produced water treatment facilities for industrial reuse and irrigation/drinking water reuse. The industrial facility will deliver from 43,300 to 43,500 bpd (2,040 to 2,050 acre ft/yr) of treated water, depending on the industrial reuse goals. The irrigation/drinking water treatment facility will reclaim 32,200 bpd (1,510 acre ft/yr) for the blending alternative, or 32,600 (1,530 acre ft/yr) for the flange-to-flange alternative treated water for potable reuse. The design criteria for each option are based on the results of the pilot study described in Chapter 6, augmented by engineering judgment where necessary. Preliminary cost estimates are based on information obtained from equipment manufacturers, pilot plant operating experience, recent Kennedy/Jenks water treatment facilities projects, and professional judgment.

DESIGN BASES FOR INDUSTRIAL TREATMENT FACILITIES

The primary goals of the industrial treatment facilities are to remove hardness to below 600 mg/L and silica to below 200 mg/L (upper silica level) or below 80 mg/L (lower silica level). The inorganic chemistry of the raw produced water suggests that removal of hardness (primarily calcium and magnesium, with traces of barium, strontium, and iron) and silica can be optimized at a pH where calcium is almost completely removed as calcium carbonate, magnesium and silica as magnesium silicates, with some magnesium hydroxide. For these industrial treatment goals, the raw water is deficient in hydroxide alkalinity, which was provided by sodium hydroxide addition. The pilot testing indicates that the hardness goal and the upper silica goal could be achieved at a pH of 7.7, with addition of 440 mg/L of NaOH, while the lower silica goal was satisfied at pH 8.6, with 770 mg/L of NaOH added. Thus, the industrial treatment facilities were designed around a warm softening process.

Both industrial water options (upper and lower silica goals) require only warm softening for hardness and silica removal. A conceptual process train was developed for a possible 44,000 barrel per day (bpd) produced water treatment plant for industrial water use. The recommended treatment process includes warm precipitative softening, equalization storage, and booster pumping. Table 7-1 provides the design criteria and Figure 7-1 provides a process schematic for the industrial reuse facility. It has been assumed that water will be delivered to the warm softening unit without pumping and that the softened water will be stored in a flow equalization tank and provided to the industrial user at a 100 psig connection.

Warm Precipitative Softening

Warm precipitative softening will be carried out in a 44,000 bpd DensaDeg clarifier, which was scaled up from the pilot testing results. This unit consists of three components; namely, a rapid mix chamber, a reaction tank, and a thickener/clarifier. The rapid mix chamber consists of a 3-ft. diameter draft tube in which a turbine mixer provides initial mixing of precipitation chemicals. The rapid mix chamber is inside a 12.5-ft. x 17 ft. deep reaction tank. The detention time at the design flow would be 12 minutes. The thickener/clarifier has a 21-ft. diameter, a 17-ft. water depth, and a 31-minute detention time at design flow. The clarified water then exists the clarifier through plate settlers with a loading rate of 185 bpd/sq.ft. (5.4 gpm/sq.ft.).

The operating temperature will be around 150-170 °F. Chemical additions will include sodium hydroxide to control pH to 7.7± (average of 440 mg/L) for the upper silica goal and to pH 8.6± (average of 770 mg/L) for the lower silica goal, with an anionic polymer (average of 3.5 mg/L) added in both cases to assist with settling of the precipitate. The process will produce approximately 13,200 lb/day of sludge (dry solids (DS), basis) or 480 bpd at 7.5 percent DS for the upper silica alternative and 18,900 lb/day DS or 680 bpd at 7.5 percent DS for the lower silica alternative. The sludge will be dewatered to 20 percent DS with a filter press and hauled to a landfill.

Equalization Storage and Booster Pumping

The DensaDeg effluent water will be routed to a 7,100 barrel (300,000 gallon) equalization tank, which will allow the flow of the softened water for industrial reuse to be equalized over the course of the day. Water from the storage tank will be pumped to an industrial water reuse connection at 100 psig. For the lower silica goal alternative, sulfuric acid will be added (average of 27 mg/L) to stabilize (lower pH to 7.7) the water entering the tank and prevent excessive scaling from occurring.

Table 7-1

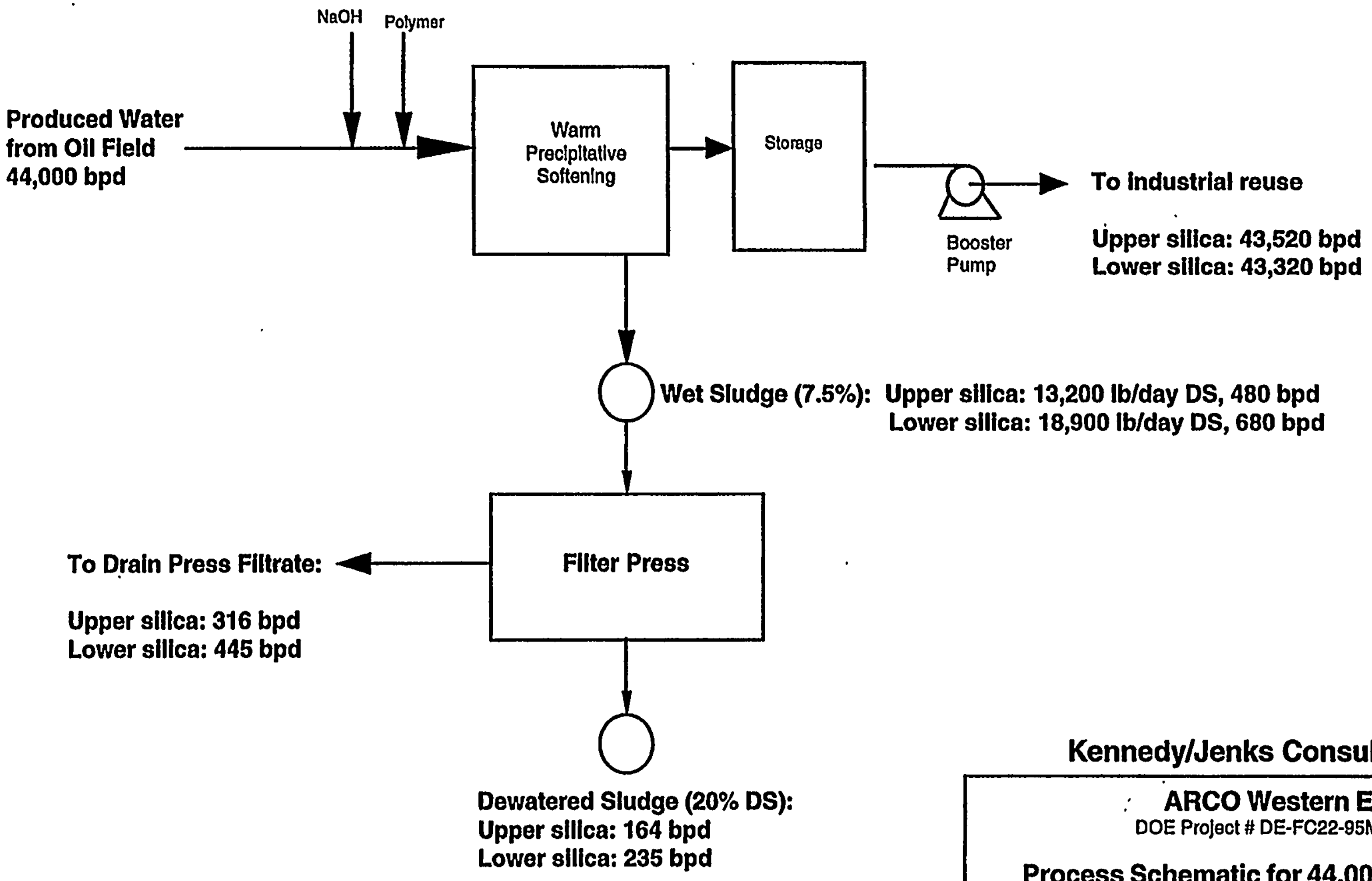
Produced Water Industrial or Plant Design Criteria

Process Parameter	Units	Upper Silica Goal	Lower Silica Goal
Plant flow rate: produced water	bpd	44,000	44,000
Production flow rate: industrial water	bpd	43,520	
Overall water recovery	Percent	98.9	98.4
WARM PRECIPITATIVE SOFTENING			
Operating pH	-	7.7	8.6
DensaDeg Clarifier			
Flow rate	bpd	44,000	44,000
Depth	ft.		17
Reaction Vessel			
diameter	ft.	12.5	12.5
volume	barrels	370	370
detention time	min.	12	12
Thickener/Clarifier			
Diameter	ft.	20	20
Volume	barrels	950	950
Detention time	min.	31	31
Settling zone area	sq.ft.	230	230
Surface loading rate	bpd/sq.ft.	185	185
CHEMICAL SYSTEMS			
Sodium hydroxide (50% solution)			
Dosage, avg.	mg/L	440	740
Use, avg.	lb/day	6,800	11,400
Storage Tank			
Chemical concentration	lb/bbl	270	270
Capacity	bbl	286	286
Supply, at avg. dose	days	11	7
Anionic Polymer			
Dosage, avg.	mg/L	3.5	3.5
Use, avg.	lb/day	52.5	52.5
Storage Tote			
Concentration	lb/bbl	350	350
Capacity	bbl	6.5	6.5
Supply, at avg. dose	days	44	44

Table 7-1

Produced Water Industrial or Plant Design Criteria

Process Parameter	Units	Upper Silica Goal	Lower Silica Goal
Sludge Handling and Treatment			
Sludge production	lb/day	13,200	18,900
Sludge volume	bpd	480	680
Percent solids	%	7.5	7.5
Sludge Filter Press			
Type	-	filter press	filter press
Capacity	lb DS/hr	2,000	2,000
Untreated sludge storage	bbls.	500	700
Dewatered sludge storage	cu.ft.	2,000	2,000
EQUALIZATION STORAGE			
Volume	bbls	7,140	7,140
Depth	ft.	19	19
Diameter	ft.	60	60
BOOSTER PUMPING			
Pumping capacity	bpd	43,500	43,500
Discharge pressure	psig	100	100
pH ADJUSTMENT (STABILIZATION)		N.A.	
Sulfuric Acid (93%)			
Dosage, avg.	mg/L	-	27
Use, avg.	lb/day	-	415
Storage Tank (1)			
Concentration (93%)	lb/bbl	-	588
Capacity	bbl	-	120
Supply	days	-	168



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Process Schematic for 44,000 bpd Industrial Plant

January 1998
K/J 964634.00

Figure 7-1

EVALUATION OF PROCESS ALTERNATIVES FOR IRRIGATION AND DRINKING WATER TREATMENT FACILITIES

The primary water quality goals of the facilities for irrigation and drinking water (flange-to-flange) reuse are to cool the produced water and remove hardness, silica, TDS, boron, ammonia, and TOC. The pilot plant testing, discussed in Chapter 6, provided insights into the performance of a number of potential treatment processes and their limitations. This section discusses process alternatives for the key water quality parameters that must be addressed by the treatment facilities.

Hardness and Silica Removal

The inorganic chemistry of the raw produced water suggests that, for the existing produced water temperature (around 160 °F), removal of hardness (primarily calcium and magnesium, with traces of barium, strontium, and iron) and silica can be optimized at a pH around 9.5±. The pilot testing suggests that the addition of 1,100 mg/L (average dosage) of NaOH would achieve this pH and almost completely remove calcium as calcium carbonate, and magnesium and silica as magnesium silicates, with some magnesium hydroxide precipitation. This operating mode would provide excellent pretreatment for high pH reverse osmosis.

The pilot testing demonstrated that adding additional magnesium (as magnesium chloride) at this pH could provide additional silica and boron removal, which might be more appropriate for operation of the RO system at lower pH.

The warm softening process substantially reduces the hardness constituents and silica, but adds to the total dissolved solids (TDS) in the softened water. The use of magnesium hydroxide as the magnesium source is a potential alternative. This concept can be evaluated with additional pilot testing.

Cooling

The ambient produced water temperature near 160 °F is ideal for warm softening, but would be detrimental to other processes such as reverse osmosis and biological processes. Thus, a temperature goal of 90 °F was adopted for the pilot study; primarily for the trickling filter operation.

An air-cooled fin fan heat exchanger was used in the pilot study. This unit was capable of dropping the softened water temperature to 10 °F above the ambient air temperature. As the pilot testing was conducted during summer months, the effluent from the heat exchanger was as high as 115 °F. Such high temperatures would not be suitable for biological treatment, but might be tolerable for RO processes, which usually have an operating temperature limit of 113 °F (45 °C).

A cooling tower could be used as an alternative means of cooling the softened water. Evaporative loss is estimated at 9 percent of the softened water by using this cooling process. Although it might be possible to recover the evaporated water, there are potential air permitting problems with air emissions of volatile organic chemicals (VOCs) and ammonia. Testing of the Placerita produced water using California South Coast Air Quality Management District (SCAQMD) method 25.2 indicated that there were no measurable volatile VOCs. A calculation for the ammonia stripping potential would have to be evaluated by SCAQMD to determine whether the ammonia would become an air permit emissions issue. Preliminary estimates indicate that neither the VOC nor ammonia emission rates should create an air permitting problem.

Another cooling alternative is the use of a cooling tower in an indirect loop where the softened water passes through a heated exchanger. The heat exchanger would be cooled by a cooling tower recirculating at four times the softened water flow rate. Using the concentrate from the reverse osmosis unit as make up water the blow down from this indirect cooling tower would be deep well injected for disposal.

TDS Removal

TDS removal would occur after the softening process, where most of the hardness and silica have been removed. Because of low hardness, total inorganic carbon, and silica levels, the RO process can be operated over a wide pH range (pilot tested RO feed pH from 8.2 to 10.8) where TDS removal was very good. This operating range allows different strategies to be considered for the removal of boron, ammonia, and organics, as discussed below.

Boron Removal

The use of precipitative softening and high pH RO were examined for boron removal during the pilot study. Although the use of additional magnesium was shown to improve boron removal in the optimized warm softening process, the pilot plant results suggest that the boron goals would be achieved only if the RO system is operated at a high pH around 10.8. The use of a boron selective ion exchange process was previously screened out as being too expensive due to resin costs of around $1,000 per cubic foot.

Ammonia Removal

The pilot plant results indicate that acceptable ammonia removal was achieved only when the RO system was operated at pH lower than 9.0. Thus, there is a fundamental operational conflict in removing both boron and ammonia simultaneously by RO. Other potential ammonia removal processes include breakpoint chlorination, air stripping, ammonium selective ion exchange, and biological treatment.

The ammonium selective ion exchange, using clinoptilolite, appears to be the best choice because it has less effect on TDS increase as compared with breakpoint chlorination and has no air emission considerations as in the air stripping option. As discussed below, biological treatment has not been affective due to the high fraction of nathalenic acids. For biological ammonia removal, a supplemental carbon source would have to be added.

Organics Removal

The organics in the produced water are largely non-biodegradable unless there is additional treatment such as advanced oxidation (e.g., ozone or UV-ozone). The biological processes would be expected to remove less than 20 percent of the organics present. In addition, the biological process would increase the microbial concentration (as many as a million bacteria per mL) as shown in the pilot plant study and create a potential biofouling problem for the RO membranes.

DESIGN BASES FOR IRRIGATION AND DRINKING WATER TREATMENT FACILITIES CONCEPTUAL PROCESSES

The operational conflict in removing both boron and ammonia by RO suggests that a blending alternative should be evaluated in addition to a flange-to-flange option that would meet drinking water quality goals. In the blending alternative, the produced water would be treated to a low TDS around 145 mg/L, but leaving boron at 5 mg/L and ammonia at 6 mg/L in the treated water. This water would be blended with a currently unusable water source (due to high TDS or a contaminant above acceptable level) to produce an acceptable non-potable water supply.

Conceptual process trains were developed for both the blending and flange-to-flange alternatives in order to develop cost estimates for a possible 44,000 barrel per day (bpd) produced water reclamation facility. It has been assumed that water will be delivered to the warm softening unit without pumping and that the organization using the treated water will convey it from the disinfection storage tank.

Conceptual Blended Water Facility

The recommended treatment process for the blending option includes warm precipitative softening, cooling, equalization storage, booster pumping, multi-media filtration, cartridge (automatic bag) filtration, reverse osmosis at the warm softening pH, and disinfection. Table 7-2 provides the design criteria for this process train. Figure 7-2 provides a flow and process schematic diagram for a 44,000 bpd (1280 gpm) produced water facility for the blending option, illustrating the functional relationship of the various water treatment processes, chemical addition points, sludge handling, wash water recovery and storage facilities

Table 7-2

Produced Water Blended and Flange to Flange Reclamation Plant Design Criteria

Process Parameter	Units	Blended	Flange to Flange
Plant flow rate: produced water	bpd	44,000	44,000
Production flow rate: reclaimed water	bpd	32,000	32,600
Overall water recovery	Percent	73.2	74.1
WARM PRECIPITATIVE SOFTENING			
Operating pH	std. units	9.5±	9.5±
DensaDeg Clarifier (1 unit)			
Flow rate	bpd	44,000	44,000
Sidewater depth	ft.	17	17
Reaction Vessel			
Diameter	ft.	12.5	12.5
Volume	barrels	370	370
Detention time	min.	12	12
Thickening/clarification			
Diameter	ft.	20	20
Volume	barrels	950	950
Detention time	min.	31	31
Settling zone surface area	sq.ft.	230	230
Surface loading rate	bbl/sq.ft.	185	185
Chemical Systems			
Sodium hydroxide (50% solution)			
Dosage, avg.	mg/L	1100	1100
Use, avg.	lb/day	16,900	16,900
Storage Tanks			
Number	-	2	2
Chemical concentration	lb/bbl	269	269
Capacity, ea.	bbl	286	286
Supply, at avg. dose	days	9	8*
Magnesium Chloride (27% solution)			N.A.
Dosage, avg.	mg/L	96	-
Use, avg.	lb/day	1,460	-
Storage tank			
Chemical concentration	lb/gal	2.78	-
Capacity	bbl	286	-
Supply, at avg. dose	days	23	-
Anionic Polymer			

Table 7-2

Produced Water Blended and Flange to Flange Reclamation Plant Design Criteria

Process Parameter	Units	Blended	Flange to Flange
Dosage, avg.	mg/L	3.5	3.5
Use, avg.	lb/day	52.6	52.5
Storage Tote			
Concentration	lb/bbl	350	350
Capacity	bbl	6.5	6.5
Supply, at avg. dose	days	44	44
Sludge Handling and Treatment			
Sludge production	lb/day	28,000	22,400
Sludge volume	bpd	1,000	800
Percent solids	%	7.6	7.6
Sludge Filter Press			
Type	-	filter press	belt filter press
Capacity	dry lb/hr	1000[†]	2,000
Untreated sludge storage	bbl	1,200	1,200
Dewatered sludge storage	cu.ft.	2,000	2,000
COOLING			
Cooling Heat Exchangers			
Type	-	fin fan	fin fan
Inlet water temperature	°F	160	160
Outlet water temperature	°F	110	110
Total Cooling capacity	tons of cooling	3,100	3,100
Design air temperature (95th percentile)	°F	95	95
Number of heat exchangers	-	4	4
Unit size	ft x ft	13 x 40	13 x 40
Number of fans per unit	-	2	2
Fan Motor size, each	HP	15	15
EQUALIZATION STORAGE			
Volume	bbl	7,100	7,100
Depth	ft.	19	19
Diameter:	ft.	60	60
BOOSTER PUMPING (2 pumps)			
Pumping capacity, each	bpd	43,000	43,000
Discharge pressure	psig	100	100

Table 7-2

Produced Water Blended and Flange to Flange Reclamation Plant Design Criteria

Process Parameter	Units	Blended	Flange to Flange
PRESSURE FILTRATION			
Number of units	-	5	5
Diameter	ft.	8	8
Surface loading rate	bpd/sq.ft.	170	170
Media Depths			
0.85-0.95 mm anthracite	inches	18	18
No. 20 sand	inches	8	8
No.30 - No.40 garnet	inches	4	4
Support Gravel depths			
No.4 quartz	inches	3	3
1/4-in.x 1/8-in. quartz	inches	3	3
1/2-in.x 1/4-in. quartz	-	Bottom fill	Bottom fill
Polymer System			
Dosage, avg.	mg/L	3.5	3.5
Use, avg.	lb/day	52.5	52.5
Storage Tote			
Concentration	lb/bbl	360	350
Capacity	bbl	6.5	6.5
Supply, at avg. dose	days	44	44
Washwater recovery system			
Equalization tank	bbl	950	950
Return pumps (2) capacity, each	bpd	1,370	1,370
CARTRIDGE FILTRATION		Auto Bag Filters	Auto Bag Filters
Number of bags	-	12	12
Nominal sized particle removed	µm	5	5
Capacity per bag	bpd	3,940	3,940
REVERSE OSMOSIS			
Operating RO feed pH	std. units	9.5±	10.8
Flow rates			
feed flow rate	bpd	43,000	43,200
recycle flow rate	bpd	21,500	21,600
permeate flow rate	bpd	32,200	32,400
reject flow rate	bpd	10,600	10,800
Elements			
Number	-	384	384
Array scheme	-	2x1x1	2x1x1

Table 7-2

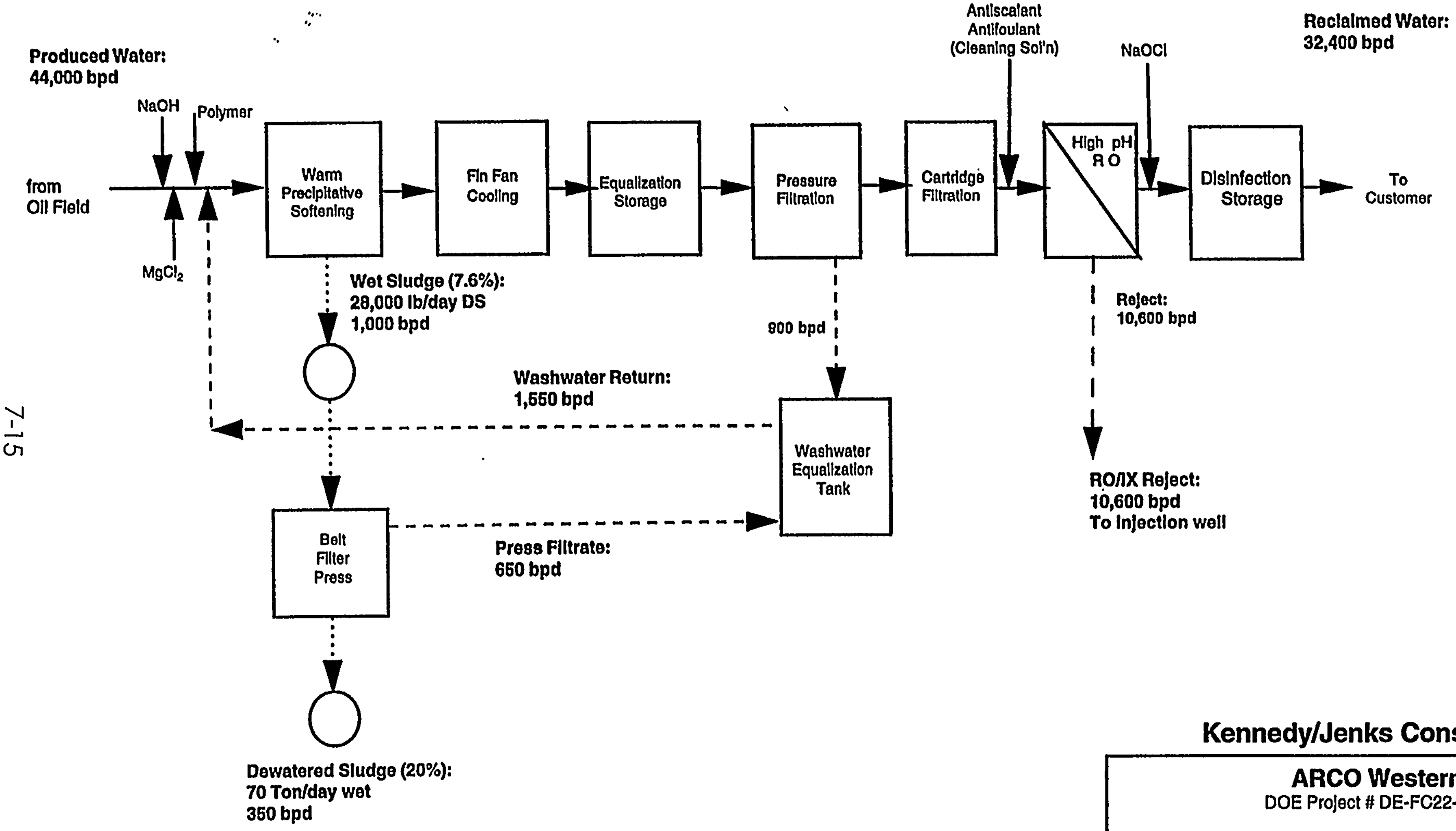
Produced Water Blended and Flange to Flange Reclamation Plant Design Criteria

Process Parameter	Units	Blended	Flange to Flange
Effective surface area, each	sq.ft.	330	330
Flux rate	bpd/sq.ft.	0.25	0.26
Chemical Systems			
Sodium hydroxide (50% solution)		N.A.	
Dosage, avg.	mg/L	-	200
Use, avg.	lb/day	-	3,000
Storage Tanks (2)	Not required*	-	*see warm softening NaOH system
Scale Inhibitor			
Dosage, avg.	mg/L	1.0	1.0
Use, avg./max.	lb/day	15.0	15.0
Storage tank			
Concentration	lb/bbl	378	378
Capacity	bbl	1.3	1.3
Supply, at avg. dose	days	33	33
Antifoulant			
Dosage, avg.	mg/L	5.0	5.0
Use, avg.	lb/day	75.0	75.0
Storage Tank	bbl	1.3	1.3
Concentration	lb/bbl	378	378
Capacity			
Supply, at avg. dose	days	7	7
RO Membrane Cleaning Solution			
Dosage, avg.	bbl sol'n: bbl water	1:40	1:40
Use, avg./max. (per cleaning)	bbl.	5.2	5.2
Storage Tanks (2)			
Capacity, ea.	bbl	55	55
pH ADJUSTMENT		N.A.	
Sulfuric Acid (93 %)			
Dosage, avg.	mg/L	-	59
Use, avg.	lb/day	-	5,000
Storage Tank			
Concentration (93%)	lb/bbl	-	588
Capacity	bbl	-	119
Supply, at avg. dose	days	-	85

Table 7-2
Produced Water Blended and Flange to Flange Reclamation Plant Design Criteria

Process Parameter	Units	Blended	Flange to Flange
AMMONIA SELECTIVE EXCHANGE			
Number of contactors	-	-	2
Contactor type	-	-	horizontal pressure
Contactor diameter	ft	-	12
Contactor length	ft	-	16
Ion Exchange Medium	-	-	clinoptilolite
Medium size		-	
Medium depth	ft	-	4.0
Exchange capacity/contactor	equivs.	-	4.900
Surface loading rate	bpd/sq.ft.	-	168
Volume loading rate	BV/hr	-	9.8
Empty Bed Contact Time	minutes	-	6
Run length	hours	-	24
Regenerant salt solution	percent	-	2
Regenerant volume (40 BVs)	bbl.	-	7,140
DISINFECTION/STORAGE			
Hypochlorite system			
Dosage, avg.	mg/L	2.0	2.0
Use, avg.	lb/day	22.5	22.5
Storage tank			
Capacity	bbl	48	48
Concentration (@8%)	lb/bbl	31.5	31.5
Supply, at avg. dose	days	67	67
Contactor/storage tank			
Diameter	ft.	60	60
Sidewater depth	ft	19	19
Storage volume	bbl	9,500	9,500
Detention time at avg. flow	minutes	425	425

*Sodium hydroxide storage common for warm softening and RO feed systems



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Process Schematic for 44,000 bpd Blending Plant

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Figure 7-2

Conceptual Flange-to-Flange Facility

The recommended treatment process for the flange-to-flange option includes warm precipitative softening, cooling, equalization storage, booster pumping, multi-media filtration, upward pH adjustment, cartridge (automatic bag) filtration, high pH reverse osmosis, pH adjustment, ammonium selective ion exchange, and disinfection. Table 7-2 also provides the design criteria for this process train. Figure 7-3 provides a flow and process schematic diagrams for a proposed 44,000 bpd (1280 gpm) produced water reclamation facility for the flange-to-flange option, illustrating the functional relationship of the various water treatment processes, chemical addition points, sludge handling, wash water recovery and storage facilities.

Warm Precipitative Softening

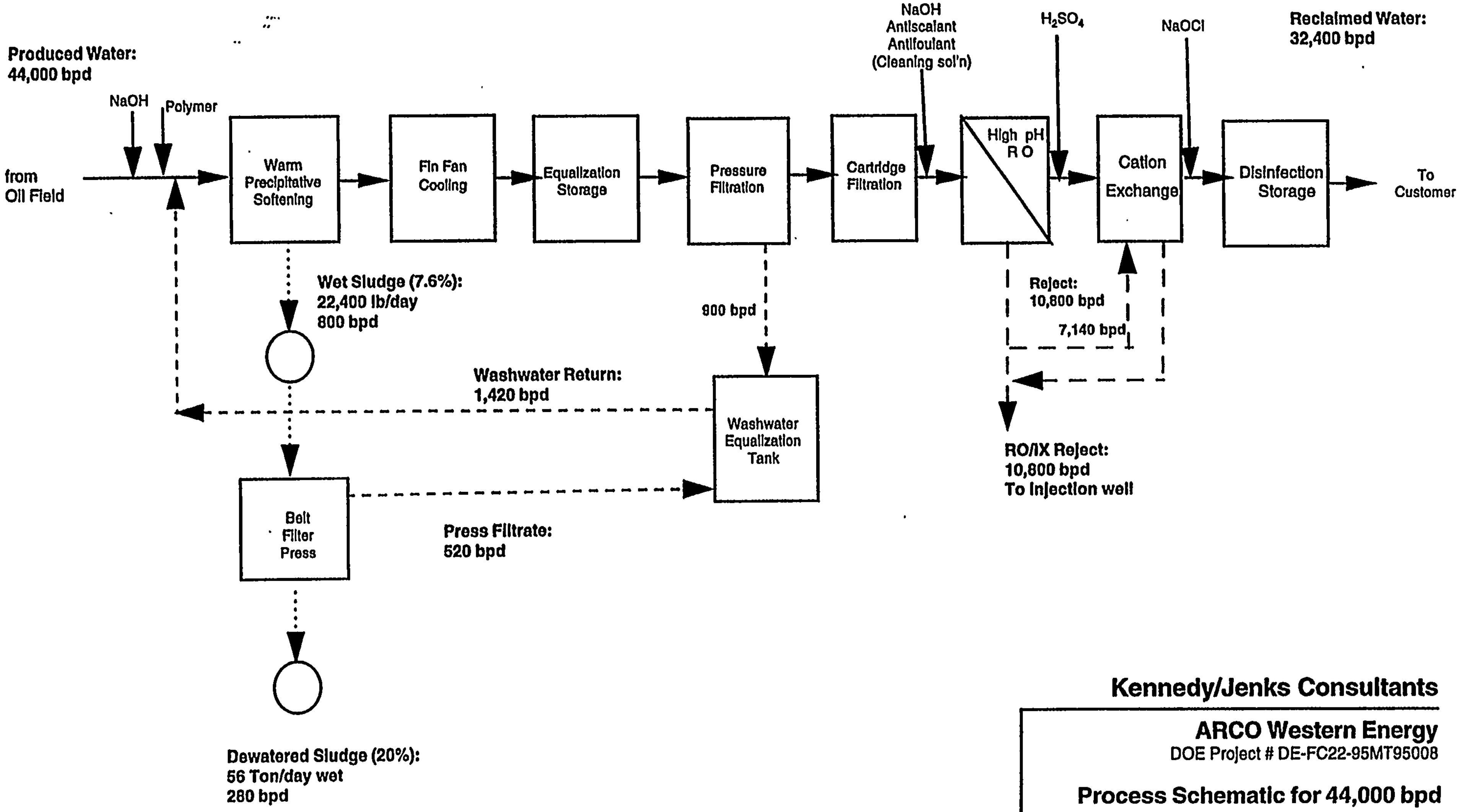
Warm precipitative softening will be carried out in a 1,280 gpm DensaDeg clarifier, which was previously described for the industrial reuse facilities. The operating temperature will be around 150-170 °F. Chemical additions will include sodium hydroxide to control pH to 9.5± (average of 1100 mg/L) for both alternatives, and magnesium chloride (average of 95 mg/L) for the blending alternative. An anionic polymer (average of 3.5 mg/L) will be added to assist with settling of the precipitate. The process will produce approximately 28,000 lb/day DS or 1,000 bpd at 7.6 percent DS for the blended option, and 22,400 lb/day of sludge (DS), or 800 bpd at 7.6 percent DS for the flange-to-flange option. The sludge will be dewatered to 20 percent DS with a belt filter press and hauled to a landfill. The filtrate from the press will be returned to the warm clarifier via the filter washwater tank.

Cooling

Four closed system fin fan coolers, each with two 15 HP fans, will be incorporated to reduce the temperature in the clarifier effluent to slightly above ambient air conditions (maximum temperature of 115°F). This will make the water more amenable to reverse osmosis separation, which operates more efficiently at warmer ambient water temperatures.

Equalization Storage and Booster Pumping

The cooled water will be routed to a 7,140 barrel equalization tank, which will allow the temperature of the softened water to be equalized over the course of the day. Water from the storage tank will be pumped to pressure filters.



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Process Schematic for 44,000 bpd Flange-to-Flange Plant

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Figure 7-3

Filtration

The pumped water will be filtered by polishing multi-media filters consisting of layers of anthracite, sand, and garnet media. There will be five 8-ft diameter pressure units in parallel. The filter units will be plumbed so that one unit can be backwashed with the filtrate being generated by the other four units. The spent washwater will be routed to the head end of the DensaDeg so that washwater is reclaimed.

Reverse Osmosis Desalting

The filtered water will be routed to the reverse osmosis (RO) units, which will include pre-cartridge filtration and chemical pretreatment consisting of pH adjustment, scale inhibition, and organic fouling control. The RO units will be run in a 2x1x1 array, with 75 percent recovery and a 50 percent (based on feed flow) recycle ratio. The array will consist of 384 8-in. diameter thin film RO elements. For the blending option, the RO system will be operated at the softening pH (approximately 9.5). For the flange to flange option, the RO feed water will be adjusted to pH 10.8 with NaOH (200 mg/L average dose).

An antiscalant (1 mg/L average) and antifoulant (5 mg/L average) will be used for both options. In addition, the membranes will be cleaned every two weeks [1.2 drums (55 gallons) of a cleaning solution will be used for each cleaning].

Water Stabilization

No pH adjustment is anticipated for the blending option. The pH of the RO permeate for the flange-to-flange option will be adjusted downward with sulfuric acid (59 mg/L average) so that the water is stable with respect to scaling and suitable for ammonia removal by selective ion exchange.

Ammonium Selective Cation Exchange (flange-to-flange option only)

For the flange-to-flange option, ammonia will be removed by selective ion exchange using clinoptilolite, which will be regenerated by a 2 percent salt solution. The treatment goal will be to reduce the ammonia concentration from 10 mg/L to 0.4 mg/L, to provide ammonia for chloramination.

Two 12-ft diameter *x* 16-ft, four cell horizontal pressure contactors will be provided. Each contactor will be filled with 768 cubic feet of clinoptilolite and will be capable of treating the entire 43,200 bpd permeate flow at a loading of 9.8 bed volumes per hour. Each run will last for 24 hours (235 bed volumes).

One contactor will be regenerated each day while the other one is in the operational mode. The regeneration will be accomplished with 40 bed volumes of RO concentrate (adjusted to 2 percent sodium chloride strength, as necessary), at a rate of 6.5 bed volumes/hr. Regeneration would take 12 hours to accomplish if two cells are regenerated simultaneously with the 10,800 bpd concentrate flow. The regeneration time could be reduced to 8 hours if a 1,700 barrel RO concentrate storage tank is provided.

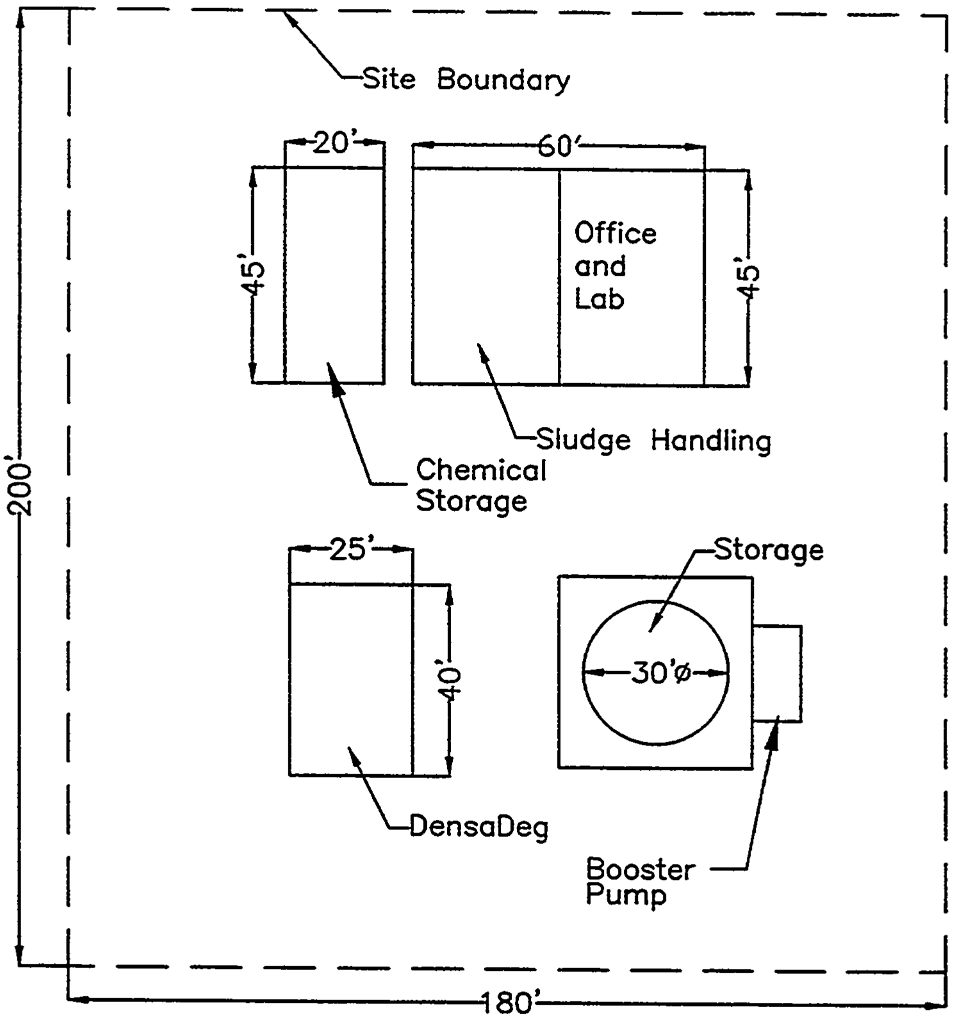
Disinfection

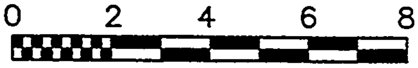
Disinfection will be accomplished by chloramination utilizing the residual ammonia in the treated water. Sufficient chlorine (about 2.0 mg/L dose) will be applied to produce a 1.5 mg/L monochloramine residual, with an approximate 1:5 NH_3-N:Cl_2 ratio. Chlorine will be fed as a sodium hypochlorite solution.

PRELIMINARY COST ESTIMATES

Preliminary capital, annual operations and maintenance, and unit treatment cost estimates were prepared for four alternatives: 1) high silica, 2) low silica industrial, 3) blended irrigational drinking, and 4) flange to flange irrigational drinking. The estimates are based on experience gained with the pilot plant operations, budgetary cost input from equipment manufacturers, cost estimating information from recent Kennedy/Jenks projects, and professional judgment.

Conceptual facility layouts for the industrial water, blended, and flange-to-flange drinking/irrigation treatment facilities are shown on Figures 7-4, 7-5, and 7-6, respectively. These layouts show the arrangement of the treatment process units, the chemical feeding and storage facilities, storage tanks, and booster pumping. The area requirements are about 0.8 acres (180-ft *x* 200-ft site) for the industrial reuse facilities and about 2.2 acres (255-ft *x* 380-ft site) for the blending and flange-to-flange options. A 2,700 sq.ft. building will be provided for industrial reuse alternatives to house sludge handling facilities and provide office and laboratory space. The blending option will not require the ammonia removal facilities. For the blending





Scale: 1"=40'

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Water Industrial Plant
Site Layout

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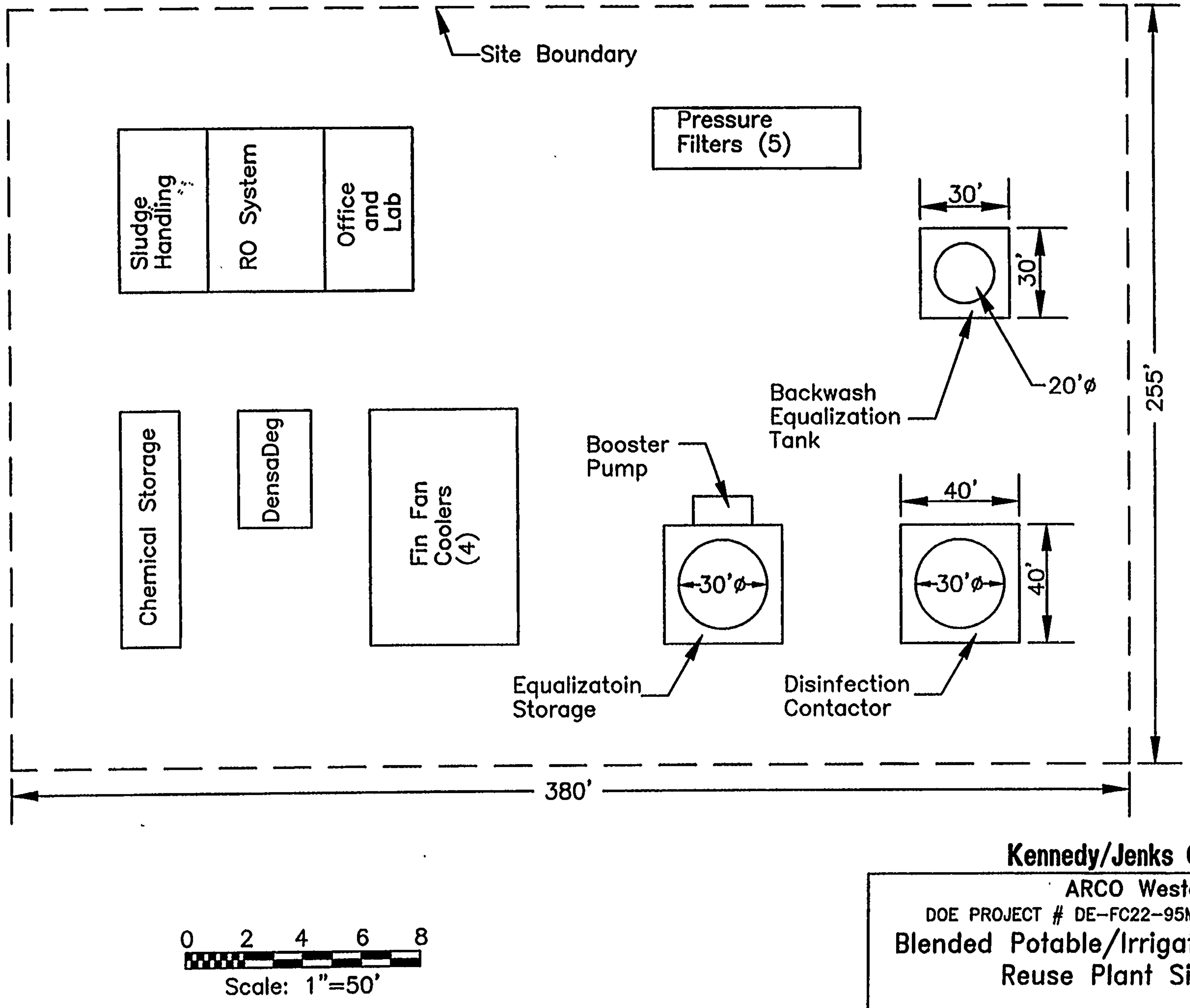
Figure 7-4



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Blended Potable/Irrigation Plant
Reuse Plant Site Layout

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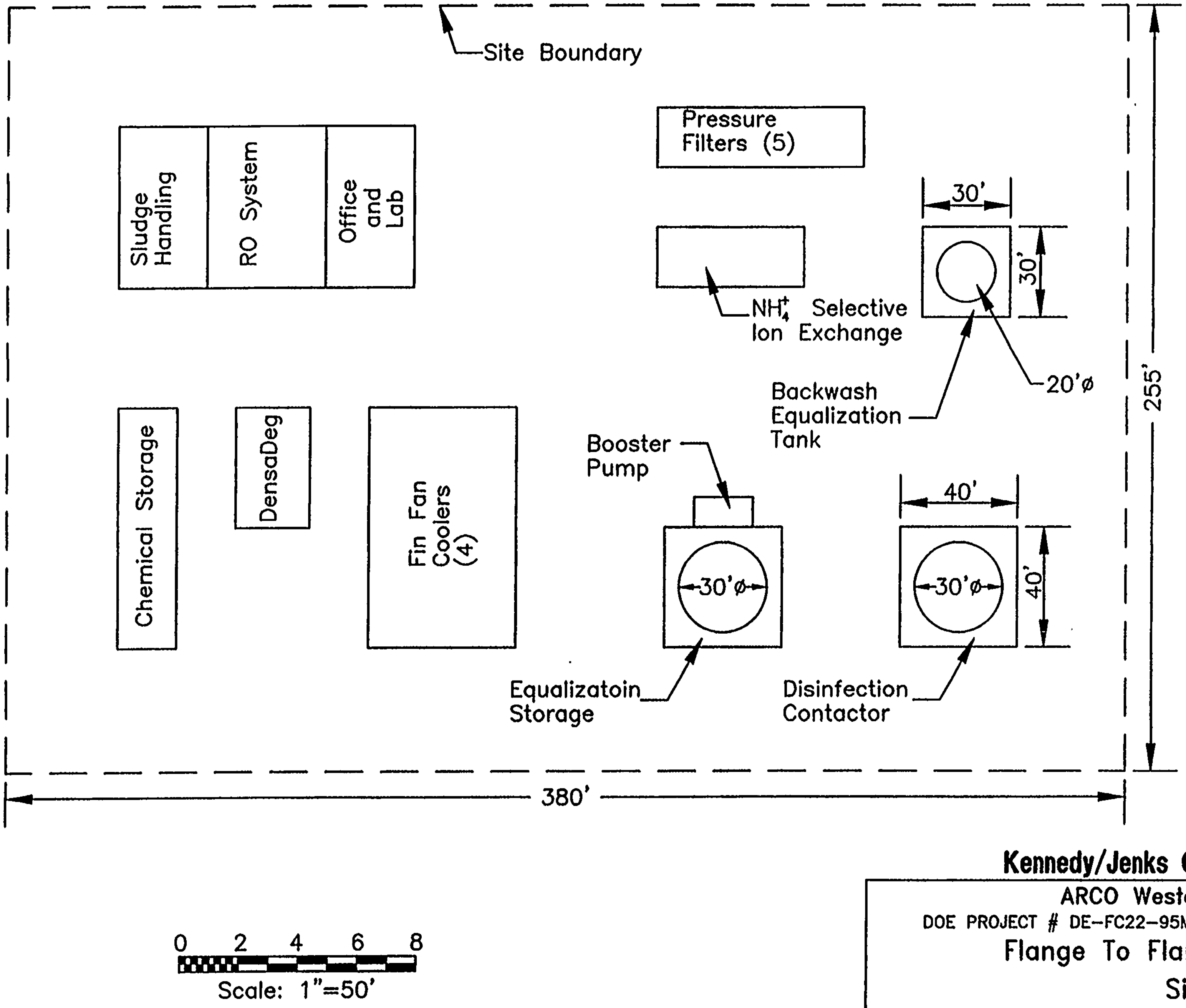
Figure 7-5



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Flange To Flange Plant
Site Layout
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Figure 7-6

and flange-to-flange options, a 5,400 sq.ft. building will be provided to house the RO system and sludge handling facilities, and to provide office and laboratory space.

The costs represent late 1997 dollars. Table 7-3 summarizes the cost factors used in the conceptual treatment facility.

Table 7-3

Cost Factors and Assigned Values

Parameter	Value	Unit
Dollar	late 1997	index year
Interest rate	7	% per annum
Capital recovery period	20	years
Capital		
Electrical and instrumentation	15	% of process train costs
Site work	10	% of process train costs
Contractor's overhead and profit	12	% of direct construction cost
Mobilization and bonding	2	% of direct construction cost
Contingency	10	% of direct construction cost
Indirect construction costs	38	% of construction "bid" cost
O&M		
Sodium hydroxide	0.14	$ per lb.
Magnesium chloride	0.12	$ per lb.
Polymer	2.40	$ per lb.
RO antiscalant	2.23	$ per lb.
RO antifoulant	3.22	$ per lb.
RO chemical cleaning solution	3.57	$ per lb.
Sodium hypochlorite	0.71	$ per lb. Cl_2
Sulfuric acid	0.046	$ per lb.
Electricity	0.05	$ per kW-hr
Labor rate	30	$ per hr
Replacement RO membrane elements	990	$ per element (18 month life)
Misc. maintenance materials	1	% of process train costs
Sludge disposal	25	$ per ton wet
Brine disposal	11	¢ per barrel
Contingencies	10	% of direct annual O&M

Construction and Total Capital Costs

Capital cost estimates include both the actual construction ("bid") costs and the indirect costs associated with implementing the project. Capital cost include costs related to purchase and installation of process and residuals handling equipment, site preparation, building and structural work, and other construction costs a contractor includes in a "bid cost" for a treatment facility such as mobilization and bonding, overhead and profit, and contingencies to account for uncertainties and unforeseen expenses. Indirect capital costs include such expenses as engineering design and construction management, financial, legal, and administrative services, interest during construction, utility connection fees, environmental impact reports, and permits. These costs have been estimated at 38 percent of the construction "bid" costs in this report. The capital cost estimates are conceptual level estimates and assume a level site and have an accuracy of approximately -15 to +30 percent.

Table 7-4 summarizes the capital cost estimate for the conceptual 44,000 bpd produced water treatment facility that would reclaim approximately 43,000 bpd (2,000 acre ft/yr) of water for industrial reuse. The estimated construction "bid" cost for the upper silica goal option is $2.2 million, with indirect capital cost of $0.86 million, for a total project capital cost of $3.1 million. The corresponding capital cost estimates for the lower silica goal option are $2.4 million, $0.89 million, and $3.2 million, respectively. The unit construction costs are $51/bpd and $53/bpd produced water treated for the upper silica and lower silica goals, respectively. The corresponding unit total capital cost for these options are $71/bpd and $74/bpd, respectively.

Table 7-5 summarizes the capital cost estimate for a conceptual 44,000 bpd produced water treatment facilities that would reclaim approximately 32,200 bpd (1,510 acre ft/yr) of water for the blending option and approximately 32,600 bpd (1,530 acre ft/yr) of water for the flange-to-flange option. The estimated construction "bid" cost for the blending option is $7.7 million, with indirect capital cost of $2.9 million, for a total project capital cost of $10.6 million. The corresponding capital cost estimates for the flange-to-flange option are $8.9 million, $3.4 million, and $12.3 million, respectively. The unit construction costs are $175/bpd and $202/bpd produced water treated for the blending and flange-to-flange options, respectively. The corresponding unit total capital cost for these options are $241/bpd and $279/bpd, respectively.

Table 7-4

Capital Cost Estimate for 44,000 Barrel Per Day Conceptual Produced Water Industrial Reuse Treatment Facilities

Cost Component		Upper Silica Level Cost ($1,000s)*	Lower Silica Level Cost ($1,000s)*
1.	Direct Process Costs		
	Warm lime softening	920	920
	Equalized storage	150	150
	Booster pumping	250	250
	Stabilization (pH adj.)		63
	Subtotal	1,300	1,400
2.	Treatment Building	150	150
3.	Process + Building Subtotal	1,500	1,500
4.	Other Direct Construction		
	Electrical + Instrumentation @ 15% of Item 1 Subtotal	200	210
	Site work @ 10% of Item 3 Subtotal	150	150
5.	Direct Construction Subtotal	1,800	1,900
6.	Contractor Markups		
	Contractor's overhead & profit @12% of Item 5 Subtotal	220	230
	Mobilization @ 2% of Item 5 Subtotal	36	38
	Contingency @ 10% of Item 5 subtotal	180	190
7.	Total Construction Cost Estimate (Bid Cost)	2,200	2,400
8.	Indirect Capital Cost Estimate @ 38% of bid cost	860	890
9.	Total Capital Cost Estimate	3,100	3,200
10.	Unit Construction Costs		
	$/bpd produced water treated	51	53
	$/bpd water reclaimed	52	54
11.	Unit Total Capital Costs		
	$/bpd produced water treated	71	74

* Values rounded to two significant figures.

Table 7-5

Capital Cost Estimate for 44,000 Barrel per Day Conceptual Produced Water Irrigation Drinking Water Reclamation Projects

Cost Component		Blending Water Cost ($1,000s)*	Flange to Flange Cost ($1,000s)*
1.	Direct Process Costs		
	Warm lime softening	1,100	1,200
	Cooling	410	410
	Equalized storage	150	150
	Booster pumping	250	250
	Granular media filtration	490	490
	Reverse Osmosis	1,900	1,900
	Stabilization (pH adj.)	-	63
	Ammonium selective ion exchange	-	810
	Disinfection/storage	250	250
	Subtotal	4,700	5,500
2.	Treatment Building	300	300
3.	Process + Building Subtotal	5,000	5,800
4.	Other Direct Construction		
	Electrical + Instrumentation @ 15% of Item 1 Subtotal	700	820
	Site work @ 10% of Item 3 Subtotal	500	580
5.	Direct Construction Subtotal	6,200	7,200
6.	Contractor Markups		
	Contractor's overhead & profit @12% of Item 5 Subtotal	740	860
	Mobilization @ 2% of Item 5 Subtotal	120	140
	Contingency @ 10% of Item 5 subtotal	620	720
7.	Total Construction Cost Estimate (Bid Cost)	7,700	8,900
8.	Indirect Capital Cost Estimate @ 38% of bid cost	2,900	3,400
9.	Total Capital Cost Estimate	10,600	12,300
10.	Unit Construction Costs		
	$/bpd produced water treated	170	200
	$/bpd water reclaimed	240	270
11.	Unit Total Capital Costs		
	$/bpd produced water treated	240	280

*Values rounded to two significant figures or nearest $100,000.

OIL PRODUCTION VERSES WATER UTILITY PERSPECTIVE

In examining the feasibility of a potential project, the oil production and water utility perspectives are different. Both have a similar perspective for total project capital costs. There may be some differences on some of the percentages used for estimating indirect capital costs (Table 7-1), but the cost elements are the same.

The relative perspective on operating cost is very different. Generally, the oil production perspective does not include amortized capital. Typically, a water utility will include amortized capital because all or part of its costs are recovered through water rates based on the amount of water sold. The amortized period for a water utility is typically 20 years because the water utility sells bonds to finance their projects. On the other hand, for the oil producer, three years is the typical period for capital amortization.

Annual Operations and Maintenance (O&M) Cost-Oil Production Perspective

Annual O&M cost includes chemicals, energy (electric power), labor, maintenance materials, and residuals disposal. In addition, a 10 percent contingency was added for administrative and unforeseen maintenance costs.

Table 7-6 summarizes the estimated annual O&M cost for the industrial reuse options. Total annual O&M cost is estimated to be $1.2 million/yr for the upper silica goal option and $1.6 million/yr for the lower silica goal option. This is equivalent to 7.4¢/bbl and 10¢/bbl of produced water treated, respectively, for the upper and lower silica goal options. The O&M cost for the upper silica goal consist of $0.39 million/yr for chemicals, $0.05 million/yr for energy, $0.31 million/yr for labor, $0.01 million/yr for maintenance materials, $0.12 million for residuals management, and $0.11 million/yr for contingencies. The corresponding O&M cost for the lower silica goal consists of $0.66 million/yr for chemicals, $0.05 million/yr for energy, $0.31 million/yr for labor, $0.01 million/yr for maintenance materials, $0.45 million for residuals management, and $0.15 million/yr for contingencies.

Table 7-6

Annual Operations and Maintenance Costs
Conceptual Produced Water Industrial Reuse Projects

Cost Component			Upper Silica Level ($1,000s/yr)*	Lower Silica Level ($1,000s/yr)*
1.	Chemicals			
	Sodium hydroxide		350	600
	Polymers		47	47
	Sulfuric acid		-	7
		Subtotal	390	660
2.	Electricity			
	Warm softening		9	9
	Booster pump		46	46
		Subtotal	55	55
3.	Labor			
	Operations		260	260
	Maintenance		44	44
		Subtotal	310	310
4.	Maintenance Materials			
	Other materials	Subtotal	13	14
5.	Residuals Disposal			
	Sludge	Subtotal	120	450
6.	Direct Annual O&M		1,100	1,500
7.	Contingency @10% of Item 6		110	150
8.	Total Annual O&M		1,200	1,600
9.	Unit Annual O&M Cost			
	¢ / bbl produced water treated		7.4	10

*Values rounded to two significant figures.

Similarly, Table 7-7 summarizes the estimated annual O&M cost for the blending and flange-to-flange options. Total annual O&M cost is estimated to be $3.8 million/yr for both the blending option and the flange-to-flange option. This is equivalent to 24 ¢/bbl of produced water treated. The O&M cost for the blending option consists of $1.3 million/yr for chemicals, $0.32 million/yr for energy, $0.53 million/yr for labor, $0.30 million/yr for maintenance materials, $1.1 million for residuals management, and $0.35 million/yr for contingencies. The corresponding O&M cost for the flange-to-flange option consists of $1.4 million/yr for chemicals, $0.32 million/yr for energy, $0.53 million/yr for labor, $0.31 million/yr for maintenance materials, $0.94 million for residuals management, and $0.35 million/yr for contingencies. The maintenance materials cost includes $0.25 million/yr for replacing two-thirds of the RO membrane elements (18 month life assumed).

The O&M cost is dominated by the costs for chemicals and sludge disposal for all alternatives. For example, the chemical and sludge disposal costs represent 42 percent and 70 percent of the O&M cost for the upper and lower silica goal industrial treatment scenario, respectively. The chemicals and residuals management costs represent 63 percent and 62 percent of the O&M cost for the blending and flange-to-flange options, respectively.

Table 7-7

Annual Operations and Maintenance Costs

Conceptual Produced Water Irrigation and Potable Reuse Projects

Cost Component		**Blending Water ($1,000s/yr)***	**Flange-to-flange ($1000s/yr)***
1. Chemicals			
Sodium hydroxide		860	1,000
Magnesium chloride		64	0
Polymers		70	69
Antiscalant		12	12
Antifoulant		88	89
RO cleaning solution		160	160
Sulfuric acid		-	9
Sodium hypochlorite		6	6
	Subtotal	1,300	1,400
2. Electricity			
Warm softening		9	9
Cooling		44	44
Booster pump		46	46
Reverse osmosis		220	220
pH and disinfection		1	1

Cost Component		Blending Water ($1,000s/yr)*	Flange-to-flange ($1000s/yr)*
	Subtotal	320	320
3. Labor			
Operations		438	438
Maintenance		88	88
	Subtotal	530	530
4. Maintenance Materials			
RO membranes		250	250
Other materials		47	55
	Subtotal	300	310
5. Residuals Disposal			
Sludge		640	510
RO concentrate		430	430
	Subtotal	1,100	940
6. Direct Annual O&M		3,500	3,500
7. Contingency @10% of Item 6		350	350
8. Total Annual O&M		3,800	3,800
9. Unit Annual O&M Cost			
¢ / bbl produced water treated		24	24

Sensitivity Analysis of Labor, Electricity, Sludge Disposal, and Sodium Hydroxide Costs

A sensitivity analysis was performed using the following changes from the base case cost assumptions on the annual O&M costs and unit cost per barrel of produced water treated:

- Changing the labor rate from $30/hour to $25/hour
- Changing the electric rate from $0.05/kw-hr to $0.03/kw-hr
- Changing the dewatered sludge concentration from 20 percent to 50 percent
- Changing the NaOH cost from $0.14/lb. to $0.07/lb
- Combined impact of making all four changes simultaneously (best case)

Tables 7-8, 7-9, 7-10, and 7-11 compare these cases for the high silica industrial water, the low silica industrial water, the blending, and the flange-to-flange options, respectively.

These summaries show that the cost of caustic has the biggest impact on annual O&M costs, ranging from about 1 ¢/bbl. of produced water treated for the high silica industrial water option to 3¢/bbl. for the flange-to-flange option. Increasing the dewatered sludge concentration to 50 percent solids reduces annual O&M costs of produced water from about 1¢/bbl for the high silica industrial water option to 2.7¢/bbl for the flange-to-flange option. The labor and electric rate changes have a smaller impact on annual O&M costs, of about 0.1 ¢/bbl for the industrial options and about 1¢/bbl. for the potable water options. If all of these cost reductions could be achieved, the annual O&M costs could be reduced by 2.9¢/bbl (39 percent reduction) for the high silica industrial option, 4.4¢/bbl (44 percent reduction) for the low silica industrial option, and 7¢/bbl (30 percent reduction) for the blending and flange-to-flange option.

Table 7-8

Upper Silica Industrial Water Option, Annual O&M Cost Comparison

Cost Component	Base Case	Labor ($25/hr)	Electricity (3¢/kWH)	Sludge 50%	NaOH (7 ¢/lb)	Cumulative Case
Annual O&M Costs	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s
Unit treatment cost	*¢/bbl*	*¢/bbl.*	*¢/bbl.*	*¢/bbl.*	*¢/bbl*	*¢/bbl.*
1. Warm softening	1,032	922	1,028	838	842	600
	6.4	*6.2*	*6.4*	*5.23.8*	*5.2*	*3.7*
2. Equalized Storage	40	34	40	40	40	34
	0.2	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
3. Booster Pumping	112	101	94	94	112	83
	0.7	*0.6*	*0.6*	*0.6*	*0.7*	*0.5*
Annual O&M	1,183	1,127	1,162	989	993	717
	7.4	*7.0*	*7.2*	*6.2*	*6.2*	*4.5*

Table 7-9

Lower Silica Industrial Water Option, Annual O&M Cost Comparison

Cost Component	Base Case	Labor ($25/hr)	Electricity (3¢/kWH)	Sludge (50%)	NaOH (7 ¢/lb)	Cumulative Case
Annual O&M Costs	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s
Unit treatment cost	*¢/bbl*	*¢/bbl.*	*¢/bbl.*	*¢/bbl.*	*¢/bbl*	*¢/bbl.*
1. Warm softening	1,455	1,417	1,451	1,178	1,122	777
	9.1	*7.6*	*8.8*	*7.3*	*7.0*	*4.8*
2. Equalized Storage	38	32	38	38	38	32
	0.2	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
3. Booster Pumping	109	99	91	109	109	81
	0.7	*0.6*	*0.6*	*0.7*	*0.7*	*0.5*
4. Stabilization (pH Adjustment)	24	21	24	24	24	21
	0.1	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
Annual O&M	1,626	1,570	1,604	1,349	1,293	911
	10.1	9.8	*10.0*	*8.4*	*8.1*	*5.7*

Table 7-10

Blending Water Option Annual O&M Cost Comparison

Cost Component	**Base Case**	**Labor ($25/hr)**	**Electricity (3¢/kWH)**	**Sludge (50%)**	**NaOH (7 ¢/lb)**	**Cumulative Case**
Annual O&M Costs	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s
Unit treatment cost	*¢/bbl*	*¢/bbl.*	*¢/bbl.*	*¢/bbl.*	*¢/bbl*	*¢/bbl.*
1. Warm softening	1,959	1,934	1,956	1,538	1,484	1,034
	12.2	*12.0*	*12.2*	*9.6*	*9.2*	*6.4*
2. Fin Fan Cooler	98	90	81	98	98	72
	0.6	*0.6*	*0.5*	*0.6*	*0.6*	*0.4*
2. Equalized Storage	19	16	19	19	19	16
	0.1	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
3. Booster Pumping	77	72	59	77	77	53
	(0.5)	(0.4)	(0.4)	(0.5)	(0.5)	(0.3)
4. Pressure Filters	81	70	80	81	81	70
	0.5	*0.4*	*0.5*	*0.5*	*0.5*	*0.4*
5. Reverse Osmosis	1,507	1,468	1,420	1,507	1,507	1,380
	9.4	*9.1*	*8.8*	*9.4*	*9.4*	*8.6*
6. Stabilization	0.0	0.0	0.0	0.0	0.0	0.0
(pH Adjustment)	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
7. Ammonium Ion	0.0	0.0	0.0	0.0	0.0	0.0
Exchange	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
8. Disinfection/Storage	41	36	41	41	41	36
	0.3	*0.2*	*0.3*	*0.3*	*0.3*	*0.2*
Annual O&M	3,782	3,686	3,655	3,360	3,306	2,662
	23.6	*23.0*	*22.8*	*20.9*	*20.6*	*16.6*

Table 7-11

Flange to Flange Drinking Water Option, Annual O&M Cost Comparison

Cost Component	**Base Case**	**Labor ($25/hr)**	**Electricity (3¢/kWH)**	**Sludge (50%)**	**NaOH (7 ¢/lb)**	**Cumulative Case**
Annual O&M Costs	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s	$1,000s
Unit treatment cost	*¢/bbl*	*¢/bbl.*	*¢/bbl.*	*¢/bbl.*	*¢/bbl*	*¢/bbl.*
1. Warm softening	1,713	1,694	1,710	1,376	1,238	877
	10.7	*10.5*	*10.6*	*8.6*	*7.7*	*5.5*
2. Fin Fan Cooler	91	84	73	91	91	66
	0.6	*0.5*	*0.5*	*0.6*	*0.6*	*0.4*
2. Equalized Storage	17	15	17	17	17	15
	0.1	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
3. Booster Pumping	74	70	56	74	74	52
	0.5	*0.4*	*0.4*	*0.5*	*0.6*	*0.3*
4. Pressure Filters	72	63	72	72	72	63
	0.4	*0.4*	*0.4*	*0.4*	*0.4*	*0.4*
5. Reverse Osmosis	1,653	1,619	1,565	1,653	1,567	1,446
	10.3	*10.1*	*9.7*	*10.3*	*9.8*	*9.0*
6. Stabilization	18	17	18	18	18	17
(pH Adjustment)	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
7. Ammonium Ion	90	77	90	90	90	77
Exchange	*0.6*	*0.5*	*0.6*	*0.6*	*0.6*	*0.5*
8. Disinfection/Storage	36	32	36	36	36	32
	0.2	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*
Annual O&M	3,765	3,670	3,638	3,428	3,205	2,645
	23.4	*22.8*	*22.6*	*21.3*	*20.0*	*16.5*

Annual Costs - Water Utility Perspective

When considering water resources alternatives, the total unit costs of the water resources are normally compared by the water utilities. For this study, total unit treatment cost include total annual costs divided by the total amount of water reclaimed (e.g., \$/acre-ft). Total annual cost consists of annual O&M cost plus amortized capital costs. Capital costs were amortized over 20 years at an annual interest rate of 7 percent (typical for municipal projects), yielding a capital recovery factor of 0.0936 because many water utility projects are financed through bonds.

Base Case Scenarios

Table 7-12 provides a summary of the amount of water reclaimed and the unit treatment costs for each of the four water reuse options considered for base case and best case O&M assumptions. This summary shows that, for the base case assumptions, the industrial reuse options ranged from \$ 720/acre-ft to \$940/acre-ft of water reclaimed for the upper and lower silica goal alternatives. In contrast, the unit treatment costs are estimated for the base case for the blending and the flange- to-flange options to be approximately \$3,200/acre-ft and \$3,300/acre-ft of water reclaimed, respectively. For the base case, the annual amortized capital payments ranged from 16 percent of the total annual cost for the lower silica goal option to 24 percent of the total annual cost for the flange-to-flange option.

Best Case Scenarios

The corresponding unit treatment costs for the best case assumptions ranged from \$490/acre-ft to \$600/acre-ft of water reclaimed for the upper and lower silica goal alternatives, and from approximately \$3,200/acre-ft and \$3,300 of water reclaimed for the blending and the flange-to-flange options, respectively.

For the best case estimates, in which lower cost assumptions are made for O&M costs, the annual amortized capital payments ranged from 29 percent of the total annual cost for the lower silica goal option to 32 percent of the total annual cost for the flange-to-flange option. This suggests that potential savings would be in the O&M expenses, as discussed in Chapter 8.

Table 7-12

Summary of Water Reclaimed and Unit Treatment Costs

	Industrial Upper Silica	Industrial Lower Silica	Irrigation Blending Water	Potable Flange-to-Flange
Produced Water Treated				
bbls/day	44,000	44,000	44,000	44,000
acre ft/yr	2,070	2,070	2,070	2,070
Water reclaimed				
bbls/day	43,520	43,320	32,200	32,600
acre-ft/year	2,050	2,040	1,510	1,530
Overall Water Recovery	98.9	98.4	73.2	74.1
Total Capital Cost($1,000s)	3,100	3,200	10,600	12,300
Annual O&M Cost ($1,000s/yr)				
Base case	1,200	1,600	3,800	3,800
Best case	720	930	2,700	2,600
Annual amortized capital costs ($1,000s/yr)	290	300	990	1,200
Total annual costs ($1,000s/yr)				
Base case	1,500	1,900	4,800	5,000
Best case	1,000	1,200	3,700	3,800
Unit treatment costs (Best case)				
$/acre-ft. reclaimed	720	940	3,200	3,300
Blended water cost ($/acre-ft.)	-	-	710*	-
Unit treatment costs (Best case)				
$/acre-ft. reclaimed	490	600	2,400	2,500
Blended water cost ($/acre-ft.)	-	-	560*	-

*Assumes reclaimed produced water is blended with marginal quality water worth $100/acre-ft. in a 1:4 (reclaimed water to marginal water).

The blending alternative was used to assess the cost of blending the treated water with TDS of approximately 145 mg/L and boron of 5 mg/L (as B) with a currently unusable water with high TDS (e.g., 1,200 mg/L) or a trace contaminant (e.g., 20 µg/L perchlorate [California DHS action limit for perchlorate is 18 µg/L]) with a cost of $100/ acre-ft. Assuming a blend of four parts of this water with the treated produced water, the resulting water resource would have a boron concentration of 1 mg/L and a TDS of 1,000 mg/L or a perchlorate concentration of 16 µg/L. The cost of the blended water would be from about $560/acre-ft. (best case) to $710/acre-ft (base case), which does not include additional infrastructure costs such as pipelines, pump station, or reservoir facilities to implement the blending option.

Table 7-13 provides a cost comparison of reclaimed water sources evaluated in this study with the value of water sources in California recently reported by Sheikh et al. (1998). This table shows that the industrial reuse costs in this study fall within the $200 to $2,000 per acre-ft. range for wastewater effluent disposal, while the blending and flange-to-flange options are significantly greater than the $300 to $1,1000 per acre-ft. range for drinking water supply. The $560 - $710 per acre-ft. value of blending treated produced water with a marginal quality water, however, is within this water supply cost range. This suggests that a subsidy would be required to use the irrigation blending or flange-to-flange water if an impaired water source is not available.

Table 7-13

Cost Comparison of Water Sources

Water Source	Value ($/acre-ft.)	Reference
Water supply	300 - 1,100	Sheikh et al. (1998)
Effluent disposal	200 - 2,000	Sheikh et al. (1998)
High silica industrial reuse	490 - 720	This study
Low silica industrial reuse	600 - 950	This study
Blending option	2,400 - 3,200	This study
Blended water with impaired supply	560 - 710	This study
Flange-to-flange option	2,500 - 3,300	This study

Chapter 8

Conclusions

CHAPTER 8

CONCLUSIONS

This chapter is divided into three sections. The first portion presents conclusions on the processes studied on a bench or pilot scale. This is followed by a discussion of the conceptual design. The last portion identifies potential additional studies that could develop information that could lower the capital or operations and maintenance costs.

PROCESS CONCLUSIONS

This section is organized from the perspective of the water traveling through the unit processes that were tested. The focus is on the processes that could be part of the conceptual design. Generally, the pilot study demonstrated that by altering operating conditions, the treated water can meet industrial, irrigation, and drinking water quality standards.

Walnut Shell Filter

The walnut shell filter performed like a typical deep bed filter in terms of headloss accumulation and filter productivity as measured by unit filter volume (UFRV). The walnut shell filter performance for removing turbidity and total oil and grease averaged 63 percent and 39 percent, respectively and did not vary significantly when the hydraulic loading rate was varied from 2 to 15 gpm/ft^2. The full scale sand pressure filters had better removals for these parameters. The greatest benefit for this process is the removal of suspended oil and grease that averaged 97.4 percent as reported by Hydromation as compared to 78 percent for the full scale sand filters as reported by Nalco. This process may have a role in removing suspended oil and grease under upset conditions of the Wemco. This unit process could be used to replace the multi-media pressure filters in the conceptual design.

DensaDeg

From the bench and pilot tests it appears that the major mechanism for silica removal is a precipitation reaction. There appears to be some additional removal through a sorption process because the silica removal in the pilot study was better than in jar testing. Silica removal was also better than expected based on the calculated percent ionized (reactive silica).

Sorption onto a large quantity of magnesium floc appears to be required to lower the boron level to less than 1 mg/L. The sludge and chemical costs for this operational scenario appear to be the limiting factors. The fraction of boron that is removed by a warm precipitation mechanism appears to be less than 30 percent without feeding additional magnesium.

The DensaDeg when operated at pH 9.5 can produce an effluent with ~25 mg/L of total hardness. Controlling the sludge blow down of the DensaDeg would be a key operational parameter to keep the hardness consistently at this target concentration.

Trickling Filter

The trickling filter removed less than 10 percent of the TOC. The type of organics in this water requires some additional treatment to make them more amenable to biological degradation. This process was removed from the conceptual design due to its poor performance. The membrane process becomes the major organics removal system in the conceptual design.

Pressure Filters

The silt density index (SDI) was high (~ 6 [see Appendix B, p. Ion-exchange 1,3,6, and 9]) during the pilot study. No significant SDI reduction was observed across the filters. During the pilot study, the filtration step was not optimized and, based on prior experience, it would appear that some additional reduction in the SDI should be expected through the use of a coagulant or filter aid. Studies to evaluate this potential reduction could impact the cleaning frequency and membrane replacement. Improvements in these areas would reduce the operating costs.

Ion Exchange Softening

The DensaDeg was able to produce a similar residual hardness as the ion exchange softener. If one was using a high magnesium dose in the DensaDeg to remove more boron, this process may be required. For the conceptual design, this method of operations was eliminated and so was the requirement for this process.

Reverse Osmosis

During the pilot study this process was able to remove more than 95 percent of the TOC and TDS and met these water quality treatment goals. Operating the RO feed water at pH ~11 produced an RO effluent of approximately 1 mg/L boron, but more than 8 mg/L of ammonia. This high level of ammonia is acceptable for irrigation water, but is not acceptable from an operational perspective for drinking water systems. This high ammonia level would probably result in operational problems for irrigation water distribution systems as well.

Operating the RO at a moderate pH of ~9.5 would produce an effluent with about 5 mg/L of boron and ammonia. Blending this water with an impaired water source because it exceeds a drinking water standard is an option. This operational scenario assumes that there is no boron or ammonia in the impaired water source.

The pilot plant was not operated long enough to determine the impact of membrane cleaning and replacement on the O&M costs. These are important issues to resolve before proceeding further with the conceptual design.

ESTIMATED COST

Four operational scenarios were identified and associated conceptual design and operational parameters were developed for each using the bench scale and pilot study results. The four scenarios were the following: 1) industrial water with a silica as SiO_2 goal of < 200 mg/L; 2) industrial water with a silica as SiO_2 goal of <80 mg/L; 3) blended irrigation/drinking water supply using 1 part treated water with 4 parts impaired water source with a treated water TDS goal of <150 mg/L, 5 mg/L of ammonia-N, and 5 mg/L of boron; and 4) flange-to-flange treated water with a TDS goal of < 150 mg/L, 1 mg/L of ammonia-N, 1 mg/L of boron, and a <2 mg/L of TOC.

A sensitivity analysis was performed using the following changes from the base case cost assumptions on the annual O&M costs and unit cost per barrel of produced water treated:

- Changing the labor rate from $30/hour to $25/hour
- Changing the electric rate from $0.05/kw-hr to $0.03/kw-hr
- Changing the dewatered sludge concentration from 20 percent to 50 percent

- Changing the NaOH cost from \$0.14/lb. to \$0.07/lb
- Combined impact of making all four changes simultaneously (best case)

High Silica Goal

The conceptual design for the high silica goal (<200 mg/L as SiO_2) would require a warm precipitation using a DensaDeg, a filter press to reduce the solids that would be hauled to a landfill, flow equalization, and a pump station delivering the water to a customer at 100 psig. The DensaDeg would be operated at a target pH of 7.7 requiring an average of 440 mg/L of caustic. The estimated construction "bid" cost for this scenario is \$2.2 million, with indirect capital costs of \$0.86 million, for a total project capital cost of \$3.1 million. The unit construction costs are \$51/bpd produced water treated and unit total capital costs are \$71/bpd. The O&M cost was estimated to be equivalent to 7.4¢ and 4.5 ¢/bbl of produced water treated for the base and best case, respectively.

Low Silica Goal

The conceptual design for the low silica goal (<80 mg/L as SiO_2) would require a warm precipitation using a DensaDeg, a filter press to reduce the solids that would be hauled to a landfill, flow equalization, and a pump station delivering the water to a customer at 100 psig. The DensaDeg would be operated at a target pH of 8.6 requiring an average of 770 mg/L of caustic. The estimated "bid" cost for the lower silica goal option was \$2.4 million, with indirect capital cost of \$0.90 million, or a total project capital cost of \$3.2 million. The O&M cost was estimated to be 10.1¢ and 5.7¢/bbl of produced water treated for the base and best case, respectively.

Irrigation and Drinking Water - Blended

The recommended treatment process for the blending option includes warm precipitative softening with magnesium, cooling, equalization storage, booster pumping, multi-media filtration, cartridge (automatic bag) filtration, reverse osmosis at pH 9.5, and disinfection. This conceptual 44,000 bpd produced water treatment facility would reclaim approximately 32,200 bpd (1,510 acre ft/yr) of water for blending another impaired water resource of 6000 acre ft/yr. The estimated construction "bid" cost for the blending option is \$7.7 million, with indirect capital cost of \$2.9 million, for a total project capital cost of \$10.6 million. The unit construction costs are $175/bpd produced water treated. The O&M cost was estimated to be 23.6¢ and 16.6¢/bbl of produced water treated for the base and best case, respectively.

Irrigation and Drinking Water - Flange-to-Flange

The recommended treatment process for the flange-to-flange option includes warm precipitative softening without magnesium, cooling, equalization storage, booster pumping, multi-media filtration, upward pH adjustment, cartridge (automatic bag) filtration, pH 11 reverse osmosis, pH adjustment, ammonium selective ion exchange, and disinfection. This process would reclaim approximately 32,600 bpd (1,530 acre ft/yr) of water. The estimated "bid" construction cost is $8.9 million with an indirect capital cost of $3.4 million, a total project capital cost of $12.3 million. The unit construction costs are $175/bpd and $202/bpd produced water treated for the blending and flange-to-flange options, respectively. The corresponding unit total capital costs are $279/bpd. The O&M cost was estimated to be 23.4¢ and 16.5¢/bbl of produced water treated for the base and best case, respectively.

TOTAL UNIT TREATMENT COSTS - WATER UTILITY PERSPECTIVE

When considering water resources alternatives, the total unit cost of the water resources are normally compared by the water utilities. For this study, total unit treatment cost include total annual costs divided by the total amount of water reclaimed (e.g., $/acre-ft). Total annual cost consist of annual O&M cost plus amortized capital costs. Capital costs were amortized over 20 years at an annual interest rate of 7 percent (typical for municipal projects), yielding a capital recovery factor of 0.0936 because many water utility projects are financed through bonds.

Base Case Scenarios

For the base case assumptions, the industrial reuse options ranged from $720/acre-ft to $940/acre-ft of water reclaimed for the upper and lower silica goal alternatives. In contrast, the unit treatment costs are estimated for the base case for the blending and the flange- to-flange options to be approximately $3,200/acre-ft and $3,300/acre-ft of water reclaimed, respectively.

Best Case Scenarios

The corresponding unit treatment costs for the best case assumptions ranged from $490/acre-ft to $600/acre-ft of water reclaimed for the upper and lower silica goal alternatives, and from approximately $2,400/acre-ft and $2,500 of water reclaimed for the blending and the flange-to-flange options, respectively.

A blending alternative with an impaired water supply was used to assess the cost of blending the treated water with TDS of approximately 145 mg/L and boron of 5 mg/L (as B) with a currently unusable water with high TDS (e.g., 1,200 mg/L) or a trace contaminant (e.g., 20 µg/L perchlorate [California DHS action limit for perchlorate is 18 µg/L]) with a cost of $100/ acre-ft. Assuming a blend of four parts of this water with the treated produced water, the resulting water resource would have a boron concentration of 1 mg/L and a TDS of 1,000 mg/L or a perchlorate concentration of 16 µg/L. The cost of the blended water would be from about $560/acre-ft. (best case) to $710/acre-ft (base case), which does not include additional infrastructure costs such as pipelines, pump station, or reservoir facilities to implement the blending option.

Sheikh et al. (1998) provided a cost comparison of reclaimed water sources indicating that the industrial reuse costs in this study fall within the $200 to $2,000 per acre-ft. range for wastewater effluent disposal, while the blending and flange-to-flange options are significantly greater than the $300 to $1,1000 per acre-ft. range for drinking water supply. The $560 - $710 per acre-ft. value of blending treated produced water with a marginal quality water, however, is within this water supply cost range. This comparison suggests that a subsidy would be required to use the irrigation blending or flange-to-flange water if an impaired water source is not available.

ADDITIONAL STUDIES

The conceptual design needs to be tested for at least 12 months. There would be two objectives of the 12 month testing program. The first objective would be to develop water quality data for the regulatory agencies. The second objective would be to refine the conceptual design and explore ways to lower the estimated operating cost.

Water Quality Data

In addition to providing additional operational data to refine the cost estimates, water quality data is needs to be collected to determine the potential impact on public health. The water quality data set generated by this study is insufficient to assist the regulatory agencies in determining the feasibility of the conceptual design to be used in the irrigation and potable water scenarios.

This evaluation indicates that the cost of treating produced water is heavily influenced by the chemicals used in warm softening. Future studies should focus on three areas: 1) optimization of the chemicals used in warm softening; 2) reducing the cost of sludge disposal; and 3) membrane cleaning and flux recovery. These areas are listed in the relative order of their impact on reducing the annual costs.

Optimization of Chemicals in Warm Softening

The use of magnesium hydroxide in place of magnesium chloride should be pilot tested to see if the warm softening costs can be further reduced. In addition to providing a magnesium source for silica removal, the magnesium hydroxide would also reduce the amount of caustic required (e.g., 58 mg/L of $Mg(OH)_2$ would reduce the NaOH requirement by 80 mg/L).

A larger cost saving may be realized if the waste caustic at ARCO's Los Angeles refinery can be used as the NaOH source. If technical and regulatory issues concerning the waste caustic can be addressed, the warm softening process should be pilot tested with treated waste caustic.

The high caustic dose requirements in part appear to be due to excess carbon dioxide in the produced water. Stripping some of the carbon dioxide (with nitrogen or methane gas or by vacuum deaeration) prior to warm precipitative softening should be investigated. This could reduce the caustic requirement by at least 200 mg/L, which would reduce O&M costs by about 1 ¢/bbl of produced water treated.

Reducing Sludge Disposal Cost

Preliminary dewatering tests of the softening sludge indicated that a 20 percent DS sludge could be produced with filter presses. Further testing with sludge dewatering should be performed to see if a dewatered sludge approaching 50 percent DS can be produced. This would help reduce the volume and costs of sludge disposal substantially. Specifically, this would reduce the disposal cost from $125/dry ton to $50/dry ton; the O&M cost reductions would range from 1.2 ¢/bbl of produced water treated for the upper silica industrial goal option to 2.6 ¢/bbl for the irrigation blending option.

The sludge could potentially be beneficially used as a constituent in soil amendments, cement mixtures, road paving, or ceramic bricks. The cost reduction could result from the sale of the sludge as a material rather than a waste for disposal. An evaluation of these should be conducted and then any promising alternatives tested on a pilot scale.

Membrane Cleaning and Flux Studies

Studies to reduce the SDI ahead of the RO unit process are needed. Reducing this parameter will require less cleaning and perhaps delay membrane replacement.

The impact of cleaning the membranes and flux recovery needs more study. This information is needed to determine whether the membrane is capable of removing both TOC and TDS under these relatively harsh conditions for an extended period.

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ACRONYMS, ABBREVIATIONS AND SYMBOLS

ACWA	Association of California Water Agencies
AEPT	ARCO Exploration and Production Technology
AES	AES, Inc.
AF	acre feet
AL	Action Level
ARCO	Atlantic Richfield Company
AWE	ARCO Western Energy
AWWA	American Water Works Association
bbl	barrel
BNA	Base Neutral Acid
BOD	biochemical oxygen demand
bpd	barrels (42 gallon = 1 barrel) per day
BTEX	benzene, toluene, ethylbenzene and xylenes
BTU	British thermal unit
BV	bed volumes
°C	degrees centigrade
CDI	Capacitive deionization
CLWA	Castaic Lake Water Agency
COD	chemical oxygen demand
CRWQCB	California Regional Water Quality Control Board
DBP	disinfection byproduct(s)
DHS	(California) Department of Health Services
DOE	US Department of Energy
DOGGR	(California) Division of Oil, Gas, and Geothermal Resources
DS	dry solids
DWR	(California) Department of Water Resources
EDR	Electrodialysis Reversal Process
EPA	US Environmental Protection Agency
EPRI	Electric Power Research Institute
°F	degree Fahrenheit
GAC	Granulated Activated Carbon
GAC-FBR	granular activated carbon-fluidized bed reactors
gpd	gallons per day
gpm	gallons per minute
gpm/ft^2	gallons per minute per square foot
gpm/ft^3	gallons per minute per cubic foot
GRI	Gas Research Institute
HAA	haloacetic acids

HP	high pressure
HPC	heterotrophic plate counts
JMM	James M. Montgomery, Consulting Engineers
K/J	Kennedy/Jenks Consultants
kWh/AF	kilowatt hour per acre foot
LACSD	Los Angeles County Sanitation District
LLNL	Lawrence Livermore National Laboratory
m^2/g	square meter per gram
m^3/d	cubic meter per day
mcf	millions of standard cubic feet
MCL	maximum contaminant level
MED	multiple effect distillation
meq	milliequivalents
mgd	million gallons per day
mg/L	milligrams per liter
mg B/L	milligram boron per liter
mL	milliliter
mm	millimeter
mmhos/cm	milli mhos/centimeter
MSF (Process)	multi-stage flash distillation
MVC	mechanical vapor compression
MWD	Metropolitan Water District of Southern California
NF	nanofiltration
nm	nanometer
NPDES	National Permit Discharge Elimination System
NTU	nepholometric turbidity unit
NWRI	National Water Research Institute
O&M	Operations and Maintenance
pCi/l	picocuries per liter
ppm	parts per million
POTW	publicly owned treatment works
psi	pounds per square inch
psid	pounds per square inch difference
psig	pounds per square inch gauge
R&D	Research and Development
RCRA	resources conservation
RWQCBLA	Regional Water Quality Control Board Los Angeles Region
RO	reverse osmosis
RO/IX	reverse osmosis/ion exchange reject
rpm	revolutions per minute

SAR	sodium absorption ratio
SCAQMD	(California) South Coast Air Quality Management District
SDI	Silt Density Index
SDWA	Safe Drinking Water Act
SWP	(California) State Water Project
TCE	trichloroethelyene
TDS	total dissolved solids
THM	trihalomethanes
TOC	total organic compound
TSS	total suspended solids
UFRV	unit filter volume
µg/L	microgram per liter
U.S.	United States
USGS	United States Geologic Survey
UV	Ultraviolet
VC	vapor compression
VOA	volatile organic analysis
WSF	walnut shell filter

Appendix A and B and C

A: Bench Scale Work Plan

B: Pilot Plant Data

C: Technology Transfer Activities

FINAL TECHNICAL REPORT

Cooperative Agreement Number: DE-FC22-95MT95008
DEVELOPING A COST EFFECTIVE ENVIRONMENTAL SOLUTION FOR
PRODUCED WATER AND CREATING A "NEW" WATER RESOURCE

ARCO WESTERN ENERGY

KENNEDY/JENKS CONSULTANTS, INC.

Appendix A

Bench Scale Work Plan

APPENDIX A

BENCH SCALE WORK PLAN

Goals

1) What combination of chemical additions and dosages removes the highest amount of silica, organics, and borate.

2) How does the performance of hot-lime processes compare with warm-lime processes in terms of silica and organics removal.

Testing Procedure

Jar tests will be performed to measure softening efficiency at variety of chemical combinations, varying dosages of lime, iron, and magnesium. Most test will be performed at warm temperatures of approximately 150 °F. Comparisons between silica, organics, and borate removal in warm lime and hot lime processes will be made by reviewing literature about hot lime.

Source Water Transport and Storage

Sample water from the Placerita site will be sent to the Kennedy/Jenks laboratory in San Francisco. The produced water was sent in sealed 5-gallon plastic containers. Samples will be drawn before shipment and analyzed for pH, temperature, alkalinity, iron, boron, total hardness, calcium, and silica concentration.

The produced water will be stored in 5 gallon containers at room temperature.

Chemicals Used

The following reagent grade chemicals will be used:

- Lime ($Ca(OH)_2$)
- Sodium Hydroxide ($NaOH$)
- Magnesium chloride ($MgCl_2$) 6-Hydrate
- Ferric chloride ($FeCl_3$) 6-Hydrate

Stock Solutions

Stock solutions will be prepared for reagent grade caustic soda (100 mg/mL), lime (100 mg/ml), magnesium chloride (100 mg/mL), and ferric chloride (100 mg/mL). A lime slurry will be maintained by constantly agitating with a magnetic stirrer.

Jar Test Procedure

Five standard square plastic jars with volumes of 2 L each will be used with a standard jar tester (Phipps and Bird). The jars will be placed in a water bath to regulate the temperature of their contents, with the water bath temperature regulated by coil-immersion heaters and hotplates.

Rotors will be operated at 150 rpm prior to chemical addition. Chemicals will be added at the hub of axis of the rotor with pipettes or syringes. A timer will be set to time = 0 when half of the base has been applied. At two minutes past the final chemical addition, the rotors will be operated at 20 rpm for 20 minutes, and then turned off to allow quiescent settling for 30 minutes. The following timeline summarizes the jar test procedure:

t = 0 min.	Mid-point of chemical addition, rotors at 150 rpm for rapid mixing
t = 60 sec.	rotors to 20 rpm for flocculation
t = 20 min.	rotors turned off for quiescent settling
t = 50 min	500 mL sample drawn at 5 cm below surface, filter though 541 Whitman paper

After the conclusion of an experiment, the contents of the jars will be disposed of down the drain.

Chemical Dosages for Screening tests

Lime	400 - 1200 ppm (will depend on titrations)
NaOH	400 - 1200 ppm (will depend on titrations)
Soda Ash	(depends on hardness and alkalinity relationship and softening goal)
Magnesium	0 - 4X influent silica on molar basis
Iron	0 - 4X influent silica on molar basis

Optimization

Promising combinations of lime, soda ash and magnesium or iron will be further tested in the optimization phase. Similar experiments, will be performed with finer variations in pH and magnesium dosages. Approximately 10 days, resulting in 50 combinations of chemicals with duplicates, will be used to determine target dosages for pilot-scale tests.

Sample Collection

For each 5-gallon jar of produced water, one 1000 mL sample will be drawn to analyze as initial condition of the produced water.

Measurements of pH, and temperature will be taken for each batch before chemical addition, and for each jar after chemical addition and rapid mixing, and after settling. Measurements will be recorded on pre-printed laboratory sheets that will also contain the chemical dosages applied and samples removed.

After settling, a 600 mL portion of supernatant from each jar will be removed and filtered through Whatman 541 filter paper into a flask. A 50 mL portion will be immediately withdrawn from the flask to measure alkalinity. The remaining sample was stored and allowed to cool to room temperature for subsequent analysis of silica, calcium, hardness, COD and boron. Sample bottles will be covered, and no preservative will be used.

Table A-1

Summary of Analytical Parameter and Sample Volumes

Parameter	Analysis	Volume (mL)
Hardness	Titration	50
Alkalinity	Titration	50
Turbidity	Colormetric	25
Calcium	Titration	50
Silica	Colormetric	5
COD	Digestion and Colormetric	5
Boron	Colormetric	5
TOC	Infared Absorption	125
Oil and Grease		250

Additional Analytical Testing for Optimization

During the optimization stage of the experiment, additional tests will be performed to evaluate the removal of TOC and heavy metals. Samples for TOC analysis will be collected in 125 mL glass bottles with teflon-lined screw top cap and sent to Castaic Lake Water Agency for analysis. They will be preserved with 5 mL of 1+1 hydrochloric acid.

Appendix B

Pilot Plant Data

1. Raw Water
2. Walnut Shell Filter
3. DensaDeg
    a. Reactor Outlet
    b. Sludge
    c. Effluent
    d. Lab and Operational Data for DensaDeg Sludge
4. Heat Exchanger Effluent
5. Trickling Filter
6. Ion Exchange Effluent
7. RO Pump and Flow Data
8. Gavimetric Oil and Grease Analyses
9. VOA, BNA, BOD, and COD Analyses
10. Waste Caustic

		Field Data									CLWA lab Data																	
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)	pH	Temp (°F)	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC (mg/L)	NH3 (mg/L as NH3)	TSS	TDS	Cl	SO4	Br
							(mg/L as CaCO3)						(mg/L as Ion)											(mg/L)		(mg/L as Ion)		
5/14/97	10:30	6.53	152.6				479	1038	630.5	208																		
5/21/97	12:30						441.8	1085	680	193																		
6/3/97	10:00	6.74						1068	642	203																		
6/3/97	18:20	6.76	140.0	16			430	1096	620	202																		
6/4/97	12:00	7.12	95.0	32			494	956	524	206																		
6/4/97	15:00	7.02	131.0	33			502	1084	648	206			16	0.07	120	260	110											
6/5/97	10:00	6.74	141.3	20			482	1100	638	176			15	0.39	110	260	97											
6/5/97	17:15	6.88	84.2				494	1108	396	160			16	0.16	110	240	120											
6/6/97	10:00	6.83	86.0	27			536	1156	612	168																		
6/6/97	12:15	6.86	86.0	17			536	1156	612	168			15	0.07	110	260	100											
6/12/97	9:45	6.76	100.4				482	1168	786	170			17	0.11	108	306	100			1.5	11.66							
6/13/97	10:30	6.89	84.2	18			476	1132	778	187			17	0.1	116	323	107			1.4	9.65							
6/13/97	16:40	6.66	104.0				454						18	0.39	102	287	91			1.7	10.6							
6/20/97	9:00	6.74	82.4				500	1077	696	183			19	0.1	105	230	97			1.6	9.39							
6/25/97	11:30												17	3.96	60	129	52			1.2	8.37							
6/25/97	16:00												19	4.54	93	208	82			1.4	10.25							
7/1/97	16:00	6.68					484	1064	618	122			17.9	0.097	112	5	90			1.27	14.3	82						
7/1/97	17:00	7.42					494	1104	690	194			16.2	0.12	108	526	87			1.24	16							
7/1/97	18:30	7.28					476	1008	562	180			13.9	0.27	110	272	91			1.1	11.1							
7/3/97	11:00	7.05					416	996	662	177			18.2	0.47	106	250	73			1.23	10							
7/3/97	16:30	7.13					424	912	592	185			19.8	0.14	114	430	79			1.32	12							
7/8/97	16:00			3																								
7/9/97	10:15	6.8					412	1044	632	166																		
7/9/97	12:30			3																								
7/9/97	13:15	6.78					428	1072	686																			
7/10/97	6:00	7.29					430	1052	650	161																		
7/14/97	17:30	6.58		3	8700		420	1104	676	181			17.9	0.51	125	205	96	75	1650	1.1	0.008			42		3180	82	
7/15/97	4:40	6.71					434	1084	718	185																		
7/15/97	5:00			5																								
7/15/97	11:00			3																								
7/15/97	17:00	6.64		2			426	1076	672	182																3170	71	
7/21/97	17:30	6.48	128.8	24		2.157	348	1016	670	179			17	0.37	117	218	80.2					135	7					
7/22/97	11:00	6.65	103.0			2.101	429	1072	694	176																		
7/22/97	18:30	6.67			8800	2.334	492	1020	694	179																		
7/23/97	7:30																					91						
7/23/97	18:00	6.5	70.9		8670	2.128	452	1192	792				17.2	0.108									8					
7/24/97	6:45	6.84			9000	2.552	438	1024	672	161			16.5	0.472	113							90	7		5546			
7/24/97	19:00	6.64		27	7800	2.358	456	1048	726	198												178	5.6					
7/25/97	7:45	6.78	75.9		10000	2.011	442	1052	688	148			16.7	0.162	119							149	5.6					
7/28/97	8:00	6.79	71.1	25	9300	2.15	500	1520	656				17.3	0.487	118							141	6					
7/28/97	17:00	6.71	68.9	0	8960	2.101	440	1320	720													138						
7/29/97	7:00	6.64	69.6	27	9600	2.027	452	1090	736				15.8	0.101	117							89	5					
7/30/97	7:30	6.63	68.6	33	9700	2.075	404	1168	730	174			16.2	0.146	135							116	5.5					
7/30/97	18:00	6.63	71.0		9600	2.312	276	1400	764				14.1	0.269	122							123						

		Field Data									CLWA lab Data																	
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)	pH	Temp	B	Fe	SI	Ca	Mg	K	Na	Ba	Sr	TOC	NH3 (mg/L as NH3)	TSS	TDS	Cl	SO4	Br
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)					(°F)	(mg/L as Ion)									(mg/L)		(mg/L)		(mg/L as Ion)		
7/31/97	8:00	6.58	69.1	29	10100	1.936	438	1340	644	165			14.3	0.457	121							118	3.2					
7/31/97	18:00	6.66	68.5		9800	2.088	474	1364	748	138			16.3	0.465	122	203	106	80.5	1674	0.98	10.3	131	5.4			3120	73	
8/1/97	10:00	6.56	70.2	30	10300	2.051	390	1344	642	56			16.6	0.37	114	274	99.7	74.1	1499			111	5.7					
8/4/97	10:00	6.57	77.1		8100	2.408	454	1184	642	179	6.69	68.2	15.2	0.806	123	267	103	73.2	1655			88	6.9					
8/6/97	4:45		154.5		10400																							
8/6/97	10:00	6.63	75.1	22	10000	2.197	458	1076	656	180	6.74	68.7	15.2	0.623	119	273	100	71	1631			132	5.2					
8/6/97	15:30		143.0																									
8/6/97	16:00	6.72	72.3	8	9800	2.613	420	1148	734	190	6.73	66.6	16	1.12	131	243	97.1	79.3	1653	1.09	11.5	112	5.5			3084	84	
8/7/97	4:45		167.7																									
8/7/97	8:30		171.7																									
8/7/97	10:00	6.54	73.4	22	9900	2.571	452	1140	776	205	6.71	67.6	14.1	1.13	129	230	88.8	80	1597			140	4.9					
8/7/97	10:00		171.7																									
8/7/97	17:00	6.59	71.9		9600	2.436	468	1150	704		6.75	67.5	16.8	1.82	123	252	84.8	74.3	1560	1.07	12.2	128	4.8			3073	96	
8/8/97	4:45		170.5																									
8/8/97	8:00	6.56	68.0	26	9500	2.28	444	1140	716		6.74	67.8	14.9	1.1	134	240	94.8	80.4	1668			123	5.4					
8/8/97	9:15		168.1																									
8/8/97	10:30		164.3																									
8/8/97	17:00	6.56	70.4		9800	2.571	524	1160	740		6.84	72.3	17.5	0.59	124	230	94.7	75.1	1629	1.11	13.9	118	12			3169	92	
8/11/97	6:30		165.3		9500																							
8/11/97	10:00	6.49	72.0	18	9700	2.28	424	1210	776		7.12	72.3	17.6	6.59		280	89.7	90.3	1540			126	12.2					
8/11/97	11:30		168.0		9500																							
8/11/97	14:30		151.8																									
8/11/97	16:30	6.47	69.8	5	9700	2.312	624	1140	716													87				3034	83	
8/12/97	4:30	6.53	161.0		9600																							
8/12/97	8:30	6.57	71.3	18	9230	2.135	476	1140	700		6.71	72.3	15.3	1.38	114	223	82.1	66.7	1500			93	11.2					
8/12/97	9:30	6.54	161.6		9600																							
8/12/97	12:00	6.44	161.5		9960																							
8/12/97	13:30	6.45	150.3		10600																							
8/12/97	14:30	6.5	154.4		10500																							
8/12/97	16:30	6.55	68.5	4	8700	2.29	532	1280	768		6.92	72.1	16.5	1.35	119	224	85	70	1560			84	11.8					
8/12/97	19:00	6.5	148.7		10000																							
8/13/97	4:30	6.41	166.6		9900																							
8/13/97	11:00	6.48	164.3		9500																							
8/13/97	12:00	6.56	163.7		9600																							
8/13/97	13:00	6.46	162.7		9600																							
8/13/97	14:30	6.48	166.5		9700																							
8/13/97	15:30	6.42	169.4		9500																							
8/13/97	16:00	6.58	69.9	4	9400	2.466	460	1490	768		6.84	72.1	16.7	1.59	121	246	88.2	74.2	1487			85	12.3					
8/13/97	19:00	6.45	168.4		9600																							
8/14/97	4:30	6.4	158.4		8520																							
8/14/97	8:30	6.4	161.6		9300																							
8/14/97	10:00	6.51	68.8	2	9500	2.408	340	1210	732		6.83	72.3	15.4	0.88	126	228	91	74.7	1602			90	12.6					
8/14/97	12:00	6.4	167.7		9500																							
8/14/97	14:00	6.34	165.2		10000																							

for Raw Water

		Field Data									CLWA lab Data																	
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)	pH	Temp (°F)	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC (mg/L)	NH3 (mg/L as NH3)	TSS	TDS	Cl	SO4	Br
							(mg/L as CaCO3)						(mg/L as Ion)											(mg/L)		(mg/L as Ion)		
8/14/97	16:00	6.42	166.8		9900																							
8/14/97	17:00	6.39	69.8	3	9180	2.334	484	950	908	202	6.66	71.6	16.5	1.35	118	244	93.2	71.1	1565			70	11.6					
8/14/97	18:15		170.2		9900																							
8/15/97	4:30	6.32	165.7		10300																							
8/15/97	9:30	6.35	159.9		10100																							
8/15/97	10:00	6.51	73.4	14	8950	2.214	452	1150	732	181	6.61	72.5	16.2	1.59	115	218	91.3	69.3	1532			70	12					
8/15/97	11:45	6.42	165.7		10300																							
8/15/97	13:45	6.44	169.2		10300																							
8/15/97	15:45	6.4	168.2		10200																							
8/15/97	16:30	6.52	71.6	4	9280	2.436	300	1250	1196	188	7.15	72.1	17	1.63	117	236	93.3	71.4	1510			89	12.9					
8/15/97	18:15	6.41	169.5		10100																							
8/18/97	7:00	6.56	167.1		10000																							
8/18/97	10:15	6.44	167.9		9300																							
8/18/97	12:15	6.38	170.6		9400																							
8/18/97	14:00	6.54	161.7		9200																							
8/18/97	16:00	6.58	70.9	5	9010	2.555	476	1470	856	206			16.5	1.89	123	259	91.5	75.8	1488			80	12.6					
8/18/97	16:15	6.66	167.3		9300																							
8/18/97	18:15	6.66	164.1		10000																							
8/19/97	5:00	6.55	164.0		10000																							
8/19/97	8:15	6.5	167.4		10300																							
8/19/97	10:00	6.56	70.2	7	9120	2.301	468	860	768	260			17.6	1.5	126	216	87	83.1	1596			77	13.2					
8/19/97	11:30	6.69	165.3		10500																							
8/19/97	13:30	6.6	166.1		10500																							
8/19/97	15:15	6.65	168.8		10400																							
8/19/97	16:00	6.82	71.9	5	9210	2.382	564	1130	848	89	6.74	72.3	14.8	1.88	124	260	96	76	1490			85	11.4					
8/19/97	18:00	6.61	170.0		10500																							
8/20/97	4:30	6.39	170.9		10800																							
8/20/97	8:30	6.39	164.1		10400																							
8/20/97	9:00	6.62	70.6	6	9020	2.29	460	1160	792	111	6.96	71.2	15.7	1.07	126	217	87	83	1600			91	10.3					
8/20/97	10:30	6.6	171.1		10600																							
8/20/97	12:30	6.62	173.1		10500																							
8/20/97	14:15	6.67	173.0		10700																							
8/20/97	17:30	6.65																										
8/20/97	18:00	6.61	71.6	7	8810	2.436	504	1230	696	218	6.85	72.5	16.3	1.28	132	250	98.2	86.8	1642			82	11.8					
8/20/97	19:00	6.62	175.2		10700																							
8/21/97	5:00	6.36	168.7		10900																							
8/21/97	6:30	6.38			10400																							
8/21/97	9:15	6.25	160.5		10500																							
8/21/97	9:45	6.45	69.8	6	9140	2.498	448	1260	796	212	6.95	72.5	16.3	0.49	122	230	89.7	78.5	1591			93	11.2					
8/21/97	11:15	6.51	172.8		10600																							
8/21/97	15:30	6.66	175.1		10700																							
8/21/97	17:00	6.5	73.0	5	9300	2.382	436	1520	920	254	7.43	71.2	16.7	0.94	124	252	96.5	82.4	1532			95	10.8					
8/21/97	19:15	6.62	79.0		10500																							
8/22/97	4:30	6.45	78.0		10400																							

Date	Time	Field Data									CLWA lab Data																	
		pH	Temp (°F)	Turb (NTU)	Cond (μmho)	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)	pH	Temp (°F)	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC (mg/L)	NH3 (mg/L as NH3)	TSS	TDS	Cl	SO4	Br
							(mg/L as CaCO3)						(mg/L as Ion)											(mg/L)		(mg/L as Ion)		
8/22/97	8:00	6.41	72.0		10400																							
8/22/97	9:00	6.57	73.4	22	8740	2.346	520	1290	788	225	7.99	71.2	16.5	0.37	140	220	96	88.7	1686			107	10.4					
8/22/97	13:00	6.43	74.0		10700																							
8/22/97	15:00	6.84	76.0		10700																							
8/22/97	16:30	6.48	73.2	26	10000	2.571	428	1210	812	218	7.9	71.6	17.4	0.88	124	252	96.5	82.4	1532			105	10.7					
8/22/97	16:45	6.92			10500																							
8/25/97	10:30	6.72	74.3	20	9040	2.346	464	1190	824	217	6.92	71.4	18.4	0.53	140	220	96	88.7	1686			99	10.3					
8/25/97	10:45	6.71	177.8		10200																							
8/25/97	12:45	6.48	177.8		10300																							
8/25/97	14:30	6.45	178.7		10500																							
8/25/97	16:30	6.52			10500																							
8/25/97	17:45	6.68	76.1	17	8670	2.29	516	1110	680	256	6.81	71.6	16.5	0.78	128	211	85.5	82.1	1624			111	9.4					
8/26/97	4:30	7.27	147.2		10400																							
8/26/97	10:15	6.75	176.0		10800																							
8/26/97	11:00	6.61	74.3	17	9020	2.552	472	1170	776	263	6.77	71.6	17.6	1.07	127	241	87.4	80.5	1542			123	11.1					
8/26/97	14:15	6.87	176.0		10500																							
8/26/97	16:15	6.91	176.0		10900																							
8/26/97	17:00	6.87	72.5	22	9180	2.683	464	1640	756	242	6.89	71.6	18.2	0.65	136	245	92.3	85.5	1639	1.1	12.8	105	11.2			3143	111	14
8/27/97	4:30	6.93	161.6		10900																							
8/27/97	8:00	6.6	167.0		10700																							
8/27/97	9:30	6.65	71.6	22	9210	2.382	436	1550	772	136	6.88	71.6	15.6	0.48	130	270	92.1	83.2	1584			107	10.7					
8/27/97	10:30	6.72	176.0		11000																							
8/27/97	12:45	6.77	176.9		11000																							
8/27/97	14:45	6.72	174.2		10600																							
8/27/97	15:45	6.57	71.6	17	9120	2.334	444	1280	812	518	6.89	71.8	16.6	0.53	142	260	94.5	78.4	1613			101	10.7					
8/28/97	6:30	6.75	163.4		10400																							
8/28/97	9:30	6.76	166.1		10400																							
8/28/97	11:30	6.46	71.6	19	8790	2.251	512	1180	792	242	6.74	71.6	16.4	0.23	129	233	91.4	77.06	1673			133	10.3					
8/28/97	11:45	6.78	167.0		10500																							
8/28/97	14:00	6.68	172.4		10800																							
8/28/97	16:00	6.78	174.2		10800																							
8/28/97	18:00	6.74	165.2		10800																							
8/28/97	19:00	6.39	71.6	18	10170	2.533	432	1070	776	234	6.69	72										107	11.8					
8/29/97	5:00	6.83	167.9																									
8/29/97	9:30	6.49	167.0																									
8/29/97	10:00	6.5	72.5	12	8980	2.346	460	1170	780	500	6.94	72.1			152	260	95.5	82.02	1633				12.4					
8/29/97	11:45	6.55	170.6		10600																							
8/29/97	14:00	6.29	170.6		10500																							
8/29/97	16:00	6.4	170.6		10600																							
8/29/97	16:00	6.55	77.0	21	8810	2.358	468	1240	836	462	6.9	53.6	16.7	0.67	116	202	87.7	68.41	1509	1.19	16.4	161	12.7			3557	138	15

Operational Data
for Raw Water

Date	Time	Meter Flow (gpm)	Volumetric Flow	Suction Side Pressure	Discharge Pressure	Date	Time	Volumetric Flow	Suction Side Pressure	Discharge Pressure
7/15/97	4:45	39.7		5	13	7/25/97	8:30		7	12
7/15/97	7:00			5	13	7/25/97	8:45	26.7		
7/15/97	7:30	39.8				7/25/97	10:30		7	12
7/15/97	8:15			5	13	7/25/97	10:45	27.3		
7/15/97	9:30	41		5	13	7/28/97	5:00		6.5	12
						7/28/97	5:45	28.38		
7/16/97	5:00	38.5				7/28/97	9:30		7	12
7/16/97	5:15		43.6			7/28/97	10:00	27.1		
7/16/97	6:30	37.8				7/28/97	11:30		7	12
7/16/97	6:45		43.6	5	13	7/29/97	4:45		6.5	12
7/16/97	8:15	37.7				7/29/97	5:30	27.98		
7/16/97	8:30		43.6			7/29/97	8:00		6.5	12
7/17/97	5:00	39.5		4	13	7/29/97	8:15	27.65		
7/17/97	7:30			5	13	7/29/97	10:30		6.5	12
7/17/97	8:30	40.7	40.5			7/29/97	10:45	27.6		
7/17/97	9:00			5	13	7/30/97	4:30		5	12
7/17/97	10:00			5	13	7/30/97	5:00	27.23		
7/17/97	10:30	39.1	38.03			7/30/97	6:30		5	12
7/18/97	4:30		38.03	5	13	7/30/97	9:00		5	12
7/18/97	4:30	40.5				7/30/97	9:15	27.57		
7/18/97	6:00			5	13	7/30/97	11:00	27.41		
7/18/97	7:30			5	13	7/31/97	4:30		5	12
7/18/97	8:00	34.4	42.9	5	13	7/31/97	5:00	26.1		
7/18/97	9:00			5	13	7/31/97	8:45		5	12
7/21/97	12:30			5.5	13	7/31/97	9:30	26.99		
7/21/97	13:00	36.1				7/31/97	12:30		5	12
7/21/97	13:15		43.1			8/1/97	4:30		5	12
7/21/97	16:30	42.7		5.5	13	8/4/97	6:00		5	12
7/22/97	10:30	42.8		5.5	13.5	8/4/97	8:00		5	12
7/22/97	14:00	43.5		5	13.5	8/4/97	9:30	27.9		
7/23/97	4:45			4	13.5	8/4/97	11:45	27.99		
7/23/97	5:00	42.8				8/4/97	12:00		5	12
7/23/97	5:10		42.38			8/5/97	5:00		4.5	12
7/23/97	9:00	37.8		4	13.5	8/5/97	7:00	28.5		
7/23/97	10:00		41.41			8/5/97	10:00		4.5	12
7/23/97	11:00			5	13	8/6/97	5:00		6	11
7/23/97	12:00		32.4			8/6/97	5:30	20.28		
7/23/97	13:00			6	13	8/6/97	8:15		5	12
7/24/97	5:00			7.5	25	8/6/97	8:30	25.1		
7/24/97	6:00		26.7			8/7/97	5:00		5	12
7/24/97	8:30			7.5	25	8/7/97	6:00	23.56		
7/24/97	9:00		26.9			8/7/97	8:00	27.48		
7/24/97	10:30			7.5	25	8/7/97	9:45		4	12
7/25/97	5:00			7	12	8/8/97	4:45		4	12
7/25/97	5:30		27.9			8/8/97	6:00	27.15		

Operational Data
for Raw Water

Date	Time	Meter Flow (gpm)	Volumetric Flow	Suction Side Pressure	Discharge Pressure
8/8/97	6:30			4	12
8/8/97	9:15			4	12
8/11/97	4:30			3.5	12
8/11/97	5:00		28.03		
8/11/97	11:00			4	12
8/11/97	14:20			4	12
8/11/97	15:30		27.33		
8/12/97	4:30			4.5	57
8/12/97	5:00		24.93		
8/12/97	6:00		28.18	4.5	57
8/12/97	6:30		27.58		
8/12/97	9:00			4.5	57
8/12/97	11:00		25.6		
8/12/97	12:45			4.5	55
8/13/97	4:30			5	57
8/13/97	5:30		28.03		
8/13/97	13:30			4	57
8/13/97	14:45			4	57
8/13/97	19:00			4	55
8/14/97	4:30			4	56
8/14/97	5:00		27.63		
8/14/97	8:30			3.5	55
8/14/97	9:00		27.67		
8/14/97	11:00			3.5	55
8/14/97	13:15			3.3	55
8/15/97	4:30			3	55
8/15/97	5:00		26.5		
8/15/97	9:30			3	55
8/15/97	13:00			3	54
8/15/97	15:00			3	54
8/18/97	6:30			3	54
8/18/97	7:00		27.24		
8/18/97	10:15			3	54
8/18/97	13:00			3	54
8/18/97	13:40		26.99		
8/18/97	20:00			3	54
8/19/97	4:30			3	54
8/19/97	6:00		27.58		
8/19/97	11:00			3	54
8/19/97	14:00			3	54
8/19/97	14:30		27.2		
8/19/97	18:30			3	54
8/20/97	4:30			3	54
8/20/97	8:30			3	54
8/20/97	12:00			3	34
8/20/97	16:00		24.3		
8/20/97	17:30		16.7		
8/20/97	19:30			5.5	60
8/21/97	5:20			5	60
8/21/97	5:30		17.28		
8/21/97	6:30		21.6		
8/21/97	7:30		20.9		
8/21/97	9:00			5	60
8/21/97	13:45			5	58
8/21/97	19:15			5	58
8/22/97	5:00		20.6	5	60
8/22/97	8:00			5	60
8/22/97	12:00		25.45		
8/22/97	12:30		17.3		
8/22/97	12:45		20.28		
8/22/97	13:30			30	84
8/22/97	14:30			30	84
8/22/97	18:00			30	85
8/25/97	5:30			30	84
8/25/97	7:00		21.36		
8/25/97	11:45			30	84
8/25/97	16:00			30	84
8/25/97	19:00			30	84
8/26/97	4:30			30	84
8/26/97	5:00		21.14		
8/26/97	8:30			30	84
8/26/97	14:30			30	84
8/26/97	15:45		19.01		
8/26/97	19:15			30	84
8/27/97	4:30			30	84
8/27/97	5:30		19.44		
8/27/97	7:30			30	84
8/27/97	18:00			30	84
8/28/97	4:30			30	84
8/28/97	6:30		17.08		
8/28/97	10:30			30	84
8/28/97	11:30		14.41		
8/28/97	16:00			30	84
8/28/97	20:00			30	84
8/29/97	4:45			30	86
8/29/97	6:30		14.18		
8/29/97	9:30			30	86
8/29/97	10:00			30	84
8/29/97	11:15		20.37	30	86

Walnut Shell Filter, 107.5 gpm
Pressure and Turbidity Results for Test #1

					Pressure Readings (psi)			Turbidity (NTU)		
Date	Time	Cum. Time (hrs)	Meter Flow (gpm)	Cum. Volume (gal)	Inlet	Outlet	Delta P	Inlet	Outlet	Removal
5/6/97	5:03 PM							5.0	5.6	-12% *
5/6/97	5:18 PM	0.25	106.7	624,717	27	23	4	3.5	3.0	14% *
5/6/97	5:33 PM	0.50	106.2	625,833	27	23	4	4.5	4.0	11% *
5/6/97	5:48 PM	0.75	105.1	627,432	27	23	4	4.5	4.9	-9% *
5/6/97	6:03 PM	1.00	104.9	629,041	27	23	4	5.3	4.5	15% *
5/6/97	6:18 PM	1.25	105.2	630,792	27	23	4	5.5	4.5	18% *
5/6/97	6:33 PM	1.50						9.0	5.2	42% *
5/6/97	6:48 PM	1.75						3.7	18.0	-386% *
5/6/97	7:03 PM	2.00	104.5	635,477	27	23	4	3.5	10.0	-186% *
5/6/97	7:18 PM	2.25						4.5	7.3	-62% *
5/6/97	7:33 PM	2.50						4.5	9.0	-100% *
5/6/97	7:48 PM	2.75						4.6	7.7	-67% *
5/6/97	8:03 PM	3.00	104.9				5	3.9	2.3	41% *
5/6/97	8:18 PM	3.25						3.3	4.2	-27% *
5/6/97	8:33 PM	3.50						3.7	2.6	30%
5/6/97	8:48 PM	3.75						3.3	1.2	64%
5/6/97	9:03 PM	4.00					5	3.2	1.2	63%
5/6/97	10:03 PM	5.00					6	3.7	2.3	38%
5/6/97	11:03 PM	6.00					6	4.2	1.8	57%
5/7/97	12:03 AM	7.00					7	5.0	2.6	48%
5/7/97	3:03 AM	10.00					7	3.7	2.1	43%
5/7/97	4:33 AM	11.50					9			
5/7/97	6:03 AM	13.00					10	5.3	4.5	15%
5/7/97	7:50 AM	14.78					11	3.7	1.2	68%
5/7/97	9:03 AM	16.00					13	3.3	1.4	58%
5/7/97	12:03 PM	19.00					13	3.2	1.0	69%
5/7/97	2:03 PM	21.00					14	3.0	0.9	70%
5/7/97	5:03 PM	24.00								

* Sampling lines not adequately flushed.

	Delta P	Inlet	Outlet	Removal
Min	4	3	0.9	15%
Median	6	3.8	3.5	57%
Average	7.2	4.3	4.3	29%
Max	14	9	18	70%

Walnut Shell Filter, 107.5 gpm
Oil and Grease Spec 20 Results for Test #1

Date	Time	Cum. Hours	Conc. (ppm) Eff	Conc. (ppm) Infl.	Removal
5/6/97	4:00 PM	0.00	7.5	17.1	56%
5/6/97	5:03 PM	1.05	13.9	19.4	29%
5/6/97	5:18 PM	1.30	14.0	18.0	22%
5/6/97	5:33 PM	1.55	12.9	16.4	21%
5/6/97	5:48 PM	1.80	7.9	15.8	50%
5/6/97	6:03 PM	2.05	8.6	13.6	36%
5/6/97	7:03 PM	3.05	10.6	11.4	7%
5/6/97	8:03 PM	4.05	8.4	22.7	63%
5/6/97	9:03 PM	5.05	9.6	12.8	26%
5/6/97	10:03 PM	6.05	9.9	13.6	27%
5/6/97	11:03 PM	7.05	7.6	17.8	57%
5/7/97	12:03 AM	8.05	10.2	13.6	25%
5/7/97	1:50 AM	9.83	10.4	16.4	36%
5/7/97	3:03 AM	11.05	9.9	10.7	7%
5/7/97	6:03 AM	14.05	10.6	17.2	38%
5/7/97	9:03 AM	17.05	10.2	17.3	41%
5/7/97	12:03 PM	20.05	9.2	17.8	48%
Min			7.5	10.7	7%
Median			9.9	16.4	36%
Average			10.1	16.0	35%
Max			14.0	22.7	63%

Walnut Shell Filter, 87.5 gpm
Pressure and Turbidity Results for Test #2

							Pressure (psi)				Turbidity (NTU)		
Date	Time	Cum. Time (hrs)	Meter Flow (gpm)	Cum. Volume (gal)	Time of Vol. Reading	Calculated Flow (gpm)	Inlet	Outlet	Delta P	Notes	Inlet	Outlet	Removal
5/7/97	5:00 PM	0.00	87.3	0	5:00 PM	87.30	38	36	2		5.5	17.0	
5/7/97	5:15 PM	0.25	88.0	1,282	5:15 PM	85.47	39	36	3		6.3	1.0	84%
5/7/97	5:30 PM	0.50	87.3	2,596	5:30 PM	87.60	40	36	4		5.0	1.0	80%
5/7/97	5:45 PM	0.75	87.6	3,852	5:45 PM	83.73	40	36	4		4.3	1.2	72%
5/7/97	6:00 PM	1.00	86.5	5,219	6:00 PM	91.13	40	36	4		5.8	1.4	76%
5/7/97	6:15 PM	1.25	87.3	6,511	6:15 PM	86.13	40	36	4		4.2	1.1	74%
5/7/97	6:30 PM	1.50	87.2	7,844	6:30 PM	88.87	40	36	4		4.1	1.3	68%
5/7/97	6:45 PM	1.75	87.9	9,125	6:45 PM	85.40	40	36	4		3.6	1.1	69%
5/7/97	7:00 PM	2.00	87.6	10,449	7:00 PM	88.27	40	36	4		4.0	1.3	68%
5/7/97	8:00 PM	3.00	87.6	15,992	8:00 PM	92.38	39	35	4		4.7	1.6	66%
5/7/97	9:00 PM	4.00	86.4	21,715	9:00 PM	95.38	39	34	5		6.0	1.6	73%
5/7/97	10:00 PM	5.00	86.1	26,206	10:00 PM	74.85	36	32	4		3.5	2.3	34%
5/7/97	11:00 PM	6.00	87.4	31,621	11:00 PM	90.25	36	32	4		5.9	1.3	78%
5/8/97	12:00 AM	7.00	86.9	36,594	12:00 AM	82.88	36	32	4		5.4	1.5	72%
5/8/97	2:00 AM	9.00	87.5	46,995	2:00 AM	86.68	36	28	8	AWE			
5/8/97	3:00 AM	10.00	87.5	53,123	3:10 AM	86.99	32	25	7		2.7	1.7	37%
5/8/97	6:00 AM	13.00	87.6	69,188	6:12 AM	88.27	34	26	8		4.0	1.5	63%
5/8/97	7:30 AM	14.50	87.4	76,868	7:40 AM	87.27	35	26	9				
5/8/97	9:00 AM	16.00	87.4	85,827	9:22 AM	87.83	35	26	9		2.9	1.4	52%
5/8/97	10:30 AM	17.50	86.7	92,578	10:40 AM	86.55	36	26	10				
5/8/97	11:00 AM	18.00	87.4	94,290	11:00 AM	85.60	35	25	10				
5/8/97	12:40 PM	19.67	88.4	104,904	12:58 PM	89.95	36	26	10		3.5	1.5	57%
5/8/97	3:00 PM	22.00	88.7	117,672	3:23 PM	88.06	36	26	10		3.0	2.0	33%
5/8/97	6:00 PM	25.00	87.60	131,964	6:05 PM	88.22	37	26	11		5.9	1.5	75%
5/8/97	8:26 PM	27.43		144,246	8:26 PM	87.11	38	26	12				
5/8/97	9:00 PM	28.00	87.7	148,187	9:11 PM	87.58	37	24	13		4.6	1.5	67%
5/9/97	12:00 AM	31.00	88.2	165,666	12:28 AM	88.73	38	26	12		4.3	1.5	65%
5/9/97	4:00 AM	35.00	87.0	185,693	4:18 AM	87.07	39	26	13		2.5	1.5	40%
5/9/97	6:00 AM	37.00	87.8	195,938	6:16 AM	86.82	40	26	14		2.6	1.5	42%
5/9/97	9:00 AM	40.00	86.8	211,680	9:16 AM	87.46	39	24	15		2.7	1.2	56%
5/9/97	12:00 PM	43.00	88.2	227,554	12:18 PM	87.22	38	22	16		3.0	1.2	60%
5/9/97	3:00 PM	46.00	91.1	242,300	3:08 PM	86.74	39	28	11		5.4	1.2	78%
5/9/97	4:00 PM	47.00	87.4	247,434	4:05 PM	90.07	39	27	12				

Total average flow 87.74 gpm

	Inlet	Outlet	Removal
Min	2.5	1	33%
Median	4.2	1.5	67%
Average	4.3	2.0	63%
Max	6.3	17	84%

Walnut Shell Filter, 87.5 gpm
Oil & Grease Spec 20 Results for Test #2

			Conc. (ppm)		
Date	Time	Cum. Hours	Eff	Infl.	Removal
5/7/97	5:00 PM	0.00	11.8	19.9	40%
5/7/97	5:15 PM	0.25	11.0	17.1	36%
5/7/97	5:30 PM	0.50	11.0	16.4	33%
5/7/97	5:45 PM	0.75	10.9	20.6	47%
5/7/97	6:00 PM	1.00	9.5	17.1	45%
5/7/97	6:15 PM	1.25	10.2	15.7	35%
5/7/97	6:30 PM	1.50	10.3	18.5	44%
5/7/97	6:45 PM	1.75	10.8	20.6	48%
5/7/97	8:00 PM	3.00	9.3	15.7	40%
5/7/97	9:10 PM	4.17	8.3	17.1	51%
5/7/97	10:00 PM	5.00	10.1	20.8	52%
5/8/97	9:00 AM	16.00	9.1	14.6	38%
5/8/97	12:40 PM	19.67	6.5	11.4	43%
5/8/97	3:00 PM	22.00	18.4	*	
5/8/97	6:00 PM	25.00		*	
5/8/97	9:00 PM	28.00	10.8	*	
5/9/97	6:00 AM	37.00	11.4	*	
5/9/97	9:00 AM	40.00	8.1	*	
5/9/97	12:00 PM	43.00	8.9	*	
5/9/97	2:00 PM	45.00	6.4	10.9	41%
5/9/97	4:00 PM	47.00	6.2	12	49%

* influent values not acidified

	Eff	Infl.	Removal
Min	6.2	10.9	33%
Median	10.2	17.1	43%
Average	10.2	16.9	43%
Max	18.4	20.8	52%

Walnut Shell Filter, 87.5 gpm
Pressure and Turbidity Results for Test #3

							Pressure (psi)			Turbidity (NTU)	
Date	Time	Cum. Time (hrs)	Meter Flow (gpm)	Cum. Volume (gal)	Time of Vol. Reading	Calculated Flow (gpm)	Inlet	Outlet	Delta P	Inlet	Outlet
5/9/97	5:32 PM	0	87.5	0	5:32 PM						
5/9/97	7:45 PM	2.22	87.6	11,665	7:45 PM	87.71	38	34	4		
5/9/97	9:45 PM	4.22	87.2	22,715	9:45 PM	92.08	39	34	5		
5/9/97	11:45 PM	6.22	87.6	33,680	11:45 PM	91.37	39	33	6		
5/10/97	1:45 AM	8.22	87.4	45,568	1:45 AM	99.07	40	33	7		
5/10/97	3:45 AM	10.22	86.6	54,861	3:45 AM	77.44	39	34	5		
5/10/97	5:45 AM	12.22	87.8	63,960	5:45 AM	75.82	40	34	6		
5/10/97	10:55 AM	17.38	85.7	90,969	10:55 AM	87.13	40	30	10		
5/10/97	1:00 PM	19.47	85.5	101,414	1:00 PM	83.56	41	30	11		
5/10/97	3:00 PM	21.47	85.9	112,266	3:00 PM	90.43	39	30	9		
5/10/97	5:00 PM	23.47	87.2	123,118	5:00 PM	90.43	41	29	12		
5/10/97	7:00 PM	25.47	87.0	133,666	7:00 PM	87.90	41	28	13		
5/10/97	9:00 PM	27.47	86.1	143,315	9:00 PM	80.41	40	26	14		
5/11/97	12:00 AM	30.47	87.5	159,408	12:00 AM	89.41	40	26	14		
5/11/97	2:00 AM	32.47	87.6	169,903	2:00 AM	87.46	39	25	14		
5/11/97	4:00 AM	34.47	87.8	180,331	4:00 AM	86.90	40	24	16		
5/11/97	6:00 AM	36.47	87.5	190,775	6:00 AM	87.03	40	24	16		
5/11/97	8:00 AM	38.47	87.3	200,840	8:00 AM	83.87	40	23	17		
5/11/97	10:00 AM	40.47	87.4	212,051	10:00 AM	93.42	41	24	17		
5/11/97	12:00 PM	42.47	87.6	221,892	12:00 PM	82.01	41	24	18		
5/11/97	2:00 PM	44.47	87.2	233,329	2:00 PM	95.31	41	23	18		
5/11/97	5:00 PM	47.47	88.3	247,900	5:00 PM	80.95	41	22	19		
5/11/97	7:00 PM	49.47	87.7	258,591	7:00 PM	89.09	42	23	19		
5/11/97	9:00 PM	51.47	87.50	269,566	9:00 PM	91.46	41	21	20		
5/11/97	11:00 PM	53.47	87.6	279,790	11:00 PM	85.20	41	21	20		
5/12/97	1:00 AM	55.47	86.4	290,458	1:00 AM	88.90	41	20	21		
5/12/97	3:00 AM	57.47	87.6	301,249	3:00 AM	89.92	41	19	22		
5/12/97	5:00 AM	59.47	86.6	311,076	5:00 AM	81.89	41	18	23		
5/12/97	7:00 AM	61.47	86.4	322,942	7:00 AM	98.88	41	17	24		
5/12/97	9:00 AM	63.47	87.8	332,178	9:00 AM	76.97	41	18	24	5.2	3.5
5/12/97	11:00 AM	65.47	87.2	342,724	11:00 AM	87.88	41	18	24		
5/12/97	1:00 PM	67.47	86.3	353,406	1:00 PM	89.02	41	17	24		

Total Average flow ra 87.30
Measurements recorded by AWE staff

Walnut Shell Filter, 87.5 gpm
Oil and Grease Spec 20 Results for Test #3

Date	Time	Cum. Hours	Conc. (ppm) Eff	Conc. (ppm) Infl.	% Removal
5/9/97	5:40 PM	0.00	8.3	9.5	13%
5/12/97	9:50 AM	64.17	6.9	12.3	44%
5/12/97	12:45 PM	67.08	7.6	10.2	25%

	Eff	Infl.	% Removal
Min	6.9	9.5	13%
Median	7.6	10.9	25%
Average	7.6	10.9	27%
Max	8.3	12.3	44%

Walnut Shell Filter, 14 gpm
Pressure and Turbidity Results for Test #4

Date	Time	Cum. Time (hrs)	Meter Flow (gpm)	Cum. Volume (gal)	Time of Vol. Reading	Calculated Flow (gpm)	Pressure (psi) Inlet	Pressure (psi) Outlet	Pressure (psi) Delta P	Turbidity (NTU) Inlet	Turbidity (NTU) Outlet
5/13/97	6:30 PM	0.00	13.8	3,936	6:30 PM		25	24	1		
5/13/97	8:30 PM	2.00	13.7	5,525	8:30 PM	13.24	25	24	1		
5/13/97	10:30 PM	4.00	14.0	7,153	10:30 PM	13.57	24	24	0		
5/14/97	12:30 AM	6.00	14.2	8,999	12:30 AM	15.38	24	24	0		
5/14/97	2:30 AM	8.00	14.4	10,674	2:30 AM	13.96	25	24	1		
5/14/97	4:30 AM	10.00	14.3	12,328	4:30 AM	13.78	24	22	2		
5/14/97	9:00 AM	14.50	14.0	16,130	9:00 AM	14.08	24	23	1	2.8	1.4

Total Average Flow 18.54

Walnut Shell Filter, 14 gpm
Oil and Grease Spec 20 Results for Test #4

Date	Time	Cum.	Conc. (ppm) Eff	Conc. (ppm) Infl.	Percent Removal
5/14/97	9:00 AM	14.50	7.0	13.6	49%

Walnut Shell Filter
Cumulative Probability for All Turbidity Results

Cumulative Probability	Probit	Influent Turbidity	Effluent Turbidity	Percent Removal
97%	1.95	6.3	4.5	84%
95%	1.63	6.0	2.6	80%
92%	1.43	5.9	2.6	78%
90%	1.27	5.9	2.3	78%
87%	1.13	5.8	2.3	76%
85%	1.02	5.4	2.1	75%
82%	0.92	5.4	2.0	74%
79%	0.82	5.3	1.8	73%
77%	0.73	5	1.7	72%
74%	0.65	5.0	1.6	72%
72%	0.57	4.7	1.6	70%
69%	0.50	4.6	1.5	69%
67%	0.43	4.3	1.5	69%
64%	0.36	4.3	1.5	68%
62%	0.29	4.2	1.5	68%
59%	0.23	4.2	1.5	68%
56%	0.16	4.1	1.5	67%
54%	0.10	4.0	1.5	66%
51%	0.03	4.0	1.5	65%
49%	-0.03	3.7	1.4	64%
46%	-0.10	3.7	1.4	63%
44%	-0.16	3.7	1.4	63%
41%	-0.23	3.7	1.3	60%
38%	-0.29	3.6	1.3	58%
36%	-0.36	3.5	1.3	57%
33%	-0.43	3.5	1.2	57%
31%	-0.50	3.3	1.2	56%
28%	-0.57	3.3	1.2	52%
26%	-0.65	3.2	1.2	48%
23%	-0.73	3.2	1.2	43%
21%	-0.82	3	1.2	42%
18%	-0.92	3.0	1.2	40%
15%	-1.02	3.0	1.1	38%
13%	-1.13	2.9	1.1	37%
10%	-1.27	2.7	1	34%
8%	-1.43	2.7	1.0	33%
5%	-1.63	2.6	1.0	30%
3%	-1.95	2.5	0.9	15%

Walnut Shell Filter
Cumulative Probability for All Spectrophotometric Oil and Grease Results

Cumulative Probability	Probit	Influent Oil and Grease	Cumulative Probability	Probit	Effluent Oil and Grease
97%	1.94	22.7	98%	2.08	18.5
95%	1.62	20.8	96%	1.78	18.4
92%	1.41	20.6	94%	1.59	17.1
89%	1.25	20.6	92%	1.44	16.6
87%	1.12	19.9	91%	1.31	14.4
84%	1.00	19.4	89%	1.21	14.0
82%	0.90	18.5	87%	1.12	13.9
79%	0.80	18.0	85%	1.03	12.9
76%	0.71	17.8	83%	0.95	11.8
74%	0.63	17.8	81%	0.88	11.4
71%	0.55	17.3	79%	0.81	11.0
68%	0.48	17.2	77%	0.75	11.0
66%	0.41	17.1	75%	0.69	10.9
63%	0.33	17.1	74%	0.63	10.8
61%	0.27	17.1	72%	0.57	10.8
58%	0.20	17.1	70%	0.52	10.6
55%	0.13	16.4	68%	0.46	10.6
53%	0.07	16.4	66%	0.41	10.4
50%	0.00	16.4	64%	0.36	10.3
47%	-0.07	16.4	62%	0.31	10.2
45%	-0.13	15.8	60%	0.26	10.2
42%	-0.20	15.7	58%	0.21	10.2
39%	-0.27	15.7	57%	0.17	10.1
37%	-0.33	14.6	55%	0.12	9.9
34%	-0.41	13.6	53%	0.07	9.9
32%	-0.48	13.6	51%	0.02	9.6
29%	-0.55	13.6	49%	-0.02	9.5
26%	-0.63	13.6	47%	-0.07	9.3
24%	-0.71	12.8	45%	-0.12	9.2
21%	-0.80	12.3	43%	-0.17	9.2
18%	-0.90	12.0	42%	-0.21	9.1
16%	-1.00	11.4	40%	-0.26	9.1
13%	-1.12	11.4	38%	-0.31	8.9
11%	-1.25	10.9	36%	-0.36	8.7
8%	-1.41	10.7	34%	-0.41	8.7
5%	-1.62	10.2	32%	-0.46	8.6
3%	-1.94	9.5	30%	-0.52	8.4
			28%	-0.57	8.3
			26%	-0.63	8.3
			25%	-0.69	8.2
			23%	-0.75	8.1
			21%	-0.81	7.9
			19%	-0.88	7.8
			17%	-0.95	7.6
			15%	-1.03	7.6
			13%	-1.12	7.5
			11%	-1.21	7.4
			9%	-1.31	7.0
			8%	-1.44	6.9
			6%	-1.59	6.5
			4%	-1.78	6.4
			2%	-2.08	6.2

Walnut Shell Filter
Gravimetric Total Oil and Grease (SM 5520 B) Compared to Spec 20 Results

Date	Time	Location	Gravimetric, mg/L	Spec 20 Result, mg/L	Grav rank	Spectro rank	Grav/Spec	Grav Inf - Eff	Spec Inf - Eff
5/12/97	1:00 PM	Effluent	61.6	7.6	9	1	8.1		
5/7/97	6:15 PM	Effluent	49.8	10.2	3	2	4.9		
5/7/97	9:03 AM	Effluent	50.8	10.2	5	3	5.0	7.0	7.1
5/7/97	12:03 PM	Effluent	62.4	10.2	10	4	6.1		
5/6/97	5:48 PM	Effluent	60.9	12.9	8	5	4.7		
5/6/97	5:18 PM	Effluent	44.7	14.9	2	6	3.0		
5/7/97	5:15 PM	Influent	50	17.1	4	7	2.9		
5/7/97	6:03 AM	Influent	44.1	17.2	1	8	2.6		
5/7/97	9:03 AM	Influent	57.8	17.3	6	9	3.3		
5/6/97	5:03 PM	Influent	58.7	19.4	7	10	3.0		

Walnut Shell Filter
Results for Total Organic Carbon (SM 5310 B)

Date	Time	Conc. (ppm) Eff	 Infl.	Percent Removal
4/30/97	1:00 PM	110.0	98.0	-12%
4/30/97	4:00 PM	108.0	99	-9%
5/1/97	1:00 PM	85.0	99	14%
Min		85.0	98.0	-12%
Median		109.0	98.5	-9%
Average		109.0	98.5	-2%
Max		110.0	99.0	14%

Walnut Shell Filter
Composite Samples for Total Suspended Solids (SM 2540)

		Conc. (ppm)					
Date	Time	Eff	Infl.	Backwash	TSS Removed	BW / (Inf - Eff) *	% BW **
composite		6.0	17.0	311.0			
composite		5.0	4.0	530.0			
composite		7.0	14	590			
composite		10.0	3	730			
Average		7.0	9.5	540.3	2.5	216	0.5%

* The average TSS in the backwash water divided by the average removal across the filter

** The percentage of water required for backwash based on mass balance

Operational Data
for DensaDeg

Date	Time	NaOH Feed Rate, ml/min	NaOH Wt%	NaOH Tank Ht, in	Polymer Feed Rate, ml/min	Polymer, ml	Water, gal	Dilution Ratio (Poly:H20)	Tank Vol (gal)	MgCl2 Feed Rate, ml/min	MgCl2 Wt%	MgCl2 Tank Vol	Antiscalant Dosing Rate, ml/n
7/9/97	9:50	880	18%	30.5									
7/9/97	22:30	1070	18%										
7/10/97	4:45	1040	18%	26									
7/10/97	9:15	1080	18%										
7/11/97	4:30	1040	18%	22.5	66								
7/11/97	6:30	880	18%										
7/14/97	4:30	910	20%	8.25	95								
7/14/97	5:30	880	20%	8.25									
7/14/97	6:15	800	20%	8.25	95								
7/14/97	8:00	760	20%	8.25									
7/14/97	10:00	700	20%	8.25									
7/14/97	10:50	600	20%	8.25									
7/15/97	4:45	760	20%	83.5	87			200	50				
7/15/97	6:00									35		4000	
7/15/97	7:30	650	20%	83.5									
7/15/97	7:45									35		4000	
7/15/97	8:15	610	20%										
7/15/97	9:00	620	20%		86			200	26				
7/15/97	10:00									25		4000	
7/15/97	11:15									38		4000	
7/15/97	11:30	560	20%										
7/16/97	5:00				87			200	15				
7/16/97	5:45	680	20%	79.75									
7/16/97	6:00									35		4000	
7/16/97	6:15	820	20%										
7/16/97	7:00	680	20%										
7/16/97	8:00	620	20%		90			200	95	35		4000	
7/16/97	8:45	580	20%										
7/16/97	9:15	580	20%										
7/16/97	10:00	520	20%										
7/16/97	11:30	400	20%										
7/17/97	5:00	875	20%	70.5	85			200	70				
7/17/97	5:15									25		4000	
7/17/97	7:45	660	20%		80			200					
7/17/97	8:15	640	20%										
7/17/97	9:00	640	20%										
7/17/97	10:00				90			200					
7/17/97	10:15	610	20%							30		4000	
7/18/97	4:30	580	20%	75.25	140			200	30	35		4000	
7/18/97	6:00	580	20%										
7/18/97	7:30	580	20%		138			200	25	40		4000	
7/18/97	8:00	610	20%										
7/18/97	9:30	610	20%										
7/21/97	12:30	630	20%	74	125			300	50				
7/21/97	12:35									40		4000	
7/21/97	13:30	630	20%										
7/21/97	13:40									40		4000	

Operational Data
for DensaDeg

Date	Time	NaOH Feed Rate, ml/min	NaOH Wt%	NaOH Tank Ht, in	Polymer Feed Rate, ml/min	Polymer, ml	Water, gal	Dilution Ratio (Poly:H20)	Tank Vol (gal)	MgCl2 Feed Rate, ml/min	MgCl2 Wt%	MgCl2 Tank Vol	Antiscalant Dosing Rate, ml/n
7/21/97	16:00	605	20%										
7/22/97	10:50	310	20%	71	125			300	2.5	30		3950	
7/22/97	13:40	600	20%										
7/22/97	14:00				125			300	50	30		3950	
7/23/97	4:30	560	20%	69									
7/23/97	5:00				125			300	16	20		3950	
7/23/97	6:00	580	20%										
7/23/97	8:00	580	20%										
7/23/97	9:00	500	20%										
7/23/97	11:00	490	20%										
7/23/97	12:00				87			300	55				
7/24/97	5:00	410	20%	66.75						35		3900	
7/24/97	5:15				88			300	22				
7/24/97	8:30	380	20%		88			300	17	40		3900	
7/24/97	10:30	390	20%		88			300	15	30		3900	
7/24/97	12:30	400	20%										
7/25/97	5:00	390	20%	64	90			300	50	30		3900	
7/25/97	8:30	390	20%		88			300	47	30		3900	
7/25/97	10:30				88			300	43	30		3900	
7/25/97	10:45	390	20%										
7/28/97	5:00	425	20%	62.5	90			300	50	30		3900	
7/28/97	8:00	400	20%										
7/28/97	9:30	390	20%		90			300	45	27		3900	
7/28/97	11:30	390	20%		85			300	42	28		3900	
7/28/97	13:30	390	20%										
7/29/97	4:45	400	20%	60	259			300	76.5	30		3900	
7/29/97	8:00	400	20%							30		3900	
7/29/97	10:30	410	20%							30		3900	
7/29/97	13:30	410	20%										
7/30/97	4:30	420	20%	58	88			300	20	25		3900	
7/30/97	6:30	390	20%		88			300	18	25		3900	
7/30/97	9:00	400	20%		88			300	15	25		3900	
7/30/97	11:00	410	20%										
7/30/97	12:00				130				50				
7/31/97	4:30	390	20%	55	128	460	50	411	15	27		3850	
7/31/97	7:00	400	20%										
7/31/97	9:00	410	20%		130				8	30		3850	
7/31/97	10:15	410	20%										
7/31/97	12:30									30		3900	
8/1/97	5:00	420	20%	53	130	615	50	308	16.5	30		3850	
8/1/97	11:30				130	615	50	308	10				
8/4/97	6:00	420	20%	52	130	500	40	303	40	30		3850	
8/4/97	7:00	420	20%										
8/4/97	11:00	445	20%										
8/4/97	12:00				130				22	30		3850	
8/5/97	5:00	410	20%	49.5	38				1	30		3800	
8/5/97	8:30				43	285	30	398	30				

Operational Data
for DensaDeg

Date	Time	NaOH Feed Rate, ml/min	NaOH Wt%	NaOH Tank Ht, in	Polymer Feed Rate, ml/min	Polymer, ml	Water, gal	Dilution Ratio (Poly:H20)	Tank Vol (gal)	MgCl2 Feed Rate, ml/min	MgCl2 Wt%	MgCl2 Tank Vol	Antiscalant Dosing Rate, ml/
8/5/97	9:30	440	20%		65				29.5				
8/5/97	10:30	440	20%		85				24				
8/5/97	20:30				130	610	50	310	50				
8/6/97	5:00	460	20%	47						30		3800	
8/6/97	5:30				140	610	50	310	32				
8/6/97	7:30	430	20%										
8/6/97	8:15	410	20%										
8/6/97	11:30	400	20%		140	610	50	310	29	27		3800	
8/7/97	4:45	400	20%	45									
8/7/97	5:00				100	610	50	310	43	27		3800	
8/7/97	7:30				103	610	50	310		30		3800	
8/7/97	8:30	360	20%		115	610	50	310	29				
8/7/97	12:30				130	610	50	310					
8/7/97	13:30	430	20%		100	610	50	310					
8/7/97	14:00				115	610	50	310					
8/7/97	20:00				115	610	50	310	13				
8/8/97	5:00	410	20%	42.75									
8/8/97	5:30									30		3800	
8/8/97	6:00				110	610	50	310	10				
8/8/97	9:15	420	20%										
8/8/97	10:15				115	610	50	310	50				
8/8/97	10:30	390	20%										
8/8/97	11:15	390	20%							30		3800	
8/11/97	4:30	420	20%	41.5	130	610	50	310	50	30		3800	
8/11/97	6:30	440	20%										
8/11/97	10:30	440	20%										
8/11/97	11:00				115	610	50	310	40				
8/11/97	14:45	440	20%	41.5									
8/11/97	15:00				115	610	50	310	31				
8/12/97	4:30	420	20%	38.5	112	610	50	310	4	30		3800	
8/12/97	8:30	420	20%										
8/12/97	9:30	410	20%										
8/12/97	12:30	390	20%										
8/12/97	13:00				102	610	50	310					
8/12/97	15:00	420	20%										
8/13/97	4:30	400	20%	36.5									
8/13/97	5:00				110	610	50	310	10	30		3800	
8/13/97	8:30	430	20%										
8/13/97	10:30				105	610	50	310	50				
8/13/97	11:00	455	20%										
8/13/97	12:00	455	20%										
8/13/97	15:00	455	20%										
8/13/97	19:00	430	20%										
8/14/97	4:30	430	20%	33	110	610	50	310	14.5	30		3800	
8/14/97	8:30	430	20%										
8/14/97	12:30	430	20%		112	610	50	310	46				
8/14/97	14:30	440	20%										

Operational Data
for DensaDeg

Date	Time	NaOH Feed Rate, ml/min	NaOH Wt%	NaOH Tank Ht, in	Polymer Feed Rate, ml/min	Polymer, ml	Water, gal	Dilution Ratio (Poly:H20)	Tank Vol (gal)	MgCl2 Feed Rate, ml/min	MgCl2 Wt%	MgCl2 Tank Vol	Antiscalant Dosing Rate, ml/n
8/14/97	16:00	430	20%										
8/15/97	4:30	450	20%	31	115	610	50	310	16	30		3800	
8/15/97	9:30	450	20%										
8/15/97	10:30				109	610	50	310	50				
8/15/97	13:00	435	20%										
8/15/97	14:30	440	20%										
8/15/97	16:00	450	20%										
8/18/97	6:45	560	20%	30									
8/18/97	7:00				112	610	50	310	50	30		3800	
8/18/97	9:30	400	20%										
8/18/97	10:30	410	20%										
8/18/97	12:30	445	20%										
8/18/97	16:30	445	20%										
8/18/97	18:30	435	20%										
8/19/97	1:45	400	20%										
8/19/97	5:00	470	20%	26	117	610	50	310	3	30		3800	
8/19/97	6:00				117	610	50	310	50				
8/19/97	8:45	440	20%										
8/19/97	13:45	430	20%										
8/19/97	18:15	480	20%										
8/20/97	4:30	500	20%		125	610	50	310	3	30		3800	
8/20/97	10:00				110	610	50	310	50				
8/20/97	12:45	385	20%										
8/20/97	14:30	400	20%										
8/20/97	16:00	450	20%										
8/20/97	16:30				113	610	50	310	37				
8/21/97	5:00	400	20%		85	610	50	310	20	30		3800	
8/21/97	6:00	400	20%										
8/21/97	8:30	350	20%										
8/21/97	11:45	295	20%										
8/21/97	13:15				87	570	30	199	50				
8/21/97	15:45	315	20%										
8/22/97	5:00	370	20%		88	570	50	332		30		3800	
8/22/97	13:15	250	20%										
8/22/97	14:15	315	20%										
8/22/97	15:45	345	20%										
8/25/97	7:00	310	20%		88	570	50	332	50	30	27	3800	35
8/25/97	9:00	310	20%										
8/25/97	13:30	280	20%										
8/25/97	15:00	325	20%										
8/26/97	4:30	400	20%		88	570	50	332	15	30	27	3750	
8/26/97	5:00												
8/26/97	8:30	320	20%										
8/26/97	10:45	265	20%										
8/26/97	13:15				86	570	50	332	50				
8/26/97	15:45												
8/27/97	4:30	335	20%		88	570	50	332	25.5	180	27	3700	

Operational Data
for DensaDeg

Date	Time	NaOH Feed Rate, ml/min	NaOH Wt%	NaOH Tank Ht, in	Polymer Feed Rate, ml/min	Polymer, ml	Water, gal	Dilution Ratio (Poly:H20)	Tank Vol (gal)	MgCl2 Feed Rate, ml/min	MgCl2 Wt%	MgCl2 Tank Vol	Antiscalant Dosing Rate, ml/n
8/27/97	5:30												
8/27/97	6:00	340	20%										
8/27/97	10:30	400	20%										
8/27/97	11:15	400	20%										
8/27/97	12:00				98	570	50	332	50				
8/27/97	13:30	365	20%										
8/27/97	13:45				98	570	50	332	47				
8/27/97	15:30				77	570	50	332					
8/27/97	18:30				105	570	50	332					
8/28/97	6:30	480	20%		130	570	50	332	15	175	27	3700	
8/28/97	7:30	480	20%										
8/28/97	9:30	420	20%										
8/28/97	11:00	420	20%		125	570	50	332	5	68	27		
8/28/97	11:30												
8/28/97	12:00	300	20%										
8/29/97	5:00	300	20%		113	570	50	332	15	68	27	3700	
8/29/97	6:30	300	20%										
8/29/97	8:30	240	20%										
8/29/97	11:15									30	27	3700	
8/29/97	11:30				88	570	50	332	50				
8/29/97	11:45	235	20%										

OPERATIONAL DATA FOR DENSADEG REACTOR OUTLET

Date	Time	pH	Date	Time	pH	Temp (°F)	Cond (µmho)	Date	Time	pH	Temp (°F)	Cond (µmho)
7/11/97	4:30	9.91	7/30/97	5:45	9.76			8/15/97	15:45	9.65	158.8	10400
7/11/97	6:30	9.68	7/30/97	6:00	9.76			8/15/97	18:15	9.65	159.6	10300
7/14/97	4:30	10.91	7/30/97	8:45	9.56			8/18/97	7:00	10.06	156	10400
7/14/97	5:30	10.84	7/30/97	10:15	9.64			8/18/97	10:15	9.3	160.1	9500
7/14/97	6:15	10.54	7/31/97	4:30	9.58	142.9		8/18/97	12:15	8.7	162.1	9200
7/14/97	8:00	10.35	7/31/97	7:00	9.51	159.2		8/18/97	14:00	9.77	159.2	9700
7/14/97	10:00	10.15	7/31/97	9:00	9.51	151		8/18/97	16:15	10.02	158.8	9600
7/15/97	4:45	10.58	7/31/97	12:30	9.68	151.9	15000	8/18/97	18:15	9.99	162.2	10400
7/15/97	7:00	9.83	7/31/97	20:30	9.56			8/19/97	5:00	9.98	160.7	10500
7/15/97	8:15	9.22	8/1/97	4:30	9.64	164.1	15000	8/19/97	8:15	9.82	163.4	10200
7/15/97	9:00	9.45	8/1/97	9:00	9.5	166.1	16000	8/19/97	9:30	9.6		10200
7/15/97	11:30	9.22	8/4/97	6:15	9.56	148.1	14500	8/19/97	11:30	9.36	164	10600
7/16/97	5:45	10.15	8/4/97	11:00	9.56	144.1	16000	8/19/97	13:30	9.55	13.4	10600
7/16/97	6:30	10.21	8/4/97	12:15	9.65	150	17000	8/19/97	15:15	9.78	165.6	10400
7/16/97	7:45	10.34	8/5/97	5:00	9.47	150.1	16500	8/19/97	18:00	9.98	162.5	10700
7/16/97	8:30	10.01	8/5/97	9:00	9.63	149.5	16500	8/20/97	4:30	10.13	165.6	10800
7/16/97	8:45	10.01	8/5/97	11:00	9.54	147.9	17500	8/20/97	8:30	9.78	158.2	10800
7/16/97	9:45	9.66	8/6/97	4:45	11.35	142.4	18500	8/20/97	10:30	9.5	163.8	10600
7/17/97	5:30	10.21	8/6/97	7:15	10.1			8/20/97	12:30	9.63	165	10800
7/17/97	7:30	10.15	8/6/97	8:15	10.05	151	17500	8/20/97	14:15	9.25	166.1	10700
7/17/97	8:15	9.83	8/6/97	9:30	9.78	147.7		8/20/97	17:30	9.72		
7/17/97	9:00	9.67	8/6/97	11:30	9.89			8/20/97	19:00	9.98	168.5	10800
7/17/97	10:00	9.55	8/6/97	15:30	9.7			8/21/97	5:00	11.1	163.7	11700
7/17/97	10:40	9.72	8/7/97	4:45	10.22			8/21/97	6:30	10.23		10900
7/18/97	4:30	9.75	8/7/97	8:30	9.83			8/21/97	9:15	9.66	155.5	10700
7/18/97	6:00	9.45	8/7/97	10:00	9.74			8/21/97	11:15	9.03	162.2	10800
7/18/97	7:30	9.09	8/7/97	13:30	9.78			8/21/97	15:30	9.03	166.7	11000
7/18/97	8:45	9.6	8/7/97	17:30	9.75			8/21/97	19:15	9.85	69	10900
7/18/97	9:30	9.6	8/8/97	4:45	9.58			8/22/97	4:30	10.26	73	10500
7/21/97	13:15	10	8/8/97	9:15	9.53			8/22/97	8:00	9.6	70	10700
7/21/97	16:30	9.92	8/8/97	10:30	9.54			8/22/97	13:00	8.96	69	10600
7/22/97	10:40	8.4	8/8/97	13:00	9.72			8/22/97	15:00	9.87	70	10600
7/22/97	13:40	9.32	8/8/97	15:00	9.65			8/22/97	16:45	9.94		11600
7/22/97	14:30	9.61	8/11/97	6:30	9.57			8/25/97	10:45	9.69	163.4	11000
7/23/97	4:30	9.55	8/11/97	11:30	9.69			8/25/97	12:45	9.5	165.2	10400
7/23/97	6:15	9.58	8/11/97	14:30	9.68			8/25/97	14:30	9.45	166.1	11000
7/23/97	9:00	9	8/12/97	4:30	9.95	159.2	10500	8/25/97	16:30	9.7	167	11100
7/24/97	5:00	10.05	8/12/97	9:30	9.75	155.2	10100	8/26/97	4:30	10.68	121.1	10300
7/24/97	6:30	9.68	8/12/97	12:00	9.49	156.4	10400	8/26/97	10:15	9.47	167	10700
7/24/97	7:30	9.58	8/12/97	13:30	9.72	154.5	10600	8/26/97	12:15	9.64	167	10100
7/24/97	8:30	9.58	8/12/97	14:30	9.75	152.6	10600	8/26/97	14:15	9.78	163.4	10300
7/24/97	10:30	9.55	8/12/97	19:00	7.32	133.4	10200	8/26/97	16:15	9.74	165.2	10600
7/24/97	12:30	9.56	8/13/97	4:30	9.3	159.4	9300	8/27/97	4:30	10.58	161.6	10700
7/25/97	4:30	9.6	8/13/97	11:00	9.86	157.5	9600	8/27/97	8:00	9.58	165.2	11900
7/25/97	8:30	9.67	8/13/97	12:00	9.88	157.5	9500	8/27/97	10:30	9.62	169.7	12200
7/25/97	9:30	9.67	8/13/97	13:00	9.82	159.5	9500	8/27/97	12:45	9.63	169.7	12300
7/25/97	11:00	9.64	8/13/97	14:30	9.87	161	9800	8/27/97	14:45	9.96	165.2	12100
7/28/97	5:00	9.08	8/13/97	15:30	9.8	162.8	9700	8/28/97	6:30	10.3	161.6	12100
7/28/97	6:00	9.73	8/13/97	19:00	9.8	161.7	9800	8/28/97	9:30	9.82	159.8	11800
7/28/97	7:00	9.82	8/14/97	4:30	9.68	154.3	9100	8/28/97	11:45	9.98	163.4	11900
7/28/97	9:30	9.75	8/14/97	8:30	9.6	158.3	9100	8/28/97	14:00	9.86	161.6	11500
7/28/97	11:30	9.63	8/14/97	12:00	9.52	160.6	10300	8/28/97	16:00	9.86	161.6	11700
7/28/97	13:30	9.42	8/14/97	14:00	9.65	158.8	10100	8/28/97	18:00	9.89	162.5	11800
7/28/97	16:00	9.59	8/14/97	16:00	9.55	159.5	10000	8/29/97	5:00	10.35	163.4	
7/29/97	4:45	9.62	8/14/97	18:15	9.44	162.8	10200	8/29/97	9:30	9.71	158	
7/29/97	8:00	9.56	8/15/97	4:30	9.73	162	10400	8/29/97	11:45	9.29	160.7	10400
7/29/97	10:45	9.78	8/15/97	9:30	9.88	155.7	10100	8/29/97	14:00	9.65	164.3	10700
7/29/97	13:30	9.41	8/15/97	11:45	9.86	157.9	10600	8/29/97	16:00	9.74	165.2	10800
7/30/97	4:30	10.26	8/15/97	13:45	9.77	159.4	10400					

Lab and Operational Data
for DensaDeg Sludge

			CLWA lab Data								
Date	Time	Location	pH	Temp (°F)	Alkalinity (mg/L as CaCO3)	B	Fe	Si	Ca	Mg	K
						(mg/L as Ion or mg/kg as solid)					
6/12/97	10:00	Sludge (liquid)				14		3	2	52	
6/25/97	11:30	Sludge (liquid)				10	0.01	3	2	52	
6/25/97	16:00	Sludge (liquid)						3	2	53	
6/26/97	10:00	Sludge (liquid) 70 gpm				11	0.11	37	7	70	
6/26/97	10:00	Sludge (Solid) 70 gpm				356	8		31000		
6/27/97	15:00	Sludge (liquid) 80 gpm				12.5	0.035	8	4	49	
6/27/97	15:00	Sludge (Solid) 80 gpm				300	6.1		24000		
7/1/97	16:00	Sludge (liquid)				13	0.046	11	5	94	
7/1/97	16:00	Sludge (Solid)				270	7.1		27000		
7/1/97	17:00	Sludge (liquid)				12.7	0.038	8	4	76	
7/1/97	17:00	Sludge (Solid)				285	6.6		27000		
7/1/97	18:30	Sludge (liquid)				18.8	0.017	3	3	110	
7/1/97	18:30	Sludge (Solid)					9.5		31000	8100	
7/9/97	9:50	Blowdown									
7/10/97	4:45	Blowdown									
7/11/97	4:30	Blowdown									
7/11/97	6:30	Blowdown									
7/14/97	4:30	Blowdown									
7/14/97	5:30	Blowdown									
7/14/97	6:15	Blowdown									
7/14/97	8:00	Blowdown									
7/14/97	10:00	Blowdown									
7/14/97	10:50	Blowdown									
7/15/97	6:00	Blowdown									
7/15/97	7:30	Blowdown									
7/16/97	5:00	Blowdown									
7/16/97	7:00	Blowdown									
7/16/97	8:00	Blowdown									
7/17/97	5:45	Blowdown									
7/17/97	8:30	Blowdown									
7/18/97	5:00	Blowdown									
7/18/97	9:00	Blowdown									
7/21/97	13:00	Blowdown									
7/21/97	13:40	Blowdown									
7/21/97	16:00	Blowdown									
7/22/97	11:30	Blowdown									
7/22/97	12:30	Blowdown									
7/22/97	13:30	Blowdown									
7/22/97	14:30	Blowdown									
7/23/97	5:15	Blowdown									
7/23/97	9:00	Blowdown									
7/24/97	5:00	Blowdown									
7/24/97	8:30	Blowdown									
7/25/97	8:00	Blowdown									
7/25/97	10:00	Blowdown									
7/25/97	11:00	Blowdown									
7/28/97	6:45	Blowdown									
7/28/97	9:30	Blowdown									
7/28/97	9:31	Blowdown									
7/28/97	11:45	Blowdown									
7/29/97	5:00	Blowdown									
7/29/97	8:00	Blowdown									
7/29/97	10:30	Blowdown									
7/30/97	4:30	Blowdown									
7/30/97	6:30	Blowdown									
7/30/97	9:00	Blowdown									
7/31/97	4:30	Blowdown									
7/31/97	9:00	Blowdown									
7/31/97	12:30	Blowdown									
7/31/97	20:30	Blowdown									
8/1/97	5:00	Blowdown									

Lab and Operational Data
for DensaDeg Sludge

			CLWA lab Data									
			Na	Ba	Sr	Mn	Mo	Cl	SO4	Br	NO3	Wt % Solids
Date	Time	Location	(mg/L as Ion or mg/kg as solid)									
6/12/97	10:00	Sludge (liquid)		0.3	0.03							
6/25/97	11:30	Sludge (liquid)		0.2	0.03							
6/25/97	16:00	Sludge (liquid)		0.2	0.02							
6/26/97	10:00	Sludge (liquid) 70 gpm		0.034	0.062							
6/26/97	10:00	Sludge (Solid) 70 gpm		112	1							10
6/27/97	15:00	Sludge (liquid) 80 gpm		0.047	0.086							
6/27/97	15:00	Sludge (Solid) 80 gpm		95	791							3.4
7/1/97	16:00	Sludge (liquid)		0.045	0.11							
7/1/97	16:00	Sludge (Solid)		92	783							
7/1/97	17:00	Sludge (liquid)		0.034	0.07							
7/1/97	17:00	Sludge (Solid)		91	842							3.3
7/1/97	18:30	Sludge (liquid)		2.61	0.001							
7/1/97	18:30	Sludge (Solid)		131								7
7/9/97	9:50	Blowdown										
7/10/97	4:45	Blowdown										
7/11/97	4:30	Blowdown										
7/11/97	6:30	Blowdown										
7/14/97	4:30	Blowdown										
7/14/97	5:30	Blowdown										
7/14/97	6:15	Blowdown										
7/14/97	8:00	Blowdown										
7/14/97	10:00	Blowdown										
7/14/97	10:50	Blowdown										
7/15/97	6:00	Blowdown										
7/15/97	7:30	Blowdown										
7/16/97	5:00	Blowdown										
7/16/97	7:00	Blowdown										
7/16/97	8:00	Blowdown										
7/17/97	5:45	Blowdown										
7/17/97	8:30	Blowdown										
7/18/97	5:00	Blowdown										
7/18/97	9:00	Blowdown										
7/21/97	13:00	Blowdown										
7/21/97	13:40	Blowdown										
7/21/97	16:00	Blowdown										
7/22/97	11:30	Blowdown										
7/22/97	12:30	Blowdown										
7/22/97	13:30	Blowdown										
7/22/97	14:30	Blowdown										
7/23/97	5:15	Blowdown										
7/23/97	9:00	Blowdown										
7/24/97	5:00	Blowdown										
7/24/97	8:30	Blowdown										
7/25/97	8:00	Blowdown										
7/25/97	10:00	Blowdown										
7/25/97	11:00	Blowdown										
7/28/97	6:45	Blowdown										
7/28/97	9:30	Blowdown										
7/28/97	9:31	Blowdown										
7/28/97	11:45	Blowdown										
7/29/97	5:00	Blowdown										
7/29/97	8:00	Blowdown										
7/29/97	10:30	Blowdown										
7/30/97	4:30	Blowdown										
7/30/97	6:30	Blowdown										
7/30/97	9:00	Blowdown										
7/31/97	4:30	Blowdown										
7/31/97	9:00	Blowdown										
7/31/97	12:30	Blowdown										
7/31/97	20:30	Blowdown										
8/1/97	5:00	Blowdown										

Lab and Operational Data for DensaDeg Sludge

			Operational Data	
Date	Time	Location	Sludge Level (ft)	Sludge Blowtime Time (sec)
6/12/97	10:00	Sludge (liquid)		
6/25/97	11:30	Sludge (liquid)		
6/25/97	16:00	Sludge (liquid)		
6/26/97	10:00	Sludge (liquid) 70 gpm		
6/26/97	10:00	Sludge (Solid) 70 gpm		
6/27/97	15:00	Sludge (liquid) 80 gpm		
6/27/97	15:00	Sludge (Solid) 80 gpm		
7/1/97	16:00	Sludge (liquid)		
7/1/97	16:00	Sludge (Solid)		
7/1/97	17:00	Sludge (liquid)		
7/1/97	17:00	Sludge (Solid)		
7/1/97	18:30	Sludge (liquid)		
7/1/97	18:30	Sludge (Solid)		
7/9/97	9:50	Blowdown	8	
7/10/97	4:45	Blowdown	8	
7/11/97	4:30	Blowdown	9	120
7/11/97	6:30	Blowdown	6	120
7/14/97	4:30	Blowdown	9	
7/14/97	5:30	Blowdown	9	
7/14/97	6:15	Blowdown	9	
7/14/97	8:00	Blowdown	9	
7/14/97	10:00	Blowdown	9	
7/14/97	10:50	Blowdown	9	
7/15/97	6:00	Blowdown	9	75
7/15/97	7:30	Blowdown	6	
7/16/97	5:00	Blowdown	9	
7/16/97	7:00	Blowdown		525
7/16/97	8:00	Blowdown	8	
7/17/97	5:45	Blowdown		75
7/17/97	8:30	Blowdown		75
7/18/97	5:00	Blowdown		600
7/18/97	9:00	Blowdown		225
7/21/97	13:00	Blowdown	3	
7/21/97	13:40	Blowdown	4	
7/21/97	16:00	Blowdown	6	225
7/22/97	11:30	Blowdown	7	150
7/22/97	12:30	Blowdown	6	150
7/22/97	13:30	Blowdown	4	225
7/22/97	14:30	Blowdown	3	150
7/23/97	5:15	Blowdown	9	75
7/23/97	9:00	Blowdown	2	
7/24/97	5:00	Blowdown	9	150
7/24/97	8:30	Blowdown	7	225
7/25/97	8:00	Blowdown	9	225
7/25/97	10:00	Blowdown	8	150
7/25/97	11:00	Blowdown	7	
7/28/97	6:45	Blowdown	8	150
7/28/97	9:30	Blowdown	4	75
7/28/97	9:31	Blowdown	3	75
7/28/97	11:45	Blowdown	3	75
7/29/97	5:00	Blowdown	4	
7/29/97	8:00	Blowdown	5	
7/29/97	10:30	Blowdown	4	225
7/30/97	4:30	Blowdown	10	75
7/30/97	6:30	Blowdown	9	150
7/30/97	9:00	Blowdown	6	75
7/31/97	4:30	Blowdown	9	
7/31/97	9:00	Blowdown	9	225
7/31/97	12:30	Blowdown	9	150
7/31/97	20:30	Blowdown	10	320
8/1/97	5:00	Blowdown	10	150

Lab and Operational Data
for DensaDeg Sludge

			CLWA lab Data								
			pH	Temp	Alkalinity	B	Fe	Si	Ca	Mg	K
Date	Time	Location		(°F)	(mg/L as CaCO3)	(mg/L as Ion or mg/kg as solid)					
8/1/97	6:30	Blowdown									
8/4/97	8:00	Blowdown									
8/5/97	10:00	Blowdown									
8/6/97	5:00	Blowdown									
8/7/97	5:00	Blowdown									
8/7/97	5:30	Blowdown									
8/7/97	20:30	Blowdown									
8/7/97	21:00	Blowdown									
8/8/97	5:30	Blowdown									
8/8/97	6:30	Blowdown									
8/8/97	8:30	Blowdown									
8/11/97	7:45	Blowdown									
8/11/97	11:45	Blowdown									
8/12/97	5:00	Blowdown									
8/12/97	7:30	Blowdown									
8/12/97	10:00	Blowdown									
8/12/97	16:30	Sludge (liquid)	9.92	71.4	12760						
8/13/97	4:30	Blowdown									
8/13/97	16:00	Sludge (liquid)	9.8	71.4	2960	10	0.001	2.8	2.9	34	80
8/13/97	16:00	Sludge (Solid)				340	530	3400	32000	12000	86
8/14/97	4:30	Blowdown									
8/14/97	10:45	Blowdown									
8/14/97	11:30	Blowdown									
8/14/97	17:00	Sludge (liquid)	9.8	71.2	4840	13	0.016	2.2	3.3	38	93
8/14/97	17:00	Sludge (Solid)				370	530	900	29000	12000	92
8/14/97	20:00	Blowdown									
8/15/97	4:30	Blowdown									
8/15/97	7:00	Blowdown									
8/15/97	8:30	Blowdown									
8/15/97	16:30	Sludge (liquid)	9.79	71.1	14480	11	0.024	1.1	3.5	48	85
8/15/97	16:30	Sludge (Solid)				350	500	1300	29000	12000	93
8/15/97	20:00	Blowdown									
8/18/97	4:30	Blowdown									
8/18/97	5:30	Blowdown									
8/18/97	6:30	Blowdown									
8/18/97	16:00	Sludge (liquid)									
8/18/97	19:30	Blowdown									
8/19/97	4:30	Blowdown									
8/19/97	8:15	Blowdown									
8/19/97	18:45	Blowdown									
8/20/97	4:30	Blowdown									
8/20/97	5:15	Blowdown									
8/20/97	6:15	Blowdown									
8/20/97	7:00	Blowdown									
8/20/97	8:00	Blowdown									
8/20/97	20:00	Blowdown									
8/21/97	5:00	Blowdown									
8/21/97	7:30	Blowdown									
8/21/97	8:30	Blowdown									
8/21/97	9:00	Blowdown									
8/21/97	20:00	Blowdown									
8/22/97	4:30	Blowdown									
8/22/97	6:00	Blowdown									
8/22/97	6:30	Blowdown									
8/25/97	5:30	Blowdown									
8/25/97	19:30	Blowdown									
8/26/97	4:30	Blowdown									
8/26/97	8:00	Blowdown									
8/26/97	9:00	Blowdown									
8/26/97	19:30	Blowdown									
8/27/97	4:30	Blowdown									

Field, Lab, and Operational Data
for DensaDeg Effluent

		Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			(mg/L as SiO2)
5/16/97	11:30	8.47					460.4	328		
5/16/97	14:30	8.69					455.7	105.7	52.2	
5/20/97	17:00		149				456	464	148	163.2
5/21/97	12:30		143.6				409.2	450	148	143.6
6/2/97	16:30	7.21	138.2				490	792	194	147.5
6/3/97	10:00	10.95						7.3	4.1	98.4
6/3/97	18:20	8.99	132.8	1.7			542	83.2	12.2	85.6
6/4/97	12:00	8.85	111.2	1.2			484	112.4	16.1	64
6/4/97	15:00	8.34	73.76	1.3			438	225.6	38.6	72
6/5/97	10:00	10.78	96.98	20			838	3.2	3.1	57.2
6/5/97	17:15	9.05	80.6				502	99.2	17.2	60
6/6/97	10:00	9.44	84.2	2.5			548	23.2	6	32.4
6/6/97	12:15	9.28	84.2	2			548	23.2	6	32.4
6/12/97	9:45	8.58	102.2				430	214.2	51.6	63.2
6/13/97	10:30	8.67	84.2	1.5			460	174.2	22.8	66.4
6/13/97	16:40	9.03	104				434	58.4	23.5	
6/20/97	9:00						448	187	17.2	83.6
6/25/97	11:30									
6/25/97	16:00									
7/1/97	16:00	8.62					414	164	19.8	84.5
7/1/97	17:00	8.76					412	108	14.2	76.4
7/1/97	18:30	9.18					416	32.4	6.4	51.2
7/3/97	11:00	9.02					404	21.6	6	92.8
7/3/97	16:30	9.28					406	15.2	7	62.4
7/8/97	16:00			3.9						
7/9/97	9:50									
7/9/97	10:15	9.95					586	64	36	42.4
7/9/97	12:30			7.7						
7/9/97	22:30									
7/10/97	4:45									
7/10/97	6:00	9.38					490	25.6	5.8	
7/11/97	4:30									
7/11/97	6:30									
7/14/97	4:30									
7/14/97	5:30									
7/14/97	6:15									
7/14/97	8:00									
7/14/97	10:00									
7/14/97	17:30	9.3		27			440	20.4	6.4	6.7
7/15/97	4:40	10.4					682	3.8	2.2	48.8
7/15/97	4:45									
7/15/97	5:00			2						
7/15/97	6:00									
7/15/97	7:00									
7/15/97	7:45									
7/15/97	8:15									
7/15/97	9:00									
7/15/97	11:00			3.3						
7/15/97	11:30									
7/15/97	17:00	9.7		1.3			488	10.6	4.6	28.2
7/16/97	5:45									
7/16/97	6:00									
7/16/97	6:30									
7/16/97	7:00									
7/16/97	7:45									
7/16/97	8:00									
7/16/97	8:30									
7/16/97	8:45									

Field, Lab, and Operational Data for DensaDeg Effluent

		CLWA Lab Data											
		pH	Temp	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC
Date	Time		(°F)	(mg/L as Ion)									(mg/L)
5/16/97	11:30												
5/16/97	14:30												
5/20/97	17:00												
5/21/97	12:30												
6/2/97	16:30			15		110	130	100					
6/3/97	10:00												
6/3/97	18:20												
6/4/97	12:00												
6/4/97	15:00			13		48	11	52					
6/5/97	10:00			13		36	1.3	0.7					
6/5/97	17:15			12		35	3.4	22					
6/6/97	10:00												
6/6/97	12:15			12	0.01	20	3.4	6					
6/12/97	9:45			17	0.01	32	6	45			0.3	0.38	
6/13/97	10:30			14	0.01	37	8	37			0.2	0.29	
6/13/97	16:40			14	0.02	26	3	11			0.2	0.17	
6/20/97	9:00			15	0.01	45	6	38			0.2	0.26	
6/25/97	11:30			14	0.07	34	5	30			0.2	0.22	
6/25/97	16:00			16	0.02	35	6	34			0.4	0.3	
7/1/97	16:00			12.4	0.013	49	13	34			0.096	0.25	100
7/1/97	17:00			14.2	0.011	35	4	21			0.071	0.16	86
7/1/97	18:30			13.2	0.019	28	2	5			0.041	0.09	98
7/3/97	11:00												
7/3/97	16:30			13.4	0.02	27	2	2			0.046	0.09	
7/8/97	16:00												
7/9/97	9:50												
7/9/97	10:15												
7/9/97	12:30												
7/9/97	22:30												
7/10/97	4:45												
7/10/97	6:00												
7/11/97	4:30												
7/11/97	6:30												
7/14/97	4:30												
7/14/97	5:30												
7/14/97	6:15												
7/14/97	8:00												
7/14/97	10:00												
7/14/97	17:30					11.2	2.4	4.1					
7/15/97	4:40												
7/15/97	4:45												
7/15/97	5:00												
7/15/97	6:00												
7/15/97	7:00												
7/15/97	7:45												
7/15/97	8:15												
7/15/97	9:00												
7/15/97	11:00												
7/15/97	11:30												
7/15/97	17:00			14.8	0.03	14.1	1.9	1.6					
7/16/97	5:45												
7/16/97	6:00												
7/16/97	6:30												
7/16/97	7:00												
7/16/97	7:45												
7/16/97	8:00												
7/16/97	8:30												
7/16/97	8:45												

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data						Operational Data		
Date	Time	NH3 (mg/L as NH3)	TSS (mg/L)	TDS (mg/L)	Cl (mg/L as Ion)	SO4	Br	pH	Temp (°F)	Conductivity (µmho)
5/16/97	11:30									
5/16/97	14:30									
5/20/97	17:00									
5/21/97	12:30									
6/2/97	16:30									
6/3/97	10:00									
6/3/97	18:20									
6/4/97	12:00									
6/4/97	15:00									
6/5/97	10:00									
6/5/97	17:15									
6/6/97	10:00									
6/6/97	12:15									
6/12/97	9:45									
6/13/97	10:30									
6/13/97	16:40									
6/20/97	9:00									
6/25/97	11:30									
6/25/97	16:00									
7/1/97	16:00									
7/1/97	17:00									
7/1/97	18:30									
7/3/97	11:00									
7/3/97	16:30									
7/8/97	16:00									
7/9/97	9:50							10.15		
7/9/97	10:15									
7/9/97	12:30									
7/9/97	22:30							9.8		
7/10/97	4:45							9.4		
7/10/97	6:00									
7/11/97	4:30							9.89		
7/11/97	6:30							9.65		
7/14/97	4:30							10.89		
7/14/97	5:30							10.81		
7/14/97	6:15							10.61		
7/14/97	8:00							10.39		
7/14/97	10:00							10.18		
7/14/97	17:30									
7/15/97	4:40									
7/15/97	4:45							10.58		
7/15/97	5:00									
7/15/97	6:00								160.6	
7/15/97	7:00							9.89		
7/15/97	7:45								164.1	
7/15/97	8:15							9.35		
7/15/97	9:00							9.32		
7/15/97	11:00									
7/15/97	11:30							9.34		
7/15/97	17:00									
7/16/97	5:45							10.15		
7/16/97	6:00								162.9	
7/16/97	6:30							10.15		
7/16/97	7:00								165.2	
7/16/97	7:45							10.21		
7/16/97	8:00								165.2	
7/16/97	8:30							10.23		
7/16/97	8:45							10.02		

Field, Lab, and Operational Data
for DensaDeg Effluent

		Field Data								
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk (mg/L as CaCO3)	Tot Hard (mg/L as CaCO3)	Ca Hard (mg/L as CaCO3)	SiO2 (mg/L as SiO2)
7/16/97	9:45									
7/17/97	5:30									
7/17/97	7:30									
7/17/97	8:00									
7/17/97	8:15									
7/17/97	9:00									
7/17/97	10:00									
7/17/97	10:40									
7/17/97	19:30			7.8						
7/18/97	4:30									
7/18/97	6:00									
7/18/97	7:30									
7/18/97	8:45									
7/18/97	9:30									
7/21/97	13:15									
7/21/97	16:30									
7/21/97	17:30	9.7	132.8	2.6		2.165	372	8.8		35.2
7/22/97	10:40									
7/22/97	11:00	8.21	124.4			2.016	356	314	78	68.8
7/22/97	13:40									
7/22/97	14:30									
7/22/97	18:30	8.33			5200		372	464	96	92
7/23/97	4:30									
7/23/97	5:45									
7/23/97	6:15									
7/23/97	8:00									
7/23/97	9:00									
7/23/97	9:00									
7/23/97	18:00	9.69	70.9			2.181	460	14.6	7.7	
7/24/97	5:00									
7/24/97	6:30									
7/24/97	6:30									
7/24/97	6:45	8.94				2.107	488	22.8	8.4	22
7/24/97	7:30									
7/24/97	8:30									
7/24/97	8:30									
7/24/97	10:30									
7/24/97	10:30									
7/24/97	12:30									
7/24/97	12:30									
7/24/97	19:00	9.48		0.83	9000	2.466	446	24.8	9.2	21.2
7/25/97	4:30									
7/25/97	7:45	8.98	73.9			2.069	342	26	14.8	31.2
7/25/97	8:30									
7/25/97	8:30									
7/25/97	9:30									
7/25/97	10:30									
7/25/97	11:00									
7/28/97	5:00									
7/28/97	6:00									
7/28/97	6:45									
7/28/97	7:00									
7/28/97	8:00	9.42	70.5	1.1		2.21	488	26.2	13.5	
7/28/97	9:30									
7/28/97	9:30									
7/28/97	11:30									
7/28/97	11:45									
7/28/97	13:30									

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data											
		pH	Temp	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC
Date	Time		(°F)				(mg/L as Ion)						(mg/L)
7/16/97	9:45												
7/17/97	5:30												
7/17/97	7:30												
7/17/97	8:00												
7/17/97	8:15												
7/17/97	9:00												
7/17/97	10:00												
7/17/97	10:40												
7/17/97	19:30												
7/18/97	4:30												
7/18/97	6:00												
7/18/97	7:30												
7/18/97	8:45												
7/18/97	9:30												
7/21/97	13:15												
7/21/97	16:30												
7/21/97	17:30			13.8	0.03	21.8	1.37	1.13					110
7/22/97	10:40												
7/22/97	11:00												
7/22/97	13:40												
7/22/97	14:30												
7/22/97	18:30												
7/23/97	4:30												
7/23/97	5:45												
7/23/97	6:15												
7/23/97	8:00												
7/23/97	9:00												
7/23/97	9:00												
7/23/97	18:00			12.1	0.003	11.5							96
7/24/97	5:00												
7/24/97	6:30												
7/24/97	6:30												
7/24/97	6:45			12.8	0.073	7.62							92
7/24/97	7:30												
7/24/97	8:30												
7/24/97	8:30												
7/24/97	10:30												
7/24/97	10:30												
7/24/97	12:30												
7/24/97	12:30												
7/24/97	19:00												140
7/25/97	4:30												
7/25/97	7:45			13	0.019	7.91							126
7/25/97	8:30												
7/25/97	8:30												
7/25/97	9:30												
7/25/97	10:30												
7/25/97	11:00												
7/28/97	5:00												
7/28/97	6:00												
7/28/97	6:45												
7/28/97	7:00												
7/28/97	8:00			11.8	0.014	14.2							144
7/28/97	9:30												
7/28/97	9:30												
7/28/97	11:30												
7/28/97	11:45												
7/28/97	13:30												

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	CLWA Lab Data						Operational Data		
		NH3 (mg/L as NH3)	TSS (mg/L)	TDS (mg/L)	Cl (mg/L as Ion)	SO4	Br	pH	Temp (°F)	Conductivity (µmho)
7/16/97	9:45							10.02		
7/17/97	5:30							10.21		
7/17/97	7:30							9.8		
7/17/97	8:00								158.4	
7/17/97	8:15							9.68		
7/17/97	9:00							9.14		
7/17/97	10:00							9.5		
7/17/97	10:40							9.59		
7/17/97	19:30									
7/18/97	4:30							9.68		
7/18/97	6:00							9.32		
7/18/97	7:30							9.04		
7/18/97	8:45							9.5		
7/18/97	9:30							9.6		
7/21/97	13:15							9.7		
7/21/97	16:30							9.71		
7/21/97	17:30	7								
7/22/97	10:40							8.4		
7/22/97	11:00									
7/22/97	13:40							9.11		
7/22/97	14:30							9.04		
7/22/97	18:30									
7/23/97	4:30							9.51		
7/23/97	5:45								162.9	
7/23/97	6:15							9.39		
7/23/97	8:00								162.9	
7/23/97	9:00							9.2		
7/23/97	9:00								162.9	
7/23/97	18:00	9								
7/24/97	5:00							10.01		
7/24/97	6:30							9.72		
7/24/97	6:30								164.1	
7/24/97	6:45	8								
7/24/97	7:30							9.51		
7/24/97	8:30							9.48		
7/24/97	8:30								152.7	
7/24/97	10:30							9.42		
7/24/97	10:30								153.8	
7/24/97	12:30							9.44		
7/24/97	12:30								155.0	
7/24/97	19:00	5.6								
7/25/97	4:30							9.62		
7/25/97	7:45	5.3								
7/25/97	8:30							9.65		
7/25/97	8:30								153.8	
7/25/97	9:30							9.56		
7/25/97	10:30								155.0	
7/25/97	11:00							9.52		
7/28/97	5:00							9.5		
7/28/97	6:00							9.4		
7/28/97	6:45								140.2	
7/28/97	7:00							9.63		
7/28/97	8:00	5.6								
7/28/97	9:30							9.62		
7/28/97	9:30								141.3	
7/28/97	11:30							9.52		
7/28/97	11:45								148.1	
7/28/97	13:30							9.38		

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk (mg/L as CaCO3)	Tot Hard (mg/L as CaCO3)	Ca Hard (mg/L as CaCO3)	SiO2 (mg/L as SiO2)
7/28/97	16:00									
7/28/97	17:00	8.51	68	0.75		2.165	480	21.4	13.3	
7/29/97	4:45									
7/29/97	6:00									
7/29/97	7:00	9.34	69.4	1.1		2.107	488	31.2	13.6	
7/29/97	8:00									
7/29/97	8:15									
7/29/97	10:30									
7/29/97	10:45									
7/29/97	13:30									
7/30/97	4:30									
7/30/97	5:45									
7/30/97	6:00									
7/30/97	6:15									
7/30/97	7:00									
7/30/97	7:30	9.43	68.4	1.9		2.15	475	10.8	4.6	42.1
7/30/97	8:45									
7/30/97	9:15									
7/30/97	10:15									
7/30/97	11:00									
7/30/97	18:00	9.48	70.4	6		2.358	480	13.2	6.8	
7/31/97	4:30									
7/31/97	4:45									
7/31/97	7:00									
7/31/97	8:00	9.33	68.9	36	10500	2.081	486	53.8	12.8	20.5
7/31/97	9:00									
7/31/97	9:30									
7/31/97	12:30									
7/31/97	12:30									
7/31/97	18:00	9.41	67.9			2.197	444	27.6	9.6	29.6
7/31/97	20:30									
8/1/97	4:30									
8/1/97	5:00									
8/1/97	9:00									
8/1/97	10:00	9.19	69.8	0.9	10600	2.045	450	21.8	11.4	20.5
8/4/97	6:15									
8/4/97	10:00	8.79	77.2		4300	2.165	450	34	12.8	30
8/4/97	10:30									
8/4/97	11:00									
8/4/97	11:30									
8/4/97	12:15									
8/5/97	5:00									
8/5/97	9:00									
8/5/97	11:00									
8/6/97	4:45									
8/6/97	7:15									
8/6/97	8:15									
8/6/97	9:30									
8/6/97	9:30									
8/6/97	10:00	9.65	74.6	0.8	10500	2.128	560	13.8	3.4	16
8/6/97	11:30									
8/6/97	15:30									
8/6/97	16:00	9.51	71.9	0.7	10200	2.26	464	22.6	3.8	28.4
8/7/97	4:45									
8/7/97	8:30									
8/7/97	8:30									
8/7/97	9:45									
8/7/97	10:00	9.24	73.4	0.8		2.436	488	12.4	6.8	40.1

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	CLWA Lab Data											
		pH	Temp (°F)	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC (mg/L)
				(mg/L as Ion)									
7/28/97	16:00												
7/28/97	17:00			12.5	0.16	17.1							119
7/29/97	4:45												
7/29/97	6:00												
7/29/97	7:00			13.1	0.15	8.99							116
7/29/97	8:00												
7/29/97	8:15												
7/29/97	10:30												
7/29/97	10:45												
7/29/97	13:30												
7/30/97	4:30												
7/30/97	5:45												
7/30/97	6:00												
7/30/97	6:15												
7/30/97	7:00												
7/30/97	7:30			12.2	0.014	15.9							130
7/30/97	8:45												
7/30/97	9:15												
7/30/97	10:15												
7/30/97	11:00												
7/30/97	18:00			12.3	0.016	4.41							110
7/31/97	4:30												
7/31/97	4:45												
7/31/97	7:00												
7/31/97	8:00			12	0.004	6							106
7/31/97	9:00												
7/31/97	9:30												
7/31/97	12:30												
7/31/97	12:30												
7/31/97	18:00			12.082	0.003	5.382	2.1	5.6	86.4	2151			97
7/31/97	20:30												
8/1/97	4:30												
8/1/97	5:00												
8/1/97	9:00												
8/1/97	10:00			10.386	0.027	8.134	11.7	4	81.5	2110			90
8/4/97	6:15												
8/4/97	10:00	8.55	67.6	10.697	0.097	13.74	4.1	6.4	74.3	2111			94
8/4/97	10:30												
8/4/97	11:00												
8/4/97	11:30												
8/4/97	12:15												
8/5/97	5:00												
8/5/97	9:00												
8/5/97	11:00												
8/6/97	4:45												
8/6/97	7:15												
8/6/97	8:15												
8/6/97	9:30												
8/6/97	9:30												
8/6/97	10:00	9.65	68.9	10.33	0.0076	5.07	0.8	2.1	74.9	2209			91
8/6/97	11:30												
8/6/97	15:30												
8/6/97	16:00	9.56	66.9	10.8	0.02	4.9	1.2	4	75	2180			119
8/7/97	4:45												
8/7/97	8:30												
8/7/97	8:30												
8/7/97	9:45												
8/7/97	10:00	9.34	67.1	12.3	0.04	10.1	1.2	2	71.8	1982			99

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data						Operational Data		
Date	Time	NH3 (mg/L as NH3)	TSS (mg/L)	TDS (mg/L)	Cl (mg/L as Ion)	SO4	Br	pH	Temp (°F)	Conductivity (µmho)
7/28/97	16:00							9.5		
7/28/97	17:00	5.4	40							
7/29/97	4:45							9.42		
7/29/97	6:00								150.4	
7/29/97	7:00	5.4								
7/29/97	8:00							9.48		
7/29/97	8:15								153.8	
7/29/97	10:30								155.0	
7/29/97	10:45							9.46		
7/29/97	13:30							9.43		
7/30/97	4:30							10.16		
7/30/97	5:45							9.63		
7/30/97	6:00							9.8		
7/30/97	6:15								155.0	
7/30/97	7:00								153.8	
7/30/97	7:30	5.8	20							
7/30/97	8:45							9.55		
7/30/97	9:15								157.2	
7/30/97	10:15							9.51		
7/30/97	11:00								158.4	
7/30/97	18:00	5.4	13							
7/31/97	4:30							9.48	142.3	
7/31/97	4:45								158.4	
7/31/97	7:00							9.42	155.4	
7/31/97	8:00	5.5	5							
7/31/97	9:00							9.53	144	
7/31/97	9:30								158.4	
7/31/97	12:30								151.6	
7/31/97	12:30							9.53	137.5	15000
7/31/97	18:00	5.3	22		3182	83				
7/31/97	20:30							9.44		
8/1/97	4:30							9.56	162.7	15500
8/1/97	5:00								158.4	
8/1/97	9:00							9.38	162.7	16000
8/1/97	10:00	5.5	8							
8/4/97	6:15							9.63	133	15500
8/4/97	10:00	6.7	9							
8/4/97	10:30								157.2	
8/4/97	11:00							9.41	141.4	16000
8/4/97	11:30								157.2	
8/4/97	12:15							9.51	148.5	17000
8/5/97	5:00							9.42	149.4	18000
8/5/97	9:00							9.47	148.8	17500
8/5/97	11:00							9.54	1417.5	17500
8/6/97	4:45							11.22	144.1	18500
8/6/97	7:15							10.45		
8/6/97	8:15							10.13	153	17500
8/6/97	9:30							9.87	147.6	
8/6/97	9:30								160.6	
8/6/97	10:00	5.2								
8/6/97	11:30							9.82		
8/6/97	15:30							9.55	151	
8/6/97	16:00	5.3			3200	85				
8/7/97	4:45							10.18	144	
8/7/97	8:30								161.8	
8/7/97	8:30							9.51	164.3	
8/7/97	9:45								164.1	
8/7/97	10:00	5.6								

Field, Lab, and Operational Data
for DensaDeg Effluent

		Field Data								
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk (mg/L as CaCO3)	Tot Hard (mg/L as CaCO3)	Ca Hard (mg/L as CaCO3)	SiO2 (mg/L as SiO2)
8/7/97	10:00									
8/7/97	10:00									
8/7/97	13:30									
8/7/97	17:00	9.8	71.7	0.69		2.395	552	12	6.7	
8/7/97	17:30									
8/8/97	4:45									
8/8/97	6:30									
8/8/97	8:00	9.26	67.1	0.9		2.334	472	23	11.7	
8/8/97	9:15									
8/8/97	9:15									
8/8/97	10:30									
8/8/97	10:45									
8/8/97	13:00									
8/8/97	15:00									
8/8/97	17:00									
8/8/97	17:00	9.52	69.6	0.62		2.422	484	22.4	8.3	
8/11/97	6:30									
8/11/97	7:45									
8/11/97	10:00	9.44	72.5	1		2.15	492	44.2	1.1	
8/11/97	11:30									
8/11/97	14:20									
8/11/97	14:30									
8/11/97	16:30	9.38	69.5	0.74		2.251	512	39.8	15.8	
8/12/97	4:30									
8/12/97	7:30									
8/12/97	8:30	9.64	70.2	1		2	604	13.6	7.9	
8/12/97	9:00									
8/12/97	9:30									
8/12/97	12:00									
8/12/97	12:45									
8/12/97	13:30									
8/12/97	14:30									
8/12/97	15:00									
8/12/97	16:30	8.98	67.8	0.66		2.121	496	172	112	
8/12/97	19:00									
8/13/97	4:30									
8/13/97	11:00									
8/13/97	12:00									
8/13/97	13:00									
8/13/97	13:30									
8/13/97	14:30									
8/13/97	14:45									
8/13/97	15:30									
8/13/97	16:00	9.59	69.7	0.62		2.358	536	19.8	6.6	
8/13/97	19:00									
8/13/97	19:00									
8/14/97	4:30									
8/14/97	8:30									
8/14/97	9:15									
8/14/97	10:00	9.37	68.5	1		2.181	512	30.6	12.1	
8/14/97	11:00									
8/14/97	12:00									
8/14/97	13:15									
8/14/97	14:00									
8/14/97	15:00									
8/14/97	16:00									
8/14/97	17:00	9.32	69.8	0.97		2.214	524	38.4	7.7	20
8/14/97	18:15									

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	CLWA Lab Data											
		pH	Temp (°F)	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC (mg/L)
				(mg/L as Ion)									
8/7/97	10:00												
8/7/97	10:00												
8/7/97	13:30												
8/7/97	17:00	9.69	67.5	12.7	0.01	9.3	0.9	1.9	74.1	2098			104
8/7/97	17:30												
8/8/97	4:45												
8/8/97	6:30												
8/8/97	8:00	9.24	67.5	12.7	0.03	9.4	1.4	3	79	2149			96
8/8/97	9:15												
8/8/97	9:15												
8/8/97	10:30												
8/8/97	10:45												
8/8/97	13:00												
8/8/97	15:00												
8/8/97	17:00			13.8		7.9	1	3.4	73.7	1973			
8/8/97	17:00	9.48	72.5										129
8/11/97	6:30												
8/11/97	7:45												
8/11/97	10:00	9.32	72.1	12.9	0.03	10.4	1.4	6.5	74.2	2118			94
8/11/97	11:30												
8/11/97	14:20												
8/11/97	14:30												
8/11/97	16:30												85
8/12/97	4:30												
8/12/97	7:30												
8/12/97	8:30	9.48	72.3	13.3	0.03	9.2	0.8	2.2	74	2122			83
8/12/97	9:00												
8/12/97	9:30												
8/12/97	12:00												
8/12/97	12:45												
8/12/97	13:30												
8/12/97	14:30												
8/12/97	15:00												
8/12/97	16:30	10.04	72.1	15.1	0.08	14	4	27	82	1560			65
8/12/97	19:00												
8/13/97	4:30												
8/13/97	11:00												
8/13/97	12:00												
8/13/97	13:00												
8/13/97	13:30												
8/13/97	14:30												
8/13/97	14:45												
8/13/97	15:30												
8/13/97	16:00	9.45	72.1	14.3	0.03	7.2	1	2.5	80.4	2165			83
8/13/97	19:00												
8/13/97	19:00												
8/14/97	4:30												
8/14/97	8:30												
8/14/97	9:15												
8/14/97	10:00	9.31	71.8	14.2	0.02	6.4	1.2	5.3	77.1	2148			75
8/14/97	11:00												
8/14/97	12:00												
8/14/97	13:15												
8/14/97	14:00												
8/14/97	15:00												
8/14/97	16:00												
8/14/97	17:00	9.4	72	13.3	0.08	5.8	1.2	7.1	79.4	2171			87
8/14/97	18:15												

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data						Operational Data		
Date	Time	NH3 (mg/L as NH3)	TSS (mg/L)	TDS (mg/L)	Cl (mg/L as Ion)	SO4	Br	pH	Temp (°F)	Conductivity (µmho)
8/7/97	10:00	6.1								
8/7/97	10:00							9.64	163.4	
8/7/97	13:30							9.71	136	
8/7/97	17:00	5.2		5548	2999	95				
8/7/97	17:30							9.71		
8/8/97	4:45							9.48	162.5	
8/8/97	6:30								161.8	
8/8/97	8:00	5.4								
8/8/97	9:15								160.6	
8/8/97	9:15							9.42	163.5	
8/8/97	10:30							9.42	161.8	
8/8/97	10:45								158.4	
8/8/97	13:00							9.56		
8/8/97	15:00							9.63		
8/8/97	17:00	11.2			3233	98				
8/8/97	17:00	12.3			3186	96				
8/11/97	6:30							9.4	145.1	10300
8/11/97	7:45								142.5	
8/11/97	10:00	10.9							148.1	
8/11/97	11:30							9.51	152	10000
8/11/97	14:20								152.7	
8/11/97	14:30							9.55	134.8	10700
8/11/97	16:30				3178	91				
8/12/97	4:30							9.77	159.4	10400
8/12/97	7:30								119.7	
8/12/97	8:30	11.3								
8/12/97	9:00								147.0	
8/12/97	9:30							9.82	151.4	10400
8/12/97	12:00							9.52	154.6	10400
8/12/97	12:45								152.7	
8/12/97	13:30							9.48	134.8	10700
8/12/97	14:30							9.6	140	10900
8/12/97	15:00								153.8	
8/12/97	16:30	11.9								
8/12/97	19:00							7.28	130.2	10100
8/13/97	4:30							9.08	156.5	9200
8/13/97	11:00							9.71	151.8	9800
8/13/97	12:00							9.72	154.2	9900
8/13/97	13:00							9.73	154.6	9900
8/13/97	13:30								153.8	
8/13/97	14:30							9.68	157.1	10000
8/13/97	14:45								156.1	
8/13/97	15:30							9.66	158.9	9900
8/13/97	16:00	11.2								
8/13/97	19:00								156.1	
8/13/97	19:00							9.73	158.6	10000
8/14/97	4:30							9.55	153.6	9250
8/14/97	8:30							9.43	156.2	9510
8/14/97	9:15								155.0	
8/14/97	10:00	11.8								
8/14/97	11:00								156.1	
8/14/97	12:00							9.43	157.7	10400
8/14/97	13:15								156.1	
8/14/97	14:00							9.38	157.9	10300
8/14/97	15:00								153.8	
8/14/97	16:00							9.44	157.6	10600
8/14/97	17:00	11.1								
8/14/97	18:15							9.38	157.4	10500

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk (mg/L as CaCO3)	Tot Hard (mg/L as CaCO3)	Ca Hard (mg/L as CaCO3)	SiO2 (mg/L as SiO2)
8/15/97	4:30									
8/15/97	6:30									
8/15/97	9:30									
8/15/97	9:30									
8/15/97	10:00	9.66	73.8	0.8		2.121	648	14.2	8.2	17.2
8/15/97	11:45									
8/15/97	13:00									
8/15/97	13:45									
8/15/97	15:00									
8/15/97	15:45									
8/15/97	16:30	9.35	70.3	1		2.241	492	37.2	10.9	21.2
8/15/97	18:15									
8/18/97	7:00									
8/18/97	8:30									
8/18/97	10:15									
8/18/97	10:15									
8/18/97	12:15									
8/18/97	13:00									
8/18/97	14:00									
8/18/97	16:00	9.59	80.9	0.6		2.312	596	20.4	8.2	20.6
8/18/97	16:15									
8/18/97	18:15									
8/18/97	20:00									
8/19/97	5:00									
8/19/97	8:00									
8/19/97	8:15									
8/19/97	9:30									
8/19/97	10:00	9.37	69.9	0.7		2.251	536	22.8	5	31.8
8/19/97	11:00									
8/19/97	11:30									
8/19/97	13:30									
8/19/97	14:00									
8/19/97	15:15									
8/19/97	16:00	9.43	73.6	0.6		2.408	484	35	7.9	22.2
8/19/97	18:00									
8/19/97	18:30									
8/20/97	4:30									
8/20/97	6:00									
8/20/97	8:30									
8/20/97	8:30									
8/20/97	9:00	9.41	69.8	1.4		2.214	552	20.2	10.5	26
8/20/97	10:30									
8/20/97	12:00									
8/20/97	12:30									
8/20/97	14:15									
8/20/97	17:30									
8/20/97	18:00	9.48	69.8	1.4		2.408	556	20.4	7.1	23.2
8/20/97	19:00									
8/20/97	19:30									
8/21/97	5:00									
8/21/97	6:30									
8/21/97	7:30									
8/21/97	9:00									
8/21/97	9:15									
8/21/97	9:45	9.84	69.8	1.5		2.498	688	17.6	4.4	25.6
8/21/97	11:15									
8/21/97	13:45									
8/21/97	15:30									

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data											
		pH	Temp	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC
Date	Time		(°F)	(mg/L as Ion)									(mg/L)
8/15/97	4:30												
8/15/97	6:30												
8/15/97	9:30												
8/15/97	9:30												
8/15/97	10:00	9.7	72.7	12.8	0.03	6.2	0.9	2.6	73.8	2050			70
8/15/97	11:45												
8/15/97	13:00												
8/15/97	13:45												
8/15/97	15:00												
8/15/97	15:45												
8/15/97	16:30	9.32	71.6	13.2	0.18	5.6	1.3	7.2	76.2	2129			87
8/15/97	18:15												
8/18/97	7:00												
8/18/97	8:30												
8/18/97	10:15												
8/18/97	10:15												
8/18/97	12:15												
8/18/97	13:00												
8/18/97	14:00												
8/18/97	16:00			13.3	0.06	5.5	1.3	7	76	2100			75
8/18/97	16:15												
8/18/97	18:15												
8/18/97	20:00												
8/19/97	5:00												
8/19/97	8:00												
8/19/97	8:15												
8/19/97	9:30												
8/19/97	10:00			13	0.03	9.7	1.1	2.8	88	2110			79
8/19/97	11:00												
8/19/97	11:30												
8/19/97	13:30												
8/19/97	14:00												
8/19/97	15:15												
8/19/97	16:00	9.443	72.3										107
8/19/97	18:00												
8/19/97	18:30												
8/20/97	4:30												
8/20/97	6:00												
8/20/97	8:30												
8/20/97	8:30												
8/20/97	9:00	9.57	72.1	13.5	0.02	10	1	3	88	2200			90
8/20/97	10:30												
8/20/97	12:00												
8/20/97	12:30												
8/20/97	14:15												
8/20/97	17:30												
8/20/97	18:00	9.56	71.2	13.8	0.02	12.6	3.1	16.9	83.1	2084			96
8/20/97	19:00												
8/20/97	19:30												
8/21/97	5:00												
8/21/97	6:30												
8/21/97	7:30												
8/21/97	9:00												
8/21/97	9:15												
8/21/97	9:45	9.74	72.3	13.2	0.01	8.8	1.6	2.6	85.4	2223			84
8/21/97	11:15												
8/21/97	13:45												
8/21/97	15:30												

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data						Operational Data		
Date	Time	NH3 (mg/L as NH3)	TSS (mg/L)	TDS (mg/L)	Cl (mg/L as Ion)	SO4	Br	pH	Temp (°F)	Conductivity (µmho)
8/15/97	4:30							9.66	161.8	10600
8/15/97	6:30								158.4	
8/15/97	9:30								152.7	
8/15/97	9:30							9.79	154.5	10000
8/15/97	10:00	10.8								
8/15/97	11:45							9.78	153.5	10700
8/15/97	13:00								152.7	
8/15/97	13:45							9.55	154.9	10500
8/15/97	15:00								155.0	
8/15/97	15:45							9.42	157.1	10600
8/15/97	16:30	12.3								
8/15/97	18:15							9.59	157.5	10600
8/18/97	7:00							10.41	148	10800
8/18/97	8:30								147.0	
8/18/97	10:15								153.8	
8/18/97	10:15							9.21	155.5	9500
8/18/97	12:15							8.98	158.8	9500
8/18/97	13:00								156.1	
8/18/97	14:00							9.54	158.3	10200
8/18/97	16:00	11.9								
8/18/97	16:15							9.79	155.3	9900
8/18/97	18:15							9.83	159.9	10300
8/18/97	20:00								153.8	
8/19/97	5:00							9.9	161.8	10500
8/19/97	8:00								158.4	
8/19/97	8:15							9.82	161	10800
8/19/97	9:30							9.63		10400
8/19/97	10:00	11.3								
8/19/97	11:00								158.4	
8/19/97	11:30							9.33	159.8	10800
8/19/97	13:30							9.35	160	10900
8/19/97	14:00								158.4	
8/19/97	15:15							9.48	161.7	10800
8/19/97	16:00	11.9								
8/19/97	18:00							9.82	160.1	11000
8/19/97	18:30								156.1	
8/20/97	4:30							10.05	163.3	11200
8/20/97	6:00								160.6	
8/20/97	8:30								153.8	
8/20/97	8:30							9.71	157.1	10800
8/20/97	9:00	10.9								
8/20/97	10:30							9.5	159.2	10700
8/20/97	12:00								158.4	
8/20/97	12:30							9.19	160.2	10800
8/20/97	14:15							9.05	161.2	10900
8/20/97	17:30							9.7		
8/20/97	18:00	8.7								
8/20/97	19:00							9.92	163.2	10900
8/20/97	19:30								153.8	
8/21/97	5:00							10.96	160.5	12500
8/21/97	6:30							10.77		11700
8/21/97	7:30								153.8	
8/21/97	9:00								144.7	
8/21/97	9:15							9.55	156.3	10900
8/21/97	9:45	9.6								
8/21/97	11:15							9.25	155.8	10800
8/21/97	13:45								155.0	
8/21/97	15:30							8.75	159.7	10900

Field, Lab, and Operational Data
for DensaDeg Effluent

		Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
Date	Time		(°F)	(NTU)	(μmho)		(mg/L as CaCO3)			(mg/L as SiO2)
8/21/97	17:00	8.8	97.7	1.4		2.301	444	91	36	37.4
8/21/97	19:15									
8/21/97	19:15									
8/22/97	4:30									
8/22/97	6:15									
8/22/97	8:00									
8/22/97	8:15									
8/22/97	9:00	9.46	72.5	1.3		2.382	528	56	18	27
8/22/97	13:00									
8/22/97	13:30									
8/22/97	14:30									
8/22/97	15:00									
8/22/97	16:30	8.84	72.68	1.4		2.37	364	152	50.3	44.8
8/22/97	16:45									
8/22/97	18:00									
8/25/97	7:00									
8/25/97	8:00									
8/25/97	9:00									
8/25/97	10:00									
8/25/97	10:30	9.66	72.5	1.75		2.358	468	17.6	7.9	48
8/25/97	10:45									
8/25/97	11:15									
8/25/97	12:15									
8/25/97	12:45									
8/25/97	12:45									
8/25/97	14:30									
8/25/97	15:30									
8/25/97	16:30									
8/25/97	16:30									
8/25/97	17:45	9.14	75.2	1.4		2.382	392	34.8	16.1	25.5
8/25/97	17:45									
8/26/97	4:30									
8/26/97	8:00									
8/26/97	8:30									
8/26/97	10:15									
8/26/97	11:00	9.37	74.3	1.3		2.37	480	18	7.8	27.5
8/26/97	11:00									
8/26/97	12:15									
8/26/97	14:15									
8/26/97	14:15									
8/26/97	16:15									
8/26/97	17:00	9.24	71.6	1.6		2.515	384	29.6	14.8	21.5
8/26/97	17:00									
8/26/97	18:30									
8/26/97	19:15									
8/27/97	4:30									
8/27/97	7:45									
8/27/97	8:00									
8/27/97	8:45									
8/27/97	9:30	9.42	71.6	1.9		2.189	352	244	24.9	10
8/27/97	9:30									
8/27/97	10:15									
8/27/97	10:30									
8/27/97	11:15									
8/27/97	12:30									
8/27/97	12:45									
8/27/97	13:30									
8/27/97	14:30									

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	CLWA Lab Data											
		pH	Temp (°F)	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC (mg/L)
				(mg/L as Ion)									
8/21/97	17:00	8.81	71.4	12.9	0.05	22.5	6.3	18.9	84.3	2046			80
8/21/97	19:15												
8/21/97	19:15												
8/22/97	4:30												
8/22/97	6:15												
8/22/97	8:00												
8/22/97	8:15												
8/22/97	9:00	9.15	71.2	13.1	0.07	10.5	1.9	2	92.7	2367			130
8/22/97	13:00												
8/22/97	13:30												
8/22/97	14:30												
8/22/97	15:00												
8/22/97	16:30	8.57	71.4	13.4	0.55	22.5	6.3	18.87	84.3	2046			111
8/22/97	16:45												
8/22/97	18:00												
8/25/97	7:00												
8/25/97	8:00												
8/25/97	9:00												
8/25/97	10:00												
8/25/97	10:30	9.35	71.8	14.1	0.06	10.5	1.9	2	92.7	2367			89
8/25/97	10:45												
8/25/97	11:15												
8/25/97	12:15												
8/25/97	12:45												
8/25/97	12:45												
8/25/97	14:30												
8/25/97	15:30												
8/25/97	16:30												
8/25/97	16:30												
8/25/97	17:45	9.04	71.4	13.6	0.09	7.4	2.8	6.23	90	2181			105
8/25/97	17:45												134
8/26/97	4:30												
8/26/97	8:00												
8/26/97	8:30												
8/26/97	10:15												
8/26/97	11:00	6.77	71.6	13.3	0.1	9.8	1.8	1.3	94.6	2292			96
8/26/97	11:00												111
8/26/97	12:15												
8/26/97	14:15												
8/26/97	14:15												
8/26/97	16:15												
8/26/97	17:00	9.14	72	13.1	0.22	6.7	2.4	5.1	92.6	2285			108
8/26/97	17:00												139
8/26/97	18:30												
8/26/97	19:15												
8/27/97	4:30												
8/27/97	7:45												
8/27/97	8:00												
8/27/97	8:45												
8/27/97	9:30	9.26	71.4	8.1	0.08	1.9	2.7	49.49	86	2250			101
8/27/97	9:30												134
8/27/97	10:15												
8/27/97	10:30												
8/27/97	11:15												
8/27/97	12:30												
8/27/97	12:45												
8/27/97	13:30												
8/27/97	14:30												

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	CLWA Lab Data						Operational Data		
		NH3 (mg/L as NH3)	TSS (mg/L)	TDS (mg/L)	Cl (mg/L as Ion)	SO4	Br	pH	Temp (°F)	Conductivity (µmho)
8/21/97	17:00	8.1								
8/21/97	19:15								158.4	
8/21/97	19:15							9.46	59	11200
8/22/97	4:30							10.11	72	11100
8/22/97	6:15								157.2	
8/22/97	8:00							9.62	70.5	10200
8/22/97	8:15								156.1	
8/22/97	9:00	9								
8/22/97	13:00							8.79	65	11200
8/22/97	13:30								156.1	
8/22/97	14:30								156.1	
8/22/97	15:00							9.23	68	1100
8/22/97	16:30	8.1								
8/22/97	16:45							9.28		10900
8/22/97	18:00								156.1	
8/25/97	7:00								139.1	
8/25/97	8:00								139.1	
8/25/97	9:00								149.0	
8/25/97	10:00								149.0	
8/25/97	10:30	7.5								
8/25/97	10:45							9.56	155.3	11300
8/25/97	11:15								154.4	
8/25/97	12:15								156.2	
8/25/97	12:45								158.0	
8/25/97	12:45							9.41	158	11100
8/25/97	14:30							9.14	161.6	11200
8/25/97	15:30								159.8	
8/25/97	16:30								161.6	
8/25/97	16:30							9.25	163.4	11400
8/25/97	17:45	8.5			3325	125	13			
8/25/97	17:45									
8/26/97	4:30							10.59	111.2	10800
8/26/97	8:00								158.0	
8/26/97	8:30							10.08	76.1	10000
8/26/97	10:15							9.62	165.2	10900
8/26/97	11:00	8.7							159.8	
8/26/97	11:00									
8/26/97	12:15							9.32	163.4	10400
8/26/97	14:15								154.4	
8/26/97	14:15							9.85	158	10800
8/26/97	16:15							9.6	159.8	10500
8/26/97	17:00	8.7			3330	119	13			
8/26/97	17:00									
8/26/97	18:30									
8/26/97	19:15								158.0	
8/27/97	4:30							10.37	160,7	10800
8/27/97	7:45								158.0	
8/27/97	8:00							9.26	161.6	11800
8/27/97	8:45								158.0	
8/27/97	9:30	10.6								
8/27/97	9:30									
8/27/97	10:15								167.0	
8/27/97	10:30							9.32	166.1	12100
8/27/97	11:15								161.6	
8/27/97	12:30								179.6	
8/27/97	12:45							9.33	166.1	
8/27/97	13:30								185.0	
8/27/97	14:30								186.8	

Field, Lab, and Operational Data
for DensaDeg Effluent

		Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			(mg/L as SiO2)
8/27/97	14:45									
8/27/97	15:30									
8/27/97	15:45	9.37	71.6	5.2		2.081	396	1260	6.9	12.5
8/27/97	15:45									
8/27/97	18:00									
8/28/97	6:30									
8/28/97	9:30									
8/28/97	10:30									
8/28/97	11:30	9.33	71.6	7.4		2.094	372	256	10.4	14.2
8/28/97	11:30									
8/28/97	11:45									
8/28/97	14:00									
8/28/97	16:00									
8/28/97	16:30									
8/28/97	18:00									
8/28/97	19:00	9.26	71.6	1.9		2.197	392	216	19.1	13.8
8/28/97	19:00									
8/29/97	5:00									
8/29/97	8:00									
8/29/97	9:00									
8/29/97	9:30									
8/29/97	10:00	9.51	71.6	1.9		2.157	452	124	12.8	12.5
8/29/97	11:45									
8/29/97	14:00									
8/29/97	16:00									
8/29/97	16:00	9.34	77	1.2		2.173	408	92	11.4	17.5
8/29/97	16:00									
8/29/97	18:00									

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data											
		pH	Temp	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC
Date	Time		(°F)	(mg/L as Ion)									(mg/L)
8/27/97	14:45												
8/27/97	15:30												
8/27/97	15:45	9.43	71.6	6.7		0.9	2.3	57.8	95.82	2698			145
8/27/97	15:45												101
8/27/97	18:00												
8/28/97	6:30												
8/28/97	9:30												
8/28/97	10:30												
8/28/97	11:30	9.34	71.6	6.7		1.7	2.6	61.6	92.36	2533			159
8/28/97	11:30												142
8/28/97	11:45												
8/28/97	14:00												
8/28/97	16:00												
8/28/97	16:30												
8/28/97	18:00												
8/28/97	19:00	9.34	72.3	9.14		2.6	2.7	41.3	98.23	2615			105
8/28/97	19:00												102
8/29/97	5:00												
8/29/97	8:00												
8/29/97	9:00												
8/29/97	9:30												
8/29/97	10:00	9.57	72.5										
8/29/97	11:45												
8/29/97	14:00												
8/29/97	16:00												118
8/29/97	16:00	9.47	55	10.29	0.01	4.5	1.3	7.8	71.12	2086			131
8/29/97	16:00												
8/29/97	18:00												

Field, Lab, and Operational Data
for DensaDeg Effluent

		CLWA Lab Data						Operational Data		
		NH3	TSS	TDS	Cl	SO4	Br	pH	Temp	Conductivity
Date	Time	(mg/L as NH3)	(mg/L)	(mg/L)	(mg/L as Ion)				(°F)	(µmho)
8/27/97	14:45							9.45	161.6	12100
8/27/97	15:30								186.8	
8/27/97	15:45	10.5			3823	149	16			
8/27/97	15:45				3821	151	16			
8/27/97	18:00								158.0	
8/28/97	6:30							10.28	158.9	12100
8/28/97	9:30							9.75	160.7	12000
8/28/97	10:30								179.4	
8/28/97	11:30	10.4								
8/28/97	11:30									
8/28/97	11:45							9.93	159.8	12100
8/28/97	14:00							9.79	157.1	11600
8/28/97	16:00							9.6	156.2	11300
8/28/97	16:30								166.1	
8/28/97	18:00							9.61	156.2	11500
8/28/97	19:00	10.4								
8/28/97	19:00									
8/29/97	5:00							9.98	161.6	
8/29/97	8:00								164.1	
8/29/97	9:00								164.1	
8/29/97	9:30							9.52	152.6	
8/29/97	10:00	11							162.0	
8/29/97	11:45							9.21	156.2	10800
8/29/97	14:00							9.31	159.8	10900
8/29/97	16:00									
8/29/97	16:00	11.9								
8/29/97	16:00							9.56	160.7	10900
8/29/97	18:00								157.2	

Lab and Operational Data for DensaDeg Sludge

Date	Time	Location	CLWA lab Data									
			Na	Ba	Sr	Mn	Mo	Cl	SO4	Br	NO3	Wt % Solids
			(mg/L as Ion or mg/kg as solid)									
8/1/97	6:30	Blowdown										
8/4/97	8:00	Blowdown										
8/5/97	10:00	Blowdown										
8/6/97	5:00	Blowdown										
8/7/97	5:00	Blowdown										
8/7/97	5:30	Blowdown										
8/7/97	20:30	Blowdown										
8/7/97	21:00	Blowdown										
8/8/97	5:30	Blowdown										
8/8/97	6:30	Blowdown										
8/8/97	8:30	Blowdown										
8/11/97	7:45	Blowdown										
8/11/97	11:45	Blowdown										
8/12/97	5:00	Blowdown										
8/12/97	7:30	Blowdown										
8/12/97	10:00	Blowdown										
8/12/97	16:30	Sludge (liquid)						3026	78	10	3	
8/13/97	4:30	Blowdown										
8/13/97	16:00	Sludge (liquid)	2000	0.017		0.001	0.013	2727	94	12	2	
8/13/97	16:00	Sludge (Solid)	2500	150		84	1					9.5
8/14/97	4:30	Blowdown										
8/14/97	10:45	Blowdown										
8/14/97	11:30	Blowdown										
8/14/97	17:00	Sludge (liquid)	2400	0.019		0.021	0.01	2505	94	11	4	
8/14/97	17:00	Sludge (Solid)	2000	150		79	1					8.4
8/14/97	20:00	Blowdown										
8/15/97	4:30	Blowdown										
8/15/97	7:00	Blowdown										
8/15/97	8:30	Blowdown										
8/15/97	16:30	Sludge (liquid)	2200	0.025		0.025	0.01	3203	108	14		
8/15/97	16:30	Sludge (Solid)	2100	130		73	1					6.6
8/15/97	20:00	Blowdown										
8/18/97	4:30	Blowdown										
8/18/97	5:30	Blowdown										
8/18/97	6:30	Blowdown										
8/18/97	16:00	Sludge (liquid)						3238	116	14		
8/18/97	19:30	Blowdown										
8/19/97	4:30	Blowdown										
8/19/97	8:15	Blowdown										
8/19/97	18:45	Blowdown										
8/20/97	4:30	Blowdown										
8/20/97	5:15	Blowdown										
8/20/97	6:15	Blowdown										
8/20/97	7:00	Blowdown										
8/20/97	8:00	Blowdown										
8/20/97	20:00	Blowdown										
8/21/97	5:00	Blowdown										
8/21/97	7:30	Blowdown										
8/21/97	8:30	Blowdown										
8/21/97	9:00	Blowdown										
8/21/97	20:00	Blowdown										
8/22/97	4:30	Blowdown										
8/22/97	6:00	Blowdown										
8/22/97	6:30	Blowdown										
8/25/97	5:30	Blowdown										
8/25/97	19:30	Blowdown										
8/26/97	4:30	Blowdown										
8/26/97	8:00	Blowdown										
8/26/97	9:00	Blowdown										
8/26/97	19:30	Blowdown										
8/27/97	4:30	Blowdown										

Lab and Operational Data
for DensaDeg Sludge

Date	Time	Location	Operational Data	
			Sludge Level (ft)	Sludge Blowtime Time (sec)
8/1/97	6:30	Blowdown	10	375
8/4/97	8:00	Blowdown	4	600
8/5/97	10:00	Blowdown	10	150
8/6/97	5:00	Blowdown	10	300
8/7/97	5:00	Blowdown	10	300
8/7/97	5:30	Blowdown	9	600
8/7/97	20:30	Blowdown	6	240
8/7/97	21:00	Blowdown		60
8/8/97	5:30	Blowdown	10	300
8/8/97	6:30	Blowdown	10	150
8/8/97	8:30	Blowdown	10	900
8/11/97	7:45	Blowdown	6	
8/11/97	11:45	Blowdown	66	180
8/12/97	5:00	Blowdown	7	180
8/12/97	7:30	Blowdown	6	600
8/12/97	10:00	Blowdown	2	
8/12/97	16:30	Sludge (liquid)		
8/13/97	4:30	Blowdown	5	
8/13/97	16:00	Sludge (liquid)		
8/13/97	16:00	Sludge (Solid)		
8/14/97	4:30	Blowdown	8	
8/14/97	10:45	Blowdown	9	300
8/14/97	11:30	Blowdown	6	600
8/14/97	17:00	Sludge (liquid)		
8/14/97	17:00	Sludge (Solid)		
8/14/97	20:00	Blowdown	6	420
8/15/97	4:30	Blowdown	8	
8/15/97	7:00	Blowdown	8	150
8/15/97	8:30	Blowdown	6	300
8/15/97	16:30	Sludge (liquid)		
8/15/97	16:30	Sludge (Solid)		
8/15/97	20:00	Blowdown	6	300
8/18/97	4:30	Blowdown	10	
8/18/97	5:30	Blowdown	10	600
8/18/97	6:30	Blowdown	4	75
8/18/97	16:00	Sludge (liquid)		
8/18/97	19:30	Blowdown	4	500
8/19/97	4:30	Blowdown	5	
8/19/97	8:15	Blowdown	5	300
8/19/97	18:45	Blowdown	4	300
8/20/97	4:30	Blowdown	7	
8/20/97	5:15	Blowdown	7	180
8/20/97	6:15	Blowdown	6	360
8/20/97	7:00	Blowdown	4	180
8/20/97	8:00	Blowdown	4	75
8/20/97	20:00	Blowdown	3	120
8/21/97	5:00	Blowdown	7	
8/21/97	7:30	Blowdown	7	300
8/21/97	8:30	Blowdown	5	600
8/21/97	9:00	Blowdown	4	300
8/21/97	20:00	Blowdown	4	120
8/22/97	4:30	Blowdown	7	
8/22/97	6:00	Blowdown	7	300
8/22/97	6:30	Blowdown	4	180
8/25/97	5:30	Blowdown	3	
8/25/97	19:30	Blowdown	4	120
8/26/97	4:30	Blowdown	6	
8/26/97	8:00	Blowdown	6	360
8/26/97	9:00	Blowdown	4	
8/26/97	19:30	Blowdown	4	360
8/27/97	4:30	Blowdown	6	

Lab and Operational Data
for DensaDeg Sludge

			CLWA lab Data								
			pH	Temp	Alkalinity	B	Fe	Si	Ca	Mg	K
Date	Time	Location		(°F)	(mg/L as CaCO3)	(mg/L as Ion or mg/kg as solid)					
8/27/97	7:30	Blowdown									
8/27/97	10:45	Blowdown									
8/27/97	13:30	Blowdown									
8/27/97	13:45	Blowdown									
8/27/97	14:45	Blowdown									
8/27/97	15:05	Blowdown									
8/27/97	15:15	Blowdown									
8/27/97	18:45	Blowdown									
8/28/97	4:30	Blowdown									
8/28/97	6:30	Blowdown									
8/28/97	8:30	Blowdown									
8/28/97	10:30	Blowdown									
8/28/97	12:00	Blowdown									
8/28/97	15:30	Blowdown									
8/28/97	19:00	Sludge (liquid)	10.2	72.7	11854	12	0.024	1.2	2.7	78	78
8/28/97	19:00	Sludge (Solid)				650	250	800	21000	16000	71
8/29/97	5:00	Blowdown									
8/29/97	7:00	Blowdown									
8/29/97	10:00	Sludge (liquid)	10.4	72.5	14866	8.8	0.02	1.6	2.7	64	86
8/29/97	10:00	Sludge (Solid)				550	280	850	17000	12000	61
8/29/97	11:00	Blowdown									
9/4/97	16:00	Sludge (Clay)				290	650	850	33000	10000	137
9/4/97	16:00	Sludge (Dry)				1100	3900	800	140000	57000	1145

Lab and Operational Data
for DensaDeg Sludge

			CLWA lab Data									
			Na	Ba	Sr	Mn	Mo	Cl	SO4	Br	NO3	Wt % Solids
Date	Time	Location	(mg/L as Ion or mg/kg as solid)									
8/27/97	7:30	Blowdown										
8/27/97	10:45	Blowdown										
8/27/97	13:30	Blowdown										
8/27/97	13:45	Blowdown										
8/27/97	14:45	Blowdown										
8/27/97	15:05	Blowdown										
8/27/97	15:15	Blowdown										
8/27/97	18:45	Blowdown										
8/28/97	4:30	Blowdown										
8/28/97	6:30	Blowdown										
8/28/97	8:30	Blowdown										
8/28/97	10:30	Blowdown										
8/28/97	12:00	Blowdown										
8/28/97	15:30	Blowdown										
8/28/97	19:00	Sludge (liquid)	2300	0.044		0.001	0.009	3643	144	14		
8/28/97	19:00	Sludge (Solid)	2300	94		44	1					2.2
8/29/97	5:00	Blowdown										
8/29/97	7:00	Blowdown										
8/29/97	10:00	Sludge (liquid)	2200	0.02		0.001	0.009	3557	138	15		
8/29/97	10:00	Sludge (Solid)	2100	81		40	1					2.6
8/29/97	11:00	Blowdown										
9/4/97	16:00	Sludge (Clay)	3700	130		72	1					18.2
9/4/97	16:00	Sludge (Dry)	18000	600		410	1					90.2

Lab and Operational Data
for DensaDeg Sludge

			Operational Data	
Date	Time	Location	Sludge Level (ft)	Sludge Blowtime Time (sec)
8/27/97	7:30	Blowdown	6	360
8/27/97	10:45	Blowdown		360
8/27/97	13:30	Blowdown		45
8/27/97	13:45	Blowdown		180
8/27/97	14:45	Blowdown		120
8/27/97	15:05	Blowdown		60
8/27/97	15:15	Blowdown		180
8/27/97	18:45	Blowdown		120
8/28/97	4:30	Blowdown	10	600
8/28/97	6:30	Blowdown	10	300
8/28/97	8:30	Blowdown	10	240
8/28/97	10:30	Blowdown	10	120
8/28/97	12:00	Blowdown	10	120
8/28/97	15:30	Blowdown		240
8/28/97	19:00	Sludge (liquid)		
8/28/97	19:00	Sludge (Solid)		
8/29/97	5:00	Blowdown	9	
8/29/97	7:00	Blowdown	9	600
8/29/97	10:00	Sludge (liquid)		
8/29/97	10:00	Sludge (Solid)		
8/29/97	11:00	Blowdown	7	120
9/4/97	16:00	Sludge (Clay)		
9/4/97	16:00	Sludge (Dry)		

OPERATIONAL DATA
FOR HEAT EXCHANGER EFFLUENT

Date	Time	Operational Data	Date	Time	Operational Data	Date	Time	Operational Data
		Temp (°F)			Temp (°F)			Temp (°F)
7/15/97	6:00	70.7	8/14/97	9:15	77.6	8/27/97	13:30	89.6
7/15/97	7:45	73.3	8/14/97	11:00	87.9	8/27/97	14:30	100.4
7/16/97	6:00	73.3	8/14/97	13:15	88.7	8/27/97	15:30	99.5
7/16/97	7:00	73.3	8/14/97	15:00	90.5	8/27/97	18:00	92.3
7/16/97	8:00	74.1	8/15/97	6:30	64.7	8/28/97	10:30	95.6
7/17/97	8:00	75.0	8/15/97	9:30	72.4	8/28/97	16:30	101.8
7/23/97	5:45	69.8	8/15/97	13:00	85.3	8/29/97	8:00	84.8
7/23/97	8:00	69.8	8/15/97	15:00	87.0	8/29/97	9:00	91.0
7/23/97	9:00	81.0	8/18/97	8:30	69.8	8/29/97	10:00	96.4
7/24/97	6:30	65.6	8/18/97	10:15	81.0	8/29/97	18:00	89.6
7/24/97	8:30	75.9	8/18/97	13:00	89.6			
7/24/97	10:30	82.7	8/18/97	20:00	92.2			
7/24/97	12:30	87.9	8/19/97	8:00	78.4			
7/25/97	8:30	75.0	8/19/97	11:00	87.9			
7/25/97	10:30	82.7	8/19/97	14:00	90.5			
7/28/97	6:45	63.8	8/19/97	18:30	81.9			
7/28/97	9:30	71.6	8/20/97	6:00	73.3			
7/28/97	11:45	75.9	8/20/97	8:30	78.4			
7/29/97	6:00	63.8	8/20/97	12:00	88.7			
7/29/97	8:15	68.1	8/20/97	19:36	83.6			
7/29/97	10:30	76.7	8/21/97	7:30	73.3			
7/30/97	6:15	63.0	8/21/97	9:00	78.4			
7/30/97	7:00	64.7	8/21/97	13:45	95.6			
7/30/97	9:15	73.3	8/21/97	19:15	89.6			
7/30/97	11:00	80.2	8/22/97	6:15	75.0			
7/31/97	4:45	73.3	8/22/97	8:15	76.7			
7/31/97	9:30	79.3	8/22/97	13:30	99.1			
7/31/97	12:30	99.1	8/22/97	14:30	107.6			
8/1/97	5:00	74.1	8/22/97	18:00	105.9			
8/4/97	10:30	94.8	8/25/97	7:00	73.4			
8/4/97	11:30	95.6	8/25/97	8:00	73.4			
8/6/97	9:30	95.6	8/25/97	9:00	77.9			
8/7/97	8:30	87.0	8/25/97	10:00	88.7			
8/7/97	9:45	88.7	8/25/97	11:15	90.5			
8/8/97	6:30	73.3	8/25/97	12:15	91.4			
8/8/97	9:15	81.9	8/25/97	12:45	93.2			
8/8/97	10:45	87.0	8/25/97	15:30	85.1			
8/11/97	7:45	64.7	8/25/97	16:30	86.0			
8/11/97	10:00	74.1	8/26/97	8:00	71.6			
8/11/97	14:20	81.9	8/26/97	11:00	91.4			
8/12/97	7:30	68.1	8/26/97	14:15	98.6			
8/12/97	9:00	73.3	8/26/97	19:15	86.0			
8/12/97	12:45	82.7	8/27/97	7:45	74.3			
8/12/97	15:00	86.2	8/27/97	8:45	77.9			
8/13/97	13:30	90.5	8/27/97	10:15	87.8			
8/13/97	14:45	91.3	8/27/97	11:15	85.1			
8/13/97	19:00	87.9	8/27/97	12:30	86.9			

OPERATIONAL DATA FOR TRICKLING FILTER

		Operational Data
Date	Time	Flow (gpm)
7/23/97	5:45	1.0
7/23/97	9:00	1.1
7/23/97	11:00	1.1
7/24/97	6:30	1.0
7/24/97	8:30	1.0
7/24/97	10:30	1.1
7/24/97	12:30	1.2
7/25/97	8:30	1.1
7/25/97	10:45	1.1
7/28/97	6:30	1.0
7/28/97	9:30	1.0
7/28/97	11:45	1.1
7/29/97	6:15	1.0
7/29/97	8:15	1.0
7/29/97	10:30	1.1
7/30/97	6:15	1.0
7/30/97	6:30	1.0
7/30/97	9:15	1.0
7/30/97	11:00	1.0
7/31/97	4:45	1.0
7/31/97	9:30	1.0
8/1/97	5:00	1.0
8/4/97	10:30	1.1
8/4/97	11:30	0.9
8/6/97	9:30	1.1
8/7/97	8:30	1.0
8/7/97	9:45	1.1
8/8/97	6:30	1.0
8/8/97	9:15	1.0
8/8/97	10:45	1.0
8/11/97	2:20	1.0
8/11/97	7:45	0.9
8/11/97	10:00	1.0
8/12/97	7:30	1.0
8/12/97	9:00	1.0
8/12/97	12:45	1.1
8/12/97	15:00	1.1
8/13/97	13:30	1.0
8/13/97	14:45	1.0
8/13/97	19:00	1.0
8/14/97	9:15	1.1
8/14/97	11:00	1.2
8/14/97	13:15	1.2
8/14/97	15:00	1.2
8/15/97	6:30	0.9
8/15/97	9:30	1.0
8/15/97	13:00	1.0
8/15/97	15:00	1.1
8/18/97	8:30	1.1
8/18/97	10:15	1.1
8/18/97	13:00	1.1
8/18/97	20:00	1.1
8/19/97	8:00	1.0
8/19/97	11:00	1.0
8/19/97	14:00	1.0
8/19/97	18:30	1.0
8/20/97	6:00	1.0
8/20/97	8:30	1.1
8/20/97	12:00	1.1
8/20/97	19:36	0.6
8/21/97	7:30	9.2
8/21/97	9:00	9.4
8/21/97	13:45	9.9
8/21/97	14:15	9.8
8/22/97	6:15	9.1
8/22/97	8:15	9.2
8/22/97	14:30	10.0
8/22/97	18:00	10.0
8/25/97	7:00	9.9
8/25/97	9:00	9.9
8/25/97	10:30	10.0
8/25/97	11:30	10.0
8/25/97	12:30	10.0
8/25/97	14:00	10.0
8/25/97	15:45	10.0
8/25/97	16:45	10.0
8/26/97	8:00	9.3
8/26/97	11:00	10.2
8/26/97	14:30	10.2
8/26/97	19:15	10.2

FIELD, LAB, AND OPERATIONAL DATA FOR TRICKLING FILTER SUMP

		Field Data			CLWA lab Data				
Date	Time	pH	Temp (°F)	UV Abs	pH	Temp (°F)	Alkalinity (mg/L as CaCO3)	TOC (mg/L)	NH3 (mg/L as NH3)
8/6/97	16:00								1.8
8/8/97	17:00								4.3
8/11/97	10:00								0.8
8/15/97	16:30							84	7.5
8/18/97	6:30							72	1
8/18/97	16:00							66	9
8/19/97	10:00							67	5.8
8/19/97	16:00				7.97	72.1		92	5.4
8/20/97	9:00							80	3.5
8/20/97	18:00							79	
8/21/97	9:45							83	4.9
8/21/97	17:00	8.59	72.5	2.301	8.2	72	1412	75	8.7
8/22/97	9:00	9.53	69.8	2.346				79	7.9
8/22/97	16:30	8.89	73.22	2.422	8.4	71.2	1197	108	8.5
8/25/97	7:00								
8/25/97	9:00								
8/25/97	10:30	9.63	72.5	2.346				114	8.4
8/25/97	10:30								
8/25/97	11:30								
8/25/97	12:30								
8/25/97	14:00								
8/25/97	15:45								
8/25/97	16:45								
8/25/97	17:45	9.22	74.3	2.37				103	5.9
8/26/97	8:00								
8/26/97	11:00	9.42	73.4	2.382				91	8.5
8/26/97	11:00								
8/26/97	14:30								
8/26/97	17:00	9.31	69.8	2.552				113	8.5
8/26/97	18:30								
8/26/97	19:15								

Field, Lab, and Operational Data
for Filter Effluent

Date	Time	Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
							(mg/L as CaCO3)			(mg/L as SiO2)
6/24/97	18:00									
7/2/97	19:00									
7/2/97	19:20							46	33	
7/2/97	19:40									
7/2/97	20:00							53	39	
7/3/97	11:00									
7/3/97	14:30									
7/3/97	18:00							17.2	5.2	
7/8/97	16:00			3.2						
7/8/97	17:00									
7/9/97	12:30			0.94						
7/10/97	6:00	9.37					448	25.2	4.8	32.8
7/14/97	17:30	9.26		3.7			438	34.8	10.2	5.6
7/15/97	4:40	10.42					656			24.8
7/15/97	5:00			0.5						
7/15/97	6:00									
7/15/97	6:00									
7/15/97	7:45									
7/15/97	7:45									
7/15/97	11:00			0.9						
7/15/97	11:15									
7/15/97	11:15									
7/15/97	17:00	9.66		0.69			466			
7/16/97	6:00									
7/16/97	6:00									
7/16/97	7:00									
7/16/97	7:00									
7/16/97	8:00									
7/16/97	8:00									
7/17/97	8:45									
7/17/97	8:45									
7/17/97	19:30			0.93						
7/22/97	18:30					2.051	382			66.8
7/23/97	5:45									
7/23/97	5:45									
7/23/97	7:30	9.25				2.057	422	26	9.6	37.6
7/23/97	9:00									
7/23/97	9:00									
7/23/97	11:00									
7/23/97	11:00									
7/23/97	18:00	9.52	71		8860	2.232	472	29.6	12.9	
7/24/97	6:30									
7/24/97	6:30									
7/24/97	6:45	8.93			9300	2.075	468	22.8	8.2	
7/24/97	8:30									
7/24/97	8:30									
7/24/97	10:30									
7/24/97	10:30									
7/24/97	12:30									
7/24/97	12:30									
7/24/97	19:00	9.46		0.62	7800	2.436	422	27.8	9.4	
7/25/97	7:45	8.99	73.6		9800	2.022	474	42.2	13.4	23.9
7/25/97	8:30									
7/25/97	8:30									
7/25/97	10:45									

Field, Lab, and Operational Data
for Filter Effluent

		CLWA lab Data									
		B	Fe	Si	Ca	Mg	Ba	Sr	TOC	NH3	TDS
Date	Time	(mg/L as Ion)							(mg/L)	(mg/L as NH3)	(mg/L)
6/24/97	18:00	15	0.12	49	5	27	0.3	0.25			
7/2/97	19:00	13.3	0.01	34	1	1	0.01	0.03			
7/2/97	19:20										
7/2/97	19:40	13.1	0.045	32	1	0.9	0.012	0.06			
7/2/97	20:00										
7/3/97	11:00	14	0.049	113	224	77	0.037	0.01			
7/3/97	14:30										
7/3/97	18:00										
7/8/97	16:00										
7/8/97	17:00										
7/9/97	12:30										
7/10/97	6:00										
7/14/97	17:30										
7/15/97	4:40										
7/15/97	5:00										
7/15/97	6:00										
7/15/97	6:00										
7/15/97	7:45										
7/15/97	7:45										
7/15/97	11:00										
7/15/97	11:15										
7/15/97	11:15										
7/15/97	17:00										
7/16/97	6:00										
7/16/97	6:00										
7/16/97	7:00										
7/16/97	7:00										
7/16/97	8:00										
7/16/97	8:00										
7/17/97	8:45										
7/17/97	8:45										
7/17/97	19:30										
7/22/97	18:30										
7/23/97	5:45										
7/23/97	5:45										
7/23/97	7:30										
7/23/97	9:00										
7/23/97	9:00										
7/23/97	11:00										
7/23/97	11:00										
7/23/97	18:00										
7/24/97	6:30										
7/24/97	6:30										
7/24/97	6:45										
7/24/97	8:30										
7/24/97	8:30										
7/24/97	10:30										
7/24/97	10:30										
7/24/97	12:30										
7/24/97	12:30										
7/24/97	19:00										
7/25/97	7:45										
7/25/97	8:30										
7/25/97	8:30										
7/25/97	10:45										

Field, Lab, and Operational Data
for Filter Effluent

Date	Time	Operational Data			
		Pressure (psi)	Flow (gpm)	SDI	Filter Aid Dosing Rate (mL/min)
6/24/97	18:00				
7/2/97	19:00				
7/2/97	19:20				
7/2/97	19:40				
7/2/97	20:00				
7/3/97	11:00				
7/3/97	14:30			5.88	
7/3/97	18:00				
7/8/97	16:00				
7/8/97	17:00			5.81	
7/9/97	12:30				
7/10/97	6:00				
7/14/97	17:30				
7/15/97	4:40				
7/15/97	5:00				
7/15/97	6:00		2.2		
7/15/97	6:00	71			
7/15/97	7:45		2.2		
7/15/97	7:45	71			
7/15/97	11:00				
7/15/97	11:15		2.2		
7/15/97	11:15	71			
7/15/97	17:00				
7/16/97	6:00		1.8		
7/16/97	6:00	110			
7/16/97	7:00		1.8		
7/16/97	7:00	110			
7/16/97	8:00		1.8		
7/16/97	8:00	110			
7/17/97	8:45		2.7		
7/17/97	8:45	58			
7/17/97	19:30				
7/22/97	18:30				
7/23/97	5:45		8.8		
7/23/97	5:45	96			
7/23/97	7:30				
7/23/97	9:00		9.8		
7/23/97	9:00	84			
7/23/97	11:00		9.8		
7/23/97	11:00	89			
7/23/97	18:00				
7/24/97	6:30		9.4		
7/24/97	6:30	100			
7/24/97	6:45				
7/24/97	8:30		9.8		
7/24/97	8:30	93			
7/24/97	10:30		9.9		
7/24/97	10:30	94			
7/24/97	12:30		10.2		
7/24/97	12:30	92			
7/24/97	19:00				
7/25/97	7:45				
7/25/97	8:30		9.7		
7/25/97	8:30	96			
7/25/97	10:45		10.0		

Field, Lab, and Operational Data
for DensaDeg Effluent

Date	Time	Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk (mg/L as CaCO3)	Tot Hard (mg/L as CaCO3)	Ca Hard (mg/L as CaCO3)	SiO2 (mg/L as SiO2)
5/16/97	11:30	8.47					460.4	328		
5/16/97	14:30	8.69					455.7	105.7	52.2	
5/20/97	17:00		149				456	464	148	163.2
5/21/97	12:30		143.6				409.2	450	148	143.6
6/2/97	16:30	7.21	138.2				490	792	194	147.5
6/3/97	10:00	10.95						7.3	4.1	98.4
6/3/97	18:20	8.99	132.8	1.7			542	83.2	12.2	85.6
6/4/97	12:00	8.85	111.2	1.2			484	112.4	16.1	64
6/4/97	15:00	8.34	73.76	1.3			438	225.6	38.6	72
6/5/97	10:00	10.78	96.98	20			838	3.2	3.1	57.2
6/5/97	17:15	9.05	80.6				502	99.2	17.2	60
6/6/97	10:00	9.44	84.2	2.5			548	23.2	6	32.4
6/6/97	12:15	9.28	84.2	2			548	23.2	6	32.4
6/12/97	9:45	8.58	102.2				430	214.2	51.6	63.2
6/13/97	10:30	8.67	84.2	1.5			460	174.2	22.8	66.4
6/13/97	16:40	9.03	104				434	58.4	23.5	
6/20/97	9:00						448	187	17.2	83.6
6/25/97	11:30									
6/25/97	16:00									
7/1/97	16:00	8.62					414	164	19.8	84.5
7/1/97	17:00	8.76					412	108	14.2	76.4
7/1/97	18:30	9.18					416	32.4	6.4	51.2
7/3/97	11:00	9.02					404	21.6	6	92.8
7/3/97	16:30	9.28					406	15.2	7	62.4
7/8/97	16:00			3.9						
7/9/97	9:50									
7/9/97	10:15	9.95					586	64	36	42.4
7/9/97	12:30			7.7						
7/9/97	22:30									
7/10/97	4:45									
7/10/97	6:00	9.38					490	25.6	5.8	
7/11/97	4:30									
7/11/97	6:30									
7/14/97	4:30									
7/14/97	5:30									
7/14/97	6:15									
7/14/97	8:00									
7/14/97	10:00									
7/14/97	17:30	9.3		27			440	20.4	6.4	6.7
7/15/97	4:40	10.4					682	3.8	2.2	48.8
7/15/97	4:45									
7/15/97	5:00			2						
7/15/97	6:00									
7/15/97	7:00									
7/15/97	7:45									
7/15/97	8:15									
7/15/97	9:00									
7/15/97	11:00			3.3						
7/15/97	11:30									
7/15/97	17:00	9.7		1.3			488	10.6	4.6	28.2
7/16/97	5:45									
7/16/97	6:00									
7/16/97	6:30									
7/16/97	7:00									
7/16/97	7:45									
7/16/97	8:00									
7/16/97	8:30									
7/16/97	8:45									

Field, Lab, and Operational Data
for Filter Effluent

		Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)
Date	Time						(mg/L as CaCO3)			
7/25/97	10:45									
7/25/97	10:45									
7/28/97	6:45									
7/28/97	6:45									
7/28/97	8:00	8.85	70.7	1	10100	2.094	464	74.8	19.6	
7/28/97	9:30									
7/28/97	9:30									
7/28/97	9:30									
7/28/97	11:45									
7/28/97	11:45									
7/28/97	17:00	8.56	68.8	0.73	9390	2.165	496	26.6	13.8	
7/29/97	6:15									
7/29/97	6:15									
7/29/97	7:00	9.15	70	1	10300	2.128	492	28.8	11	
7/29/97	8:15									
7/29/97	8:15									
7/29/97	10:15									
7/29/97	10:30									
7/29/97	10:30									
7/30/97	6:15									
7/30/97	6:15									
7/30/97	6:30									
7/30/97	6:30									
7/30/97	7:30	9.33	69.6	0.9	10100	2.157	500	11	7	
7/30/97	9:15									
7/30/97	9:15									
7/30/97	11:00									
7/30/97	11:00									
7/30/97	18:00	9.63	69.7	0.63	9990	2.358	492	12	7	
7/31/97	4:45									
7/31/97	4:45									
7/31/97	8:00	9.28	69.2	1.1	10600	2.088	494	32.6	10.4	
7/31/97	9:30									
7/31/97	9:30									
7/31/97	12:30									
7/31/97	18:00	9.46	67.9		10200	2.223	442	25.8	9.6	
7/31/97	10:00									
8/1/97	5:00									
8/1/97	5:00									
8/1/97	10:00	9.03	70.2	0.8	10600	2.033	470	33.8	12.8	29.4
8/4/97	10:00	8.52	77.5		4500	2.107	466	46	25.2	42.6
8/4/97	10:30									
8/4/97	11:30									
8/6/97	9:30									
8/6/97	9:30									
8/6/97	10:00	9.71	74.3	0.8	10800	2.121	530	10.4	6.8	28.8
8/6/97	16:00	9.52	72.3	0.57	10300	2.27	466	21.6	8.4	
8/7/97	8:30									
8/7/97	8:30									
8/7/97	9:45									
8/7/97	9:45									
8/7/97	10:00	9.26	73.1	0.75	10100	2.436	492	17.4	11.5	
8/7/97	17:00	9.84	71.3	0.58	9700	2.358	592	13.4	6.7	
8/8/97	6:30									
8/8/97	6:30									

Field, Lab, and Operational Data
for Filter Effluent

		CLWA lab Data									
		B	Fe	Si	Ca	Mg	Ba	Sr	TOC	NH3	TDS
Date	Time	(mg/L as Ion)							(mg/L)	(mg/L as NH3)	(mg/L)
7/25/97	10:45										
7/25/97	10:45										
7/28/97	6:45										
7/28/97	6:45										
7/28/97	8:00										
7/28/97	9:30										
7/28/97	9:30										
7/28/97	9:30										
7/28/97	11:45										
7/28/97	11:45										
7/28/97	17:00										
7/29/97	6:15										
7/29/97	6:15										
7/29/97	7:00										
7/29/97	8:15										
7/29/97	8:15										
7/29/97	10:15										
7/29/97	10:30										
7/29/97	10:30										
7/30/97	6:15										
7/30/97	6:15										
7/30/97	6:30										
7/30/97	6:30										
7/30/97	7:30										
7/30/97	9:15										
7/30/97	9:15										
7/30/97	11:00										
7/30/97	11:00										
7/30/97	18:00										
7/31/97	4:45										
7/31/97	4:45										
7/31/97	8:00										
7/31/97	9:30										
7/31/97	9:30										
7/31/97	12:30										
7/31/97	18:00										
7/31/97	10:00										
8/1/97	5:00										
8/1/97	5:00										
8/1/97	10:00										
8/4/97	10:00										
8/4/97	10:30										
8/4/97	11:30										
8/6/97	9:30										
8/6/97	9:30										
8/6/97	10:00										
8/6/97	16:00										
8/7/97	8:30										
8/7/97	8:30										
8/7/97	9:45										
8/7/97	9:45										
8/7/97	10:00										
8/7/97	17:00										
8/8/97	6:30										
8/8/97	6:30										

Field, Lab, and Operational Data
for Filter Effluent

Date	Time	Operational Data			
		Pressure (psi)	Flow (gpm)	SDI	Filter Aid Dosing Rate (mL/min)
7/25/97	10:45	93			
7/25/97	10:45			6.14	
7/28/97	6:45		9.4		
7/28/97	6:45	79			
7/28/97	8:00				
7/28/97	9:30			6.31	
7/28/97	9:30		9.6		
7/28/97	9:30	76			
7/28/97	11:45		9.8		
7/28/97	11:45	85			
7/28/97	17:00				
7/29/97	6:15		9.5		
7/29/97	6:15	88			
7/29/97	7:00				
7/29/97	8:15		9.4		
7/29/97	8:15	87			
7/29/97	10:15			6.3	
7/29/97	10:30		9.7		
7/29/97	10:30	85			
7/30/97	6:15		9.5		
7/30/97	6:15	88			
7/30/97	6:30		9.5		
7/30/97	6:30	90			
7/30/97	7:30				
7/30/97	9:15		9.7		
7/30/97	9:15	84			
7/30/97	11:00		9.7		
7/30/97	11:00	83			
7/30/97	18:00				
7/31/97	4:45		15.4		
7/31/97	4:45	40			
7/31/97	8:00				
7/31/97	9:30		9.9		
7/31/97	9:30	84			
7/31/97	12:30	84			
7/31/97	18:00				
7/31/97	10:00			5.32	
8/1/97	5:00		8.3		
8/1/97	5:00	90			
8/1/97	10:00				
8/4/97	10:00				
8/4/97	10:30		9.8		
8/4/97	11:30		14.9		
8/6/97	9:30		9.8		
8/6/97	9:30	90			
8/6/97	10:00				
8/6/97	16:00				
8/7/97	8:30	10			
8/7/97	8:30		19.2		
8/7/97	9:45		9.8		
8/7/97	9:45	88			
8/7/97	10:00				
8/7/97	17:00				
8/8/97	6:30		9.5		
8/8/97	6:30	92			

Field, Lab, and Operational Data
for Filter Effluent

		Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			(mg/L as SiO2)
8/8/97	8:00	9.21	67.3	0.8	10200	2.334	460	24	13.1	
8/8/97	9:15									
8/8/97	9:15									
8/8/97	9:30									
8/8/97	10:45									
8/8/97	10:45									
8/8/97	17:00	9.59	68.9	0.6	10200	2.422	440	22.4	11.2	
8/11/97	7:45									
8/11/97	7:45									
8/11/97	10:00	9.39	72.5	0.7	10300	2.165	496	40	12	
8/11/97	10:00									
8/11/97	10:00									
8/11/97	14:20									
8/11/97	14:20									
8/11/97	16:30	9.36	69.4	0.65	10300	2.241	488	31.4	14.1	
8/12/97	7:30									
8/12/97	7:30									
8/12/97	8:30	9.72	70.1	0.85	9240	2	608	13.4	5.2	
8/12/97	9:00									
8/12/97	9:00									
8/12/97	10:00									
8/12/97	12:45									
8/12/97	12:45									
8/12/97	15:00									
8/12/97	15:00									
8/12/97	16:30	8.64	67.7	0.6	9070	2.063	460	272	190	
8/13/97	13:30									
8/13/97	13:30									
8/13/97	14:45									
8/13/97	14:45									
8/13/97	16:00	9.63	69	0.57	9900	2.382	524	16.4	9.2	
8/13/97	19:00									
8/13/97	19:00									
8/14/97	9:15									
8/14/97	9:15									
8/14/97	10:00	9.25	68.2	0.85	9670	2.165	520	78	37.7	
8/14/97	10:30									
8/14/97	11:00									
8/14/97	11:00									
8/14/97	13:15									
8/14/97	13:15									
8/14/97	15:00									
8/14/97	15:00									
8/14/97	17:00	9.36	69.8	0.75	9690	2.251	520	39.8	17.7	
8/15/97	6:30									
8/15/97	6:30									
8/15/97	9:30									
8/15/97	9:30									
8/15/97	10:00	8.16	72.6	0.75	9480	2.069	460	26.8	15.7	
8/15/97	13:00									
8/15/97	13:00									
8/15/97	13:15									
8/15/97	15:00									
8/15/97	15:00									
8/15/97	16:30	8.34	70.9	0.67	9770	2.241	404	46	19.1	

Field, Lab, and Operational Data
for Filter Effluent

		CLWA lab Data									
		B	Fe	Si	Ca	Mg	Ba	Sr	TOC	NH3	TDS
Date	Time	(mg/L as Ion)							(mg/L)	(mg/L as NH3)	(mg/L)
8/8/97	8:00										
8/8/97	9:15										
8/8/97	9:15										
8/8/97	9:30										
8/8/97	10:45										
8/8/97	10:45										
8/8/97	17:00										
8/11/97	7:45										
8/11/97	7:45										
8/11/97	10:00										
8/11/97	10:00										
8/11/97	10:00										
8/11/97	14:20										
8/11/97	14:20										
8/11/97	16:30										
8/12/97	7:30										
8/12/97	7:30										
8/12/97	8:30										
8/12/97	9:00										
8/12/97	9:00										
8/12/97	10:00										
8/12/97	12:45										
8/12/97	12:45										
8/12/97	15:00										
8/12/97	15:00										
8/12/97	16:30										
8/13/97	13:30										
8/13/97	13:30										
8/13/97	14:45										
8/13/97	14:45										
8/13/97	16:00										
8/13/97	19:00										
8/13/97	19:00										
8/14/97	9:15										
8/14/97	9:15										
8/14/97	10:00								78		
8/14/97	10:30										
8/14/97	11:00										
8/14/97	11:00										
8/14/97	13:15										
8/14/97	13:15										
8/14/97	15:00										
8/14/97	15:00										
8/14/97	17:00								66		5862
8/15/97	6:30										
8/15/97	6:30										
8/15/97	9:30										
8/15/97	9:30										
8/15/97	10:00								74	13.2	
8/15/97	13:00										
8/15/97	13:00										
8/15/97	13:15										
8/15/97	15:00										
8/15/97	15:00										
8/15/97	16:30								100		5896

Field, Lab, and Operational Data for Filter Effluent

		Operational Data			
Date	Time	Pressure (psi)	Flow (gpm)	SDI	Filter Aid Dosing Rate (mL/min)
8/8/97	8:00				
8/8/97	9:15		9.9		
8/8/97	9:15	88			
8/8/97	9:30			6.4	
8/8/97	10:45		9.6		
8/8/97	10:45	88			
8/8/97	17:00				
8/11/97	7:45		9.2		
8/11/97	7:45	94			
8/11/97	10:00				
8/11/97	10:00		9.6		
8/11/97	10:00	90			
8/11/97	14:20		9.8		
8/11/97	14:20	89			
8/11/97	16:30				
8/12/97	7:30		9.4		
8/12/97	7:30	92			
8/12/97	8:30				
8/12/97	9:00		9.6		
8/12/97	9:00	90			
8/12/97	10:00			6.31	
8/12/97	12:45		10.1		
8/12/97	12:45	90			
8/12/97	15:00		9.8		
8/12/97	15:00	88			
8/12/97	16:30				
8/13/97	13:30		12.6		
8/13/97	13:30	89			
8/13/97	14:45		12.6		
8/13/97	14:45	89			
8/13/97	16:00				
8/13/97	19:00		9.7		
8/13/97	19:00	77			
8/14/97	9:15		9.4		
8/14/97	9:15	82			
8/14/97	10:00				
8/14/97	10:30			6.306	
8/14/97	11:00		9.9		
8/14/97	11:00	75			
8/14/97	13:15		9.5		
8/14/97	13:15	79			
8/14/97	15:00		9.6		
8/14/97	15:00	77			
8/14/97	17:00				
8/15/97	6:30		9.2		
8/15/97	6:30	90			
8/15/97	9:30		9.8		
8/15/97	9:30	84			
8/15/97	10:00				
8/15/97	13:00		9.8		
8/15/97	13:00	83			
8/15/97	13:15			6.31	
8/15/97	15:00		9.7		
8/15/97	15:00	83			
8/15/97	16:30				

Field, Lab, and Operational Data
for Filter Effluent

Date	Time	Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)
							(mg/L as CaCO3)			
8/18/97	8:30									
8/18/97	8:30									
8/18/97	10:15									
8/18/97	10:15									
8/18/97	11:00									
8/18/97	13:00									
8/18/97	13:00									
8/18/97	16:00	8.5	71	0.65	9550	2.301	424	39.8	17.1	
8/18/97	20:00									
8/18/97	20:00									
8/19/97	8:00									
8/19/97	8:00									
8/19/97	10:00	8.8	69.7	0.7	9340	2.241	392	8	8	
8/19/97	10:15									
8/19/97	11:00									
8/19/97	11:00									
8/19/97	14:00									
8/19/97	14:00									
8/19/97	16:00	8.27	69.9	0.66	9620	2.301	360	29	12.4	
8/19/97	18:30									
8/19/97	18:30									
8/20/97	6:00									
8/20/97	6:00									
8/20/97	8:30									
8/20/97	8:30									
8/20/97	9:00	8.03	69.5	0.8	9540	2.181	432	24	9.1	
8/20/97	11:15									
8/20/97	12:00									
8/20/97	12:00									
8/20/97	18:00	9.07	69.8	0.66	9700	2.436	488	19.2	7.8	
8/20/97	19:00									
8/20/97	19:00									
8/21/97	7:30									
8/21/97	7:30									
8/21/97	9:00									
8/21/97	9:00									
8/21/97	9:45	9.86	68.9	0.9	9990	2.533	680	14.4	2.6	
8/21/97	13:45									
8/21/97	13:45									
8/21/97	17:00	8.68	72.5	0.83	9500	2.301	416	83.8	68	
8/21/97	18:30									
8/21/97	19:15									
8/21/97	19:15									
8/22/97	6:15									
8/22/97	6:15									
8/22/97	8:15									
8/22/97	8:15									
8/22/97	9:00	9.53	71.6	1	9550	2.346	536	42	8.8	
8/22/97	13:30									
8/22/97	13:30									
8/22/97	14:30									
8/22/97	14:30									
8/22/97	16:30	8.96	73.4	0.76	10000	2.37	372	134	33	
8/22/97	18:00									
8/22/97	18:00									

Field, Lab, and Operational Data
for Filter Effluent

Date	Time	CLWA lab Data									
		B	Fe	Si	Ca	Mg	Ba	Sr	TOC	NH3	TDS
		(mg/L as Ion)							(mg/L)	(mg/L as NH3)	(mg/L)
8/18/97	8:30										
8/18/97	8:30										
8/18/97	10:15										
8/18/97	10:15										
8/18/97	11:00										
8/18/97	13:00										
8/18/97	13:00										
8/18/97	16:00								77	12.6	
8/18/97	20:00										
8/18/97	20:00										
8/19/97	8:00										
8/19/97	8:00										
8/19/97	10:00								86	12.9	
8/19/97	10:15										
8/19/97	11:00										
8/19/97	11:00										
8/19/97	14:00										
8/19/97	14:00										
8/19/97	16:00								87		6107
8/19/97	18:30										
8/19/97	18:30										
8/20/97	6:00										
8/20/97	6:00										
8/20/97	8:30										
8/20/97	8:30										
8/20/97	9:00								91	10.6	
8/20/97	11:15										
8/20/97	12:00										
8/20/97	12:00										
8/20/97	18:00								97		6184
8/20/97	19:00										
8/20/97	19:00										
8/21/97	7:30										
8/21/97	7:30										
8/21/97	9:00										
8/21/97	9:00										
8/21/97	9:45								93	8.6	
8/21/97	13:45										
8/21/97	13:45										
8/21/97	17:00								83		5894
8/21/97	18:30										
8/21/97	19:15										
8/21/97	19:15										
8/22/97	6:15										
8/22/97	6:15										
8/22/97	8:15										
8/22/97	8:15										
8/22/97	9:00								98	8.4	
8/22/97	13:30										
8/22/97	13:30										
8/22/97	14:30										
8/22/97	14:30										
8/22/97	16:30								84		5902
8/22/97	18:00										
8/22/97	18:00										

Field, Lab, and Operational Data
for Filter Effluent

		Operational Data			
Date	Time	Pressure (psi)	Flow (gpm)	SDI	Filter Aid Dosing Rate (mL/min)
8/18/97	8:30		9.2		
8/18/97	8:30	89			
8/18/97	10:15		9.5		
8/18/97	10:15	85			
8/18/97	11:00			6.47	
8/18/97	13:00		9.6		
8/18/97	13:00	84			
8/18/97	16:00				
8/18/97	20:00		9.6		
8/18/97	20:00	85			
8/19/97	8:00		9.5		
8/19/97	8:00	88			
8/19/97	10:00				
8/19/97	10:15			6.53	
8/19/97	11:00		9.8		
8/19/97	11:00	83			
8/19/97	14:00		9.7		
8/19/97	14:00	84			
8/19/97	16:00				
8/19/97	18:30		9.7		
8/19/97	18:30	85			
8/20/97	6:00		9.3		
8/20/97	6:00	90			
8/20/97	8:30		9.5		
8/20/97	8:30	86			
8/20/97	9:00				
8/20/97	11:15			6.53	
8/20/97	12:00		9.8		
8/20/97	12:00	84			
8/20/97	18:00				
8/20/97	19:00		9.7		
8/20/97	19:00	84			
8/21/97	7:30		9.2		
8/21/97	7:30	90			
8/21/97	9:00		9.2		
8/21/97	9:00	62			
8/21/97	9:45				
8/21/97	13:45		9.6		
8/21/97	13:45	87		6.32	
8/21/97	17:00				
8/21/97	18:30				
8/21/97	19:15		9.6		
8/21/97	19:15	88			
8/22/97	6:15		9.1		
8/22/97	6:15	90			
8/22/97	8:15		9.5		
8/22/97	8:15	88			
8/22/97	9:00				
8/22/97	13:30		1.7		
8/22/97	13:30	89			
8/22/97	14:30		9.5		
8/22/97	14:30	87			
8/22/97	16:30				
8/22/97	18:00		9.5		
8/22/97	18:00	87			

Field, Lab, and Operational Data
for Filter Effluent

		Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			(mg/L as SiO2)
8/25/97	10:30	9.67	72.5	1	9600	2.382	500	18.4	10.9	
8/25/97	11:45									
8/25/97	16:00									
8/25/97	17:45	9.15	75.2	0.85	9430	2.358	388	42	18.4	
8/25/97	19:00									
8/26/97	8:00									
8/26/97	8:00									
8/26/97	11:00	9.54	74.3	0.9	9480	2.323	472	14.4	6.3	
8/26/97	11:00									
8/26/97	11:00									
8/26/97	11:30									
8/26/97	14:30									
8/26/97	14:30									
8/26/97	17:00	9.27	70.7	0.85	9750	2.552	404	96	17	
8/26/97	17:45									
8/26/97	19:15									
8/26/97	19:15									
8/27/97	7:30									
8/27/97	7:45									
8/27/97	7:45									
8/27/97	9:30	9.46	71.6	0.7	10350	2.165	356	144	28.9	
8/27/97	10:45									
8/27/97	10:45									
8/27/97	11:45									
8/27/97	11:45									
8/27/97	12:00									
8/27/97	15:45	9.43	71.6	0.71	10370	2.081	372	1140	17	
8/27/97	17:00									
8/28/97	11:30	9.31	71.6	7.4	10610	2.057	388	278	10.8	
8/28/97	12:00									
8/28/97	12:15									
8/28/97	12:15									
8/28/97	13:15									
8/28/97	13:15									
8/28/97	14:00									
8/28/97	14:40									
8/28/97	14:40									
8/28/97	15:30									
8/28/97	15:30									
8/28/97	19:00	9.35	71.6	3.4	9730	2.121	396	224	10.8	
8/29/97	7:30									
8/29/97	7:30									
8/29/97	8:15									
8/29/97	9:00									
8/29/97	9:00									
8/29/97	10:00	9.56	71.6	1.8	9860	2.128	440	118	18	
8/29/97	11:15									
8/29/97	11:15									
8/29/97	16:00	9.35	77	2.8	9390	2.142	416	61	10	
8/29/97	17:00									
8/29/97	18:00									
8/29/97	18:00									

Field, Lab, and Operational Data for Filter Effluent

		CLWA lab Data									
		B	Fe	Si	Ca	Mg	Ba	Sr	TOC	NH3	TDS
Date	Time	(mg/L as ion)							(mg/L)	(mg/L as NH3)	(mg/L)
8/25/97	10:30								110	8.5	
8/25/97	11:45										
8/25/97	16:00										
8/25/97	17:45								93		6082
8/25/97	19:00										
8/26/97	8:00										
8/26/97	8:00										
8/26/97	11:00								105	8.7	
8/26/97	11:00										
8/26/97	11:00										
8/26/97	11:30										
8/26/97	14:30										
8/26/97	14:30										
8/26/97	17:00								109		5978
8/26/97	17:45										
8/26/97	19:15										
8/26/97	19:15										
8/27/97	7:30										
8/27/97	7:45										
8/27/97	7:45										
8/27/97	9:30								102	11.2	
8/27/97	10:45										
8/27/97	10:45										
8/27/97	11:45										
8/27/97	11:45										
8/27/97	12:00										
8/27/97	15:45								137		6532
8/27/97	17:00										
8/28/97	11:30								112	11.3	
8/28/97	12:00										
8/28/97	12:15										
8/28/97	12:15										
8/28/97	13:15										
8/28/97	13:15										
8/28/97	14:00										
8/28/97	14:40										
8/28/97	14:40										
8/28/97	15:30										
8/28/97	15:30										
8/28/97	19:00										
8/29/97	7:30										
8/29/97	7:30										
8/29/97	8:15										
8/29/97	9:00										
8/29/97	9:00										
8/29/97	10:00									11	
8/29/97	11:15										
8/29/97	11:15										
8/29/97	16:00								124		
8/29/97	17:00										
8/29/97	18:00										
8/29/97	18:00										

Field, Lab, and Operational Data for Filter Effluent

Date	Time	Operational Data			
		Pressure (psi)	Flow (gpm)	SDI	Filter Aid Dosing Rate (mL/min)
8/25/97	10:30				
8/25/97	11:45	87	9.8	6.53	
8/25/97	16:00	86	9.7		
8/25/97	17:45				
8/25/97	19:00	87	9.6		
8/26/97	8:00				10
8/26/97	8:00	90			
8/26/97	11:00				
8/26/97	11:00		9.8		
8/26/97	11:00	86			
8/26/97	11:30			6.56	
8/26/97	14:30		9.8		
8/26/97	14:30	85			
8/26/97	17:00				
8/26/97	17:45				
8/26/97	19:15		9.8		
8/26/97	19:15	86			
8/27/97	7:30				5
8/27/97	7:45	90			
8/27/97	7:45	92	8.9		
8/27/97	9:30				
8/27/97	10:45	81			
8/27/97	10:45	83	9.9		
8/27/97	11:45	79			
8/27/97	11:45	82	10.0		
8/27/97	12:00			4.66	
8/27/97	15:45				
8/27/97	17:00				
8/28/97	11:30				
8/28/97	12:00				30
8/28/97	12:15	85			
8/28/97	12:15	85	9.9		
8/28/97	13:15	83			
8/28/97	13:15	83	9.9		
8/28/97	14:00			5.49	
8/28/97	14:40	83			
8/28/97	14:40	83	9.8		
8/28/97	15:30	82			
8/28/97	15:30	82	9.9		
8/28/97	19:00				
8/29/97	7:30	87			
8/29/97	7:30	87	9.0		29
8/29/97	8:15				29
8/29/97	9:00	85			
8/29/97	9:00	86	9.6		
8/29/97	10:00				
8/29/97	11:15	82		6	
8/29/97	11:15	82	9.8		
8/29/97	16:00				
8/29/97	17:00				
8/29/97	18:00	83			
8/29/97	18:00	83	9.7		

Field, Lab, and Operational Data
for Ion Exchange Effluent

		Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			(mg/L as SiO2)
6/24/97	18:00									
7/2/97	19:00									
7/2/97	19:20							26	19	
7/2/97	19:40									
7/2/97	20:00							22	10	
7/3/97	11:00							4.1	1.6	
7/3/97	16:30									
7/3/97	16:30							8	3	
7/3/97	18:00	9.01						4.2	3.2	
7/8/97	16:00			2						
7/9/97	12:30			0.8						
7/10/97	6:00	9.35					456	6	2.8	
7/14/97	17:30	9.28		1.3			450	11	2.6	6.3
7/15/97	4:40	10.43					668	21.4	7.6	44
7/15/97	5:00			1.1						
7/15/97	6:00									
7/15/97	7:45									
7/15/97	11:00			0.8						
7/15/97	11:15									
7/15/97	17:00	9.56		0.68			474	12.4	5.8	25.2
7/16/97	6:00									
7/16/97	7:00									
7/16/97	8:00									
7/17/97	8:45									
7/17/97	19:30			0.74						
7/21/97	17:00	8.34	92	1.3		2.197	464	15.2	9.4	32
7/22/97	18:30	8.76			8800	2.142	384	9	5.8	60
7/23/97	5:45									
7/23/97	7:30	9.34			7200		462	43.8	20.4	
7/23/97	9:00									
7/23/97	11:00									
7/23/97	18:00									
7/24/97	6:30									
7/24/97	6:45	8.92			9280		478	10.2	7.4	
7/24/97	8:30									
7/24/97	10:30									
7/24/97	12:30									
7/24/97	19:00	9.46		0.62	9500	2.408	424	34.7	7.8	
7/25/97	7:45	9.2	73.6		5300	1.954	480	42.2	13.6	24.9
7/25/97	8:30									
7/25/97	10:30									
7/25/97	10:45									
7/28/97	6:45									
7/28/97	8:00	8.96	70.3	0.75	10100		496	61.6	13.5	
7/28/97	9:00									
7/28/97	9:30									
7/28/97	11:45									
7/28/97	17:00	8.56	68.8	0.71	9240		484	25.8	15.2	
7/29/97	6:15									
7/29/97	7:00	9.12	69.6	1	10300		488	28	14.4	
7/29/97	8:15									
7/29/97	9:45									
7/29/97	10:30									
7/30/97	6:15									
7/30/97	6:30									

Field, Lab, and Operational Data for Ion Exchange Effluent

		CLWA lab Data													
		B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC	NH3	TDS	Cl	SO4
Date	Time	(mg/L as Ion)									(mg/L)	(mg/L as NH3)	(mg/L)	(mg/L as Ion)	
6/24/97	18:00	15	0.1	51	13	2			0.2	0.1					
7/2/97	19:00	13	0	33	500	0.7			0.003	0.06					
7/2/97	19:20														
7/2/97	19:40	14	0	32	0.7	0.8			0.002	19.8					
7/2/97	20:00														
7/3/97	11:00	14	0	33	0.5	0.4			0.001	0.02					
7/3/97	16:30														
7/3/97	16:30	14	0	3	0	0			0.001	0.01					
7/3/97	18:00														
7/8/97	16:00														
7/9/97	12:30														
7/10/97	6:00														
7/14/97	17:30	13	0	11	1.3	1.8					74			3260	95
7/15/97	4:40														
7/15/97	5:00														
7/15/97	6:00														
7/15/97	7:45														
7/15/97	11:00														
7/15/97	11:15														
7/15/97	17:00	14	0.1	19	2.3	2.4					82			3210	83
7/16/97	6:00														
7/16/97	7:00														
7/16/97	8:00														
7/17/97	8:45														
7/17/97	19:30														
7/21/97	17:00	14	0.1	19	2.3	2.4					95	7	5550		
7/22/97	18:30														
7/23/97	5:45														
7/23/97	7:30	12	0	7.6							105	7			
7/23/97	9:00														
7/23/97	11:00														
7/23/97	18:00	13	0.1	12							126	10	5501		
7/24/97	6:30														
7/24/97	6:45	12	0	7.6								5	5564		
7/24/97	8:30														
7/24/97	10:30														
7/24/97	12:30														
7/24/97	19:00										94	5.5			
7/25/97	7:45											3.6	5000		
7/25/97	8:30														
7/25/97	10:30														
7/25/97	10:45														
7/28/97	6:45														
7/28/97	8:00										100	6	5593		
7/28/97	9:00														
7/28/97	9:30														
7/28/97	11:45														
7/28/97	17:00										101	3.7			
7/29/97	6:15														
7/29/97	7:00										88	5.8			
7/29/97	8:15														
7/29/97	9:45														
7/29/97	10:30														
7/30/97	6:15														
7/30/97	6:30														

Field, Lab, and Operational Data
for Ion Exchange Effluent

Date	Time	Operational Data	
		Pressure (psi)	SDI
6/24/97	18:00		
7/2/97	19:00		
7/2/97	19:20		
7/2/97	19:40		
7/2/97	20:00		
7/3/97	11:00		
7/3/97	16:30		5.84
7/3/97	16:30		
7/3/97	18:00		
7/8/97	16:00		
7/9/97	12:30		
7/10/97	6:00		
7/14/97	17:30		
7/15/97	4:40		
7/15/97	5:00		
7/15/97	6:00	69	
7/15/97	7:45	69	
7/15/97	11:00		
7/15/97	11:15	71	
7/15/97	17:00		
7/16/97	6:00	110	
7/16/97	7:00	110	
7/16/97	8:00	110	
7/17/97	8:45	58	
7/17/97	19:30		
7/21/97	17:00		
7/22/97	18:30		
7/23/97	5:45	92	
7/23/97	7:30		
7/23/97	9:00	85	
7/23/97	11:00	84	
7/23/97	18:00		
7/24/97	6:30	96	
7/24/97	6:45		
7/24/97	8:30	90	
7/24/97	10:30	90	
7/24/97	12:30	89	
7/24/97	19:00		
7/25/97	7:45		
7/25/97	8:30	92	
7/25/97	10:30		6.27
7/25/97	10:45	90	
7/28/97	6:45	74	
7/28/97	8:00		
7/28/97	9:00		6.38
7/28/97	9:30	72	
7/28/97	11:45	80	
7/28/97	17:00		
7/29/97	6:15	84	
7/29/97	7:00		
7/29/97	8:15	83	
7/29/97	9:45		6.29
7/29/97	10:30	81	
7/30/97	6:15	82	
7/30/97	6:30	86	

Field, Lab, and Operational Data
for Ion Exchange Effluent

Date	Time	Field Data								
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2
			(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			(mg/L as SiO2)
7/30/97	7:30	9.44	69.4	0.9	10100		496	19.6	9.2	
7/30/97	9:15									
7/30/97	11:00									
7/30/97	18:00	9.5	70.4	0.63	10400		476	23.4	18	
7/31/97	4:45									
7/31/97	8:00	9.21	69.7	0.75	10400		502	45	24.8	
7/31/97	9:30									
7/31/97	10:30									
7/31/97	12:30									
7/31/97	18:00	9.4	68.3	0.6	10300		430	30	18.4	
8/1/97	5:00									
8/1/97	10:00	9.12	70.3	0.7	10600	2.039	504	21	12.2	30
8/4/97	10:00	8.75	77.9		4500		522	20.6	13.4	42.6
8/6/97	9:30									
8/6/97	10:00	9.76	74.6	0.8	10800		534	24.2	1.6	29.2
8/6/97	16:00	9.46	72.5	0.61	10300		466	15.8	9.4	
8/7/97	9:45									
8/7/97	10:00	9.04	73.4	0.75	10100		502	16.6	9.3	
8/7/97	17:00	9.82	70.9	0.56	9800		564	2.6	10.4	
8/8/97	6:30									
8/8/97	8:00	9.18	67.2	0.75	10000		508	22.4	13.9	
8/8/97	9:15									
8/8/97	9:45									
8/8/97	10:45									
8/8/97	17:00	9.51	68	0.57	10000		460	20.6	12	
8/11/97	7:45									
8/11/97	10:00	9.4	73.2	0.7	10200		500	23.6	12.8	
8/11/97	10:00									
8/11/97	14:20									
8/11/97	16:30	9.36	68.7	0.65	10300		508	28.6	12.7	
8/12/97	7:30									
8/12/97	8:30	9.48	70.9	0.7	9250		572	32.6	12.6	
8/12/97	9:00									
8/12/97	12:45									
8/12/97	15:00									
8/12/97	16:30									
8/13/97	13:13									
8/13/97	14:45									
8/13/97	16:00									
8/14/97	10:00									
8/15/97	6:30									
8/15/97	9:30									
8/18/97	8:30									
8/18/97	10:15									
8/19/97	8:00									
8/20/97	6:00									
8/20/97	8:30									
8/21/97	7:30									
8/21/97	9:00									
8/22/97	6:15									
8/22/97	8:15									
8/26/97	8:00									
8/27/97	7:45									
8/27/97	10:45									
8/27/97	11:45									

Field, Lab, and Operational Data
for Ion Exchange Effluent

		CLWA lab Data													
		B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC	NH3	TDS	Cl	SO4
Date	Time	(mg/L as Ion)									(mg/L)	(mg/L as NH3)	(mg/L)	(mg/L as Ion)	
7/30/97	7:30										115	5.7	5695		
7/30/97	9:15														
7/30/97	11:00														
7/30/97	18:00										101		5700		
7/31/97	4:45														
7/31/97	8:00										111	5.3	5706		
7/31/97	9:30														
7/31/97	10:30														
7/31/97	12:30														
7/31/97	18:00	12	0	6.1	5.5	3.1	76	2144			101				
8/1/97	5:00														
8/1/97	10:00										89	6.2			
8/4/97	10:00										117	3.7			
8/6/97	9:30														
8/6/97	10:00										114	5.2			
8/6/97	16:00										114				
8/7/97	9:45														
8/7/97	10:00										131				
8/7/97	17:00										101				
8/8/97	6:30														
8/8/97	8:00										107	5.2			
8/8/97	9:15														
8/8/97	9:45														
8/8/97	10:45														
8/8/97	17:00										94		5684		
8/11/97	7:45														
8/11/97	10:00										87	12			
8/11/97	10:00														
8/11/97	14:20														
8/11/97	16:30										94		5113		
8/12/97	7:30														
8/12/97	8:30										77	12.9			
8/12/97	9:00														
8/12/97	12:45														
8/12/97	15:00														
8/12/97	16:30										79		5676		
8/13/97	13:13														
8/13/97	14:45														
8/13/97	16:00										95	13.5			
8/14/97	10:00											13.8			
8/15/97	6:30														
8/15/97	9:30														
8/18/97	8:30														
8/18/97	10:15														
8/19/97	8:00														
8/20/97	6:00														
8/20/97	8:30														
8/21/97	7:30														
8/21/97	9:00														
8/22/97	6:15														
8/22/97	8:15														
8/26/97	8:00														
8/27/97	7:45														
8/27/97	10:45														
8/27/97	11:45														

Date	Time	Operational Data Pressure (psi)	SDI
7/30/97	7:30		
7/30/97	9:15	80	
7/30/97	11:00	80	
7/30/97	18:00		
7/31/97	4:45	36	
7/31/97	8:00		
7/31/97	9:30	82	
7/31/97	10:30		5.79
7/31/97	12:30	82	
7/31/97	18:00		
8/1/97	5:00	80	
8/1/97	10:00		
8/4/97	10:00		
8/6/97	9:30	88	
8/6/97	10:00		
8/6/97	16:00		
8/7/97	9:45	84	
8/7/97	10:00		
8/7/97	17:00		
8/8/97	6:30	87	
8/8/97	8:00		
8/8/97	9:15	84	
8/8/97	9:45		6.44
8/8/97	10:45	85	
8/8/97	17:00		
8/11/97	7:45	90	
8/11/97	10:00		
8/11/97	10:00	86	
8/11/97	14:20	85	
8/11/97	16:30		
8/12/97	7:30	87	
8/12/97	8:30		
8/12/97	9:00	86	6.35
8/12/97	12:45	85	
8/12/97	15:00	85	
8/12/97	16:30		
8/13/97	13:13	91	
8/13/97	14:45	91	
8/13/97	16:00		
8/14/97	10:00		
8/15/97	6:30	88	
8/15/97	9:30	82	
8/18/97	8:30	88	
8/18/97	10:15	85	
8/19/97	8:00	86	
8/20/97	6:00	88	
8/20/97	8:30	85	
8/21/97	7:30	88	
8/21/97	9:00	61	
8/22/97	6:15	90	
8/22/97	8:15	87	
8/26/97	8:00	89	
8/27/97	7:45	89	
8/27/97	10:45	79	
8/27/97	11:45	79	

Field, Lab, and Operational Data
for Ion Exchange Effluent

Date	Time	Field Data								
		pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk (mg/L as CaCO3)	Tot Hard (mg/L as CaCO3)	Ca Hard (mg/L as CaCO3)	SiO2 (mg/L as SiO2)
8/28/97	10:15									
8/28/97	11:30	9.58	71.6	7.4	10400		388	116	17.8	
8/28/97	12:15									
8/28/97	13:15									
8/28/97	14:40									
8/28/97	15:30									
8/28/97	19:00	9.4	71.6	1.8	10240		388	92	20.6	
8/29/97	7:30									
8/29/97	9:00									
8/29/97	10:00	9.49	70.7	1.9	10800		432	122	25	
8/29/97	11:15									
8/29/97	11:30									
8/29/97	16:00	9.36	77	0.89	9260		404	70	14.4	
8/29/97	18:00									

Field, Lab, and Operational Data for Ion Exchange Effluent

Date	Time	CLWA lab Data													
		B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC	NH3	TDS	Cl	SO4
		(mg/L as Ion)									(mg/L)	(mg/L as NH3)	(mg/L)	(mg/L as Ion)	
8/28/97	10:15														
8/28/97	11:30										95		6671		
8/28/97	12:15														
8/28/97	13:15														
8/28/97	14:40														
8/28/97	15:30														
8/28/97	19:00										98		6274		
8/29/97	7:30														
8/29/97	9:00														
8/29/97	10:00												6102		
8/29/97	11:15														
8/29/97	11:30														
8/29/97	16:00														
8/29/97	18:00														

Field, Lab, and Operational Data for Ion Exchange Effluent

Date	Time	Operational Data	
		Pressure (psi)	SDI
8/28/97	10:15		
8/28/97	11:30		
8/28/97	12:15	80	
8/28/97	13:15	5	
8/28/97	14:40	74	
8/28/97	15:30	83	
8/28/97	19:00		
8/29/97	7:30	73	
8/29/97	9:00	71	
8/29/97	10:00		
8/29/97	11:15	67	
8/29/97	11:30		6.17
8/29/97	16:00		
8/29/97	18:00	65	

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
7/14/97	12:30		600	225	215		3					3				
7/14/97	14:30		600	165	155		3					3				
7/14/97	16:15		600	210	200		1.8	2.4				1.8				
7/14/97	19:30		600	210	205		1.75	2.3				1.75				
7/15/97	16:00		600	220	205		1.8	2.4				1.8				
7/21/97	14:40		605	225	215	6	1.8	2.4				1.8				
7/21/97	16:20		605	225	215	5.5	1.8	2.4				1.8				
7/21/97	17:00		605	235	225	5.5	1.8	2.4				1.8				
7/21/97	19:30		605	205	195	6	1.8	2.4				1.8				
7/22/97	14:00		580	265	240		3.7	4.7	1.95	235	1.35	7				
7/22/97	16:30		580	360	330	50	4	4.7	1.9	330	1.1	7				
7/22/97	18:30		580	370	340	50	4	4.75	1.8	340	1	6.8				
7/23/97	6:00	88	590	380	355	50	3.8	4.7	1.8	360	1	7				
7/23/97	7:00	88	590	395	360	50	3.8	4.7	1.8	365	1	7				
7/23/97	8:00	84	590	395	360	50	3.8	4.7	1.8	380	1	7				
7/23/97	9:00	88	590	390	355	50	4	4.7	1.8	355	1	7				
7/23/97	11:00	88	590	370	340	50	4.2	4.7	1.8	340	0.9	7				
7/23/97	21:10		590	365	330	50	4.1	4.7	1.8	335	1.1	7				
7/24/97	6:30	96	595	405	390	50	3.9	4.7	1.8	380	1.2	7				
7/24/97	7:30	94	595	410	380	50	4	4.7	1.8	380	1.1	7				
7/24/97	8:30	92	595	400	375	50	4	4.7	1.8	375	1.1	7				
7/24/97	10:30	94	595	390	360	50	4.2	4.7	1.8	360	1	7				
7/24/97	12:30	93	595	375	340	50	4.2	4.7	1.8	345	0.9	7				
7/24/97	15:00	96	595	375	340	50	4.2	4.7	1.8	345	0.9	7				
7/24/97	17:30	90	595	375	340	50	4.2	4.7	1.8	345	0.9	7				
7/24/97	20:30	94	595	395	360	50	4.1	4.7	1.8	365	1	7				
7/25/97	7:15	96	595	405	380	50	3.9	4.7	1.8	380	1.1	7				
7/25/97	8:15	94	595	415	380	50	3.9	4.7	1.8	380	1.1	7				

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
7/25/97	9:15	93	595	410	380	5	4	4.7	1.8	380	1.1	7				
7/25/97	10:15	91	595	400	380	50	4.2	4.7	1.8	380	1.1	7				
7/25/97	12:00	93	595	395	360	50	4.1	4.7	1.8	360	1	7				
7/25/97	14:30		475	375	345	50	4.2	4.7	1.8	340	0.9	7				
7/28/97	6:45		570	400	380	47	3.75	4.7	1.9	370	1.1	7				
7/28/97	9:30		570	415	400	46	3.9	4.7	1.9	400	1.1	7				
7/28/97	11:30		580	412	400	50	4	4.7	1.9	395	1.1	7				
7/28/97	13:30	81	580	415	380	50	4	4.5	1.9	385	1.1	7				
7/28/97	20:00	83	575	420	380	50	3.9	4.7	1.9	385	1.2	7				
7/29/97	6:15	88	590	405	380	50	3.5	4.7	1.8	375	1.1	7				
7/29/97	8:00	85	580	450	420	50	3.6	4.7	1.8	420	1.1	7				
7/29/97	10:45	83	580	440	400	50	3.9	4.7	1.9	400	1.1	7				
7/29/97	12:00	82	585	440	405	50	3.9	4.7	1.9	410	1.1	2				
7/30/97	6:15	85	580	415	380	50	3.5	4.7	1.9	380	1.3	7				
7/30/97	7:15	85	580	465	430	50	3.5	4.7	1.9	430	1.2	7				
7/30/97	9:00	84	580	450	420	50	3.4	4.7	1.9	420	1.2	7				
7/30/97	11:00	84	580	420	395	50	3.9	4.7	1.9	395	1.1	7				
7/30/97	13:30	80	580	400	370	50	4	4.7	1.9	365	1.1	7				
7/30/97	16:00	84	580	390	360	50	4	4.7	1.9	360	1	7				
7/30/97	20:30	81	580	420	390	50	3.9	4.7	1.9	390	1.2	7				
7/31/97	6:30	89	590	395	360	50	3.5	4.7	1.9	360	1.25	7				
7/31/97	9:30	85	585	415	400	50	3.9	4.7	1.9	400	1.2	7				
7/31/97	14:30	87	585	400	365	50	4.1	4.7	1.9	365	1	7				
7/31/97	18:00	85	585	400	370	50	4.1	4.7	1.9	365	1	7				
7/31/97	20:30	87	585	415	380	50		4.7		380		7				
8/4/97	9:30	80	585	510	480	50	3.25	4.7	2.2	475	1.4	7				
8/4/97	9:30						4.1		2.2		1.4	7				
8/4/97	10:00						4.1									

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
8/6/97	9:15	88	575	360	325	53	3.9	4.7	1.8	320	1	7				
8/6/97	12:30	72	575	370	335	50	4	4.7	1.9	335	0.9	7	11.82938	20%		
8/6/97	15:00	87	575	370	335	50	4.1	4.7	1.9	335	0.9	7	7.229063	20%		
8/6/97	16:00	72	570	390	360	50	4.1	4.7	1.9	360	1.1	7				
8/6/97	20:30						3.8									
8/7/97	9:45						3.9									
8/7/97	9:45	88	575	385	360	48	3.6	4.7	2	360	1.2	7				
8/7/97	11:30	74	575	385	355	50	3.9	4.7	1.9	355	1.1	7	22.34438	20%		
8/7/97	13:30	88	575	385	355	50	3.9	4.7	1.9	355	1	7	22.34438	20%		
8/7/97	16:30	73	575	385	350	50	4	4.7	1.9	350	1	7				
8/7/97	17:00	90	575	420	390	50	4	4.7	1.9	390	1.2	7	9.857813	20%		
8/7/97	20:30						4									
8/8/97	7:00	89	590	430	400	48	3.5	4.7	1.9	400	1.25	7	7.88625	20%		
8/8/97	9:15	86	590	430	400	50	3.6	4.7	1.9	400	1.25	7				
8/8/97	10:15	88	590	420	390		3.8	4.7	1.9	390	1.1	7				
8/8/97	13:00	90	590	410	380	50	3.8	4.7	1.9	380	1.1	7				
8/8/97	15:30		590	405	375	50	3.9	4.7	1.9	375	1	7	22.34438	20%		
8/8/97	18:30	87	590	415	385	50	3.8	4.7	1.9	385	1.1	7				
8/11/97	7:45	92	590	435	420	48	3.5	4.7	1.9	420	1.3	7	26.94469	20%		
8/11/97	10:00	88	590	475	445	50	3.7	4.7	1.9	445	1.3	7	29.57344	20%		
8/11/97	12:40	89	590	440	405	50	3.8	4.7	1.9	405	1.3	7	29.57344	20%		
8/11/97	14:00	88	590	440	405	50	3.9	4.6	1.9	405	1.3	7	34.17375	20%		
8/11/97	16:30	88	590	445	415	50	3.8	4.7	1.9	415	1.2	2	35.48813	20%		
8/11/97	20:00						4									
8/12/97	7:00	89	585	460	425	50	3.5	4.7	1.9	425	1.3	7	39.43125	20%		
8/12/97	8:00	90	585	480	445	50	4	4.7	1.9	445	1.3	7	32.85938	20%		
8/12/97	9:00	89	585	470	440	50	3.9	4.7	1.9	440	1.3	7				
8/12/97	10:00	88	585	455	420	50	3.9	4.7	1.9	420	1.3	7				

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
8/12/97	12:00	88	590	440	410	50	3.8	4.5	1.9	410	1.2	7				
8/12/97	14:00	89	590	435	400	50	4	4.6	1.8	400	1.2	7				
8/12/97	15:00	88	590	435	400	50	3.7	4.6	1.8	400	1.2	7				
8/12/97	16:00	89		430	400	50	3.8	4.7	1.9	400	1.1	7				
8/12/97	19:00	90	590	435	400	50		4.7	1.8	400	1.2	6.8				
8/13/97	15:15	82	590	380	240	50	3.5	4.5	1.9	345	1.1	7	28.91625	20%		
8/13/97	19:00	80	575	415	380	50	3.9	4.5	1.9	385	1.2	7				
8/14/97	9:15	84	575	385	355	50	3.5	4.7	1.9	360	1.3	7				
8/14/97	11:00	79	570	410	380	50	3.7	4.6	2	380	1.3	7				33
8/14/97	13:15	83	575	410	380	50	3.75	4.7	1.9	380	1.1	7				
8/14/97	15:00	82	575	410	390	50	3.8	4.7	1.9	380	1	7	29.57344	20%		
8/14/97	17:00	83	575	415	395	49	3.9	4.7	1.9	395	1.2	7				
8/14/97	18:30						3.9									
8/15/97	6:30	90	585	460	425	50	3.5	4.7	1.9	425	1.3	7				35
8/15/97	7:30	90	585	460	430	50	3.9	4.7	1.9	430	1.3	7				
8/15/97	8:30	90	585	495	465	50	4	4.7	1.4	465	1.3	7				
8/15/97	9:30	88	585	500	425	50	4.1	4.2	2	465	1.3	7				
8/15/97	10:30	89	590	460	430	50	4	4.7	1.9	430	1.3	7				
8/15/97	12:15	88	590	445	420	50	3.9	4.7	1.9	415	1.2	7			23.65875	
8/15/97	13:15	89	590	445	410	49	4	4.7	1.9	415	1.2	7				
8/15/97	14:45	88	590	445	410	49	4	4.7	1.9	410	1.2	7				
8/15/97	19:30	89	590	475	420	50	3.8	4.7	1.8	440	1.3	7				
8/18/97	8:15	90	580	400	380	50	3.6	4.7	1.9	375	1.4	7			8.543438	
8/18/97	9:00														8.543438	35
8/18/97	9:30														13.80094	
8/18/97	11:00	89	590	460	430	49	3.6	4.7	1.9	425	1.2	7				
8/18/97	12:00	88	580	445	415	50	3.9	4.7	1.9	415	1.1	7				
8/18/97	13:15	88	590	440	410	50	4	4.7	1.9	405	1.1	7			13.80094	

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
8/18/97	14:30	87	590	435	400	50	4	4.7	1.9	400	1.1	7				
8/18/97	15:45	89	590	435	400	50	4	4.7	1.9	400	1.1	7				
8/18/97	17:00	89	590	435	400	50	4	4.7	1.9	400	1.1	7				
8/18/97	18:15	90	590	440	400	50	3.8	4.7	1.9	400	1.1	7				
8/18/97	20:00	89	590	445	420	50	3.8	4.7	1.9	420	1.1	7				
8/19/97	7:45	90	585	410	395	50	3.4	470	1.95	390	1.3	7			17.74406	
8/19/97	8:00	90	585	450	410	50	3.55	4.7	1.95	410	1.25	7				
8/19/97	10:00	89	590	440	400	50	3.6	4.7	1.95	400	1.1	7			18.40125	
8/19/97	11:15	89	590	440	400	50	3.6	4.7	1.95	405	1.1	7				
8/19/97	12:30	88	590	440	410	50	3.9	4.7	1.95	405	1.1	7				
8/19/97	14:00	90	590	435	400	50	3.9	4.7	1.9	400	1.1	7			11.17219	
8/19/97	15:00	88	590	435	400	50	3.9	4.7	1.95	400	1.1	7				
8/19/97	16:00	91	590	440	400	50	3.9	4.7	1.9	405	1.1	7				
8/19/97	17:30	89	590	445	410	50	3.8	4.7	1.9	410	1.1	7				
8/19/97	18:30	90	590	455	410	50	3.8	4.7	1.9	420	1.2	7				
8/20/97	5:45	95	585	320	305	50	3.5	4.7	1.8	300	1.4	7				
8/20/97	6:00	90	585	420	405	50	3.5	4.7	1.9	400	1.25	7				
8/20/97	7:00	91	585	470	420	50	3.7	4.7	1.9	420	1.25	7				
8/20/97	8:00	90	585	470	420	50	3.75	4.7	1.9	420	1.2	7				
8/20/97	10:00	87	585	455	410	50	3.95	4.7	1.9	410	1.2	7				
8/20/97	11:00	90	590	440	410	50	3.95	4.7	1.9	405	1.2	7				
8/20/97	12:15	89	590	430	395	50	3.95	4.7	1.9	395	1.1	7				
8/20/97	13:15	89	590	430	400	50	3.95	4.7	1.9	395	1.1	7				
8/20/97	14:15	87	590	430	395	50	4	4.7	1.9	395	1.1	7				
8/20/97	19:30	89	590	460	425	50	3.95	4.7	1.9	425	1.3	7				
8/21/97	7:15	93	590	400	37	50	4	4.7	1.9	365	1.25	7				
8/21/97	7:30	93	590	410	375	50	3.1	4.7	1.9	370	1.25	7				
8/21/97	8:30	92	590	480	425	50	3.95	4.7	1.9	420	1.25	7				

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
8/21/97	9:30	64	560	470	420	50	3.9	4.7	1.9	420	1.1	7				
8/21/97	10:30	62	580	455	425	50	4.1	4.7	1.9	425	1.1	7				
8/21/97	11:45	70	680	450	415	50	3.95	4.7	1.9	415	1.1	7				
8/21/97	13:00	93	590	445	410	49	4	4.7	1.9	410	1.1	7				
8/21/97	14:00	90	590	445	410	49	4	4.7	1.9	410	1.1	7				
8/21/97	16:00	95	590	445	410	49	3.9	4.7	1.9	405	1.1	7				
8/21/97	19:30	91	590	445	415	50	4	4.7	1.9	415	1.1	7				
8/22/97	14:00		590	190	185	42	4	4.7	1.8	150	1.45	7				
8/22/97	14:30	90	590	400	380	45	4	4.7	1.8	370	1.1	7				
8/22/97	15:30	92	590	420	380	45	4	4.7	1.9	385	1.1	7				
8/22/97	17:00	90	590	420	390	45	4	4.7	1.8	390	1.1	7				
8/22/97	18:00	94	590	425	395	45	4	4.7	1.7	395	1.05	7				
8/25/97	10:00	95	590	410	370	49	3.6	4.7	1.8	360	1.1	7				
8/25/97	11:00	90	585	430	395	48	3.9	4.7	1.8	395	1	7				
8/25/97	12:15	93	590	430	400	48	3.9	4.7	1.8	395	1	7				
8/25/97	13:15	91	590	430	400	48	4	4.7	1.8	395	1	7				
8/25/97	14:15	94	590	430	400	47	4.1	4.7	1.8	395	1	2				
8/25/97	15:15	89	590	430	395	50	4.1	4.7	1.8	395	1	7				
8/25/97	16:15	93	590	430	395	50	4.1	4.7	1.8	395	1	7				
8/25/97	18:15	90	590	430	400	50	4	4.7	1.8	395	1	7				
8/25/97	19:00	93	590	375	400	50	4	4.7	1.8	395	1	7				
8/26/97	7:50	94	585	992	345	47	3.8	4.7	1.85	340	1.25	7				
8/26/97	8:00	91	585	415	400	47	3.9	4.7	1.85	400	1.2	7				
8/26/97	9:00	92	585	415	400	47	4.1	4.7	1.85	400	1.2	7				
8/26/97	10:00	91	585	410	395	47	4.1	4.7	1.85	390	1.1	7				
8/26/97	11:00	92	590	425	395	46	4.4	4.7	1.85	390	1	7				
8/26/97	12:00	91	590	425	395	46	4.3	4.7	1.8	390	1	7				
8/26/97	13:00	93	590	425	395	46	4.2	4.7	1.8	390	1	2				

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
8/26/97	14:00	91	590	425	395	46	4.4	4.7	1.8	390	1	7				
8/26/97	17:45	94	590	425	395	48	4	4.7	1.8	390	1	7				
8/26/97	19:15	90	590	425	395	50	3.95	4.7	1.8	390	1	7				
8/27/97	7:45	90	580	415	400	50	3.9	4.7	1.9	400	1.2	7				
8/27/97	8:45	89	580	460	420	50	4.1	4.7	1.8	415	1.05	7				
8/27/97	10:00	88	585	460	430	50	4.2	4.7	1.8	430	1	7				
8/27/97	11:00	83	590	455	420	50	4.4	4.7	1.8	420	0.95	7				
8/27/97	12:00	85	590	455	420	50	4.2	4.7	1.8	420	0.9	7				
8/27/97	13:00	85	590	450	410	50	4.1	4.7	1.7	420	0.85	7				
8/27/97	14:00	85	590	445	410	48	4.2	4.7	1.75	410	0.8	7				
8/27/97	15:00	85	590	445	410	50	4.1	4.7	1.7	410	0.8	7				
8/27/97	17:00	85	590	445	410	50	4.2	4.7	1.7	415	0.8	7				
8/27/97	18:00	85	590	455	420	50		4.7	1.7	425	0.8	7				
8/28/97	11:30						4									
8/28/97	12:15	86	585	395	365	50	4	4.7	1.85	360	1.2	7				
8/28/97	13:15	81	580	465	430	50	4	4.7	1.8	430	0.95	7				
8/28/97	14:30	81	580	460	430	50	4	4.7	1.8	425	0.95	7				
8/28/97	15:30	80	580	455	425	50	4	4.7	1.8	420	0.95	7				
8/28/97	16:30	80	580	450	420	50	4	4.7	1.8	420	0.95	7				
8/28/97	17:30	80	580	450	420	50		4.7	1.8	415	1	7				
8/28/97	19:00	79	580	460	425	50		4.7	1.8	425	1	7				
8/28/97	20:00	79	580	465	425	50		4.7	1.8	425	1	7				
8/29/97	7:30	78	560	400	365	50		4.7	1.9	365	1.25	7				
8/29/97	8:30	80	560	480	450	5		4.7	1.8	450	1.1	7				
8/29/97	9:30	78	560	480	450	50		4.7	1.85	450	1.1	7				
8/29/97	10:30	74	580	460	430	50	4	4.7	1.9	425	1	7				
8/29/97	12:30	73	575	445	410	50	4	4.7	1.85	410	1	7				
8/29/97	13:30	71	575	440	410	50	4	4.7	1.85	405	1	7				

RO Pump and Flow Data

Date	Time	Cartridge Filter, psig	RO Booster Pump Discharge, psig	RO Feed Pressure	RO Stage 1 Reject, psig	RO Stage 1 Permeate Backpressure, psig	RO Stage 1 Permeate Flow	RO Recycle Flow, gpm	RO Stage 2 Permeate flow	RO Stage 3 Reject, psig	RO Stage 3 Permeate flow	RO Effluent Flow	NaOH Feed Rate, ml/min	NaOH Wt%	H2SO4 Feed Rate, ml/min	Antiscalant Dosing Rate, ml/min
8/29/97	14:30	53	575	440	400	50		4.7	1.9	400	1	7				
8/29/97	15:45	73	580	425	390	50		4.7	1.9	390	1	7				
8/29/97	17:00	70	580	425	390	50		4.7	1.9	390	1	7				
8/29/97	18:00	70	580	430	400	50		4.7	1.9	395	1	7				

Water Quality Data
for RO Stages

		Cartridge Filter					RO Stage 1 Permeate			RO Stage 2 Permeate			RO Stage 3 Permeate		
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	SDI	Temp (°F)	Cond (µmho)	NH3 (mg/L as NH3)	Temp (°F)	Cond (µmho)	NH3 (mg/L as NH3)	Temp (°F)	Cond (µmho)	NH3 (mg/L as NH3)
7/15/97	16:00	9.48													
7/17/97	18:00					5.86									
7/17/97	19:30			0.68											
7/17/97	19:30					6.1									
7/23/97	18:00		86				69.6	171		69.4	180		69.3	271	
7/24/97	19:00		83.3	0.62				390			310			400	
7/25/97	11:00					6.3									
7/28/97	9:45					6.21									
7/28/97	17:00		82.3												
7/29/97	10:30					6.35									
7/30/97	18:00	10.07	82	0.58				340	4.4		330	4.7		370	4.6
7/31/97	10:45					6.41									
7/31/97	18:00	10	92.3	0.64				400	4.6		420	5		520	5
8/4/97	10:00								2.3			2.3			2.7
8/6/97	10:00	10.14	95.2						3.6			4			4
8/6/97	11:00	10.14	95.4												
8/6/97	15:00	10.09	105.6												
8/6/97	15:30	10	106												
8/6/97	16:00	10	106	0.57			104	570	4.1	102.2	550	4.3	102.2	700	4.5
8/7/97	9:45	9.82	86.2												
8/7/97	10:00	9.9	87.3						4.6			4.9			4.8
8/7/97	13:30	10.44	98.3												
8/7/97	16:30	10.12	98.6												
8/7/97	17:00	10.01	97.7				92	360	4.5	92	370	4.5	92	450	5
8/7/97	17:00	10.01	95	0.54											
8/7/97	17:30	10.01	95												
8/8/97	6:30	10	73.1												
8/8/97	9:15	9.7	78.9			6.32			2.8			2.9			3.2
8/8/97	10:15	9.95	86.6												
8/8/97	15:00	10.3	94.8												
8/8/97	15:30	10.57	94.8												
8/8/97	17:00	10.62	93.3	0.54			100.7	470	11.7	100.7	500	12.5	101.2	650	12.9
8/11/97	7:30	10.77	67.1		10700										
8/11/97	9:30	10.63	67.3		10500										
8/11/97	11:45	10.72	77.4		11200				9.8			10			11
8/11/97	14:00	10.67	80.6		9900										
8/11/97	16:30	10.69	86	0.57											
8/11/97	16:45	10.62					83.4	370	12.1	83.8	360	11.8	83.6	430	12.9
8/11/97	17:00	10.69	86		10500										
8/12/97	7:30	10.76	65.1		10600										
8/12/97	9:30	10.61	71.6		10300				11.3			11.9			12.7
8/12/97	10:30					6.33									
8/12/97	12:30	10.62	80.8		10500		89.9	320	13.3	90.7	320	13.6	90.6	400	14.3
8/12/97	15:00	10.62	87.5		10500										
8/12/97	16:30	10.85	92.7												
8/13/97	15:15	9.69	94		9600										
8/13/97	16:00	10.75	94.3		10000		94	400	12.5	95.5	410	12.8	95.3	500	13.5
8/13/97	19:00	10.72	87.1		10000										
8/14/97	11:00					6.131			8			8.7			9.7
8/14/97	11:45	9.43	90.9		10000										
8/14/97	13:45	9.37	91.9		10100										
8/14/97	15:30	9.75	92.4		10100										
8/14/97	17:00	10.72	90.1				94.9	390	12.4	95.6	410	13.5	95.5	580	13.5
8/14/97	17:30	10.72	90.1		10500										
8/14/97	18:30	10.69	87.7		10400										
8/15/97	9:30	8.2	72.3		10400				1.2			1.5			2.3
8/15/97	12:15	8.01	85		10400										
8/15/97	13:00	8.19	86.7		10400										
8/15/97	13:45					6.32									
8/15/97	14:45	7.78	88.2		10300										
8/15/97	16:30	8.25	89.6		10400		84.2	150	2	84.1	180	2.3	84.1	290	3
8/15/97	16:30	8.25	89.6		10400										
8/18/97	10:30	8.02	80.9		9300										
8/18/97	11:30					6.43									
8/18/97	12:45	7.32	91												

Water Quality Data
for RO Stages

		Cartridge Filter					RO Stage 1 Permeate			RO Stage 2 Permeate			RO Stage 3 Permeate		
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	SDI	Temp (°F)	Cond (µmho)	NH3 (mg/L as NH3)	Temp (°F)	Cond (µmho)	NH3 (mg/L as NH3)	Temp (°F)	Cond (µmho)	NH3 (mg/L as NH3)
8/18/97	15:45	8.25			9500										
8/18/97	16:00	8.25					86	280	1	87.1	280	2.6	87.4	370	1.7
8/19/97	8:15	8.52	77		10500										
8/19/97	9:30	7.75	83.9		10100										
8/19/97	9:45	8.2	83.9		10100										
8/19/97	10:45					6.55			1.4			1.9			2.8
8/19/97	12:00	7.61	91.4		10100										
8/19/97	12:45	8.25	89.7		10300										
8/19/97	15:00	8.3	93.2		10400										
8/19/97	16:45	8.24	87.7		10400		93.5	160	0.9	94	200	1.3	94	320	2.1
8/20/97	6:15	9.26	73.1		10300										
8/20/97	6:45	9.22													
8/20/97	8:30	8.37	77.7		10900										
8/20/97	9:00	8.23							0.9			1.2			2
8/20/97	11:00	7.93	88.7		10200										
8/20/97	11:45					6.55									
8/20/97	13:00	7.23	94.1		10200										
8/20/97	18:00	8.27	90.2		10200		91	160	1	90.8	200	1.4	91.4	300	2.2
8/20/97	19:00	8.27	89.8		10200										
8/21/97	9:30	9.9	79.1		10600				7.9			8.5			9.2
8/21/97	12:00	9.55	86.7		10600										
8/21/97	14:15					5.99									
8/21/97	16:00	8.96	85.7		10500										
8/21/97	17:00	8.75	88.4	0.75	10500		95.1	210	4.6	94.1	230	4.7	93.6	330	5.2
8/21/97	18:00	8.75	88.4		10500										
8/22/97	9:00								6.1			6.1			6.5
8/22/97	16:30	9.17	100.4		10300		100.4	220	4.8	100.4	250	5	100.4	370	5.3
8/25/97	10:00								6.4			6.5			7
8/25/97	11:00	9.46	86		10600										
8/25/97	12:30					6.39									
8/25/97	14:00	9.38	86		10500										
8/25/97	16:00	9.18	86		10500										
8/25/97	17:45	9.15	86	0.84	10500		86	210	5	86	240	5.1	86	360	5.6
8/25/97	18:00	9.15	86		10500										
8/26/97	11:00	9.64	80.6		10200				5.9			6.2			6.8
8/26/97	12:30					6.55									
8/26/97	14:45	9.38	82.4		10400										
8/26/97	17:00	9.36	82.4	0.87	10300		82.4	200	4.4	82.4	240	5.3	82.4	380	5.8
8/26/97	17:45	9.36	82.4		10300										
8/27/97	8:00	9.61	65.3		10800										
8/27/97	9:30								6.1			6.4			7.2
8/27/97	10:45	9.41	89.6		10300										
8/27/97	12:30					4.58									
8/27/97	14:15	9.36	89.6		11600										
8/27/97	15:45	9.58	95	0.55	11500		95	260	7.4	95	330	7.7	95		8.4
8/27/97	17:00	9.58	95		11500										
8/28/97	11:30	9.96	89.6		11500		89.6	280	9	89.6	360	8.5	89.6	530	10.2
8/28/97	12:00	9.84	89.6		11500										
8/28/97	13:00	9.92	89.6		11600										
8/28/97	14:45					4.76									
8/28/97	15:00	9.75	92.3		11100										
8/28/97	17:00	9.7	91.4		11000										
8/28/97	19:00	9.71	86	0.84	10000		86	240	6.7	86	280	6.7	86	410	7.6
8/29/97	7:30	9.69	75.2												
8/29/97	9:30	9.73	82.4												
8/29/97	10:00								7.8			8.6			9.4
8/29/97	12:30					5.1									
8/29/97	13:30														
8/29/97	14:30	9.33	86		10500										
8/29/97	16:00	9.4	93.2		10100		93.2	250	8.8	93.2	310	9.2	93.2	420	10
8/29/97	17:00	9.4	93.2		10100										

Field and Lab Data
for RO Permeate

		Field Data									CLWA lab Data													
		pH	Temp	Turb	Cond	UV Abs	Alk	Tot Hard	Ca Hard	SiO2 (mg/L	pH	Temp	Alk (mg/L	B	Fe	Si	Ca	Mg	K	Na	TOC	NH3 (mg/L	TDS	Cl (mg/L
Date	Time		(°F)	(NTU)	(µmho)		(mg/L as CaCO3)			as		(°F)	as	(mg/L as Ion)							(mg/L)	as	(mg/L)	as
7/14/97	17:30	10.5		0.04	215		42	0.8	0	1.4				7.1							1.6		169	27
7/15/97	17:00	10.8		0.13	165		86	0.8	0.6	0.9				4.7		0.4					2		160	22
7/21/97	17:00	9.5	92.2	0.19		0.027	50	0.2	0	0.2				6.59		0.2	0.04	0			0.3	1	106	
7/22/97	18:30	9.83			180		56	1	0.2	0.1														
7/23/97	7:30	10.7			175	0.019				0.3				4.42		0.4						4	155	
7/23/97	18:00	10.8	71.5		330	0.042								6.16	0	2.5						8	158	
7/24/97	6:45	10.3			200					1.1				4.34	0.02	0.8					2	2	108	
7/24/97	19:00	10.8			350					1											2.1	3.5		
7/25/97	7:45	9.87	73.7		218					2.5				4.01		1					2	1.6	119	
7/28/97	8:00	10.2	69.7	0.05	505	0.008								4.84		0.2					2	3	108	
7/28/97	17:00	9.4	68.7	0.73	225	0.008								6.75		0.2					1.8	0.9		
7/29/97	7:00	10.4	69.9	0.08	550	0.008								3.75		1.2					1.3	3		
7/30/97	7:30	10.7	69.8	0.11	433	0.009				3.7				3.25		2.5					1.8	5.6	78	
7/30/97	18:00	11	70.3	0.11	594	0.042								2.95	0	3.6					2	4.4	98	
7/31/97	8:00	10.6	69.4	0.04	500	0.013				4.2											2	5.6	70	
7/31/97	18:00	10.1	67.5	0.13	567	0.039				4.6											2.1	4.5	96	
8/4/97	10:00	10.6	77.4		370	-0.002				1.3				5.2		0.1			1.8	71	2.4	2.5	147	
8/6/97	10:00	11	74.3	0.09	518	0.028								4.3		0.3			1.6	87	4.2	3.8	197	
8/6/97	16:00	11	72.7	0.04	580	0.022				2.4				5.2		0.2			2.4	80	4.1	4.3		
8/7/97	10:00	11.1	73.4	0.07	457	0.018				1.5				3.8		0.1	0.3		1.7	69	3.7	5.3	173	
8/7/97	17:00	11.1	71.1	0.11	492	0.043								4.6		0.6			1.6	67	3.1	5	176	
8/8/97	8:00	10.8	67.3	0.07	482	0.022								3.7		0			1.1	45	2.5	2.8	127	
8/8/97	17:00	11.3	67.9	0.07	482	0.023								2.3		0.9			1.4	72	6.7	11.2	156	
8/11/97	10:00	10	71.4	0.06	303	0.004								1.1		0.1			1.2	42	2.8	9.9	108	
8/11/97	16:30	11.2	68.3	0.15	405	0.002								1.9							3.2	11.6	182	
8/12/97	8:30	10.7	71.5	0.085	304	0.015								1.5							2.4	10.6	164	
8/12/97	16:30	10.8	68.2	0.12	528	0.064								2.2							2.9	11.5	160	
8/13/97	16:00	11.2	69.8	0.05	450	0.052								2.3	0.01						2.4	10.6	130	
8/14/97	10:00	10.5	68.4	0.85	294	0.04															2.1	8.3	120	
8/14/97	17:00	11.3	70.7	0.06	437	0.132				5.7				2		1.5	0.1	0	2.3	68	2.3	11.4	174	
8/15/97	10:00	8.6	72.7	0.13	200	0.0002				0.5				5.4	0.01	0.3	0.7	0.3	1.7	41	2.1	1.2	97	
8/15/97	16:30	9.4	72.5	0.15	181	0.01				1				5.6		0			0.5	41	2	2.2	122	
8/18/97	16:00	8.22	71.8		275	0.026				0.9				8.5					0.5	39	2.7	1.6	155	
8/19/97	10:00	9.04	69.7	0.07	211	-1.111				0.3				7.3		0.2	0.3	0.2	2.1	44	2.4	1.7	151	
8/19/97	16:00	8.89	68.9	0.07	205	-0.106				0.4				6.8		0.3	0.1	0.1	1	54	2.6	1.3	152	
8/20/97	9:00	8.69	70	0.12	180	-0.112				0.3				5.9		0.2	0.3	0.2	2	42	2.5	1.1	145	
8/20/97	18:00	8.96	69.8	0.16	236	-0.101				0.5	7.78	70.9	49	6.8	0.01	0.5	0.2	0.1	1.3	51	2.4	1.4	147	
8/21/97	9:45	11.2	68.9	0.09	292	0.113				3.4				2.7		2.6	0.9	1.1	4.7	147	1.8	8.6	154	
8/21/97	17:00	10	72.5	0.12	281	0.123				1.1				6.6		1.1	1	0.1	1.4	53	1.8	4.7	147	
8/22/97	9:00	10.9	69.8	0.09	224	0.015				3.6				4.6	0.01	0.2			0.9	54	1.7	6.5	133	
8/22/97	16:30	10.5	73	0.07	246	0.083				1.7				6.9		1.1	1	0.1	1.4	53	2.1	3.9	167	

Field and Lab Data
for RO Permeate

		Field Data									CLWA lab Data														
Date	Time	pH	Temp (°F)	Turb (NTU)	Cond (µmho)	UV Abs	Alk	Tot Hard (mg/L as CaCO3)	Ca Hard	SIO2 (mg/L as	pH	Temp (°F)	Alk (mg/L as	B	Fe	Si (mg/L as Ion)	Ca	Mg	K	Na	TOC (mg/L)	NH3 (mg/L as	TDS (mg/L)	Cl (mg/L as
8/25/97	10:30	11.1	72.5	0.08	303	0.019				2.2				4.7		0.2			0.9	54	2.1	5.7	156	
8/25/97	17:45	10.5	74.3	0.15	254	0.024				1.7				6		0.1			1	48	2.2	4.2	135	
8/26/97	11:00	11	73.6	0.09	267	0.015				1.4				4.6					0.9	58	1.8	5.8	150	
8/26/97	17:00	10.7	69.8	0.06	286	0.01				0.9				5.7		0.2			1.9	55	2.2	4.7	136	
8/27/97	9:30	11	71.6	0.11	329	0.023				0.2				3.1							3.7	6.2	153	
8/27/97	15:45	11	71.6	0.09	470	0.081				1.2				2.76		0.1		0.7	2.6	96	5.1	8	234	
8/28/97	11:30	11.1	71.6	0.15	371	0.054				1.2				2.93		3.2	0.5	0.1	2.1	67	3.8	9.4	173	
8/28/97	19:00	10.9	71.6	0.17	310	0.029				1.6				3.92	0.02	3.9	1.3	0.1	1.3	57	3.4	6.7	154	
8/29/97	10:00	11.1	70.7	0.09	292	0.33				0.5						4.6	0.5	0	1.8	59		8.1	147	
8/29/97	16:00	10.9	77	0.57	303	0.025				0.5				4.94	0.03	3.5	0.4		1.5	57	4.1			

Water Quality Data
for RO Concentrate

		Field Data								CLWA lab Data														
Date	Time	pH	Temp	Turb	Cond	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)	pH	Temp	Alk (mg/L as CaCO	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC	NH3 (mg/L as NH3)	TDS
			(°F)	(NTU)	(µmho)		(mg/L as CaCO3)				(°F)						(mg/L as Ion)					(mg/L)		(mg/L)
7/22/97	18:30	8.39			26500	1230		20.8																
7/23/97	7:30	8.85			26000	1420		29.6					24.7	3.65	44								20	5,759
7/23/97	18:00	8.99	71.9		31000	1470	67	17.6																
7/24/97	6:45	8.82			32500	1752	52	21.2					20	0.51	4.45							321	10	21,769
7/24/97	19:00	9.03			30000	1478	124	30																
7/25/97	7:45	8.8	73.6		33500	1708	180	29.8	65.5				24	0	18.3							351	8.8	22,051
7/28/97	8:00	8.77	68.9		34700	1970	124	39.2					25.6	0.16	0.83								15	22,623
7/28/97	17:00	8.18	68.5		35700	1920	122	30																
7/29/97	7:00	8.88	69.6		33600	1910	104	36					29.5	1.29	3.25								13	
7/30/97	7:30	9.06	69.8		33900	1908	78	39.8	113.5				27.7	1.48	5.62								5.6	23,036
7/30/97	18:00	9.68	70.3			2070	84	30.8					18	0.05	28.7									22,940
7/31/97	8:00	9.41	69.5		33700	2216	202	98.6	69.5				35	0.19	19.1								8	23,206
7/31/97	18:00	9.62	68.4		36500	2108	132	67.4	134				25.3	1.79	1.4									24,644
8/4/97	10:00	9.43	77.9		16000	2332	62	36.8	137.5	9.27		2000	14.1	0.02										24,689
8/6/97	10:00	9.71	74.7		36000	2284	102	72	113.5	9.63	68	1400	2.5	0.01	4.03									23,187
8/6/97	16:00	9.4	73.1		34000	1848	108	31.2	83	9.38	67.8											120		23,678
8/7/97	10:00	9.65	73.2		35400	2200	78	33.6	102.5	9.64		2200												23,200
8/7/97	17:00	9.73	71.6		35100	2400	109	32		9.55	68.9													23,030
8/8/97	8:00	9.23	67.9			2090	91	32.9		9.23	2000													22,854
8/8/97	17:00	10.2	67.5		37800	2780	99	34.4		10.1	71.6	2620												24,934
8/11/97	10:00	10.2	71.8		38200	3330	114	36		10	71.6	2790												24,960
8/11/97	16:30	10.2	68.2		39300	3290	114	34		10.1	21.9		58	0.13	40	29	19	313	9,379	0.14	0.59			25,184
8/12/97	8:30	10.2	71.8		37500	3570	131	49.6		10.1	71.4	3200	56	0.03	37	14	23	303	9,475	0.23	0.27			24,184
8/12/97	16:30	10.1	68.4		38900	3360	154	47.6		10.1	71.9	2820	60	0.02	33	7.5	17	359	10,713	0.11	0.48			22,898
8/13/97	16:00	10.2	68.9		37600	2910	107	18		10.1	71.6	2610	59	0.03	33	5.7	7.5	348	10,365	0.13	0.25			23,156
8/14/97	10:00	9	68.1	0.9	35400	3010	121	28		8.88	71.4	1670	45	0.06	25	21	24	306	8,961	0.24	0.28			22,402
8/14/97	17:00	10.2	71.6	0.41	38700	3390	168	71	82	10.2	71.8	3130	62	0.01	25	7.9	26	361	11,162	0.19	0.17			25,866
8/15/97	10:00	7.89	72.9		38900	1940	72	39.6	96.5	7.98	71.4	1800	47	0.33	30	16	16	336	10,164	0.22	0.41			24,774
8/15/97	16:30	8.03	72.2		37100	1600	163	31.2	82.5	8.14	71.4		44	0.11	41	18	26	332	9,910	0.17	0.65			24,870
8/18/97	16:00	7.88	71.4		38900	1650	196	20	97.5				38	0.6	39	11	32	344	10,243	0.27	0.31			25,382
8/19/97	10:00	7.72	69.8		39100	1512	196	22.2	170				40	1.09	32	11	12	324	9,545	0.17	0.05			24,582
8/19/97	16:00	7.84	68.5		38500	1356	206	26	111.5				38	0.93	31	6.7	22	345	10,019	0.26	0.32			25,326
8/20/97	9:00	7.65	69.9		39500	1620	176	24.2	155	7.98	72.3	1560	38	0.81	42	7.1	13	334	10,028	0.23	0.38			25,304
8/20/97	18:00	7.74	68.9		39100	1556	284	138	123	7.78	74.5	1385	40	0.6	32	47	18	336	10,096	0.39	2.11			25,114
8/21/97	9:45	9.5	68.9		41500	2668	134	40	142	9.47	72.1	2843	52	0.32	41	2.5	2.3	340	10,526	0.1	0.2			26,540
8/21/97	17:00	8.35	72.5		39700	1710	412	167	176				38	0.37	48	20	72	344	9,787	0.42	0.48			24,948
8/22/97	9:00	9.12	70.7		38900	2260	98	47	109	9.06	71.1	1914	47	0.16	47	6	10	346	10,198	0.23	0.21			25,598
8/22/97	16:30	8.51	72.86		38500	1432	368	84	223				36	0.09	88	19	70	335	9,821	0.33	0.7			24,260
8/25/97	10:30	9.22	72.5		37100	2010	82	46	129	9.14	71.8	1519	46	0.1	39	11	11	315	9,258	0.48	0.41			23,450

Water Quality Data
for RO Concentrate

		Field Data								CLWA lab Data														
		pH	Temp	Turb	Cond	Alk	Tot Hard	Ca Hard	SiO2 (mg/L as SiO2)	pH	Temp	Alk (mg/L as CaCO	B	Fe	Si	Ca	Mg	K	Na	Ba	Sr	TOC	NH3 (mg/ L as NH3)	TDS
Date	Time		(°F)	(NTU)	(µmho)	(mg/L as CaCO3)					(°F)		(mg/L as Ion)									(mg/L)		(mg/L)
8/25/97	17:45	8.65	74.3		38400	1430	209	63	116	8.31	71.4	1346	42	0.14	31	12	27	339	9,885	0.28	0.37			24,362
8/26/97	11:00	9.08	73.4		37600	1790	49	38	128	9	71.8	1935	44	0.24	41	9	6.2	345	10,080	0.13	0.41			24,976
8/26/97	17:00	8.75	82.4		37800	1530	142	66	106	8.7	72.1	1326	38	0.07	27	17	23	315	9,314	0.31	0.45			24,698
8/27/97	9:30	8.89	71.6		41300	1350	940	120	63	8.75	71.6	1316	28	0	17	15	205	331	9,804	0.37	0.66			25,870
8/27/97	15:45	8.87	71.6		42600	1400	854	186	134	8.97	71.6	1339	21	0.01	6	10	207	345	10,870	0.23	0.55			28,686
8/28/97	11:30	9.07	71.6		40900	1320	416	146	62	9.18	72	1279	26	0.02	26	28	61	359	10,879	0.43	0.66			26,426
8/28/97	19:00	8.81	71.6		40400	1490	248	104	56	8.93	72.5	1448	33	0.01	15	21	40	371	11,228	0.19	0.96			26,157
8/29/97	10:00	9.04	70.7		41900	1690	364	118	130	9.14	72.3	1661												26,546
8/29/97	16:00	8.82	76.1		37300	1520	378	90	176	9.01	57.7	1463												

GRAVIMETRIC OIL AND GREASE ANALYSES PERFORMED BY TRUESDAIL LABS

Date	Time	Location	O&G (mg/L)
8/28/97	10:00	Raw Water	13.3
8/21/97	18:30	Raw Water	14.1
8/25/97	19:00	Raw Water	14.2
8/28/97	10:15	IX Effluent	18.3
8/21/97	18:30	Filter Effluent	29
8/27/97	17:00	Filter Effluent	30.6
8/29/97	17:00	Raw Water	37.9
8/26/97	17:00	Raw Water	40.3
8/27/97	17:00	Raw Water	43.4
8/29/97	17:00	Filter Effluent	44.1
8/26/97	17:45	Filter Effluent	46.6

VOA, BASE NEUTRAL ACIDS, BOD, AND COD ANALYSES PERFORMED BY TRUESDAIL LABS

	Date	8/26/97	8/26/97	8/26/97
	Time	18:30	18:30	18:30
Parameter (mg/L)	Location	RO Permeate	Trickling Filter Sump	Densadeg Effluent
BOD			26.3	38.4
COD			493	526
Benzene		ND		
CHBrCl2		ND		
CHBr3		ND		
2-Butanone		53.1		
CS2		ND		
CH3Br		ND		
CCl4		ND		
Clorobenzene		ND		
C2H5Cl		ND		
2-Chloroethyl vinyl ether		ND		
CHCl3		ND		
CH3Cl		ND		
CHBr2Cl		ND		
1,1 - C2H4Cl2		ND		
1,2 - C2H4Cl2		ND		
1,1 - C2H2Cl2		ND		
trans -1,2 - C2H2Cl2		ND		
1,2 - C3H6Cl2		ND		
cis - 1,3 - C3H4Cl2		ND		
trans - 1,3 - C3H4Cl2		ND		
Ethyl Benzene		4.85		
2-Hexanone		ND		
4-methyl-2-pentanone		ND		
CH2Cl2		ND		
styrene		ND		
1,1,2,2 - C2H2Cl4		ND		
C2Cl4		ND		
toluene		ND		
1,1,1 - C2H3Cl3		ND		
1,1,2 - C2H3Cl3		ND		
C2HCl3		ND		
CFCl3		ND		
vinyl acetate		ND		
vinyl chloride		ND		
m,p - xylene		ND		
o - xylene		ND		
total xylenes		ND		
1,2 dichlorobenzene		ND		
1,3 dichlorobenzene		ND		
1,4 dichlorobenzene		ND		
acenaphthene		ND		
acenaphthylene		ND		
anthracene		ND		
benzoic acid		ND		

VOA, BASE NEUTRAL ACIDS, BOD, AND COD ANALYSES PERFORMED BY TRUESDAIL LABS

	Date	8/26/97	8/26/97	8/26/97
	Time	18:30	18:30	18:30
Parameter (mg/L)	Location	RO Permeate	Trickling Filter Sump	Densadeg Effluent
benzo 9a) anthracene		ND		
benzo (b) fluoranthene		ND		
benzo (k) flouranthene		ND		
benzo (g,h,i) perylene		ND		
benzo (a) pyrene		ND		
benzyl alcohol		ND		
bis (2-chlorethoxy) methane		ND		
bis (2-chloroethyl) ether		ND		
bis (2-chloroisopropyl) ether		ND		
bis (2-ethylhexyl) phthalate		ND		
4 - bromophenyl phenyl ehter		ND		
butyl benzyl phthalate		ND		
4 - chloroanaline		ND		
carbazole		ND		

RESULTS OF ANAYLSES FOR ARCO REFINERY WASTE CAUSTIC

			CLWA lab Data											
			B	Fe	Si	Ca	Mg	K	Na	NH3	Cl	SO4	Br	NO3
Date	Time	Location	(mg/L as Ion)							(mg/L as NH3)	(mg/L as Ion)			
8/29/97	16:00	Waste Caustic	0.19	0.16	2.9	0.5	0.2	5.2	3241	8.2	1190	2262		13
8/13/97	16:00	Waste Caustic Titration	10.7	0.06							2242	786	6	7

Appendix B

Full Scale ARCO Sand Filters

Full Scale AWE Sand Filters
Total Suspended Solids by In-line Filtration measured by Nalco

Date	Tank 30	Sand Filter	Percent Removal
Jan-95	NST	NST	
Feb-95	14.1	DWN	
Mar-95	NST	NST	
Apr-95	28.12	23.21	17%
May-95	23.21	4.2	82%
Jun-95	23.6	0.9	96%
Jul-95	16.14	0.3	98%
Aug-95	14.57	0.6	96%
Sep-95	7.15	0.5	93%
Oct-95	9.2	0.6	93%
Nov-95	13.65	2.3	83%
Dec-95	19.42	11.2	42%
Jan-96	10.26	1.97	81%
Feb-96	6.87	0.66	90%
Mar-96	5.56	0.54	90%
Apr-96	8.34	2.03	76%
May-96	10.77	2.43	77%
Jun-96	9.48	1.63	83%
Jul-96	10.83	3.38	69%
Aug-96	12.2	1.48	88%
Sep-96	11.98	1.99	83%
Oct-96	8.42	2.39	72%
Nov-96	11.05	3.24	71%
Dec-96	13.07	5.38	59%
Min	5.56	0.3	17%
Median	11.52	1.99	83%
Average	13.09	3.38	78%
Max	28.12	23.21	98%

NST = No Sample Taken
DWN = Unit Offline

Full Scale AWE Sand Filters
Total Oil and Grease by (Spec 20) measured by Nalco

Date	Tank 30	Sand Filter	Percent Removal
Jan-95	1.3	1.3	0%
Feb-95	1	0.3	70%
Mar-95	1	1	0%
Apr-95	10	4	60%
May-95	2	2	0%
Jun-95	1	1	0%
Jul-95	0.5	0.5	0%
Aug-95	0.5	0.5	0%
Sep-95			
Oct-95			
Nov-95	1	1	0%
Dec-95	5	1	80%
Jan-96	4	1	75%
Feb-96	1	0	100%
Mar-96	1	0	100%
Apr-96	1	0	100%
May-96	1	0	100%
Jun-96	10	1	90%
Jul-96	3	1	67%
Aug-96	6	1	83%
Sep-96	10	0	100%
Oct-96	5	0	100%
Nov-96	4	0	100%
Dec-96	3	1	67%
Min	0.5	0	0%
Median	1.65	1.00	73%
Average	3.29	0.80	59%
Max	10.00	4.00	100%

0 = <0.5

Appendix B

EPRI/Southern California Edison Data

Membrane Treatment of Produced Water at an Oil Drilling Field

A Report on Membrane Trials Conducted for
ARCO Western Energy, Santa Clarita, California

Draft for review

Southern California Edison, CTAC, Irwindale, California - Client # 18
April, 1997

Background

Heavy oil fields generate about 10 to 15 barrels of produced water for every barrel of oil. The annual production of produced water is USA was estimated as 14.5 billion barrels in 1990. ARCO Western Energy's Placerita Oil Field in Santa Clarita, California has commenced a pilot project for the production of drinking water from produced water.

Heavy oil production involves injecting steam at 800 F to the ground which causes the oil pumped from the ground to be mixed with water. A dissolved gas flotation is used to separate oil from water. Produced water has high levels of inorganic salts and traces of petroleum oils. At present, produced water is injected to the ground. The company has evaluated thermal evaporation and reverse osmosis as possible methods for recovery of drinking water from produced water and selected reverse osmosis for the pilot project based on its favorable cost.

The pilot plant presently being built at Placerita Field, involves a walnut filter for removal of petroleum traces, warm softening to remove Si, Ca, Mg, and B compounds, a trickling filter to remove biodegradable organics, ion exchange softening and reverse osmosis. The objective of the membrane trials conducted for ARCO Western Energy was to evaluate the technical feasibility of the reverse osmosis to meet the expectations.

Two barrels each of water samples from two points in the pilot process train were obtained for the trials. The first sample was after treatment from the walnut filter. The second sample was after the ion exchange softening process. Some quality characteristics of these two samples together with reported characteristics of typical produced water are listed in Table 1.

Table 1. Quality Characteristics of Samples and Produced Water

	Walnut Filtered	IX Softened	Produced Water
Electrical Conductivity (µS/cm)	8,430	10,870	7,633
pH	8.1	10.0	7.0
COD (mg/L)	750	610	-
Turbidity (FTU)	81	23	4.7 (NTU)
Total Solids (mg/L)	7,000	6,800	-
Total Dissolved Solids (mg/L)	-	-	5,068
Total Suspended Solids (mg/L)	2	0	8.9
Hardness (Mg/L as CaCO3)			912
Sodium (mg/L)			1,247
Calcium (mg/L)			247
Magnesium (mg/L)			72
Bicarbonate (mg/L)			722
Chloride (mg/L)			2,399
Sulfate (mg/L)			32
Silica (mg/L)			179
Boron (mg/L)			15

Membrane Treatment of Produced Water

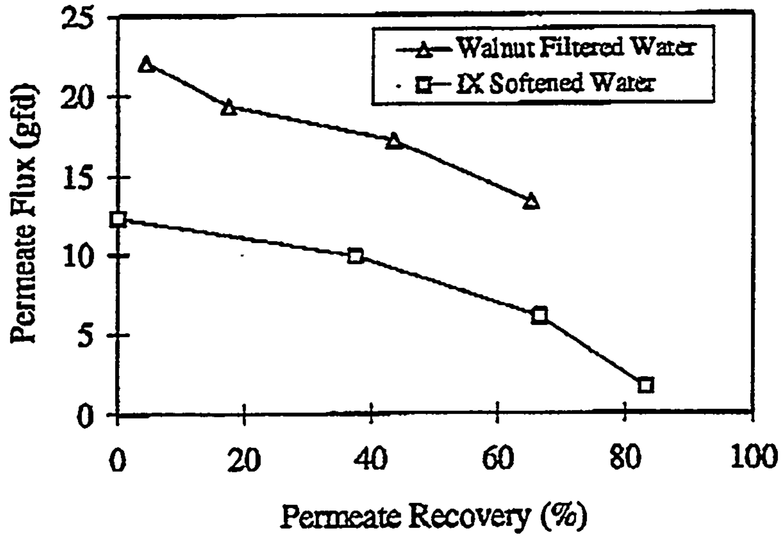
In the pilot project reverse osmosis is intended for removal of dissolved solids to meet the drinking water limit of 500 mg/L. Produced water is softened by warm lime treatment and also by ion exchange before reverse osmosis. The IX softened water sample is a representative of the feed to the reverse osmosis system in the pilot project. It contained about 4,000 mg/L of dissolved solids and was free of suspended solids. Therefore, a spiral brackish water RO membrane was used to test this sample. This was a thin film composite membrane made by Fluid Systems Company.

Conventional reverse osmosis of hard water uses several pretreatment processes to remove hardness. A more attractive alternative would be to use seeded reverse osmosis and eliminate all the intermediate processes. Hard water forms precipitates of calcium and magnesium salts when their solubility limit is exceeded. In conventional reverse osmosis, the precipitate forms at the membrane surface where the concentration of salts is highest. In seeded reverse osmosis, seeds of the precipitating salts are introduced to the feed. When the solubility limits are reached the precipitation occurs at these seeds and not on the membrane.

The walnut filtered water sample contained all the hardness of the typical produced water. Magnesium hydroxide was introduced to this water to increase the pH and to create seeds.

Presence of seeds prevents the use of spiral membrane modules due to potential for fouling of the feed spacer grid. Therefore, a tubular reverse osmosis membrane module made by PCI Company was used in this trial. Figure 1 is an illustration of flux characteristics observed in these two trials. Permeate fluxes are normalized to 77 F in both cases.

Figure 1. Flux Characteristics During Reverse Osmosis of Produced Water
Walnut Filtered Sample - Seeded Reverse Osmosis - PCI AFC99 - 600 psi
IX Softened Sample - Conventional Reverse Osmosis - FSC ROBW - 450 psi



The trials were conducted as concentration scans where over three fold concentration of the feed volume was achieved. These recovery levels are close to the expectations of the final project. The trials produced acceptable permeate fluxes. The osmotic pressure build-up caused by the high concentration of dissolved solids was the primary reason for the gradual decline in permeate flux with increase in concentration in both trials. Both membranes restored to original condition when cleaned with a caustic solution which was a favorable observation.

Table 2. Rejection Characteristics During Reverse Osmosis of Produced Water

Reverse Osmosis of Coarse Filtered Feed						Reverse Osmosis of Ultrafiltered Feed					
Recovery (%)	Total Solids mg/L	Electrical Conductivity uS/cm		Chemical Oxygen Demand mg/L		Recovery (%)	Total Solids mg/L	Electrical Conductivity uS/cm		Chemical Oxygen Demand mg/L	
	Reten.	Reten	Perm.	Reten	Perm.		Reten	Reten	Perm.	Reten	Perm.
4.3	8,100	9,380	283	770	120	0.0	14,300	21,720	1,162	1,290	150
17.4	9,600	11,080	191	980	110	37.5	17,100	25,900	1,489	1,530	140
43.5	13,600	15,200	244	1,330	100	66.7	15,800	36,600	3,120	2,260	170
65.2	19,700	21,650	345	1,860	150	83.3	33,100	45,500	5,950	3,040	240

The rejection characteristics for chemical oxygen demand (COD) and electrical conductivity recorded during the two trials are summarized in Table 2. COD rejection in both trials ranged around 95% to 90%. The permeate COD remained in the range of 100 to 240 mg/L and did not show a strong correlation with the retentate COD. Samples of permeate from both trials were submitted to ARCO for analytical work. The results of these analysis when available should help the decision making process.

Seeded reverse osmosis trials with walnut filtered water rejected over 97% of the electrical conductivity and the permeate TDS levels were low enough to meet drinking water standard. Conventional reverse osmosis trial of IX softened water rejected about 87% to 95% % of the electrical conductivity and the TDS levels of the permeate did not meet the drinking water standard. Two trials were conducted under different pressures which also contributes to the difference in flux and rejection characteristics. Therefore, the results should be interpreted with due caution.

Summary and Conclusions

Two produced water samples, drawn for two different stages of pretreatment were received from ARCO Western Energy Company. The ion exchange softened sample was treated by conventional reverse osmosis while the walnut filtered sample was treated by seeded reverse osmosis. Both trials produced acceptable permeate fluxes.

Seeded reverse osmosis of walnut filtered water resulted in relatively higher fluxes and higher rejection. Seeded reverse osmosis of walnut filtered water resulted in TDS levels meeting drinking water standards in a single pass while conventional reveres osmosis of ion exchange softened water would require two passes to achieve the same TDS level.

In addition to observed flux and rejection advantages, seeded reverse osmosis of walnut filtered water avoids several pretreatment operations required for conventional reverse osmosis, thus reducing the capital and operational cost. However, seeded reverse osmosis requires more expensive tubular membrane modules compared to spiral membrane modules used in conventional reverse osmosis. Multiple advantages of seeded reverse osmosis of walnut filtered water may justify the additional expenditure involved in the tubular membrane system.

This study was limited to one trial with each of the samples, conducted under different conditions. Therefore, the results should be interpreted with due caution. Pilot trials of longer duration should be conducted to validate the observations of this study. Inclusion of seeded reverse osmosis as an alternative to the conventional reverse osmosis together with the associated pretreatment train in the pilot program merits consideration at this time.

Appendix B

Komline - Sanderson Data

Komline-Sanderson
12 Holland Av Peapack, NJ 07977-0257
908-234-1000 Fax: 908-234-9487
info@komline.com

- Fax Cover Sheet -

Date: 10/23/97 1:50 PM
Pages: 12
To: Mr. Sonny Huang
Kennedy/Jenks Consultants
1000 Hill Road
Suite 200
Ventura, California 93003 - USA
Fax Phone: (805) 650-1522
Voice: (805) 658-0607 106
From: Don Miller
Subject: K-S Laboratory Test Report No. L-3420
Project No. W-0094

Message:

Report attached, please give me a call if you have any questions. We have sample remaining if further tests are required.

Sincerely,

Don Miller
Applications Specialist

cc.

Please call (908) 234-1000 with questions regarding this transmittal
K-S Fax Number is (908) 234-9487

because performance counts

Komline-Sanderson
12 Holland Av
908-234-1000
Peapack, NJ 07977-0257
Fax: 908-234-9487
info@komline.com

KOMLINE-SANDERSON

LABORATORY TEST REPORT

for

Kennedy/Jenks Consultants

Ventura, California

Evaluation of Dewatering Technologies

Oilfield Produced Water

K-S Project W-0094

Prepared by

Donald R. Miller

October 23, 1997

1.0 Background

Kennedy/Jenks Consultants operated a warm lime clarifier system to treat produced water from oil well fields (ARCO Western Energy -Newhall, CA). The warm lime clarifier system generates magnesium silicate and calcium carbonate waste suspended solids at a concentration of 2-5%. Kennedy/Jenks Consultants contacted Komline-Sanderson to evaluate potential dewatering technologies for dewatering this sludge to reduce disposal volume and associated costs.

Contacts on this project include Mr. Sonny Huang, Kennedy/Jenks Consultants Staff Engineer; and Mr. Donald Miller, Komline-Sanderson Applications Specialist.

2.0 Summary

This test work confirms two (2) dewatering technologies are applicable. The K-S Kompress® belt filter press and K-S Avery filter press both achieved significant volume reduction and a filter cake which passes the paint filter test. The K-S Kompress® belt filter press is a continuous process, the Avery filter press is a batch process.

A K-S Kompress® G-GRSL-2 Series III will process the waste solids at a rate of up to 2000 pounds of dry solids per hour, given 3% solids influent (135 gallons per minute). This rate will permit 8 hours per day dewatering operation, provided adequate solids holding facilities exist. Alternately, a smaller Kompress® could be applied for 16 or 24 hour per day operation. Chemical (polymer flocculant) costs are estimated at $2.00 per ton of dry solids processed, or $33 per day. Cake discharge concentration ranges from 17 - 22% total solids, with a friable cake easily passing the paint filter test. Process efficiency, or solids capture rate, is predicted to be greater than 98%.

A K-S Avery 1500mm filter press will process the waste solids at a rate of up to 2000 pounds of dry solids per cycle, given 3% solids influent. Allowing 2 hours per cycle, this rate will permit 16 hours per day dewatering operation, provided adequate solids holding facilities exist. No treatment chemical (polymer flocculant) is required. Cake discharge concentration will be 20% total solids, with a friable cake easily passing the paint filter test. Process efficiency, or solids capture rate, is predicted to be greater than 99%.

Refer to the attached data tables and performance chart for additional insight to the process performance relationships discussed.

3.0 Calcium Carbonate Slurry Sample Analysis

A sample of the magnesium silicate and calcium carbonate slurry was obtained in October, 1997.

Total Solids, % TS	3.51%
Total Suspended Solids, mg/L	29,100
Total Dissolved Solids, mg/L	6,000
Specific Gravity, g/cm^3	1.00
pH	9.8

4.0 Test Objective

Evaluate the effectiveness of the K-S Kompress® belt filter press as a dewatering process for reducing solids handling costs and / or increasing solids disposal options. Chemical additives are to be used only if necessary and minimized to extent practical.

5.0 Test Program

Using a bench scale filtration models, evaluate filtration rates to define process relationships and determine full scale equipment performance and sizing parameters.

6.0 Narrative

No adjustments were made to the samples before filtration tests were conducted.

Chemical conditioning with an organic flocculant was found to be essential for effective processing with the Kompress® GRS Series III belt filter press. Initial polymer screening concluded with the selection of Cytec Magnifloc 866A (high anionic charge, high molecular weight organic polymer) as it produced the best results with respect to filtration rate and lower dosage. A series of filtration rate tests were performed to determine the filtration rate of the chemically conditioned sludge and to provide a basis for sizing a belt filter press installation.

The standard Kompress® GRS Series III belt filter press produced a cake with 17% to 22% dry solids, easily passing the paint filter test. Further, cake solids are only minimally affected by production rate, allowing the potential for a single Kompress® GRS Series III belt filter press to process the entire waste slurry volume in one (1) 8-hour shift per day.

6.0 Narrative, continued

In general terms, the magnesium silicate and calcium carbonate slurry exhibited a moderate resistance to filtration, a very low filter cake compressibility and is fairly low in initial concentration. These characteristics tend to minimize the effect of increased pressure with respect to filtration rate and final cake concentration. This then suggests that despite the range of available "delta pressure" across the range from vacuum to high pressure filtration, the actual process results (cake dryness) will be similar. Further, these technologies may offer other advantages with respect to filtrate clarity, installation space required, and equipment, operating and labor costs.

The K-S / Avery Filter Press was evaluated without benefit of the high pressure membrane sequence. Consistent with our general observations above, a 100 psig "delta pressure" K-S / Avery Filter Press produced a cake with 20% dry solids, essentially equal to the Kompress® GRS Series III filter cake. The membrane squeeze sequence may increase the cake solids, however the chief advantage of the membrane press will likely be reduction in cycle time. The K-S / Avery (Membrane) Filter Press does not require chemical pretreatment (polymer flocculant) to achieve these results, in contrast to the Kompress® GRS Series III.

The K-S / Avery Filter Press is a variable rate, sequential process, consisting of:
1.) Feed
2.) Cake Formation
3.) Cake Washing (If required)
4.) Membrane Squeeze (If applicable)
5.) Core Blow
6.) Cake Discharge

The complete cycle time determined in our tests are quite short, approximately forty-two (42) minutes from the start of feed to the completion of the air blow, not including the membrane squeeze. The membrane squeeze sequence will require 5 - 10 minutes, however it can be started early in the filtration cycle for a net reduction in cycle time. Cake discharge time will be a function of filter size, chamber thickness, degree of automation and whether or not the membrane squeeze sequence is employed. In general it appears evident that a complete cycle will not exceed 1-1/2 hours.

A single 1500 mm K-S / Avery Membrane Filter Press with approximately eighty six (86) chambers (25 mm cake) will process 16,000 lb. of dry solids with 8 cycles per day.

7.0 Budgetary Costs

Equipment	Model	System Cost
Kompress® Belt Filter Press	G-GRSL-2	$225,000
K-S / Avery Filter Press	1500 mm	$175,000

The above equipment prices include the filter indicated, together with typical auxiliary equipment and electrical controls. This pricing is provided for general comparisons and should be reviewed for scope, materials of construction, engineering standards, etc.

8.0 Attachments

Test data tables and filtration performance charts are attached for reference. Specifications, general arrangement and typical installation drawings accompany this report.

9.0 Komline-Sanderson appreciates the opportunity to provide this service and report to Kennedy/Jenks Consultants. Questions or comments regarding this report are welcome. Please feel free to contact Komline-Sanderson at:

12 Holland Avenue
Peapack, New Jersey 07977
Tel: (908) 234-1000
Voice Mail: (908) 234-1008
Fax: (908) 234-9487
email: info@komline.com

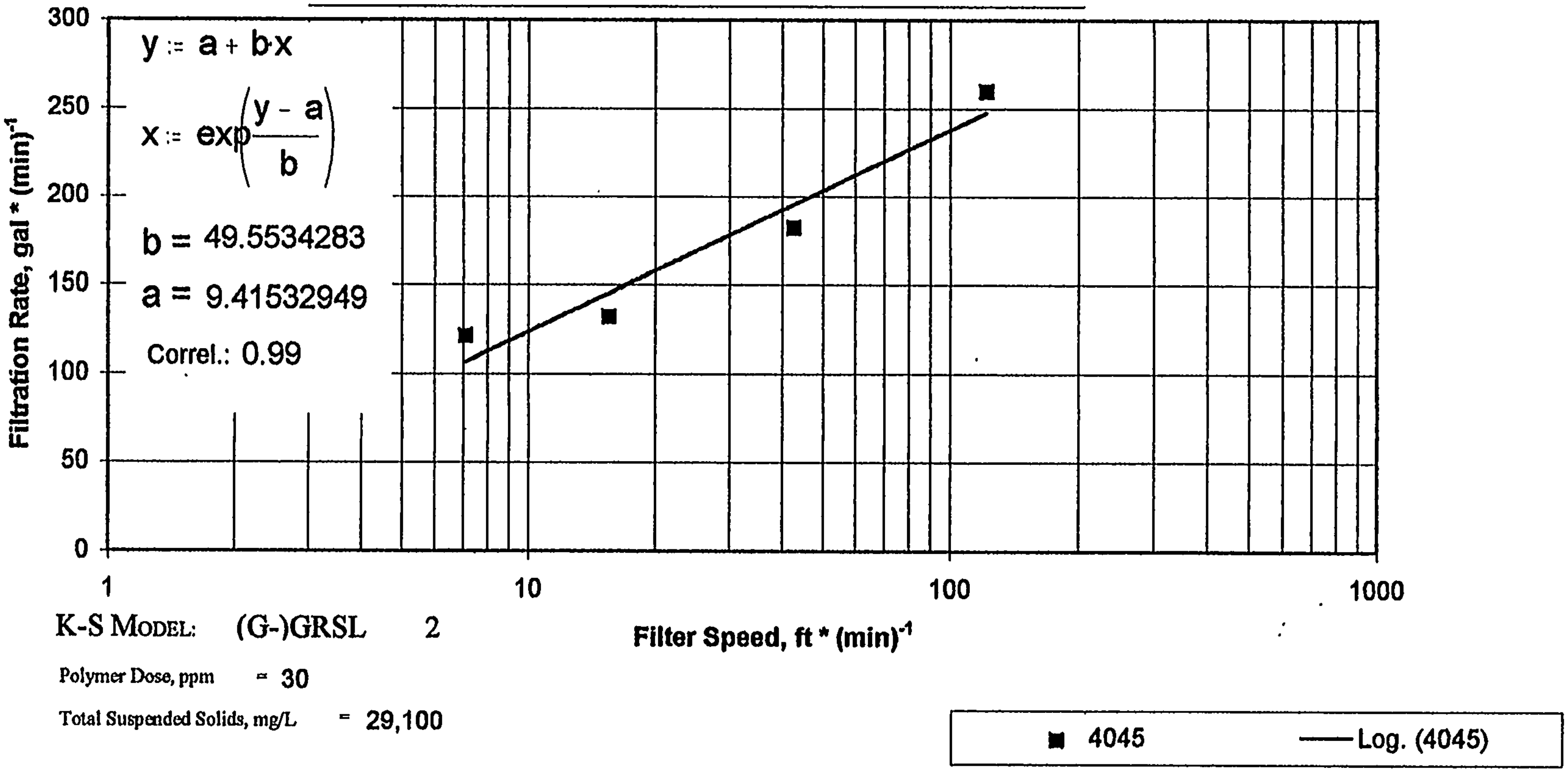
KOMLINE-SANDERSON ENGINEERING CORPORATION

Kennedy/Jenks Consultants

Ventura, California

Oilfield Produced Water

FILTRATION RATE, *f* (FILTER SPEED)



K-S MODEL: (G-)GRSL 2

Polymer Dose, ppm = 30

Total Suspended Solids, mg/L = 29,100

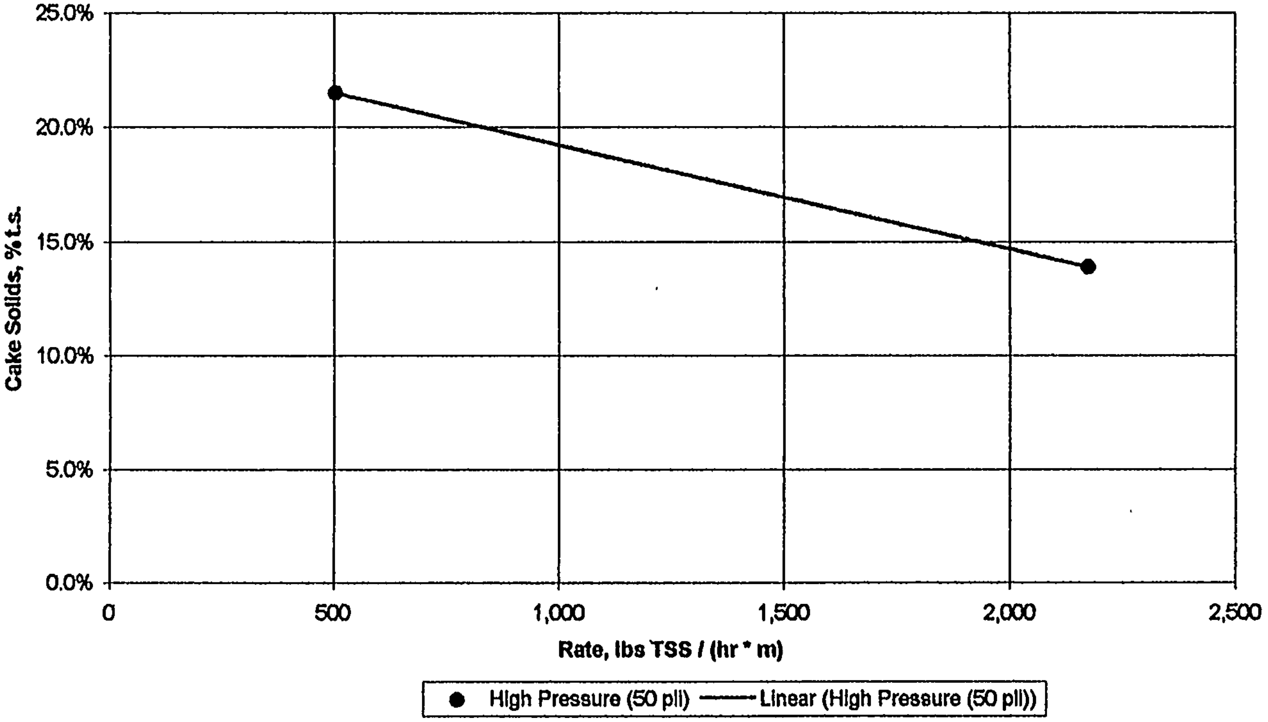
Gravity Filtration Curve Worksheet

KOMLINE-SANDERSON ENGINEERING CORPORATION

Kennedy/Jenks Consultants
Produced Water
Cake Solids f(Rate)

thicken dewater dry heat cool filter clarify pump

because performance counts



K-S Project No.: W-0094
Date: October 23, 1997

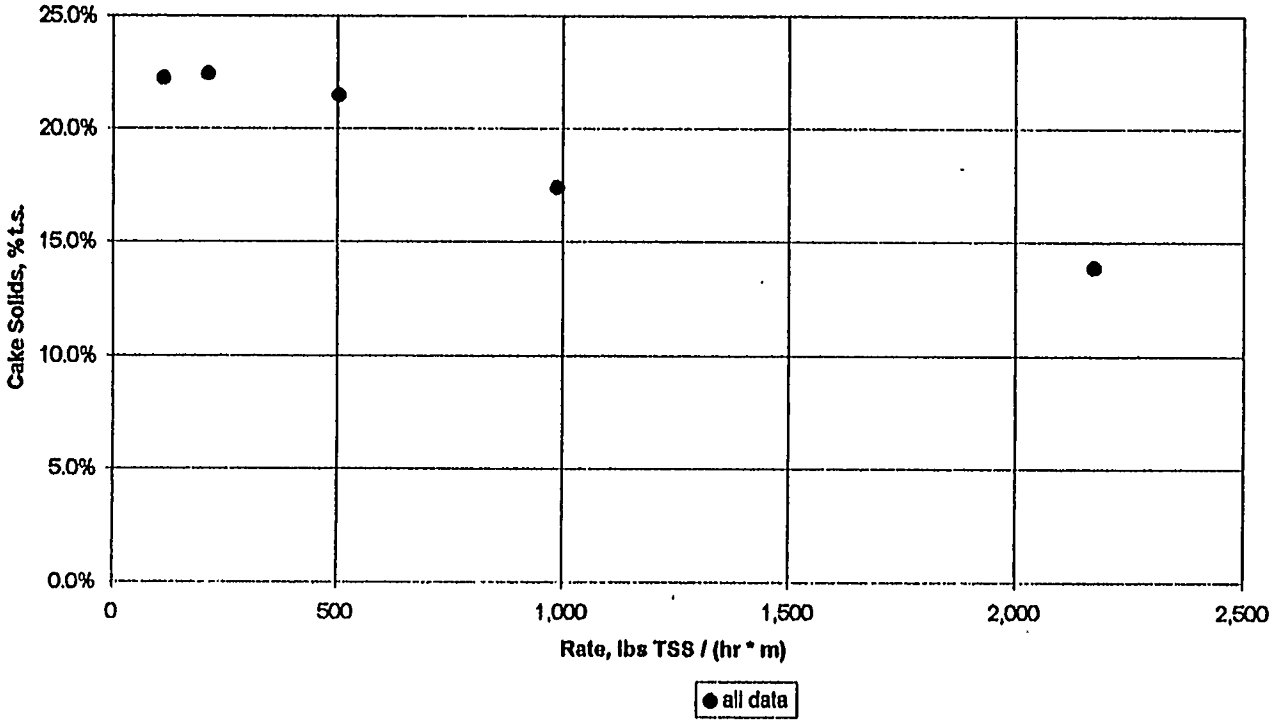
The best observed results occur with lower rate. This chart best represents expected Kompress performance over the full range of operation.

KOMLINE-SANDERSON ENGINEERING CORPORATION

Kennedy/Jenks Consultants

Produced Water

Cake Solids f(Rate)



thicken dewater dry heat cool filter clarify pump

because performance counts

K-S Project No.: W-0094
Date: October 23, 1997

A series of tests were run with variable solids loading, both by varying filter speed and cake thickness. Each test used 300 ppm Cytec 866A flocculant and no coagulant or filter aid. All data is included, therefore review additional charts and read the written report before drawing conclusions. The overall results indicate the solids have a moderate specific resistance. The greatest removal of water ocurrs with thinner cakes at low filter speed. The greatest filter yield ocurrs with thick cakes at high filter speed.

KOMLINE-SANDERSON ENGINEERING CORPORATION

... because performance counts

KOMPRESS BELT FILTER PRESS LABORATORY TEST DATA
for
Kennedy/Jenks Consultants

Date: October 23, 1997
K-S Project No.: W-0094

TEST NO.	1	2	3	4	5		
PROCESS	Produced Water						
PROCESS REQUIREMENTS	**PROCESS REQUIREMENTS**						
FILTRATION RATE, gpd	65,000						
FILTRATION RATE, lbs TSS / day	16,000						
OPERATION, hrs / day	24						
CAKE DISCHARGE, % t.s. ()	20%						
CHEMICAL COST, $ / ton TSS							
CAPTURE EFFICIENCY, %	95%						
INFLUENT DATA	**INFLUENT DATA**						
INFLUENT % t.s. ()	3.51%	3.51%	3.51%	3.51%	3.51%		
INFLUENT % t.s.s.	2.91%	2.91%	2.91%	2.91%	2.91%		
INFLUENT S.G., g / mL	1.00	1.00	1.00	1.00	1.00		
TSS S.G., g / mL	1.00	1.00	1.00	1.00	1.00		
INFLUENT pH	9.8	9.8	9.8	9.8	9.8		
CHEMICAL PRETREATMENT	**CHEMICAL PRETREATMENT**						
PRODUCT	866A	866A	866A	866A	866A		
EST. COST, $ / lb	$2.00	$2.00	$2.00	$2.00	$2.00		
DOSAGE, ppm	30	30	30	30	30		
DOSAGE, lbs / ton TSS	2.1	2.1	2.1	2.1	2.1		
COST, $ / day	$ 32.99	$ 32.99	$ 32.99	$ 32.99	$ 32.99		
CHEMICAL PRETREATMENT	**CHEMICAL PRETREATMENT**						
PRODUCT							
COST, $ / lb							
DOSAGE, ppm							
DOSAGE, lbs / ton TSS							
COST, $ / day							
FILTRATION RATE	**FILTRATION RATE**						
GRAVITY FILTRATION RATE, gal / (min * m)	8	15	35	68	149		
PRESSURE FILTRATION RATE, lbs TS / (hr * m)	114	212	504	989	2,175		
SOLIDS	**SOLIDS**						
CAKE DISCHARGE, % t.s.	22.25%	22.45%	21.48%	17.39%	13.87%		
CAKE DISCHARGE, ft^3 / day	1,153	1,142	1,194	1,475	1,849		
WATER CONTENT, lbs / hr	55,910	55,269	58,488	76,007	99,357		
CAKE THICKNESS, mm	2.00	4.00	8.00	16.00	10.00		
LIQUID	**LIQUID**						
FILTRATE RATE, gal / (min * m)	7	13	30	57	118		
TOTAL EFFLUENT, gal / (min * m)	34	40	57	84	145		
FILTRATE t.s.s., mg / L	334	532	881	1,180	1,496		
OPERATION CONDITIONS	**OPERATION CONDITIONS**						
KOMPRESS MODEL	A	A	A	A	A		
GRAVITY DEWATERING FILTER SPEED, ft / min	6	6	6	6	18		
PRESSURE DEWATERING FILTER SPEED, ft / min	6	6	6	6	18		
PRESSURE BELT TENSION, pli	50	50	50	50	50		
PRESSURE BELT DRIVE HORSEPOWER	1.0	1.0	1.0	1.0	1.0		
WASHWATER PRESSURE, psig	85	85	85	85	85		
WASHWATER NOZZLE No.	2.0	2.0	2.0	2.0	2.0		
WASHWATER RATE, gal / (min * m)	27	27	27	27	27		
OBSERVATIONS	**OBSERVATIONS**						
CAKE DISCHARGE	EXC	EXC	EXC	EXC	EXC		

Komline-Sanderson Engineering Corporation
Avery Filter Press
Series 177 Test Data Information
Test #: 1

CUSTOMER:	Kennedy-Jenks Consultants	TEST REPORT #:	L-3420
PLANT LOCATION:	Ventura, CA	K-S PROJECT #:	W-0094
TEST OPERATOR:	Mike Heraghty	DATE:	10/15/97

SAMPLE CHARACTERISTICS	
Material Identification	Oil Field Waste Water Slurry
Total Solids, %TS	3.51
Suspended Solids, %TSS	2.91
Analysis Temperature, °C	19
pH	9.55
Density, gm/mL	1.010

TEST CONDITIONS			
Media	46409-4	Filtration Temperature, °C	Ambient
No. of Chambers	2	Chamber Thickness, inch	1
Type of Precoat	-		
Type of Body Feed	-	Wash	No
Body Feed Conc., %Lbs.	0	Wash Temperature, °C	-
Adj. Feed Conc., %TSS	2.91	Air Blow	Yes
Volume of Feed, L		Air Blow Pressure, psi	40

OBSERVED RESULTS			
Filtration Time, min	40		
Final Feed Pressure, psi	80	Cake Discharge Quality	Excellent
Filtrate Volume, mL	3759	Cake Thickness, inch	1
Cycle Filt. Rate, gal/ft^2/min	0.052	Condition of Cake	Excellent
Wash Time, min	0	Air Blow Time, min	2
Wash Volume, mL	0	Air Blow Volume, mL	70

CAKE ANALYSIS	Chamber 1			Chamber 2	
Tare, gm (Weighing Dish)	69.56		Tare, gm (Weighing Dish)	90.23	
Gross Weight, gm (wet)	400.26		Gross Weight, gm (wet)	409.93	
Total Weight, gm (wet)	330.70		Total Weight, gm (wet)	319.70	
Cake Density, lbs./ft^3	73.58		Cake Density, lbs./ft^3	71.13	
Tare, gm (Weighing Dish)	69.56		Tare, gm (Weighing Dish)	90.23	
Gross Weight, gm (wet)	316.17		Gross Weight, gm (wet)	409.93	
Gross Weight, gm (dry)	118.53		Gross Weight, gm (dry)	154.57	
Cake Solids, %DS	19.86		Cake Solids, %DS	20.13	
Cake Gen., ft^3/gal Feed	0.017		Cake Gen., ft^3/gal Feed	0.017	

FILTRATE ANALYSIS	1	2	3	4	5
Time Period, min	0-4	4-10	10-18	18-28	28-40
Tare, gm (Paper)					
Sample Size, gm					
Gross Weight, gm (dry)					
PPM, Filtrate					
Tare, gm (Weighing Dish)					
Gross Weight, gm (wet)					
Gross Weight, gm (dry)					
%TS, Filtrate					

Komline-Sanderson Engineering Corporation
Avery Filter Press
Series 177 Test Log

CUSTOMER: Kennedy-Jenks Consultants
PLANT LOCATION: Ventura, CA
TEST OPERATOR: Mike Heraghty

TEST REPORT #: L-3420
K-S PROJECT #: ~~-0-~~ W-0094
DATE: 10/15/97

MATERIAL ID: Oil Field Waste Water Slurry

TEST #: Test #: 1

Time, min	Feed Pressure, psi	Change in Filtrate Volume, mL	Cumulative Filtrate Volume, mL	Comments	Time, min	Feed Pressure, psi	Change in Filtrate Volume, mL	Cumulative Filtrate Volume, mL	Comments
0	20	0	0	Start Fill Cycle					
0:31	20	0	0	Chamber Filled, Open Lower Eyes					
2	20	364	364						
4	20	390	754						
6	20	331	1085						
8	20	224	1309						
10	20	198	1507						
12	30	238	1745						
14	30	214	1959						
16	30	190	2149						
18	40	190	2339						
20	40	168	2507						
22	50	164	2671						
24	50	142	2813						
26	60	144	2957						
28	70	138	3095						
30	80	145	3240						
32	80	123	3363						
34	80	111	3474						
36	80	103	3577						
38	80	92	3669						
40	80	90	3759						
0	20	0	3759						
2	40	70	3829						

Appendix B

Orange County Water District Data

Biodegradation Test of Oil Field Produced Water

My contact: Dr. Larry Leong, Kennedy-Jencks Engineering, Irvine

Sample delivery date/time: Thursday 20 March, mid morning

Quantity: 2 gallons with no head space in non-sterile glass bottles

Please check the pH of the water before doing the biodegradation tests described below. If the pH is <5.5, re-adjust to about 7.0 with sodium hydroxide. If it is alkaline, say >8.5, re-adjust with HCl to about 7.0.

Biodegradation (CO^2 production) tests to include (in triplicate):

1. 'no nutrient' (unsupplemented) control + Q1 cells*
2. HCMM2** + $HgCl_2$ (0.1wt%?) + Q1 cells*
3. HCMM2** + Q1 cells*
4. HCMM2** only (no Q1 cells)

~~5 - no Additions (minus cells, minus nutrients)~~ ⑤ {no Additions}

Above conditions to be incubated for a minimum of one week prior to acidification and CO^2 analysis

Other analyses: TOC analysis of original water sample by Main Lab

*Q1 cells = 1.0 ml of Q1 cells captured on a 25mm diameter polycarbonate (Nuclepore) membrane filter (sterility unnecessary)

**0.1 strength HCMM2 final

BIODEGRADATION ASSAY: CO_2 PRODUCTION
SAMPLES FROM ARCO WEST ENERGY

3/20/97

EXPERIMENT PURPOSE: TO DETERMINE IF THE TOC IN SAMPLES SUBMITTED FROM KENNEDY/JENKS ON BEHALF OF ARCO WEST ENERGY CONTAIN BIODEGRADABLE CARBON WHICH CAN BE MINERALIZED. BECAUSE THE WATER SAMPLES WERE INITIALLY SUBJECTED TO TEMPERATURES AND PRESSURES SUFFICIENT TO KILL MICROORGANISMS, THE SAMPLES WILL BE INOCULATED WITH A MIXED MICROBIAL CULTURE DERIVED FROM Q1 WATER COLLECTED AT WF 21 (OCWD). A POPULATION OF BACTERIA WILL BE RECOVERED FROM THIS WATER BY FILTRATION OF 1ml OF Q1 WATER ON A 0.2µ MILLIPORE FILTER, FOLLOWED BY A WASH OF 1ml OF dH_2O TO REMOVE ANY INDIGENOUS ORGANICS PRESENT IN THE Q1. THE NUTRIENT REQUIREMENTS WILL BE TESTED BY AMENDING ONE OF THE SAMPLES c̄ 1/10 DILUTED HCMM2 INORGANIC NUTRIENTS. A KILLED CONTROL WILL CONSIST OF AMENDMENT WITH $HgCl_2$ TO 0.1% FINAL CONC. pH WILL BE ADJUSTED c̄ NaOH OR HCl IF IT IS < 5.5 OR > 8.8 (ADJUSTMENTS WILL BE MADE TO pH 7.0). FURTHER ANALYSIS FOR HEAVY METALS, N, P, S WILL BE PERFORMED BY THE OCWD MAIN LAB. TOC ANALYSIS WILL BE PERFORMED BY THE OCWD MAIN LAB.

REMOVED 250ml FROM EACH BOTTLE TO DO THIS

	AWE-1	AWE-2	AES-1	AES-2	AES-3	~~AES~~
pH	6.64	6.64	9.96	9.98	9.97	
ADJ. pH	—	—	6.88	6.92	7.34	

KC	45ml SAMPLE + 5ml HCMM2 + Q1 CELLS (FILTERED BUGS) + 1ml 5% $HgCl_2$ (0.1%)
HCMM2 ONLY	45ml SAMPLE + 5ml HCMM2 + 1ml dH_2O (TOTAL = 51ml)
HCMM2 + Q1 BUGS	45ml SAMPLE + 5ml HCMM2 + 1ml dH_2O + FILTER c̄ BUGS
Q1 BUGS	45ml SAMPLE + 5ml dH_2O + 1ml dH_2O + FILTERED BUGS

NOTE: 1ml OF 5% $HgCl_2$ IN 51ml ≅ 0.1% (ACTUALLY 0.098%)

ARRAY OF CONDITIONS

COMPONENT	KC	+HEMM2	+BUGS +HEMM2	+ BUGS	NO AM
45ml SM	X	X	X	X	X
5ml HEMM2	X	X	X		
5ml H_2O				X	X
1ml H_2O		X	X	X	X
1ml 5% $HgCl_2$	X				
BUG FILTER	X		X	X	

STARTED INCUBATION AT 3/20 AT 4:30 PM, 200 RPM @ 26-27°C (ORBITAL SHAKER AT AMBIENT TEMPERATURE)

3/24/97

NO VISIBLE GROWTH IN ANY OF THE EXPERIMENTAL MICROCOSMS TODAY. SET UP ANOTHER SET OF BOTTLES CONTAINING 1/10 HEMM2 [45ml], SAMPLES (5ml), dH_2O (1ml) AND A 0.22μ MILLIPORE FILTER CONTAINING 1x dH_2O WASHED OIL CELLS. CURRENTLY PUT ON SHAKER AT 9:00 AM. THIS 1/10 DILUTION OF THE FIVE SAMPLES WAS DONE TO SEE IF A TOXIC CONTAMINANT(S) IS KEEPING GROWTH FROM OCCURRING. THESE DILUTED SAMPLES ARE THE EQUIVALENT OF AMENDED, +CELL MICROCOSMS ALREADY SET UP. THESE BOTTLES HAD TO BE TAPED TO THE RACK, AS THERE WAS NO ROOM FOR THEM IN THE ARRAY.

AT 9:00 AM 3/24 - NO VISIBLE TURBIDITY INCREASE OVER THAT OBSERVED ON 3/21. THE KCs DEVELOPED A WHITE PPT, WHICH IS NORMAL FOR $HgCl_2$ ADD'N TO HEMM2 MEDIUM. WILL CONTINUE INCUBATION UNTIL SOME TURBIDITY OCCURS. TEMP = 26.0°C, 200 RPM

4/8/97 TAKEDOWN AT 4:30PM

1) ADDED 1ml 5N NaOH TO ALL BOTTLES (FINAL VOL = 52ml) TO YIELD ~0.1N FINAL CONC

2) ASSAYED 1ml OF EACH CULTURE AFTER SHAKING AT 200 RPM FOR 10' - ALSO SHOOK EACH BOTTLE VIGOROUSLY JUST PRIOR TO ASSAY

SAMPLE	CO2/1ml	FACTOR	ADJUSTED CO2/ml OF SAMPLE	MG CO2/L
AWS1-KC	10.74			
AWS1-KC				
AWS2-KC	10.47			
AWS2-KC				
AES1-KC	6.08			
AES1-KC				
AES2-KC	6.08			
AES2-KC				
AES3-KC	6.22			
AES3-KC				
AWS1-HCMM2	11.95			
AWS1-HCMM2				
AWS2-HCMM2	11.81			
AWS2-HCMM2				
AES1-HCMM2	6.46			
AES1-HCMM2				
AES2-HCMM2	6.39			
AES2-HCMM2				
AES3-HCMM2	6.56			
AES3-HCMM2				
AWS1-COLS	11.99			
AWS1-COLS				
AWS2-COLS	12.33			
AWS2-COLS				

1210 = 1/10 DILUTION

	1	2	3	4	5	6	7	8	9
1	#	SAMPLE		CO_2/ml	Blank	CO_2/ml SAMPLE			NET CO_2/ml
2	AES1 - CELLS			6.53					
3	AES1 - CELLS								
4	AES2 - CELLS			6.59					
5	AES2 - CELLS								
6	AES3 - CELLS			6.56					
7	AES3 - CELLS								
8	AWE1 - Hemm2 - CELLS			12.67					
9	AWE1 - Hemm2 - CELLS								
10	AWE2 - Hemm2 - CELLS			12.64					
11	AWE2 - Hemm2 - CELLS								
12	AES1 - Hemm2 - CELLS			6.87					
13	AES1 - Hemm2 - CELLS								
14	AES2 - Hemm2 - CELLS			6.83					
15	AES2 - Hemm2 - CELLS								
16	AES3 - Hemm2 - CELLS			7.14					
17	AES3 - Hemm2 - CELLS								
18	AWE1 - MAT			11.02					
19	AWE1 - MAT								
20	AES1 - MAT			6.28					
21	AES1 - MAT								
22	AES2 - MAT			6.49					
23	AES2 - MAT								
24	AES3 - MAT			6.53					
25	AES3 - MAT								
26	AWE1 - 1210 - Hemm2 - CELLS			2.30					
1/10 27	AWE1 - 1210 - Hemm2 - CELLS								
28	AWE2 - 1210 - Hemm2 - CELLS			2.37					
'10 29	AWE2 - 1210 - Hemm2 - CELLS								
30	AES1 - 1210 - Hemm2 - CELLS			1.99					
31	AES1 - 1210 - Hemm2 - CELLS								

1210: 1/10 DILUTION

	1	2	3	4	5	6	7	8	9
1		SAMPLE		CO_2/ml	Frenn	CO_2/ml SAMPLE			Mg CO_2/ml
2	AES2-1210-Hemm2-cells			2.10					
3	AES2-1210-Hemm2-cells								
4	AES3-1210-Hemm2-cells			2.16					
5	AES3-1210-Hemm2-cells								
6	AMS1-KC			10.82					
7	AMS1-KC								
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
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31									

Orange County Water District Main Laboratory

Kaukaba Naggar

3/24/97 12:00:02 PM

5310DH Workload Report

	Lab #	Test	Result	Date Samp'd	Date Rec'd	Time Rec'd	ALN	Low Limit	High Limit	Date Due	Sample ID	WS#
	97030553-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD5	0
	97030554-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD16A	0
	97030555-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD16B	0
	97030556-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD19A	0
	97030557-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD19B	0
	97030558-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD13A	0
	97030559-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD13B	0
	97030560-01	TOC	______	3/20/97	3/20/97	7:30				4/7/97	WF21-RD14	0
	97030563-01	TOC	______	3/20/97	3/20/97	8:30				4/7/97	WF21-RD18	0
	97030564-01	TOC	______	3/20/97	3/20/97	8:30				4/7/97	WF21-RD7A	0
	97030565-01	TOC	______	3/20/97	3/20/97	8:30				4/7/97	WF21-RD7B	0
-1	97030571-01	TOC	126.331	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
-2	97030572-01	TOC	101.999	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
(dil ES-1	97030573-01	TOC	110.461	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
S-2	97030574-01	TOC	108.942	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
-3	97030575-01	TOC	109.223	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
07	97030576-01	TOC	______	3/20/97	3/21/97	7:30		7.5	12.9	4/7/97	WF21-Q1	0
	97030577-01	TOC	______	3/20/97	3/21/97	7:30				4/7/97	WF21-Q2	0
	97030578-01	TOC	______	3/20/97	3/21/97	7:30				4/7/97	WF21-Q6	0
	97030581-01	TOC	______	3/20/97	3/21/97	7:30		7.5	12.9	4/7/97	WF21-MDP1	0
	97030582-01	TOC	______	3/20/97	3/21/97	7:30		-0.05	12.9	4/7/97	WF21-MDP2	0
	97030583-01	TOC	______	3/20/97	3/21/97	7:30		-0.05	12.9	4/7/97	WF21-MDP3	0
	97030592-01	TOC		3/21/97	3/21/97	14:30				4/7/97	MISC	0
	97030593-01	TOC		3/21/97	3/21/97	14:30				4/7/97	MISC	0

Orange County Water District Main Laboratory

Angelita Navia

3/24/97 11:59:41 AM

X200.7 Workload Report

Lab #	Test	Result	Date Samp'd	Date Rec'd	Time Rec'd	ALN	Low Limit	High Limit	Date Due	Sample ID	WS#
97030571-01											
	Na	1860	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	K mg/L	98.6	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Mg	59.2	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Ca	156	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Al	4.3	3/20/97	3/20/97	14:30	800		1000	4/3/97	RESEARCH	0
	Ba	1125	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Be	0.28	3/20/97	3/20/97	14:30	3.2		4	4/3/97	RESEARCH	0
	Cd	0.71	3/20/97	3/20/97	14:30	5		5	4/3/97	RESEARCH	0
	Cr ug/L	0.0	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Co	0.3	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Cu	2.6	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Fe	560	3/20/97	3/20/97	14:30	300		300	4/3/97	RESEARCH	0
	Mn	375	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Ni	1.31	3/20/97	3/20/97	14:30	100		100	4/3/97	RESEARCH	0
	Zn	0.91	3/20/97	3/20/97	14:30	5000		5000	4/3/97	RESEARCH	0

AWG-1

Orange County Water District Main Laboratory

Angelita Navia

3/24/97 11:59:42 AM

X200.7 Workload Report

Lab #	Test	Result	Date Samp'd	Date Rec'd	Time Rec'd	ALN	Low Limit	High Limit	Date Due	Sample ID	WS#
97030572-01											
	Na	1830	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	K mg/L	98.5	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Mg	59	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Ca	157	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Al	7.5	3/20/97	3/20/97	14:30	800		1000	4/3/97	RESEARCH	0
AWS-2	Ba	1121	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Be	0.3	3/20/97	3/20/97	14:30	3.2		4	4/3/97	RESEARCH	0
	Cd	0.4	3/20/97	3/20/97	14:30	5		5	4/3/97	RESEARCH	0
	Cr ug/L	0.0	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Co	0.0	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Cu	0.5	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Fe	516	3/20/97	3/20/97	14:30	300		300	4/3/97	RESEARCH	0
	Mn	374	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Ni	1.5	3/20/97	3/20/97	14:30	100		100	4/3/97	RESEARCH	0
	Zn	0.9	3/20/97	3/20/97	14:30	5000		5000	4/3/97	RESEARCH	0
97030573-01											
	Na	4540	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	K	144	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Mg mg/L	3.7	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
ABS-1	Ca	1.1	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Al	19.2	3/20/97	3/20/97	14:30	800		1000	4/3/97	RESEARCH	0
	Ba	14.1	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Be	0.2	3/20/97	3/20/97	14:30	3.2		4	4/3/97	RESEARCH	0
	Cd	0.2	3/20/97	3/20/97	14:30	5		5	4/3/97	RESEARCH	0
	Cr ug/L	0.0	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Co	0.0	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Cu	3.4	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Fe	16.8	3/20/97	3/20/97	14:30	300		300	4/3/97	RESEARCH	0
	Mn	2.3	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Ni	0.0	3/20/97	3/20/97	14:30	100		100	4/3/97	RESEARCH	0
	Zn	0.0	3/20/97	3/20/97	14:30	5000		5000	4/3/97	RESEARCH	0

A

Orange County Water District Main Laboratory

Angelita Navia

3/24/97 11:59:42 AM

X200.7 Workload Report

Lab #	Test	Result	Date Samp'd	Date Rec'd	Time Rec'd	ALN	Low Limit	High Limit	Date Due	Sample ID	WS#
97030574-01											
	Na	4420	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	K mg/L	140	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Mg	3.5	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Ca	1.0	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Al	15.7	3/20/97	3/20/97	14:30	800		1000	4/3/97	RESEARCH	0
	Ba	15.4	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
AES-2	Be	0.2	3/20/97	3/20/97	14:30	3.2		4	4/3/97	RESEARCH	0
	Cd	0.03	3/20/97	3/20/97	14:30	5		5	4/3/97	RESEARCH	0
	Cr µg/L	0.0	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Co	0.0	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Cu	2.8	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Fe	9.9	3/20/97	3/20/97	14:30	300		300	4/3/97	RESEARCH	0
	Mn	1.2	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Ni	0.0	3/20/97	3/20/97	14:30	100		100	4/3/97	RESEARCH	0
	Zn	0.0	3/20/97	3/20/97	14:30	5000		5000	4/3/97	RESEARCH	0
97030575-01											
	Na	4280	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	K mg/L	134	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Mg	3.5	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Ca	1.0	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
AES-3	Al	16.0	3/20/97	3/20/97	14:30	800		1000	4/3/97	RESEARCH	0
	Ba	15.3	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Be	0.2	3/20/97	3/20/97	14:30	3.2		4	4/3/97	RESEARCH	0
	Cd	0.1	3/20/97	3/20/97	14:30	5		5	4/3/97	RESEARCH	0
	Cr µg/L	0.0	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Co	0.0	3/20/97	3/20/97	14:30				4/3/97	RESEARCH	0
	Cu	2.2	3/20/97	3/20/97	14:30	1000		1000	4/3/97	RESEARCH	0
	Fe	10.3	3/20/97	3/20/97	14:30	300		300	4/3/97	RESEARCH	0
	Mn	1.2	3/20/97	3/20/97	14:30	50		50	4/3/97	RESEARCH	0
	Ni	0.0	3/20/97	3/20/97	14:30	100		100	4/3/97	RESEARCH	0
	Zn	0.0	3/20/97	3/20/97	14:30	5000		5000	4/3/97	RESEARCH	0

OIL FIELD PRODUCED WATER SAMPLES
REC: 3/20/97
FROM: LARRY LEONG, KENNEDY-JENCKS ENGINEERING, IRVIVE, CA

SAMPLE pH ADJUSTMENT PRIOR TO CO2 ANALYSIS

SAMPLE	pH INITIAL	FINAL
AWE1	6.64	6.64
AWE2	6.64	6.64
AES1	9.96	6.88
AES2	9.98	6.92
AES3	9.97	7.34

HYDROCARBON MINERALIZATION ASSAY BY CO2 ANALYSIS:

ASSAY CONDITIONS:

			SAMPLE	HCMM2	FILTER**	dH2O	5% $HgCl_2$
START:3/20/19	FINISH 4/8/97	NEAT*	45ml			5ml	
INCUBATION TIME=	19 DAYS	HCMM2	45ml	5ml		1ml	
		HCMM2-CELLS	45ml	5ml	YES	1ml	
		KC	45ml		YES		1ml

*1:10 SAMPLES (1210)=NEAT SAMPLES DILUTED 10X WITH DISTILLED WATER
**1ml OF Q1 WATER COLLECTED ON 0.2u MILLIPORE FILTER AND WASHED 1X WITH DISTILLED WATER

NEAT SAMPLES	GROSS (MOLES CO2/ML CULTURE) REP 1	REP 2	MEAN	S.D.	DIL FACTOR	(MOLES CO2/ML) GROSS*** MEAN	S.D.	NET**** MEAN	S.D.	SAMPLE I.D.
AES1-CELLS	6.524725	6.456044	6.490385	0.048565	1.15555556	7.5	0.0561196	0.476191	0.003149	AES1-CELLS
AES1-HCMM2	6.456044	6.456044	6.456044	0	1.15555556	7.460318	0	0.436508	0	AES1-HCMM2
AES1-HCMM2-CELL	6.868132	6.696428	6.78228	0.121413	1.15555556	7.837301	0.1402995	0.813491	0.010684	AES1-HCMM2-CELLS
AES1-NEAT	6.28434	6.28434	6.28434	0	1.15555556	7.261904	0	0.238094	0	AES1-NEAT
AES1-KC	6.078297	6.078297	6.078297	0	1.15555556	7.02381	0			AES1-KC
AES2-CELLS	6.593406	6.593406	6.593406	0	1.15555556	7.619047	0	0.615078	0.02806	AES2-CELLS
AES2-HCMM2	6.387362	6.490385	6.438874	0.072848	1.15555556	7.440477	0.0841799	0.436508	0.035147	AES2-HCMM2
AES2-HCMM2-CELL	6.660714	6.660714	6.660714	0	1.15555556	7.696825	0	0.692856	0.02806	AES2-HCMM2-CELLS
AES2-NEAT	6.490385	6.421703	6.456044	0.048566	1.15555556	7.460318	0.0561207	0.456349	0.03121	AES2-NEAT
AES2-KC	6.078297	6.043956	6.061127	0.024283	1.15555556	7.003969	0.0280604			AES2-KC
AES3-CELLS	6.659066	6.596428	6.627747	0.09713	1.15555556	7.65873	0.1122391	0.456349	0.040658	AES3-CELLS
AES3-HCMM2	6.659066	6.596428	6.627747	0.09713	1.15555556	7.65873	0.1122391	0.456349	0.040658	AES3-HCMM2
AES3-HCMM2-CELL	7.142857	7.177197	7.160027	0.024282	1.15555556	8.273809	0.0280592	1.071428	0.028848	AES3-HCMM2-CELLS
AES3-NEAT	6.524725	6.593406	6.559066	0.048565	1.15555556	7.579365	0.0561196	0.376984	0.03121	AES3-NEAT
AES3-KC	6.215659	6.25	6.23283	0.024283	1.15555556	7.202381	0.0280604			AES3-KC
AWE1-CELLS	11.98489	11.91621	11.95055	0.048564	1.15555556	13.80952	0.0561184	1.388885	0.059268	AWE1-CELLS
AWE1-HCMM2	11.95055	12.01923	11.98489	0.048564	1.15555556	13.84921	0.0561184	1.428567	0.059268	AWE1-HCMM2
AWE1-HCMM2-CELL	12.6717	12.80907	12.74039	0.097135	1.15555556	14.72223	0.1122449	2.301589	0.068717	AWE1-HCMM2-CELLS
AWE1-NEAT	11.02335	11.16071	11.09203	0.097128	1.15555556	12.81746	0.1122368	0.396818	0.068718	AWE1-NEAT
AWE1-KC	10.71429	10.78297	10.74863	0.048564	1.15555556	12.42064	0.0561184			AWE1-KC
AWE1-KC	10.61731	10.65165	10.63448	0.024282	1.15555556	12.28884	0.0280592			AWE1-KC
AWE2-CELLS	12.3283	12.36264	12.34547	0.024282	1.15555556	14.26588	0.0280592	2.182544	0.028847	AWE2-CELLS
AWE2-HCMM2	11.81319	11.50412	11.65866	0.218546	1.15555556	13.47223	0.2525409	1.388897	0.091836	AWE2-HCMM2
AWE2-HCMM2-CELL	12.63736	12.60302	12.62019	0.024282	1.15555556	14.58333	0.0280592	2.499998	0.028847	AWE2-HCMM2-CELLS
AWE2-KC	10.4739	10.43956	10.45673	0.024282	1.15555556	12.08333	0.0280592			AWE2-KC

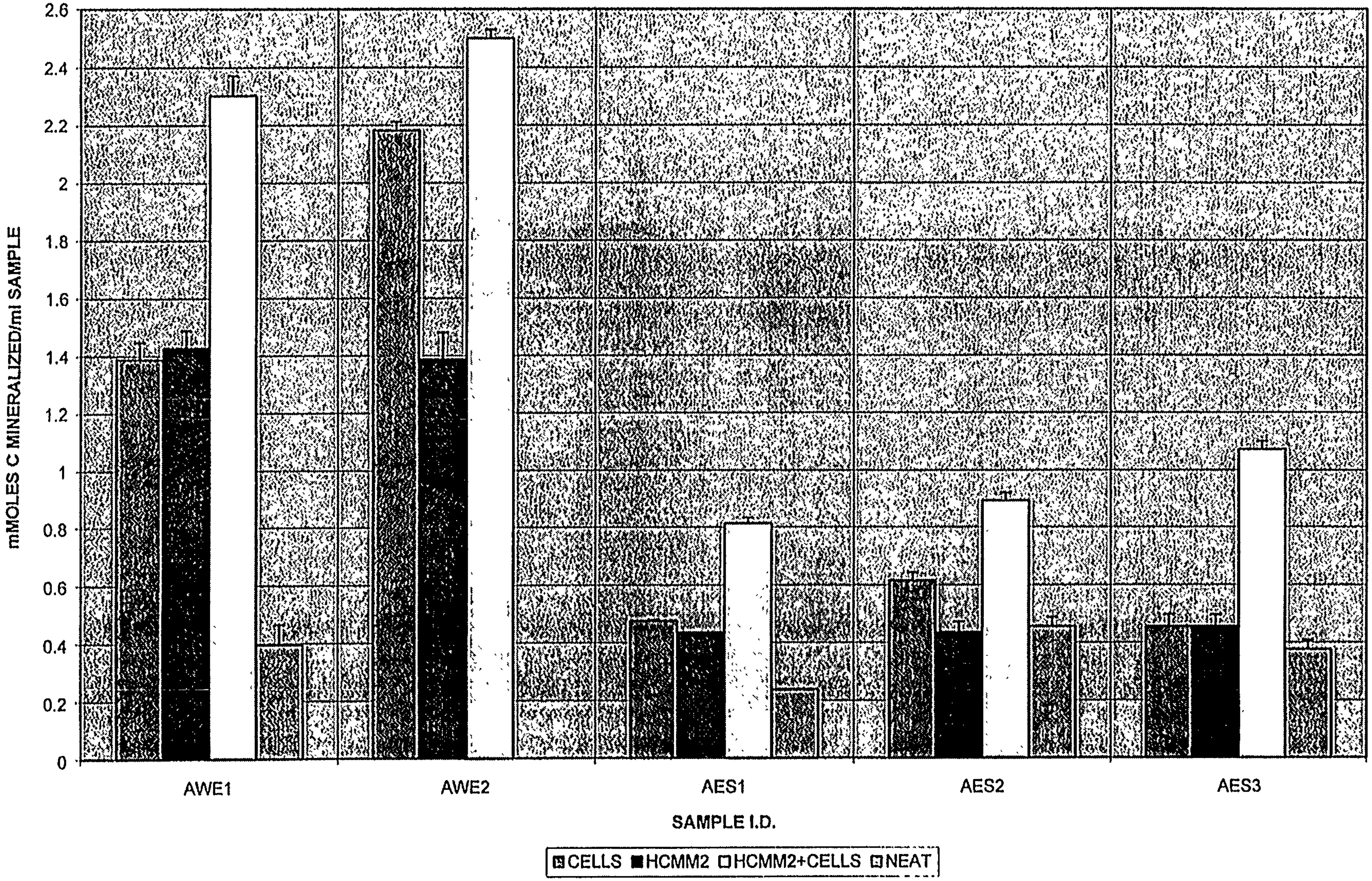
***AMOUNT OF CO2/ml ORIGINAL SAMPLE (CORRECTED FOR ASSAY DILUTION)
****DIFFERENCE BETWEEN SAMPLE AND KILLED CONTROL(KC)

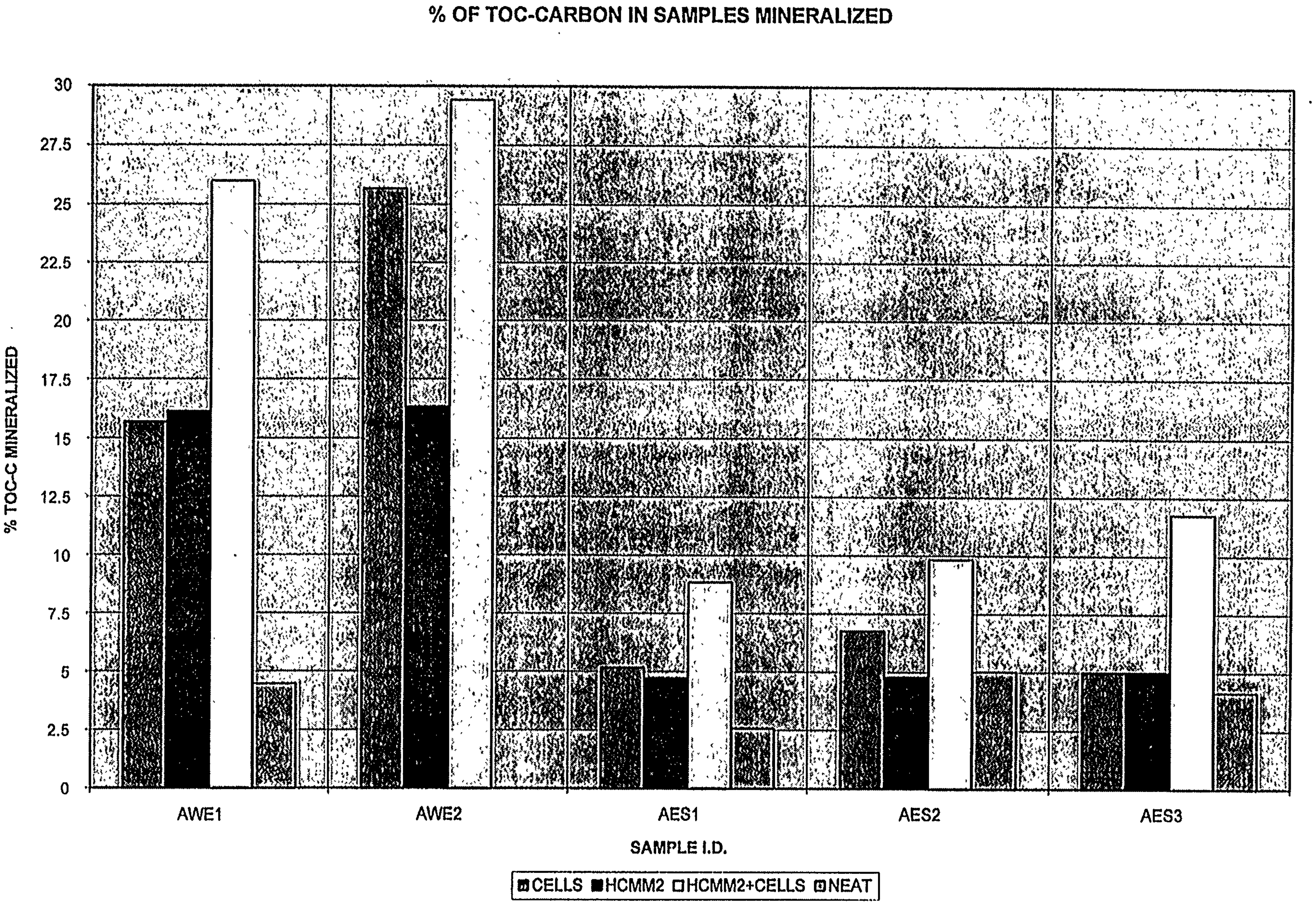
1:10 DILUTED SAMPLES	REP 1	REP 2	MEAN	S.D.	DIL RATIO	GROSS (MOLES CO2/ML) 1:10	S.D.	NEAT	S.D.
AES1-1210-HCMM2-	1.991758	2.026099	2.008929	0.024283	11.5555556	23.21429	0.2806038	7.837301	0.140299
AES2-1210-HCMM2-	2.09478	2.09478	2.09478	0	11.5555556	24.20635	0	7.619047	0
AES3-1210-HCMM2-	2.163461	2.163461	2.163461	0	11.5555556	24.99999	0	7.160027	0.024282
AWE1-1210-HCMM2-	2.300824	2.300824	2.300824	0	11.5555556	26.5873	0	14.72223	0.112245
AWE2-1210-HCMM2-	2.369505	2.369505	2.369505	0	11.5555556	27.38095	0	14.58333	0.028059

MINERALIZATION EFFICIENCY

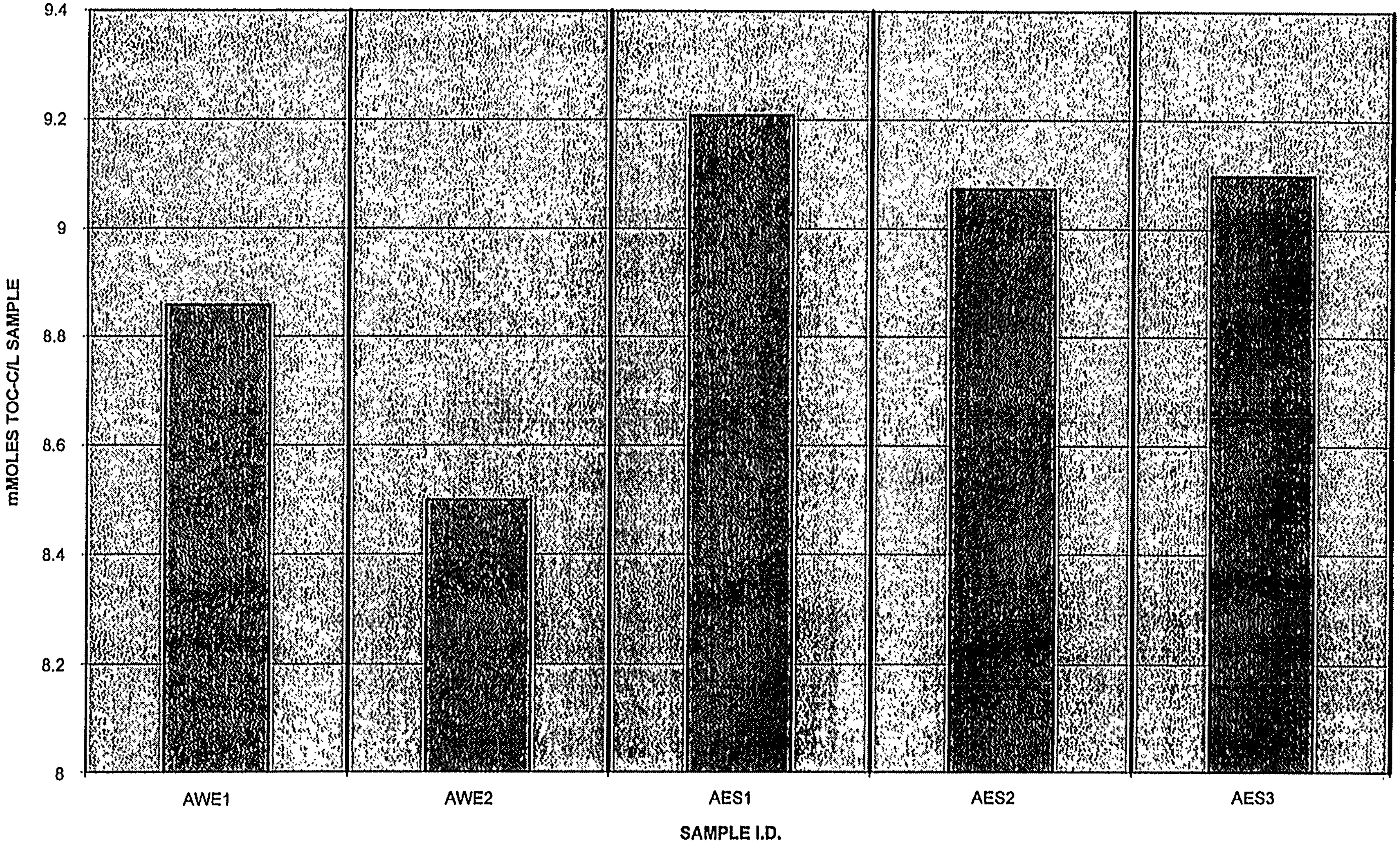
SAMPLE I.D.	CO2-C	TOC-C	% TOC-C MINERALIZED
AES1-CELLS	0.476191	9.208333	5.1713
AES1-HCMM2	0.436508	9.208333	4.740358
AES1-HCMM2-CELL	0.813491	9.208333	8.834296
AES1-NEAT	0.238094	9.208333	2.585638
AES2-CELLS	0.615078	9.076	6.777719
AES2-HCMM2	0.436508	9.076	4.810002
AES2-HCMM2-CELL	0.692856	9.076	7.633936
AES2-NEAT	0.456349	9.076	5.028034
AES3-CELLS	0.456349	9.1	5.014819
AES3-HCMM2	0.456349	9.1	5.014819
AES3-HCMM2-CELL	1.071428	9.1	11.77393
AES3-NEAT	0.376984	9.1	4.142679
AWE1-CELLS	1.388885	8.858333	15.67888
AWE1-HCMM2	1.428567	8.858333	16.12682
AWE1-HCMM2-CELL	2.301589	8.858333	25.98219
AWE1-NEAT	0.396818	8.858333	4.479599
AWE1-KC			
AWE2-CELLS	2.182544	8.5	25.67699
AWE2-HCMM2	1.388897	8.5	16.33996
AWE2-HCMM2-CELL	2.499998	8.5	29.41174

NET MINERALIZATION BY SAMPLES

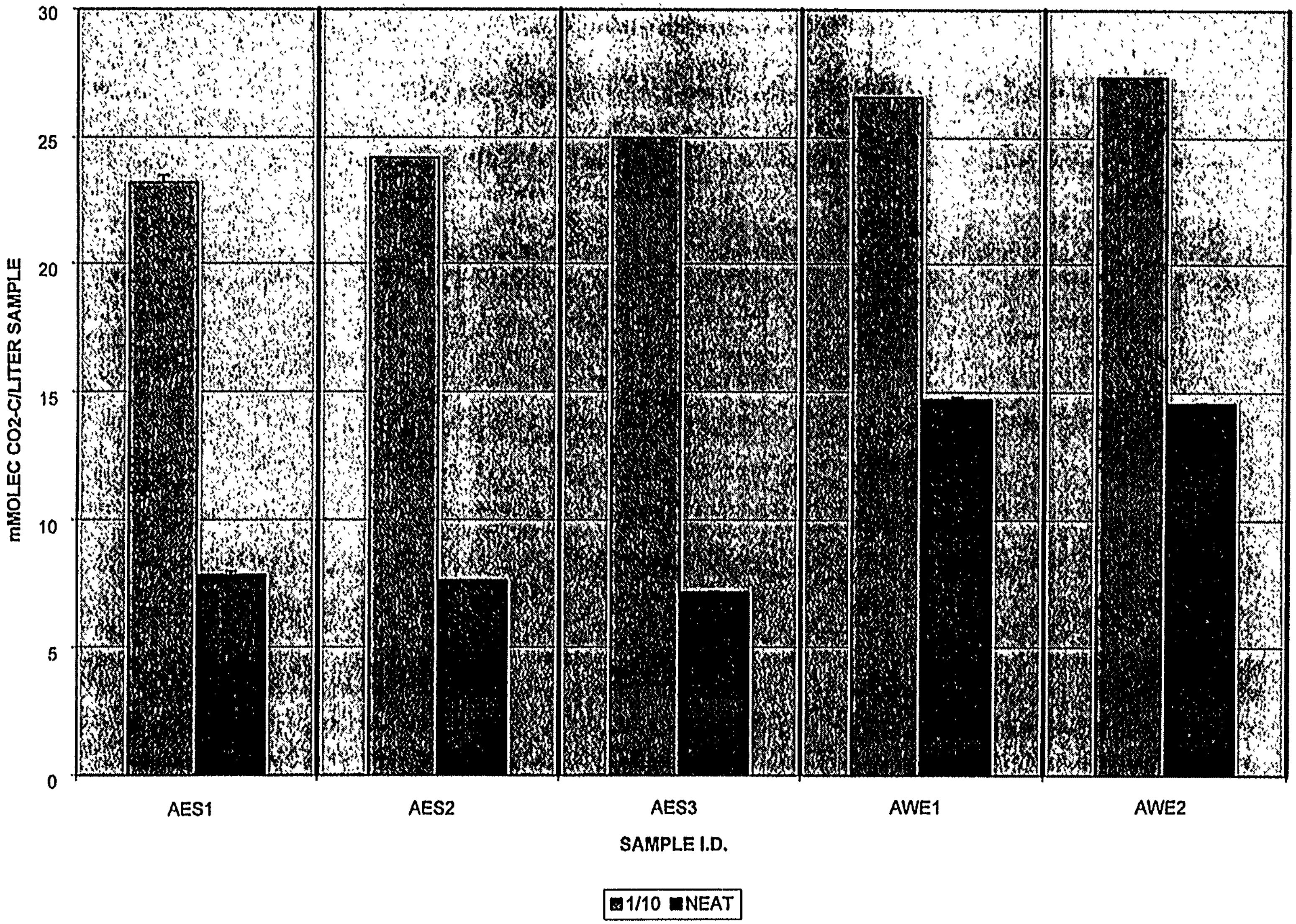



% OF TOC-CARBON IN SAMPLES MINERALIZED
% TOC-C MINERALIZED
30
27.5
25
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
AWE1
AWE2
AES1
AES2
AES3
SAMPLE I.D.
▨CELLS ■HCMM2 □HCMM2+CELLS ▨NEAT

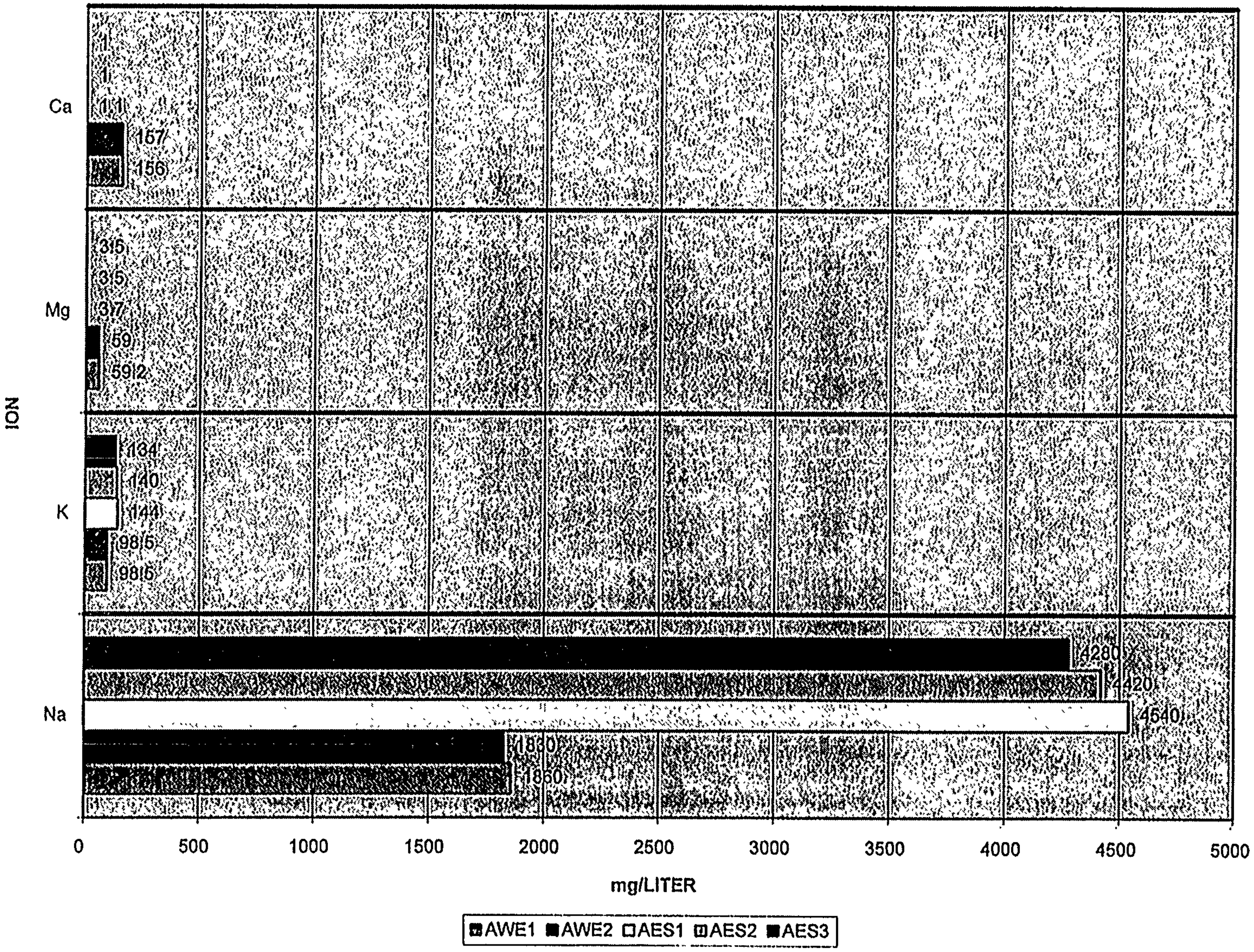
TOC-C IN SAMPLES



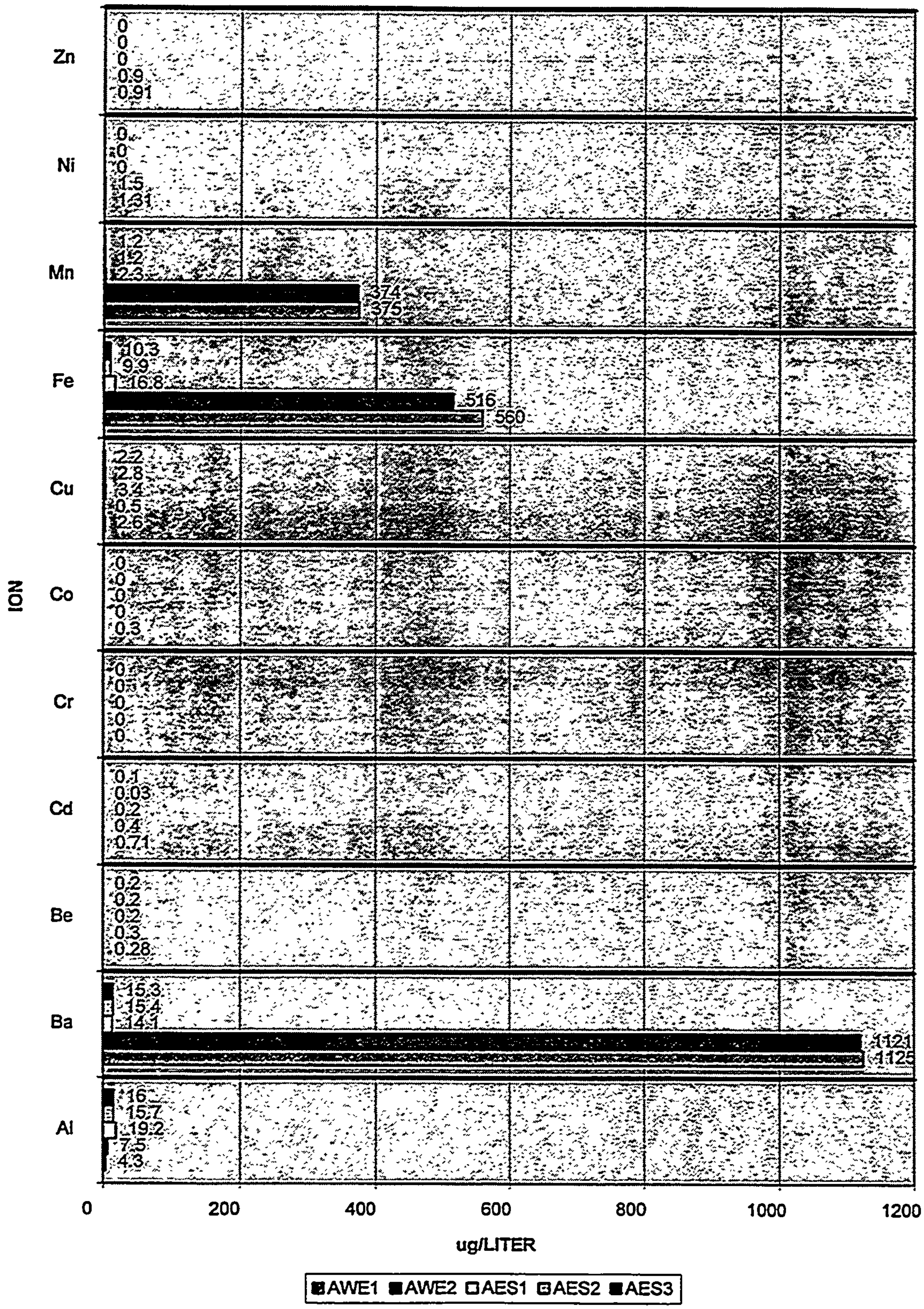
GROSS CO2 PRODUCTION BY SAMPLES BEFORE AND AFTER 10X DILUTION



INORGANIC ION ANALYSIS,



INORGANIC ION ANALYSIS



Appendix B

USGS Data

March 3, 1849

United States Department of the Interior

GEOLOGICAL SURVEY

Water Resources Division
345 Middlefield Road, MS-427
Menlo Park, CA 94025
E-Mail: ykharaka@usgs.gov
Tel: 415-329-4535
Fax: 415-329-4538

February 26, 1997

Lawrence Y.C. Leong
Kennedy/Jenks Consultants
2151 Michelson Drive, Ste 100
Irvine, CA 92612

Dear Larry:

I am enclosing the preliminary results of chemical analysis on samples that we collected from Placerita oil field. The results for some components are not completed, but I am forwarding what we have to you now because of the forthcoming meeting. Looking forward to seeing you next week. Best wishes.

Sincerely,

Yousif Kharaka

PLACERITA OIL FIELD 11/96 YKK DATA POF1196.XLS\ykk 2/18/97GA

YKK, Jim Walker, Mark Huebner

SAMPLE	DATE 1996	site	EC uS/cm	pH	T °C	Li mg/L	Na mg/L	K mg/L	NH4+ mg/L	Mg mg/L	Ca mg/L	Sr mg/L
96POF-11	11/20	PLA30 (#1) (tank)	9867	6.7	76	1.05	1532	73.5	14	117	269	9.91
96POF-12	11/20	Wickham Ferrier, Arco 7-31	14730	6.9	43	1.11	1941	22.2	4.1	348	752	26.8
96POF-13	11/20	Kraftlease well #6-20	13193	7.1	53	1.53	2126	61.4	9.0	319	498	16.9
96POF-14	11/21	PLA30 (#2) (tank)	9520	6.7	73	1.06	1650	73.7	13	116	261	9.36
96POF-15	11/21	GPM #50 LA053735	9810	6.6	32	0.837	1150	38.6	6.4	391	485	17.8
96POF-16	11/21	Fresh water well #9-22	1490	8.1	20	0.112	293	3.49	1.9	12.7	17.0	0.969

SAMPLE	Ba mg/L	Mn mg/L	Fe mg/L	F mg/L	Cl mg/L	Br mg/L	SO4 mg/L	titr HCO3 mg/L	titr H2S mg/L	SIO2 mg/L	B mg/L	TDS calc	CATS meq/L	ANS meq/L	CATS/ ANS
96POF-11	1.19	0.670	<0.08	3	2831	11.2	75.2	615	1.3	227	15.7	5873	92.79	91.82	1.01
96POF-12	0.747	0.398	<0.08	6	4976	18.6	8.9	695	0.7	108	16.3	9002	152.17	152.47	1.00
96POF-13	0.223	0.440	1.34	2	3846	13.8	795	993	0.7	186	14.2	8951	146.30	141.59	1.03
96POF-14	1.22	0.649	n 0.09	4	2858	11.5	79.6	655	1.5	236	15.9	6062	97.32	93.38	1.04
96POF-15	1.53	0.578	16.5	3	2784	9.8	0.12	1681	1.4	146	9.6	6789	108.92	106.38	1.02
96POF-16	0.163	0.0120	0.087	0.4	214	1.9	30.9	490		44	2.2	1123	14.86	14.76	1.01

SAMPLE	TDS/ EC	% HCO3 /ANS	% Na/ CATS	SUCC mg/L	FORM mg/L	ACET mg/L	PROP mg/L	BUTY mg/L	Oil & Grease mg/L	DOC mg/L	Total Phenol ug/L
96POF-11	0.60	11	72	0.15	0.06	12	1.5	<0.3	64	110	690
96POF-12	0.61	7	55	<0.2	0.08	0.8	<0.1	<0.3		44	50
96POF-13	0.68	11	63	<0.2	<0.06	1.5	0.04	<0.3		110	190
96POF-14	0.64	12	74	0.15	<0.06	11	1.5	0.2	49	120	610
96POF-15	0.69	26	46	<0.2	0.15	1.1	<0.1	<0.3		96	190
96POF-16	0.75	54	86								

SCH 1385 REPORT - 96POF SAMPLES TEXT **POF96ORG.SAM 2/18/97GA**
(EMAILED BY CENTRAL LAB 2/12/97) **(see companion data file 96POFORG.XLS)**

Return-path: sgsmith@ojflcoarv.cr.usgs.gov
Received: from ojflcoarv.cr.usgs.gov (ojflcoarv.cr.usgs.gov [136.177.19.89]) by mailrcamnl.wr.usgs.gov (Geomail 1.2.3) with ESMTP id MAA29007; Wed, 12 Feb 1997 12:35:22 -0800
Received: from localhost (orglcoarv [136.177.19.59]) by ojflcoarv.cr.usgs.gov (Geomail 1.2.3) with ESMTP id NAA15308; Wed, 12 Feb 1997 13:38:29 -0700 Message-id: <199702122038.NAA15308@ojflcoarv.cr.usgs.gov>
X-mailer: exmh version 1.5.2 12/21/94 To: "Yousif K Kharaka, Hydrologist, Menlo Park, CA" <ykharaka>
Cc: "Gil Ambats, Chemist, Menlo Park, CA" <gambats>,
"Michael P Schroeder, Chemist, Denver, CO" <schroede@ojflcoarv.cr.usgs.gov>,
"Steven G Smith, Chemist, Denver, CO" <sgsmith@ojflcoarv.cr.usgs.gov>
Subject: 1385 unknown results
From: "Steven G Smith, Chemist, Denver, CO" <sgsmith@ojflcoarv.cr.usgs.gov>
Date: Wed, 12 Feb 1997 13:30:06 -0700
Sender: "Steven G Smith, Chemist, Denver, CO" <sgsmith@ojflcoarv.cr.usgs.gov>

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TO: YKHARAKA DATE: 01/27/97 FROM: Steven Zaugg

THROUGH: Mike Schroeder SUBJECT: Reports and Statistics of data from lab schedule 1385

Samples from your district were analyzed by USGS procedures outlined in TWRI book 5, chapter A3 (0-3118-83) according to the appropriate lab schedule. If you requested GC/MS library searches for FID scans (schedule 1381), you may need to determine the sample station ID, date, and time from the initial FID scan reports you should have already received. However, this information should already be included in this report for all schedule 1385 and 1386 samples and most FID scan follow-ups. if you have trouble determining this information please contact Steve Zaugg (303) 467-8207 at the NWQL. For each sample, Table I contains specific compound results for "priority pollutants". These target compounds have been identified, confirmed and quantitated based on the corresponding reference standards. Compound names have been truncated at 30 characters so you may need to use the CAS number to retrieve the complete compound name.

Table II contains non-target compound results. Since these results have not been confirmed and quantitated at the same high level of confidence as for the target compounds, they should be referred to as "tentatively identified organic compounds" and must be qualified appropriately. All U.S. Geological Survey reports which contain non-target compound data must include a disclaimer as outlined in the U.S. Geological Survey Office of Water-Quality Technical Memorandum 90.11, 3p.

Spectra at the peak maxima of non-target compounds were compared by computerized library searches against National Bureau of Standards (NIST) library reference spectra, and spectra from reference compounds as they have been added to an in-house spectral library. The best library matches have been inspected manually and have been reported at a level of confidence that the analyst and data reviewers consider reasonable, ie.; name with any appropriate qualifiers, only a compound class, or just "unknown". Table II also contains name flags which reflect this level of confidence. In cases where the spectra and retention index of the non-target compound matches that of an in-house reference compound, the identification of the compound is more certain (an "S" is reported in Table II under the name flag to indicate the spectra matches that of a compound in the in-house library, and an "R" under the RI column is reported to indicate that the retention index matches that of a compound in the in-house library). Compound names have also been truncated to 32 characters, so you may want to use the CAS number if the complete name or more information is desired.

Non-target compound results are reported only if they have not been found in laboratory blanks, unless they are detected at a significantly higher concentration level (at least 10 times the blank level), in which case the resulting concentration is flagged with a "B" qualifier. Concentrations of non-target compounds are calculated relative to that of the internal

standard, perdeuteronaphthalene. Concentration values do not take into consideration the differences in chemical properties of the compound relative to the internal standard. Therefore, the values are treated as semi-quantitative and are rounded to one significant figure using scientific notation (100 = 1e+02), although concentrations should be interpreted as approximations good to a factor from one to five times in most cases. However, quantitation is expected to be more reliable if based on the response of an in-house reference standard (indicated by a "Q" flag in the concentration column of the data table).

The retention index (RI) is a useful tool for estimating the carbon number of a non-target compound and has been included in the data report. For the Kovat's index, this number is an approximation for the carbon number (100 = 1 carbon, 1000 = 10 carbons) based on the retention times which have been determined for a series of normal alkane hydrocarbons. Compounds reported in Table II which have molecular weights consistent with their calculated Kovat's indices have been flagged with a "K" qualifier under the "RI" column. For those compounds which are "alkane-like" this flag adds a level of confidence in the assigned compound identification. For those compounds that are not "alkane-like" the "K" qualifier has little or no meaning, however, the Kovat's retention index is still a valid reference number. The retention index is also more useful for characterizing a compound than retention times which may vary considerably. It may also be used to characterize a general class of contaminants, such as different fuel types.

As of March 1, 1995 most of the non-target compound reports include a brief historical summary of the sample site, unless there were computer problems retrieving the site record file. In this case the site will be identified as "nosite", and should be little cause for concern unless this occurs multiple times for a particular site over a period of time. If this seems to be a problem and you are interested in obtaining this site information, contact Steve Zaugg (303) 467-8207 at the NWQL.

The number of detections for each TIOC at a given site is reported under the "#" column in the site information field.

Compounds which can only be identified by compound class may occasionally have more tentative identifications reported than the number of samples analyzed from the site because of an attempt to summerize a general class of compounds occurring within a defined RI window (0.2 carbon units).

The concentration average is based on the total number of samples taken at a particular site, so that samples for which the compound was not detected contribute "0.0" to the sum of the concentrations for that compound. The concentration range, on the other hand, only considers the low and high values which have been observed.

After the reports for each sample at a given site, a historical summary of tentatively identified compounds found at that site is reported if the site record file could be accessed by computer and there has been more than just the one current sample analyzed at that site since March, 1995. This report is similar to the sample reports, except for the addition of a column indicating the "match quality" of the library match with the sample spectrum (a value between 1-100). This computer generated number does not take into consideration the amount of contamination in a given spectrum, instrumental conditions or differences, expected compound volatility based on molecular weight (RI), as well as several other factors. A high value (probably greater than 90) may increase the confidence in a particular match somewhat, but a lower value probably has little or no significance. In either case, the name flags, data qualifiers, and analyst experience is much more meaningful.

Finally, after all of the sample data has been reported, if there was more than one similar site ID number in this current report, an attempt was made to compile the non-target data for similar site ID numbers to generate a table(s) of tentatively identified compounds for the study area(s). This summary report may be useful for tracking the occurrence of certain compounds, and for evaluating the possibility that some non-target compounds with similar retention indices and molecular formulas may be the same compounds. or more closely related than perhaps the computer assigned names might indicate.

In the future, with regards to non-target information, we would like to provide customized help to assist with your specific project needs. Please include the correct project account and your same name printed on the Analytical Services Request (ASR) form when submitting samples requesting a library search (Laboratory Schedules 1385 and 1386) so we can return your results as soon as possible. Also, please indicate either by phone or on the comment line of the ASR form what particular type of contamination you are most interested in (PAHs, pesticides, specific waste effluents, industrial or agricultural compounds, etc) so we can focus our efforts on your particular project needs. Since the following report file may be quite lengthy, you may want to copy it to a results file or a spread sheet. Please acknowledge receipt of this document.

If you would like more assistance with the interpretation of your data, please contact one of the following analysts at the NWQL (area code 303):

Jamie Alexander	467-8216
Steve Smith	467-8181
Frank Weibe	467-8178
Mary Olson	467-8203
Jana Iverson	467-8223

SCH 1385 REPORT - 96POF SAMPLES TEXT POF96ORG.SAM 2/18/97GA
(EMAILED BY CENTRAL LAB 2/12/97) (see companion data file 96POFORG.XLS)

SCH 1385 SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\notes 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

NA -- Not applicable
NF -- Not found

** NAME FLAGS:
S -- Spectra matched that of an in-house reference standard
C -- Only the compound class is identified
N -- Another compound having the same CAS number and name was reported. These componds may be closely related, but are probably not the same based on their retention index differences.
A -- This compound has the same CAS number but different names from another reported compound. The two compounds may be the same compound with different names (compare the molecular formula), closely related compounds, or quite often one of the compounds has been assigned the wrong CAS number.
I -- Other isomers are possible

OTHER QUALIFIERS:
R -- Retention index (RI column) matched that of an in-house reference standard
K -- The Kovat's retention index (RI column) was consistent (within one carbon) with the reported molecular weight.
Q -- Quantitation (Conc column) was based on the response of an in-house reference standard
D -- Quantitation (Conc column) yielded a different result when calculated by another method. The result has been reported which usually has less interference problems.
B -- The compound was also detected in a lab blank (Conc column), but at a level less than 10 percent of that found in the sample

TABLE I

```
Lab Schedule: 1385       Site ID: 96POF11  Date: 961120  Time: 1120
Lab Sample ID: 963310085x100.d     Run Date: 11-DEC-9616        Operator: sgs
Inst Btch: 1385P96331dil       Prep Btch: 3821    Volume (ml or g): 918

  Watstore #     Compound Name              Con-(ug/l)    Report Limit-(ug/l)
-------------------------------------------------------------------------------
 1.   34438  N-NITROSO-N,N-DIMETHYLAMINE           <5          <5
 2.   34694  PHENOL                              260.1         <5
 3.   34586  PHENOL, 2-CHLORO-                     <5          <5
 4.   34273  BIS(2-CHLOROETHYL)ETHER               <5          <5
 5.   34566  BENZENE, 1,3-DICHLORO-                <5          <5
 6.   34571  BENZENE, 1,4-DICHLORO-                <5          <5

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 7.   34536  BENZENE, 1,2-DICHLORO-                <5          <5
 8.   34283  BIS(2-CHLOROISOPROPYL)ETHER           <5          <5
 9.   34396  HEXACHLOROETHANE                      <5          <5
10.   34428  N-NITROSO-DI-N-PROPYLAMINE            <5          <5
11.   34447  NITROBENZENE                          <5          <5
12.   34408  ISOPHORONE                            <5          <5
13.   34591  PHENOL, 2-NITRO-                      <5          <5
14.   34606  PHENOL, 2,4-DIMETHYL-               73.2          <5
15.   34278  BIS(2-CHLOROETHOXY)METHANE            <5          <5
16.   34601  PHENOL, 2,4-DICHLORO-                 <5          <5
17.   34551  BENZENE, 1,2,4-TRICHLORO-             <5          <5
18.   34696  NAPHTHALENE                        138.0          <5
19.   39702  HEXACHLOROBUTADIENE                   <5          <5
20.   34452  PHENOL, 4-CHLORO-3-METHYL-           <30         <30
21.   34386  HEXACHLOROCYCLOPENTADIENE             <5          <5
22.   34621  PHENOL, 2,4,6-TRICHLORO-             <20         <20
23.   34581  NAPHTHALENE, 2-CHLORO-                <5          <5
24.   34200  ACENAPHTHYLENE                        <5          <5
25.   34341  DIMETHYL PHTHALATE                    <5          <5
26.   34626  TOLUENE, 2,6-DINITRO-                 <5          <5
27.   34205  ACENAPHTHENE                          <5          <5
28.   34616  PHENOL, 2,4-DINITRO-                 <20         <20
29.   34646  PHENOL, 4-NITRO-                     <30         <30
30.   34611  TOLUENE, 2,4-DINITRO-                 <5          <5
31.   34381  FLUORENE                              <5          <5
32.   34336  DIETHYL PHTHALATE                     <5          <5
33.   34641  PHENYLPHENYLETHER, 4-CHLORO-          <5          <5
34.   34657  PHENOL, 2-METHYL, 4,6-DINITR         <30         <30
35.   34433  N-NITROSODIPHENYLAMINE                <5          <5
36.   82626  AZO-BENZENE                           <5          <5
```

SCH 1385 REPORT - 96POF SAMPLES TEXT **POF96ORG.SAM 2/18/97GA**

(EMAILED BY CENTRAL LAB 2/12/97) **(see companion data file 96POFORG.XLS)**

37.	34636	PHENYLPHENYLETHER, 4-BROMO-	<5	<5
38.	39700	HEXACHLOROBENZENE	<5	<5
39.	39032	PHENOL, PENTACHLORO-	<30	<30
40.	34461	PHENANTHRENE	<5	<5
41.	34220	ANTHRACENE	<5	<5
42.	39110	DI-N-BUTYLPHTHALATE	<5	<5
43.	34376	FLUORANTHENE	<5	<5
44.	39120	BENZIDINE	<40	<40
45.	34469	PYRENE	<5	<5
46.	34292	BUTYLBENZYLPHTHALATE	<5	<5
47.	34526	BENZ(A)ANTHRACENE	<10	<10
48.	34631	3,3'-DICHLOROBENZIDENE	<20	<20
49.	34320	CHRYSENE	<10	<10
50.	39100	BIS(2-ETHYLHEXYL)PHTHALATE	<5	<5
51.	34596	DI-N-OCTYLPHTHALATE	<10	<10
52.	34230	BENZO(B)FLUORANTHENE	<10	<10
53.	34242	BENZO(K)FLUORANTHENE	<10	<10
54.	34247	BENZO(A)PYRENE	<10	<10
55.	34403	INDENO(1,2,3-C,D)PYRENE	<10	<10
56.	34556	DIBENZ(A,H)ANTHRACENE	<10	<10
57.	34521	BENZO(G,H,I)PERYLENE	<10	<10
58.	SURRO	SUR (%REC) PHENOL, D-5	81.47	
59.	SURRO	SUR (%REC) BENZENE, 1,4-DIBR	51.17	
60.	SURRO	SUR (%REC) PHENOL, 2,4-DIBRO	119.39	
61.	SURRO	SUR (%REC) BIPHENYL, 2,2'-DI	87.20	
62.	SURRO	SUR (%REC) PHENOL, 2,4,6-TRI	118.93	

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63.	SURRO	SUR (%REC) BIPHENYL, 4,4'-DI	84.14

NOTE -- Values reported on this form may not reflect the appropriate number of significant figures as for the values transmitted over the PRIME. Values below the the reporting limit may not be transmitted over the Prime so have been included here with an "E" (estimated) qualifier. Compounds which have demonstrated poor method performance or have had unusual QA/QC problems may also have an "E" qualifier.

There may be an occasional discrepancy between values reported here, and those received over the PRIME. If this is the case, the PRIME values are more accurate, having been reviewed more thoroughly. The last compounds reported with names of SURRO or SUR are surrogate compounds which are added to the sample to give some indication of method efficiency for this specific sample, and these results are reported in percent recovery (%REC).

Lab Schedule: 1385 Site ID: 96POF11 Date: 961120 Time: 1120
Lab Sample ID: 963310085x100.d Run Date: 11-DEC-9616 Operator: sgs
Inst Btch: 1385P96331dil Prep Btch: 3821 Volume (ml or g): 918

SCH 1385 SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\11 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

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Dec 18 14:03 1996 LAB ID: 963310085x100.d Page 3
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1/100 dilution, I believe

SCHEDULE: 1385 TENTATIVELY IDENTIFIED COMPOUND SUMMARY REPORT FOR SITE: 96POF11

	COMPOUND NAME	**NAME FLAGS	CONC	RI	CAS #	MW	MOL	SITE: 96POF11....... HISTRY		
			(ug/l)	(KOVAT)			FORMULA	MQ	#	CONC RANGE
1	Butanoicacid		2.00E+01	762	107-92-6	88	$C_4H_8O_2$	90	1	2.0e+01-2.0e+01
2	3-Hexanone	I	1.70E+00	767	589-38-8	100	$C_6H_{12}O$	53	1	1.7e+00-1.7e+00
3	Cyclopentanone		1.40E+02	773	120-92-3	84	C_5H_8O	86	1	1.4e+02-1.4e+02
4	Butanoicacid,3-methyl-	I	2.60E+01	819	503-74-2	102	$C_5H_{10}O_2$	64	1	2.6e+01-2.6e+01
5	Cyclopentanone,3-methyl-	I	9.00E+01	830	1757-42-2	98	$C_6H_{10}O$	91	1	9.0e+01-9.0e+01
6	Benzene,ethyl-		6.90E+01	845	100-41-4	106	C_8H_{10}	95	1	6.9e+01-6.9e+01
7	Benzene,1,4-dimethyl-	I	2.8e+01 B	852	106-42-3	106	C_8H_{10}	97	1	2.8e+01-2.8e+01
8	OrganicAcid	C	1.90E+01	858	NA	NA		0	1	1.9e+01-1.9e+01
9	Cyclohexanol		1.50E+01	866	108-93-0	100	$C_6H_{12}O$	64	1	1.5e+01-1.5e+01
10	2-Hexene,2,5-dimethyl-	I	5.30E+00	873	3404-78-2	112	C_8H_{16}	72	1	5.3e+00-5.3e+00
11	3-Heptene,2-methyl-,(E)-	I	4.20E+00	880	692-96-6	112	C_8H_{16}	72	1	4.2e+00-4.2e+00
12	Unknown		1.2e+01 B	889	NA	NA		0	1	1.2e+01-1.2e+01
13	Benzene,(1-methylethyl)-	I	4.10E+01	905	98-82-8	120	C_9H_{12}	91	1	4.1e+01-4.1e+01
14	Unknown		2.8e+01 B	920	NA	NA		0	1	8.8e+00-1.9e+01
15	Benzene,propyl-		4.20E+01	934	103-65-1	120	C_9H_{12}	90	1	4.2e+01-4.2e+01
16	3-Ethylcyclopentanone	I	1.60E+01	938	10264-55-8	112	$C_7H_{12}O$	80	1	1.6e+01-1.6e+01
17	2-Cyclopenten-1-one,3-methyl-	I	4.40E+01	946	2758-18-1	96	C_6H_8O	91	1	4.4e+01-4.4e+01
18	2,4-Hexadiene,2,5-dimethyl-	I	9.50E+00	974	764-13-6	110	C_8H_{14}	58	1	9.5e+00-9.5e+00
19	Cyclopropane,tetramethylmethylen		3.10E+00	1002	54376-39-5	110	C_8H_{14}	64	1	3.1e+00-3.1e+00
20	1H-Indene,2,3-dihydro-	I	1.60E+02	1019	496-11-7	118	C_9H_{10}	95	1	1.6e+02-1.6e+02
21	Phenol,4-methyl-	I	1.80E+02	1048	106-44-5	108	C_7H_8O	96	1	1.8e+02-1.8e+02
22	Benzene,4-ethenyl-1,2-dimethyl-	I	1.30E+01	1064	27831-13-6	132	$C_{10}H_{12}$	93	1	1.3e+01-1.3e+01
23	Benzene,(2-methyl-1-propenyl)-	I	6.50E+01	1070	768-49-0	132	$C_{10}H_{12}$	76	1	6.5e+01-6.5e+01
24	Benzene,1-ethyl-2,3-dimethyl-	I	1.60E+01	1095	933-98-2	134	$C_{10}H_{14}$	62	1	1.6e+01-1.6e+01
25	Phenol,2-ethyl-	I	6.30E+00	1110	90-00-6	122	$C_8H_{10}O$	81	1	6.3e+00-6.3e+00
26	Phenol,3-ethyl-	I	9.20E+01	1140	620-17-7	122	$C_8H_{10}O$	87	1	9.2e+01-9.2e+01
27	Unknown		1.90E+01	1148	NA	NA		0	1	1.9e+01-1.9e+01
28	Phenol,2,5-dimethyl-	I	3.40E+01	1152	95-87-4	122	$C_8H_{10}O$	91	1	3.4e+01-3.4e+01
29	CIS-UNDEC-4-ENAL	I	2.00E+01	1180	68820-32-6	168	$C_{11}H_{20}O$	43	1	2.0e+01-2.0e+01
30	Cyclohexane,1-methyl-4-(1-methyl	I	6.60E+01	1185	1678-82-6	140	$C_{10}H_{20}$	38	1	6.6e+01-6.6e+01
31	Unknown		5.5e+01 B	1203	NA	NA		0	1	2.5e+01-3.0e+01
32	Unknown		1.4e+02 B	1227	NA	NA		0	1	4.7e+01-8.8e+01
33	Phenol,2,3,5-trimethyl-	I	1.60E+02	1245	697-82-5	136	$C_9H_{12}O$	97	1	1.6e+02-1.6e+02
34	Unknown		1.0e+02 B	1269	NA	NA		0	1	2.1e+01-5.2e+01
35	Naphthalene,1-methyl-	I	1.10E+02	1290	90-12-0	142	$C_{11}H_{10}$	76	1	3.6e+01-7.0e+01
36	Unknown		1.9e+01 B	1291	NA	NA		0	1	1.9e+01-1.9e+01
37	Unknown		7.50E+01	1313	NA	NA		0	1	2.0e+01-5.5e+01
38	m-Tolylaceticacid		3.00E+01	1315	621-36-3	150	$C_9H_{10}O_2$	93	1	3.0e+01-3.0e+01
39	2-Methylthio-4-methoxypyrimidine	I	4.60E+01	1336	76541-59-8	156	$C_6H_8N_2O$	43	1	4.6e+01-4.6e+01
40	Unknown		6.50E+01	1356	NA	NA		0	1	1.4e+01-5.1e+01
41	Unknown		9.80E+01	1369	NA	NA		0	1	1.3e+01-8.5e+01
42	Unknown		2.20E+01	1399	NA	NA		0	1	2.2e+01-2.2e+01

SCH 1385 SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\11 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

43	Ethanol,2-xylyl- I	5.50E+01	1403	27577-96-4	150	C10H14O	49	1	5.5e+01-5.5e+01
44	Pyridine,5-ethenyl-2-methyl- I	3.10E+02	1414	140-76-1	119	C8H9N	52	1	3.1e+02-3.1e+02
45	Benzene,2-ethyl-1,4-dimethyl- I	1.30E+02	1426	1758-88-9	134	C10H14	62	1	1.3e+02-1.3e+02
46	Benzene,4-ethyl-1,2-dimethyl- I	4.70E+01	1436	934-80-5	134	C10H14	64	1	4.7e+01-4.7e+01
47	Naphthalene,1,4-dimethyl- I	1.70E+01	1442	571-58-4	156	C12H12	70	1	1.7e+01-1.7e+01
48	4-Aminostyrene I	2.00E+01	1447	1520-21-4	119	C8H9N	47	1	2.0e+01-2.0e+01
49	Cyclopropane,1-(1-methylethyl)-2 I	1.40E+01	1475	56259-17-7	152	C11H20	38	1	1.4e+01-1.4e+01
50	Benzenamine,N,N-diethyl-4-nitros I	2.30E+01	1492	120-22-9	178	C10H14N2	46	1	2.3e+01-2.3e+01
51	Cyclopropanecarboxylicacid,1-ph I	2.70E+01	1498	6120-95-2	162	C10H10O2	50	1	2.7e+01-2.7e+01
52	Benzene,2-(chloromethyl)-1,3,5-t I	4.80E+01	1515	1585-16-6	168	C10H13Cl	35	1	4.8e+01-4.8e+01
53	Benzene,1-ethyl-4-(1-methylethyl I	1.10E+02	1535	4218-48-8	148	C11H16	43	1	1.1e+02-1.1e+02
54	Benzene,1,3-dimethyl-5-(1-methyl I	7.90E+01	1550	4706-90-5	148	C11H16	50	1	7.9e+01-7.9e+01
55	Benzene,1,4-diethyl-2-methyl- I	4.90E+01	1559	13632-94-5	148	C11H16	35	1	4.9e+01-4.9e+01
56	3-Pentenoicacid,4-phenyl- I	2.30E+01	1564	53774-19-9	176	C11H12O2	58	1	2.3e+01-2.3e+01
57	6-Hepten-2-one,7-phenyl- I	1.40E+02	1579	33046-88-7	188	C13H16O	72	1	1.4e+02-1.4e+02
58	1,4-Methanonaphthalen-9-ol,1,2,3 I	2.20E+01	1621	1198-20-5	160	C11H12O	40	1	2.2e+01-2.2e+01
59	Acenaphthylene,1,2,2a,3,4,5-hexa I	1.20E+02	1644	480-72-8	158	C12H14	45	1	1.2e+02-1.2e+02
60	Benzene,1-cyclopenten-1-yl- I	6.10E+01	1660	825-54-7	144	C11H12	42	1	6.1e+01-6.1e+01
61	Unknown	3.3e+01 B	1674	NA	NA		0	1	3.3e+01-3.3e+01
62	1H,3H-Naphtho[1,8-cd]pyran,3a,4, I	2.90E+01	1680	36051-81-7	174	C12H14O	53	1	2.9e+01-2.9e+01
63	Amide C	7.90E+00	2126	NA	NA		0	1	7.9e+00-7.9e+00
64	Phenol,4-[[(4-methoxyphenyl)meth I	9.90E+00	2160	3230-39-5	227	C14H13NO	58	1	9.9e+00-9.9e+00
65	3-PHENYL-2,1-BENZISOXAZOLE I	1.60E+01	2205	5176-14-7	195	C13H9NO	80	1	1.6e+01-1.6e+01
	Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 17								
	Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 18								
	Total nontarget samples at the time of this report generation = 1								
	Total nontarget samples which were "clean" for site: 96POF11 = 0								

SCH 1385 · SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\11 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

Note to the user: The amount of extractable material from this sample exceeded the method capacity for normal
** analysis. It thus became necessary to dilute the original extract by a factor of 10.

SCHEDULE: 1385 TENTATIVELY IDENTIFIED COMPOUND REPORT FOR LAB SAMPLE ID:
963310085 diluted ten fold
Site ID: 96POF11 Date: 961120 Time: 1120 ***1/10 dilution.***
Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 8
SITE 96POF11 historical observations since March 1, 1995:
Total number of nontarget samples at the time of this report generation = 1 Total nontarget samples which were "clean" for the site = 0
Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 9
Dec 18 14:02 1996 LAB ID: 963310085x10.d Page 2

	COMPOUND NAME	**NAME FLAGS	CONC	RI	CAS #	MW	MOL	SITE: 96POF11....... HISTRY		
			(ug/l)	(KOVAT)			FORMULA	#	CON AVE	CONC RANGE
1	Cyclopentane,2-isopropyl-1,3-dim	I	1.00E+00	. 701	32281-85-9	140	$C_{10}H_{20}$	1	1.00E+00	1.0e+00-1.0e+00
2	2-Pentanol,2-methyl-	I	2.00E+00	710 K	590-36-3	102	$C_6H_{14}O$	1	2.00E+00	1.6e+00-1.6e+00
3	1,2,4-TRIMETHYL-CYCLOPENTANE	I	8.00E-01	718 K	4850-28-6	112	C_8H_{16}	1	8.00E-01	8.3e-01-8.3e-01
4	2-Pentanone,4-methyl-	I	4e+00 B	721 K	108-10-1	100	$C_6H_{12}O$	1	4.00E+00	3.9e+00-3.9e+00
5	Disulfide,dimethyl		1.00E+00	726 K	624-92-0	94	$C_2H_6S_2$	1	1.00E+00	1.2e+00-1.2e+00
6	2-Pentanone,3-methyl-	I	1.00E+00	734 K	565-61-7	100	$C_6H_{12}O$	1	1.00E+00	1.1e+00-1.1e+00
7	2-Pentanol,4-methyl-	I	7.00E-01	738 K	108-11-2	102	$C_6H_{14}O$	1	7.00E-01	6.5e-01-6.5e-01
8	Thiophene,2-methyl-	I	2.00E+00	754 K	554-14-3	98	C_5H_6S	1	2.00E+00	1.5e+00-1.5e+00
9	Thiophene,3-methyl-	I	1.00E+00	761 K	616-44-4	98	C_5H_6S	1	1.00E+00	1.2e+00-1.2e+00
10	3-Hexanone	I	7.00E+00	767 K	589-38-8	100	$C_6H_{12}O$	1	7.00E+00	6.7e+00-6.7e+00
11	Cyclopentanone		2.00E+02	774	120-92-3	84	C_5H_8O	1	2.00E+02	1.6e+02-1.6e+02
12	Cyclohexane,1,3-dimethyl-,trans	I	6.00E-01	779 K	2207-03-6	112	C_8H_{16}	1	6.00E-01	5.7e-01-5.7e-01
13	2-Hexanol	I	5.00E-01	781 K	626-93-7	102	$C_6H_{14}O$	1	5.00E-01	5.4e-01-5.4e-01
14	Unknown		2e+00 B	788	NA	NA		1	2.00E+00	1.6e+00-1.6e+00
15	Cyclohexane,1,2-dimethyl-,cis-	I	8.00E-01	812 K	2207-01-4	112	C_8H_{16}	1	8.00E-01	8.3e-01-8.3e-01
16	Cyclopentanone,3-methyl-	I	1.00E+02	831	1757-42-2	98	$C_6H_{10}O$	1	1.00E+02	1.0e+02-1.0e+02
17	2-Hexanone,5-methyl-	I	2.00E+00	839 K	110-12-3	114	$C_7H_{14}O$	1	2.00E+00	2.5e+00-2.5e+00
18	Benzene,ethyl-		8.00E+01	845	100-41-4	106	C_8H_{10}	1	8.00E+01	7.6e+01-7.6e+01
19	2-Propanone,(1-methylethylidene)	I	1.00E+00	849 K	627-70-3	112	$C_6H_{12}N_2$	1	1.00E+00	9.8e-01-9.8e-01
20	Benzene,1,2-dimethyl-	I	3.00E+01	852	95-47-6	106	C_8H_{10}	1	3.00E+01	2.8e+01-2.8e+01
21	Thiophene,2-ethyl-	I	1.00E+00	860 K	872-55-9	112	C_6H_8S	1	1.00E+00	1.2e+00-1.2e+00
22	Cyclohexanol		2.00E+01	866	108-93-0	100	$C_6H_{12}O$	1	2.00E+01	1.8e+01-1.8e+01
23	2-Heptanone	I	4.00E+00	871 K	110-43-0	114	$C_7H_{14}O$	1	4.00E+00	3.5e+00-3.5e+00
24	2-Hexene,2,5-dimethyl-	I	5.00E+00	873 K	3404-78-2	112	C_8H_{16}	1	5.00E+00	4.9e+00-4.9e+00
25	1-Penten-3-one,2,4-dimethyl-	I	4.00E+00	880 K	3212-68-8	112	$C_7H_{12}O$	1	4.00E+00	4.1e+00-4.1e+00
26	Heptane,4-methylene-	I	1.00E+01	889	15918-08-8	112	C_8H_{16}	1	1.00E+01	1.1e+01-1.1e+01
27	Bicyclo[3.3.1]nonane	I	2.00E+00	901 K	280-65-9	124	C_9H_{16}	1	2.00E+00	2.0e+00-2.0e+00
28	Benzene,(1-methylethyl)-	I	5.00E+01	905 K	98-82-8	120	C_9H_{12}	1	5.00E+01	4.6e+01-4.6e+01
29	Ethanone,1-cyclopentyl-	I	1.00E+00	911	6004-60-0	112	$C_7H_{12}O$	1	1.00E+00	1.4e+00-1.4e+00
30	Unknown		6e+00 B	915	NA	NA		1	6.00E+00	6.0e+00-6.0e+00
31	5-Ethylcyclopentanone	I	2.00E+01	920	61215-75-6	112	$C_7H_{12}O$	1	2.00E+01	1.5e+01-1.5e+01
32	1H-Indene,3-methyl-	I	4.00E+00	926 K	767-60-2	130	$C_{10}H_{10}$	1	4.00E+00	4.0e+00-4.0e+00
33	Unknown		2e+00 B	930	NA	NA		1	2.00E+00	2.4e+00-2.4e+00
34	Benzene,propyl-		3.00E+01	935 K	103-65-1	120	C_9H_{12}	1	3.00E+01	3.4e+01-3.4e+01
35	3-HEXENE,2,2-DIMETHYL-	I	2.00E+01	939	NF	112	C_8H_{16}	1	2.00E+01	2.0e+01-2.0e+01
36	Pentanoicacid,4-methyl-	I	2.00E+01	944	646-07-1	116	$C_6H_{12}O_2$	1	2.00E+01	1.9e+01-1.9e+01
37	Unknown		1e+00 B	946	NA	NA		1	1.00E+00	9.8e-01-9.8e-01
38	2-Cyclopenten-1-one,3-methyl-	I	3.00E+01	949	2758-18-1	96	C_6H_8O	1	3.00E+01	2.8e+01-2.8e+01
39	2(3H)-Furanone,dihydro-4,4-dimet	I	1.00E+01	968	13861-97-7	114	$C_6H_{10}O_2$	1	1.00E+01	1.3e+01-1.3e+01
40	OrganicAcid	C	2e+00 B	972	NA	NA		1	2.00E+00	2.4e+00-2.4e+00
41	2,4-Hexadiene,3,4-dimethyl-,(E,	I	6.00E+00	976	2417-88-1	110	C_8H_{14}	1	6.00E+00	5.7e+00-5.7e+00
42	Unknown		1e+00 B	980	NA	NA		1	4.00E+00	8.3e-01-1.5e+00
43	Unknown		8e-01 B	984	NA	NA		1	4.00E+00	8.3e-01-1.5e+00
44	Unknown		2e+00 B	986	NA	NA		1	4.00E+00	8.3e-01-1.5e+00
45	1,3-Cyclopentanedione,2,4-dimeth	I	4.00E+00	995	34598-80-6	126	$C_7H_{10}O_2$	1	4.00E+00	4.1e+00-4.1e+00
46	Benzene,1,2,3-trimethyl-	I	2.00E+01	1004	526-73-8	120	C_9H_{12}	1	2.00E+01	2.4e+01-2.4e+01
47	Unknown		4e+00 B	1010	NA	NA		1	4.00E+00	3.6e+00-3.6e+00
48	1H-Indene,2,3-dihydro-	I	2.00E+02	1020	496-11-7	118	C_9H_{10}	1	2.00E+02	1.7e+02-1.7e+02

SCH 1385 SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\11 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

49	Unknown	5e+00 B	1036	NA	NA		1	5.00E+00	5.3e+00-5.3e+00
50	Hexanoicacid,4-methyl-	4.00E+00	1041	1561-11-1	130	C7H14O2	1	4.00E+00	3.5e+00-3.5e+00
51	Phenol,4-methyl-	2.00E+02	1051	106-44-5	108	C7H8O	1	2.00E+02	1.7e+02-1.7e+02
52	3-ETHYLCYCLOPENT-2-EN-1-ONE	1.00E+00	1061	NF	110	C7H10O	1	1.00E+00	1.4e+00-1.4e+00
53	Benzene,4-ethenyl-1,2-dimethyl-	2.00E+01	1065	27831-13-6	132	C10H12	1	2.00E+01	2.4e+01-2.4e+01
54	Benzene,(2-methyl-2-propenyl)-	2.00E+01	1070	3290-53-7	132	C10H12	1	2.00E+01	2.1e+01-2.1e+01
55	2-Cyclopenten-1-one,2,3,4-trimet	4.00E+00	1073	28790-86-5	124	C8H12O	1	4.00E+00	4.1e+00-4.1e+00
56	Unknown	5e+00 DB	1080	NA	NA		1	2.00E+01	5.3e+00-1.5e+01
57	Unknown	2e+01 DB	1085	NA	NA		1	2.00E+01	5.3e+00-1.5e+01
58	Benzene,1,2,3,4-tetramethyl-	2e+01 D	1097	488-23-3	134	C10H14	1	2.00E+01	1.5e+01-1.5e+01
59	Phenol,2-ethyl-	2e+01 D	1112	90-00-6	122	C8H10O	1	2.00E+01	2.2e+01-2.2e+01
60	1H-Indene,2,3-dihydro-5-methyl-	1e+01 D	1135	874-35-1	132	C10H12	1	1.00E+01	1.1e+01-1.1e+01
61	Phenol,3,4-dimethyl-	8e+01 D	1143	95-65-8	122	C8H10O	1	8.00E+01	7.5e+01-7.5e+01
62	Naphthalene,1,2,3,4-tetrahydro-	5e+00 D	1149	119-64-2	132	C10H12	1	5.00E+00	5.0e+00-5.0e+00
63	Unknown	4e+00 D	1159	NA	NA		1	4.00E+00	3.6e+00-3.6e+00
64	Unknown	8e+01 DB	1209	NA	NA		1	4.00E+00	3.6e+00-3.6e+00
65	Unknown	1e+01 DB	1213	NA	NA		1	1.00E+02	5.5e+00-8.2e+01
66	Ethanone,1-(1-cyclohexen-1-yl)-	1e+01 D	1219	932-66-1	124	C8H12O	1	1.00E+01	1.0e+01-1.0e+01
67	Unknown	6e+00 DB	1223	NA	NA		1	1.00E+02	5.5e+00-8.2e+01
68	Unknown	7e+01 D	1231	NA	NA		1	7.00E+01	6.7e+01-6.7e+01
69	CYCLOBUTENE,1,2,3,4-TETRAMETHYL-	3e+01 D	1245	3200-65-5	110	C8H14	1	3.00E+01	3.2e+01-3.2e+01
70	Phenol,2,4,6-trimethyl-	4e+01 D	1248	527-60-6	136	C9H12O	1	4.00E+01	4.2e+01-4.2e+01
71	Unknown	1e+02 D	1258	NA	NA		1	1.00E+02	2.7e+00-1.1e+02
72	Unknown	3e+00 D	1264	NA	NA		1	1.00E+02	2.7e+00-1.1e+02
73	Unknown	1e+01 D	1266	NA	NA		1	1.00E+02	2.7e+00-1.1e+02
74	Unknown	4e+01 DB	1277	NA	NA		1	5.00E+01	1.1e+01-3.9e+01
75	Unknown	1e+01 DB	1279	NA	NA		1	5.00E+01	1.1e+01-3.9e+01
76	Naphthalene,1-methyl-	1e+01 D	1282	90-12-0	142	C11H10	1	1.00E+01	1.1e+01-1.1e+01
77	Camphor	3e+01 D	1287	76-22-2	152	C10H16O	1	3.00E+01	3.4e+01-3.4e+01
78	endo-Borneol	2e+01 D	1292	507-70-0	154	C10H18O	1	2.00E+01	2.1e+01-2.1e+01
79	Naphthalene,2-methyl-	7e+01 D	1297	91-57-6	142	C11H10	1	7.00E+01	6.9e+01-6.9e+01
80	Unknown	3e+01 DB	1305	NA	NA		1	3.00E+01	2.8e+01-2.8e+01
81	2-Methyl-1-(methylamino)-1-cyanop	5.00E+01	1316	73171-64-9	110	C6H10N2	1	5.00E+01	4.8e+01-4.8e+01
82	Unknown	3e+01 B	1327	NA	NA		1	3.00E+01	2.8e+01-2.8e+01
83	m-Tolylaceticacid	2.00E+01	1340	621-36-3	150	C9H10O2	1	2.00E+01	1.6e+01-1.6e+01
84	Unknown	2e+01 B	1344	NA	NA		1	2.00E+01	2.1e+01-2.1e+01
85	3,5-OCTADIEN-2-ONE	2.00E+01	1352	30086-02-3	124	C8H12O	1	2.00E+01	2.1e+01-2.1e+01
86	METHYLENECYCLOOCTANE	5.00E+01	1357	3618-18-6	124	C9H16	1	5.00E+01	4.5e+01-4.5e+01
87	Unknown	2e+02 B	1367	NA	NA		1	2.00E+02	8.3e+00-1.6e+02
88	Unknown	8e+00 B	1377	NA	NA		1	2.00E+02	8.3e+00-1.6e+02
89	Unknown	3e+01 B	1384	NA	NA		1	3.00E+01	2.7e+01-2.7e+01
90	Naphthalene,2,6-dimethyl-	2.00E+01	1390	581-42-0	156	C12H12	1	2.00E+01	2.0e+01-2.0e+01
91	Naphthalene,1,5-dimethyl-	1.00E+01	1407	571-61-9	156	C12H12	1	1.00E+01	1.1e+01-1.1e+01
92	1H-Imidazole-4-ethanamine,1-meth	8.00E+00	1410	501-75-7	125	C6H11N3	1	8.00E+00	8.4e+00-8.4e+00
93	Unknown	2.00E+01	1423	NA	NA		1	2.00E+01	1.8e+01-1.8e+01
94	Benzene,1-ethyl-3,5-dimethyl-	8.00E+01	1440	934-74-7	134	C10H14	1	8.00E+01	8.2e+01-8.2e+01
95	Benzene,2-ethyl-1,4-dimethyl-	7.00E+01	1454	1758-88-9	134	C10H14	1	7.00E+01	7.4e+01-7.4e+01
96	Benzene,1-ethyl-2,4-dimethyl-	6.00E+01	1463	874-41-9	134	C10H14	1	6.00E+01	5.8e+01-5.8e+01
97	Unknown	4e+01 B	1502	NA	NA		1	4.00E+01	4.4e+01-4.4e+01
98	1-PROPANOL,3-(2,4,6-TRIMETHYLPHE	1.00E+02	1562	NF	178	C12H18O	1	1.00E+02	1.2e+02-1.2e+02
99	4-Methyl-5-(2,6-dimethylphenyl)-2	2.00E+01	1616	90454-77-6	190	C11H14N2	1	2.00E+01	2.2e+01-2.2e+01
100	1,4-Ethanonaphthalen-2-ol,1,2,3,	1.00E+02	1675	13153-78-1	174	C12H14O	1	1.00E+02	1.0e+02-1.0e+02
101	4-(1-CYCLOPENTENYL)PYRIDINE	7.00E+00	1683	56698-37-4	145	C10H11N	1	7.00E+00	6.8e+00-6.8e+00
102	Benzene,1-cyclopenten-1-yl-	2.00E+02	1710	825-54-7	144	C11H12	1	2.00E+02	1.6e+02-1.6e+02
103	4-METHYLCARBAZOLE	9.00E+00	1906	3770-48-7	181	C13H11N	1	9.00E+00	8.6e+00-8.6e+00
104	4-Methyl-2-(3-thienyl)pyridine	2.00E+01	1967	56421-81-9	175	C10H9NS	1	2.00E+01	2.2e+01-2.2e+01
105	Azepino[3,2,1-hi]indole, 8-ethyl-	1.00E+01	2091	18108-56-0	241	C17H23N	1	1.00E+01	1.0e+01-1.0e+01
106	Ametryn	7.00E+00	2184	834-12-8	227	C9H17N5S	1	7.00E+00	6.8e+00-6.8e+00
107	6(5H)-Phenanthridinone	1.00E+01	2254	1015-89-0	195	C13H9NO	1	1.00E+01	9.9e+00-9.9e+00
108	9-Octadecenamide,(Z)-	6.00E+01	2326	301-02-0	281	C18H35NO	1	6.00E+01	5.7e+01-5.7e+01

SCH 1385 SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\12 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 22

Dec 18 14:04 1996 LAB ID: 963310088x100.d Page 2

Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 23 *1/100 dilution, I believe (only dil done on this sample)*

SCHEDULE: 1385 TENTATIVELY IDENTIFIED COMPOUND SUMMARY REPORT FOR SITE: 96POF12

	COMPOUND NAME	**NAME FLAGS	CONC	RI	CAS #	MW	MOL	SITE: 96POF12........ HISTRY		
			(ug/l)	(KOVAT)			FORMULA	MQ	#	CONC RANGE
1	Cyclopentanone		9.60E+00	773	120-92-3	84	C5H8O	72	1	9.6e+00-9.6e+00
2	Benzene,ethyl-		1.70E+01	845	100-41-4	106	C8H10	95	1	1.7e+01-1.7e+01
3	Benzene,1,4-dimethyl-	I	3.10E+00	852	106-42-3	106	C8H10	27	1	3.1e+00-3.1e+00
4	Benzene,1-ethyl-2-methyl-	I	6.70E+00	905	611-14-3	120	C9H12	91	1	6.7e+00-6.7e+00
5	Benzene,propyl-		5.50E+00	935	103-65-1	120	C9H12	76	1	5.5e+00-5.5e+00
6	2-Cyclopenten-1-one,3-methyl-	I	3.40E+00	947	2758-18-1	96	C6H8O	80	1	3.4e+00-3.4e+00
7	1H-Indene,2,3-dihydro-	I	1.30E+01	1019	496-11-7	118	C9H10	91	1	1.3e+01-1.3e+01
8.	2-Pentene,4,4-dimethyl-	I	5.80E+00	1064	26232-98-4	98	C7H14	43	1	5.8e+00-5.8e+00
9	2,3-DIHYDRO-1-METHYLINDENE	I	5.70E+00	1070	27133-93-3	132	C10H12	81	1	5.7e+00-5.7e+00
10	Phenol,2,5-dimethyl-	I	1.80E+01	1124	95-87-4	122	C8H10O	94	1	1.8e+01-1.8e+01
11	Phenol,2,3-dimethyl-	I	5.00E+00	1143	526-75-0	122	C8H10O	91	1	5.0e+00-5.0e+00
12	Unknown		2.2e+01 B	1186	NA	NA		0	1	2.2e+01-2.2e+01
13	CYCLOBUTANE,ISOPROPYLIDEN-		1.80E+01	1208	NF	96	C7H12	40	1	1.8e+01-1.8e+01
14	Unknown		6.9e+01 B	1227	NA	NA		0	1	2.4e+01-4.5e+01
15	Unknown		1.40E+01	1264	NA	NA		0	1	1.4e+01-1.4e+01
16	Naphthalene,2-methyl-	I	6.70E+00	1281	91-57-6	142	C11H10	81	1	6.7e+00-6.7e+00
17	2,2-Dimethyl-3-methoxycyclopentan	I	1.60E+01	1299	84625-13-8	142	C8H14O2	46	1	1.6e+01-1.6e+01

Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 24

Total nontarget samples at the time of this report generation = 1 Total nontarget samples which were "clean" for site: 96POF12 = 0

SCH 1385 SEMI-VOLATILE RESULTS - POF1196 samples POF96ORG.XLS\13 2/18/97GA

EMAILED BY CENTRAL LAB 2/12/97 (see companion text 96POFORG.SAM)

Dec 18 14:03 1996 LAB ID: 963310087x100.d Page 2
Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 29

SCHEDULE: 1385 TENTATIVELY IDENTIFIED COMPOUND SUMMARY REPORT FOR SITE: 96POF13

Jan 27 17:25 1997 NWQL SCHEDULE: 1385 REPORT Page 30 *1/100 dilution, I believe (only dil done on this sample)*

	COMPOUND NAME	**NAME FLAGS	CONC (ug/l)	RI (KOVAT)	CAS #	MW	MOL FORMULA	SITE HISTORICAL DATA MQ	HIT	CONC RANGE
1	Cyclopentanone		5.70E+01	773	120-92-3	84	C5H8O	64	1	5.7e+01-5.7e+01
2	Cyclopentanone,3-methyl-	I	4.60E+01	830	1757-42-2	98	C6H10O	91	1	4.6e+01-4.6e+01
3	Cyclohexane,1,3,5-trimethyl-	I	1.30E+00	833	1839-63-0	126	C9H18	72	1	1.3e+00-1.3e+00
4	Pentanoicacid		1.60E+00	836	109-52-4	102	C5H10O2	42	1	1.6e+00-1.6e+00
5	Benzene,ethyl-		1.40E+01	844	100-41-4	106	C8H10	90	1	1.4e+01-1.4e+01
6	Cyclohexanone,3-methyl-,(R)-	I	4.10E+00	880	13368-65-5	112	C7H12O	64	1	4.1e+00-4.1e+00
7	Benzene,(1-methylethyl)-	I	1.70E+01	905	98-82-8	120	C9H12	91	1	1.7e+01-1.7e+01
8	5-Ethylcyclopentanone	I	8.60E+00	920	61215-75-6	112	C7H12O	47	1	8.6e+00-8.6e+00
9	Benzene,propyl-		2.20E+01	935	103-65-1	120	C9H12	90	1	2.2e+01-2.2e+01
10	3-Heptene,3-methyl-	I	9.40E+00	939	7300-03-0	112	C8H16	64	1	9.4e+00-9.4e+00
11	2-Cyclopenten-1-one,3-methyl-	I	2.60E+01	947	2758-18-1	96	C6H8O	91	1	2.6e+01-2.6e+01
12	2,4-Hexadiene,3,4-dimethyl-,(Z,	I	6.10E+00	974	21293-01-6	110	C8H14	87	1	6.1e+00-6.1e+00
13	2,4-Hexadiene,2,5-dimethyl-	I	1.30E+01	1002	764-13-6	110	C8H14	83	1	1.3e+01-1.3e+01
14	2,3-Dimethylcyclopent-2-en-1-one	I	8.00E+01	1020	NF	110	C7H10O	83	1	8.0e+01-8.0e+01
15	Phenol,3-methyl-	I	8.20E+01	1052	108-39-4	108	C7H8O	96	1	8.2e+01-8.2e+01
16	1H-Indene,2,3-dihydro-2-methyl-	I	9.20E+00	1064	824-63-5	132	C10H12	89	1	9.2e+00-9.2e+00
17	2-Cyclopenten-1-one,2,3,4-trimet	I	3.80E+01	1070	28790-86-5	124	C8H12O	84	1	3.8e+01-3.8e+01
18	Phenol,2,3-dimethyl-	I	9.60E+00	1113	526-75-0	122	C8H10O	47	1	9.6e+00-9.6e+00
19	Benzene,(2-methyl-1-propenyl)-	I	5.40E+00	1135	768-49-0	132	C10H12	58	1	5.4e+00-5.4e+00
20	Phenol,3-ethyl-	I	1.90E+01	1143	620-17-7	122	C8H10O	87	1	1.9e+01-1.9e+01
21	Phenol,2,5-dimethyl-	I	1.70E+01	1154	95-87-4	122	C8H10O	97	1	1.7e+01-1.7e+01
22	SubstitutedPhenol	C	7.40E+01	1247	NA	NA		0	1	7.4e+01-7.4e+01
23	Unknown		1.40E+01	1255	NA	NA		0	1	1.4e+01-1.4e+01
24	2,3-Pyrazinedione,1,4-dihydro-6-	I	3.90E+01	1339	61481-37-6	156	C6H8N2O3	47	1	3.9e+01-3.9e+01
25	Unknown		1.50E+01	1362	NA	NA		0	1	1.5e+01-1.5e+01
26	Naphthalene,2,7-dimethyl-	I	1.20E+01	1390	582-16-1	156	C12H12	90	1	1.2e+01-1.2e+01
27	Naphthalene,1,8-dimethyl-	I	1.90E+01	1405	569-41-5	156	C12H12	83	1	1.9e+01-1.9e+01
28	Naphthalene,1,2-dimethyl-	I	2.60E+01	1443	573-98-8	156	C12H12	70	1	2.6e+01-2.6e+01
29	1H-Indole-2,3-dione,5-methyl-	I	1.40E+01	1638	608-05-9	161	C9H7NO2	38	1	1.4e+01-1.4e+01
30	3-METHOXY-4,7-DIMETHYL-1H-ISOINDO	I	1.90E+01	1685	NF	175	C11H13NO	53	1	1.9e+01-1.9e+01
31	9H-Fluorene,9-methyl-	I	5.20E+00	1695	2523-37-7	180	C14H12	68	1	5.2e+00-5.2e+00
32	Aceticacid,trifluoro-,esterwi		1.30E+01	1828	31083-17-7	232	C10H7F3O3	53	1	1.3e+01-1.3e+01
33	10-Methylbenz[a]azulene	I	6.50E+00	1893	78926-60-0	192	C15H12	53	1	6.5e+00-6.5e+00
34	Azepino[3,2,1-hi]indole,8-ethyl-	I	5.20E+00	2072	18108-56-0	241	C17H23N	38	1	5.2e+00-5.2e+00

PLACERITA OIL FIELD 11/96 ORG CL DATA POF1196.XLS\vol 2/14/97GA

YKK, Jim Walker, Mark Huebner

CENTRAL LAB VOLATILES SCH 1392 DATA (ug/L): (samples corrected for 1/20 analytical dilution)

SAMPLE	Benzene	Toluene	Ethyl- benzene	(total) Xylenes	Isopropyl benzene	N-Propyl benzene	sec-Butyl benzene	1,2,3- Trimethyl benzene	1,2,3,5- Tetramethyl benzene	1090 C_9H_{10} Benzene, propenyl-	1096 $C_{10}H_{14}$ C4- Benzene
96POF-11	11.3	5.2	65.4	40.5	42.0	22.1	5.6	12.3	3		3
96POF-12	<4	<4	10.3	<4	4.5	3.2	<4			6	
96POF-13	<4	<4	6.8	<4	12.6	7.1	2.1				

SAMPLE	1170 $C_{10}H_{14}$ C4- Benzene	1137 $C_{10}H_{12}$ Benzene, methyl- (propenyl)-	1137 $C_{10}H_{12}$ Benzene, ethenyl- dimethyl-	1196 $C_{10}H_{12}$ Benzene, ethenyl- dimethyl-	560 C_3H_8O Isopropyl alcohol	Acetone	2- butanone	741 $C_5H_{10}O$ Pentanone	861 C_5H_8O Cyclo- pentanone
96POF-11		20		3	2	1040	325	3	2
96POF-12						74.5			
96POF-13	2		4			323	177		

SAMPLE	Naph- thalene	1180 $C_{11}H_{14}$ Naphthal- ene,tetra- hydro-1	1192 $C_{11}H_{14}$ Naphthal- ene,tetra- hydro-1	1229 $C_{10}H_{12}$ Naphthal- ene,tetra- hydro	1389 $C_{11}H_{10}$ C1-Naph- thalene	1090 C_9H_{10} Indane	1142 $C_{10}H_{12}$ Indan, methyl	1143 $C_{10}H_{12}$ Dihydro- methyl- indene
96POF-11	E150	2	2	9	4		30	
96POF-12	E10							4
96POF-13	E25.3					10	8	

SAMPLE	Chloro- ethane	480 C_5H_{12} C5 Alkane	565 C_6H_{14} C6 Alkane	672 C_6H_{12} Cyclo- hexane	732 C_8H_{16} C3-Cyclo- pentane	748 C_8H_{16} C3-Cyclo- pentane	812 C_8H_{16} C2-Cyclo- hexane	891 C_8H_{14} C8- Alkene	1089 C_9H_{10} C_9H_{10} Hydro- carbon	1080 $C_6H_{16}Si_2$ C2-Disil- acyclo- butane,te
96POF-11	2.3	3	3	6	9	6	3	3	80	2
96POF-12	2.1				2					
96POF-13	<4	7	6		2					

SAMPLE	704 C_4H_4S Thiophene	808 C_5H_6S Thiophene methyl-	819 C_5H_6S Thiophene methyl-	919 C_6H_8S Thiophene, ethyl	952 C_6H_8S Thiophene, dimethyl	1026 $C_7H_{10}S$ Thiophene, trimethyl	1065 $C_7H_{10}S$ Ethyl- methyl thiophene
96POF-11	10	3	4	4	4	2	3
96POF-12							
96POF-13			2				

Appendix C

Technology Transfer Activities

APPENDIX C

TECHNOLOGY TRANSFER ACTIVITY

This appendix contains copies of the presentations or proceedings of the five formal technology transfer activities. These activities were part of Tasks 10A and 10B and are summarized below. The information is organized by title, sponsoring organization, conference title, location, and date. The technology transfer activities were done for 3 meetings each for the two major audiences that would likely use a similar project approach, the water industry and the oil industry. It is anticipated that a final presentation would be done to the oil industry at the 1998 SPE meeting at no cost to the project.

Task 10A: Technology Transfer, Phase I Activities

1) Converting Produced Water to a New Water Resource
Department of Energy
Contractor s Review Meeting
Houston, Texas
June 19, 1997

2) Developing a New Water Resource from Oil Field Produced Water
AWWA Sponsored Specialty Conference
Water Resources 97,
Seattle, Washington
August 10-13, 1997

3) Evaluation of Technologies to Treat Oil Field Produced Water to Drinking Water or Reuse Quality
Society of Petroleum Engineers
1997 Annual Conference
San Antonio, TX
October 6-8, 1997

4) Simultaneous Removal of Silica and Boron from Produced Water by Chemical Precipitation
Engineer s Society of Western Pennsylvania
1997 International Water Conference,
Pittsburgh, PA
November 3-5, 1997

Task 10B: Technology Transfer, Phase II Activities

1) Developing a Cost Effective Environmental Solution for Produced Water and Creating a New Water Resource
South-central Environmental Resource Alliance, University of Tulsa, and DOE
Fourth Annual International Petroleum Environmental Conference
San Antonio, TX
September 9-12, 1997

2) Treating Oil Field Produced Water to Drinking Water Standards: Pilot-scale Process Evaluation
American Water Works Association
Water Quality Technology Conference,
Denver CO,
November 7-11, 1997

CONVERTING PRODUCED WATER TO A NEW WATER RESOURCE

CONTRACTOR REVIEW MEETING
19 JUNE 1997
HOUSTON, TX

Glenn F. Doran
ARCO Western Energy
4550 California Avenue
Bakersfield, CA 93309

Lawrence Y.C. Leong
Kennedy/Jenks Consultants
2151 Michelson Drive, Ste 100
Irvine, CA 92612

Objectives

Convert Produced Water to a Water Resource

  Meet Regulatory Requirements

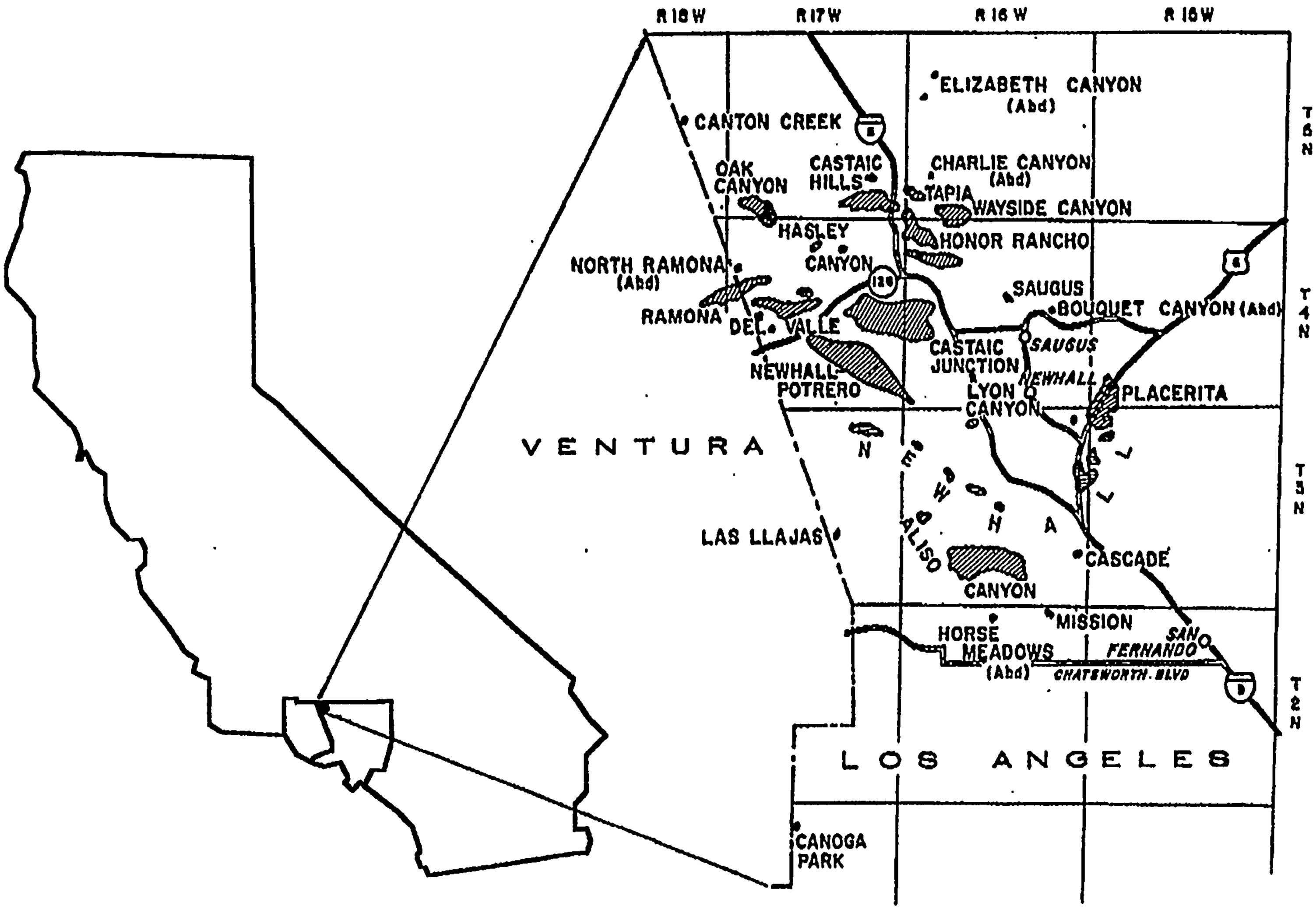
  Cost Competitive

Build a Full Scale Plant

State Wide Institutional Approvals

- California Department of Health Services
- Regional Water Quality Control Board

Coastal Basin - Placerita



Project Tasks

- Phase I - Select Process Train
  - Literature Review
  - Bench Testing to Optimize Target Processes
- Phase II - Pilot Study
  - Pilot Plant Work Plan
  - Pilot Study
  - Final Report

Project Funding

Department of Energy
ARCO Western Energy
Kennedy/Jenks Consultants
Southern California Edison
Electric Power Research Institute, Chemicals and Petroleum Office
Castaic Lake Water Agency
National Water Research Institute

Technical Benefits

Improve Thermal Recovery Efficiencies

Lower Produced Water Handling Costs

Reduce Water Recirculation

Reduce Potential for Reservoir Damage

Recovery More Oil in Place

Social Benefit

New Water Resource

Reduce Produced Water Disposal Volume

Minimize Chemical Usage

Local Produced Water Flows

Los Angeles - 64 MGD

Coastal - 27 MGD

Kern County - 129 MGD

Water Resource Alternatives

Potable Water

Tradable Potable Water Equivalent

Reclaimed Water

Status of Deliverables

- Completed Deliverables
  - Phase I Topical Report - Lit Review
  - Phase I Tech Transfer in Progress
- Future Deliverables
  - Phase II Final Report
  - Phase II Tech Transfer in Progress

Literature Review

- Treatment Alternatives
  - Evaporative - Mechanical Vapor Compression (MVC)
  - Membrane - Reverse Osmosis (RO)
- Treatment Cost
- Water Quality Issues

Parameters of Concern

TDS	~6,000 mg/L
Temperature	150-175 F
Borate	~60 mg/L
Ammonia	~13 mg/L
Sulfide	~10 mg/L
Iron	1-5 mg/L
Organics	100 - 200mg/L

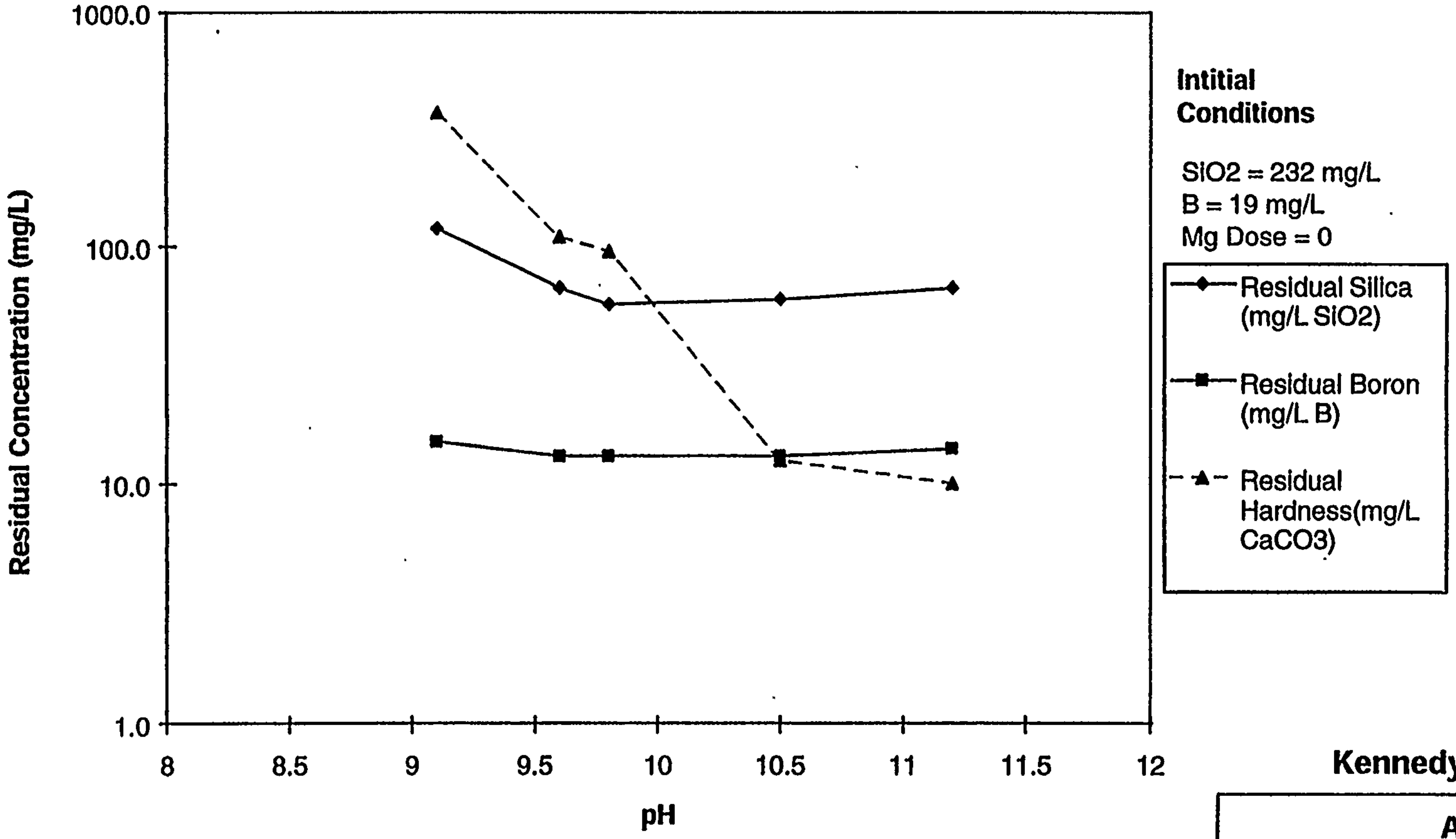
Bench Scale Warm Softening

Boron

Silica

Hardness

Organics



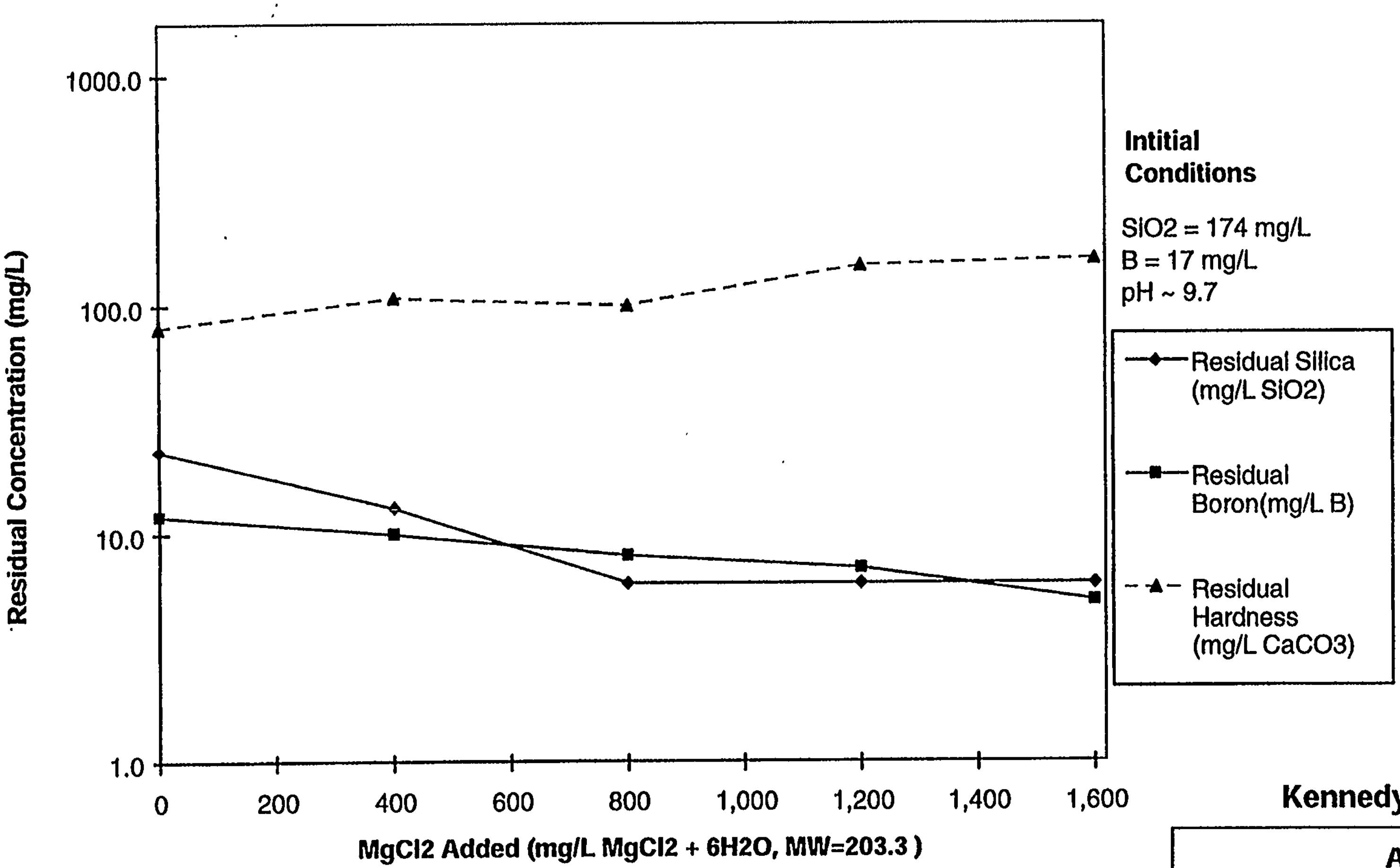
Kennedy/Jenks Consultants

ARCO Western Energy
DOE Project # DE-FC22-95MT95008

Results of Bench Tests with Caustic Soda Addition

January 1997
K/J 964634.00

Figure 4-1



Kennedy/Jenks Consultants

ARCO Western Energy
DOE Project # DE-FC22-95MT95008

Results of Bench Tests with Various Dosages of $MgCl_2$ Added

January 1997
K/J 964634.00

Figure 4-3

Cost Issues

- Capital and O & M Costs
- Context
  - Competitive with Water Rates
  - Competitive with Disposal Costs

Disposal/Treatment Costs

$0.10 per Barrel for Injection

$0.06 per Barrel for State Project Water (SPW) for Castaic Lake Water Agency

Incremental Cost for New Water Supply

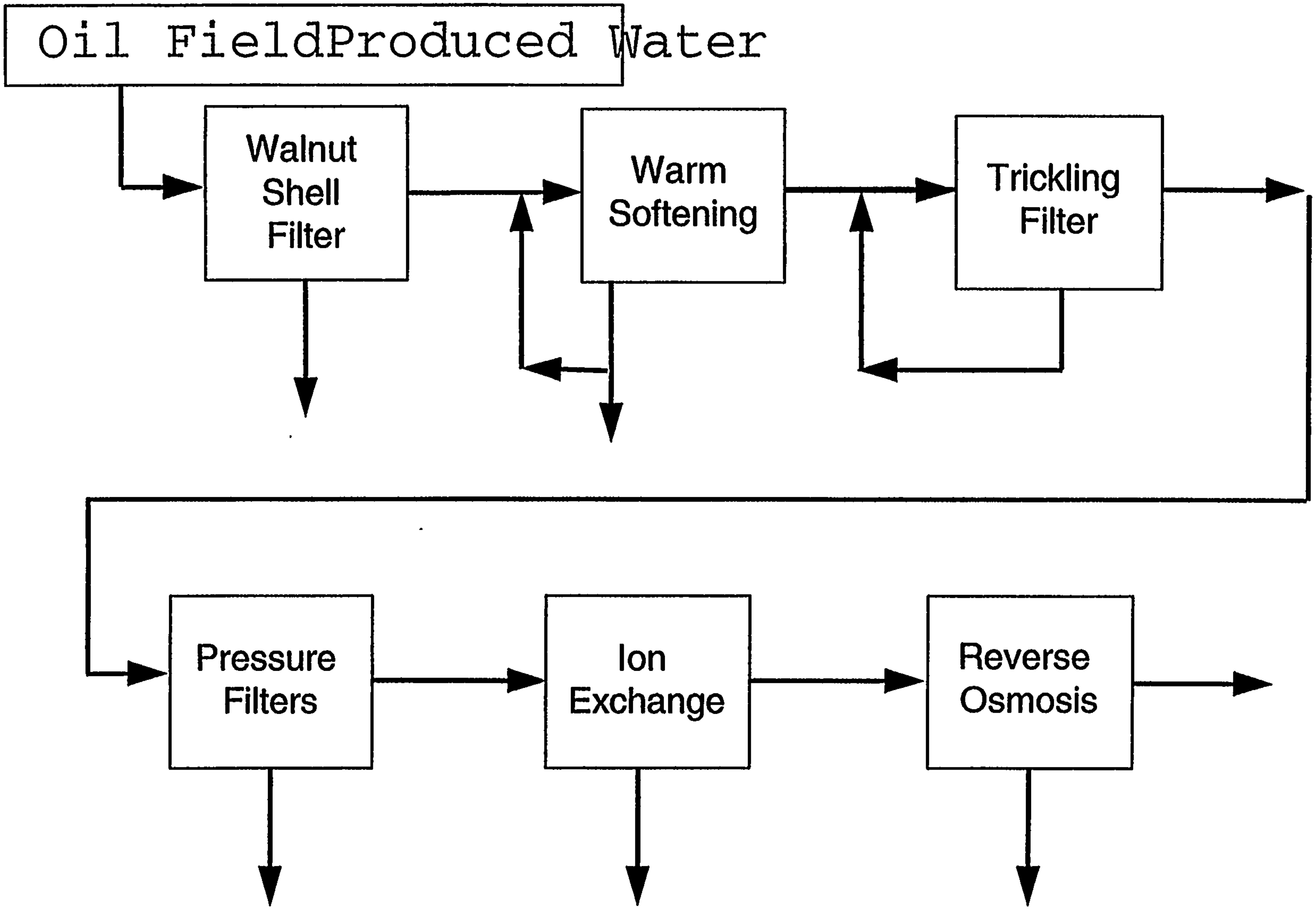
Est. Cost-43,000 BPD Plant

Technology	Percent Recovery	Capital, $M	O & M, $M/Yr	Cents/ Treated Barrel
RO w/ pretreatment	80	11	2.1-2.9	15-21
MVC w/ pretreatment	90	29	6.1	43
MVC, Seeded Slurry	98	28	7.7	54

RO System Est. Costs

Process	**Capital, $M**	**O & M, $K/Yr**	**Cents/ Barrel**
Warm Softening	2.3	1,000-1,800	7-13
Cooling	0.6	60	0.4
Fixed Film Organics Removal	1.0	50	0.4
Filtration	1.3	130	0.9
Ion Exchange Softening	1.3	150	1
RO	4.1	600	4
pH/Disinfection	0.2	60	0.4
Total	11	2,100-2,900	15-21

Pilot Treatment Deliverable



Oil FieldProduced Water

Walnut Shell Filter

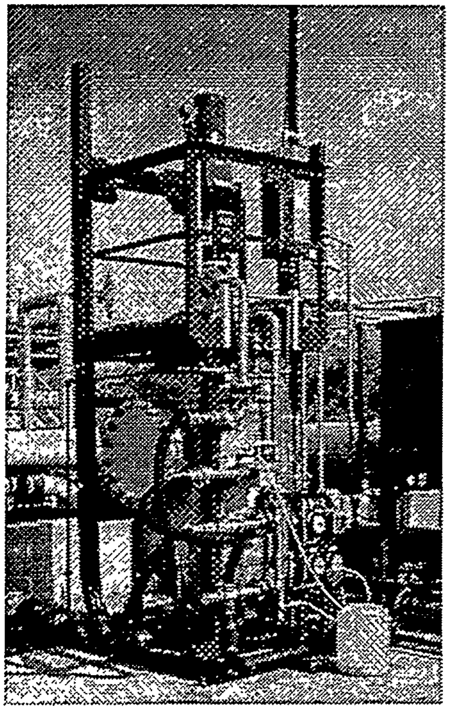
Warm Softening

Trickling Filter

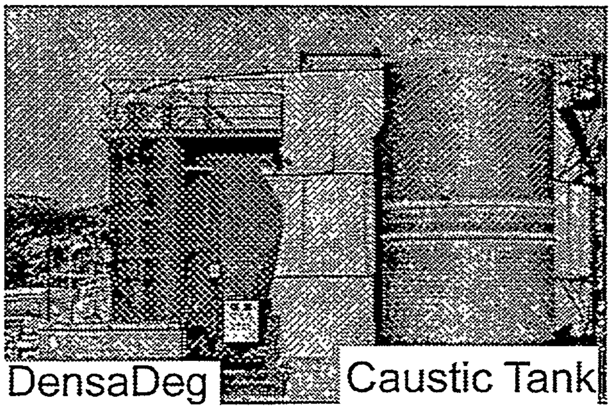
Pressure Filters

Ion Exchange

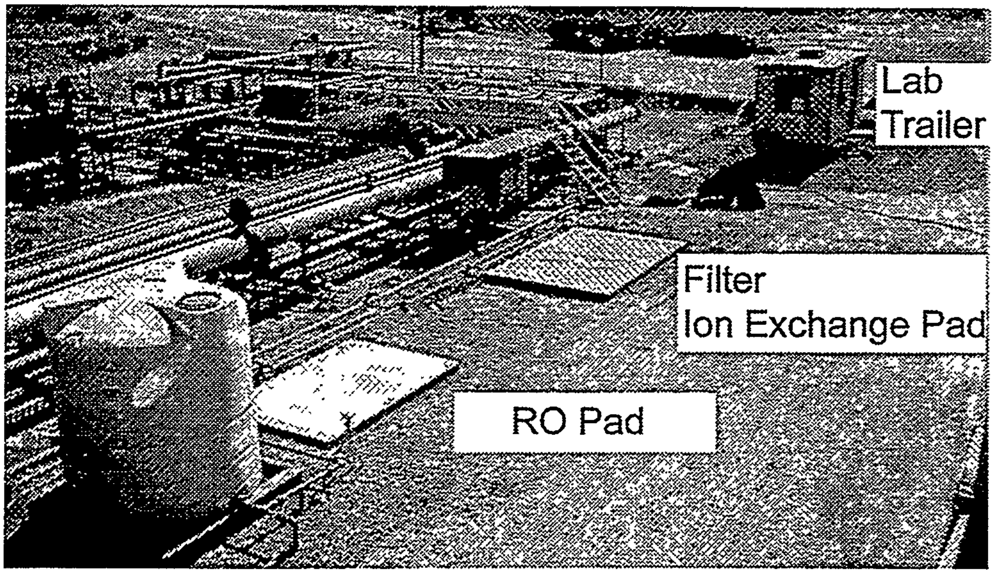
Reverse Osmosis



Walnut Shell Filter



DensaDeg
Caustic Tank


Lab
Trailer
Filter
Ion Exchange Pad
RO Pad

Tech Transfer Deliverables

Phase	Sponsor	Conference	Date
1	SPE	72nd Annual	10/97
1	Eng Soc of W. Penn	Int l Water	11/97
1	Am Water Works Assn	Water Resources	8/97
2	Am Water Works Assn	Water Quality Technology	11/97
2	U of Tulsa	4th Int l Environmental	9/97

Uncertainties

- Institutional State Wide Approval
- Technical Performance
  - Organics Removal
  - Boron Removal
  - Membrane fouling
- O & M Costs
  - Warm Softening Pretreatment
  - Membrane Life

Conclusions

Project on Budget and Schedule

Technical Proof of Concept is Challenging

Institutional Acceptance is Uncertain

Costs Are Promising - Need Optimization

DEVELOPING A NEW WATER RESOURCE FROM OILFIELD PRODUCED WATER

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Presented at
Water Resources '97
AWWA Sponsored Specialty Conference
Seattle, Washington
August 10-13, 1997

DEVELOPING A NEW WATER RESOURCE FROM OILFIELD PRODUCED WATER

ABSTRACT

This paper discusses the opportunities and challenges associated with converting an "unusable by-product" of hydrocarbon production into a valuable water resource while remaining competitive with new water resources. The paper analyzes the quantity and quality of California oil field produced water in relation to the location and needs of potential users, including residential, industrial, and agricultural, and evaluates the economics of treating produced water for direct or indirect a variety of water uses, including potable use.(direct or indirect), industrial, and agricultural.

BACKGROUND

Oil production generates a significant by-product, commonly known as "produced water". As the oil is produced from an oil field, produced water can reach > 90 percent or more of the fluids pumped from an oil well. In fact, heavy oil fields in California produce 10 to 15 barrels (420 to 630 gallons) of water for every barrel of oil. In 1993 approximately 25.3 billion barrels, or 3.6 million acre-feet of produced water were generated through hydrocarbon production in the US, including production within the three mile coastal water limits. This represents a significant potential reclaimed water source in water short areas such as California. However, the feasibility of water reclamation is highly dependent on the chemical composition of the produced water, which is typically highly saline. The salinity can range from about 3,000 to more than 350,000 mg/l total dissolved solids (TDS), with sodium and chloride generally comprising 70 - 90 percent of the ions and concentrations of calcium, iron, manganese, boron, and dissolved organics generally high (Kharaka et al 1995).

Current Disposal Practices and Beneficial Use Opportunities

The most prevalent method of handling oil field produced water is through underground injection, often at pressures exceeding 1,000 pounds per square inch (psi). Over 65 percent of the produced water from onshore sources is currently reinjected into producing zones for enhanced oil recovery (water and steam flooding and subsidence control) and another 30 percent is injected into deep wells. The Clean Water Act only allows on-shore surface discharge west of the 98th Meridian (a north-south line approximately running just west of Minnesota and through Dallas, Texas) if the produced water is of acceptable quality for beneficial uses such as stream flow augmentation. Other potential beneficial uses of produced water include water source for cogeneration or cooling, agricultural irrigation, drinking water supply, and groundwater recharge.

Available Produced Water Resources in California

The California Division of Oil, Gas, and Geothermal Resources (DOGGR 1996) reports that about 250,000 acre-feet (acre-ft) of produced water were generated from oil and gas production in 1995. Table 1 summarizes the distribution of produced water for counties generating over 1 million barrels (130 acre-ft) of produced water annually. About 50 percent of this produced water is likely to be unavailable due to offshore or reservoir reinjection and subsidence control or high salinity. Thus, over 100,000 acre-ft are potentially available to augment water supplies.

As Figure 1 illustrates, the produced water occurs primarily in 10 counties that are congregated along the southern and central coast and lower central valley areas of California, where there is significant interest in water reclamation. In fact, estimates indicate that by the year 2010 California's need for water will outstrip its delivery system (Water Reuse 1993). The updated California Water Plan (DWR 1994) estimates that by the year 2020 annual reductions in total water supply for urban and agricultural uses could be in the range of 500,000 acre-ft to 1 million acre-ft in average years and 2 to 3 million acre-ft in drought years. Accordingly, wastewater, including produced water, is beginning to be considered as a viable water resource. In the Water Recycling Act of 1991, the California legislature declared that reclaimed water is a valuable resource and encouraged its use in all appropriate applications.

DOGGR records from injection projects indicate that in the top ten producing counties, the majority of oil fields produce water with total dissolved solids (TDS) concentrations between 15,000 and 35,000 mg/l. A number of large fields in these counties produce water with TDS levels below 10,000 mg/L, including Midway-Sunset, Kern River, Placerita, and Oak Ridge. The produced water from these lower salinity fields would be more amenable to treatments that are competitive with other new sources of water.

Demonstration project

The authors have recently begun work on a project to demonstrate the feasibility of treating produced water to various water quality criteria. To accomplish the project goal, the project team plans to operate a pilot plant to treat oil field produced water to current and anticipated California potable and reuse criteria water standards. This project will attempt to obtain California Department of Health Services (DHS) approval of the proof of concept process train similar to the wastewater reclamation reuse regulations in California's Title 22 that were developed around the Pomona Virus Study. This project approach will significantly reduce the additional work required for other California projects. If the project obtains DHS approval, a 1.4 mgd treatment plant may be built in Santa Clarita, California.

Project Participants

Several entities with diverse interests are contributing funds to this project. They include the U.S. Department of Energy, ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company, Castaic Lake Water Agency, Electric Power Research Institute Chemicals and Petroleum Office, Southern California Edison, the National Water Research Institute and Kennedy/Jenks Consultants.

WATER QUALITY CHALLENGES

The ARCO Western Energy Placerita oilfield operations yield 50,000 barrels of produced water per day (2.1 mgd or 2,350 acre-ft annually) with 3,500 barrels of heavy oil per day. The produced water is characterized by high temperature, and moderate to high concentrations of total dissolved solids (TDS), ammonia, total hardness, boron, and total organic chemicals (TOC). Table 2 provides a summary of key water quality parameters for the Placerita produced water characteristics of the .

Water Quality Goals and Treatment Technology Selection

Produced water requires treatment for a number of constituents depending on the intended use. Because the produced water is delivered around 1660(F, pathogenic microorganisms are not of concern as with most wastewaters. However, the water temperature must be controlled for some of the processes to be effective. For example, warm precipitative softening, air stripping, and vapor compression desalination can be accomplished at the produced water temperature, while the other processes considered generally perform better at cooler temperatures.

Table 2 summarizes the key water quality goals to be met through treatment for this project. The major water quality concerns are the removal of dissolved salts (4,000 - 6,000 mg/l TDS), ammonia (>10 mg/l - N), boron ((18 mg/l B), and organics (oil and grease up to 50 mg/l, TOC up to ~ 100+). The concentrations of silica (~150 - 200+ mg/l $SiO2$) and hardness (600 - 1,500 mg/L) presents well-known problems as potential foulants for TDS removal technologies. In addition, confirmation that residual TOC does not present a disinfection by-product formation issue is necessary to met future drinking water regulations.

Dissolved Salt Removal

TDS of produced water must be reduced to below 500 mg/l for potable use. Treatment technologies to remove dissolved salt from water include thermal distillation and membrane processes. The most promising treatment technologies considered for removing dissolved salts from produced water are distillation by mechanical vapor compression (MVC) and membrane separation by reverse osmosis (RO). Within the desalination industry, membrane technologies such as RO are generally the technology of choice for brackish water applications.

Both of these proven technologies are capable of removing a large fraction (but not all) of organics and boron under certain pH conditions. Thus, supplemental TOC removal will likely be required. Silica removal, generally achieved by precipitative softening, is required for both processes, although some MVC systems incorporate silica removal as part of the main process, using a seeded silica slurry.

Organics

The TOC goal is in the 1 - 2 mg/l range to satisfy future drinking water regulations and potential California DHS concerns. The removal of organics will be a major challenge because produced water from heavy oil fields are high in low molecular weight aromatic compounds and naphthenic acids. Both fixed-film biological oxidation and granular activated carbon (GAC) are candidate processes for organics removal. Because many of these organics are refractory, pilot tests are necessary to determine the efficacy of these processes.

Silica Removal

Although there is no silica drinking water standard, low silica concentrations are desirable for steam production and other industrial uses, and a project goal of 30 mg/l has been set. Silica removal can be accomplished by precipitative softening. For the Placerita produced water, bench tests have indicated this can be most effectively achieved under warm (150 to 170 (F) conditions at a pH of 9.6 to 10.0, by adding magnesium and sodium hydroxide. Silica can also be removed by anion exchange.

Hardness Removal

Moderate hardness in the range of 80 - 120 mg/l is generally desirable for drinking water, but lower levels may be needed to control scaling in the desalination process. Total hardness, including calcium and magnesium can also be removed concurrently with silica in the warm softening process. In addition, residual hardness remaining in the softened water can be removed by cation exchange. This is important if salinity removal is carried out at high pH.

Ammonia Removal

Ammonia levels needs to be controlled below 1 mg/l to preclude a number of operational problems including increased corrosion in copper and copper alloys, additional chlorine demand, and increased biological activity in potable distribution systems that can lead to nitrification and enhanced biofilm formation. Some of the ammonia may be removed in the biological oxidation process and perhaps the RO process, but the remainder will have to be removed by air stripping. This may be accomplished in the cooling process or in separate strippers at high pH.

Boron Removal

Boron removal is particular important for water used for irrigation (typical goals of 0.5 - 0.7 mg/l), and a project treatment goal of 1 - 2 mg/l is being evaluated. A large portion of the boron can be removed concurrently with silica in the warm softening process if sufficient magnesium is added. Boron can also be removed by RO at high pH or by ion exchange using special anion exchange resins.

Brine and Sludge Management

The production of sludge in the precipitative softening process and brine in the desalination processes may be significant issues in operating the treatment processes. The recovery, or level of concentration in the brine, in part determines the amount of pretreatment necessary to prevent fouling of inorganic constituents, as well as the volume of the waste brine. The composition of the sludge will be important in determining whether the residuals have to be managed as a non hazardous waste. The volumes and compositions of the sludge and brine wastes are must be confirmed by pilot studies.

Pilot Plant Study

The project team is currently performing a pilot plant study to further confirm the ability of selected technologies to treat produced water. The pilot plant consists of warm (1540 - 170 F) precipitative softening, cooling, fixed film biological oxidation (optional), filtration, cation exchange softening, and high -pH reverse osmosis. Figure 2 presents a schematic of the pilot plant treatment train. This study will be completed in the second half of 1997.

COSTS OF TREATED PRODUCED WATER

Preliminary planing level costs (accuracy of approximately -30 to +50 percent) were prepared for 1.8 mgd RO and MVCP systems for the Placerita produced water source addressed in this project (Doran and Leong 1997). Costs were compared on the basis of total capital costs (including direct construction "bid" cost plus 38 percent of "bid" cost for indirect capital costs), annual operations and maintenance (O&M) costs, and total annual costs (annual O&M plus amortized capital costs, using 7 percent interest rate and 20 year project life typical of municipal projects). Table 2 presents the costs comparison for RO with pretreatment, MVC with pretreatment, and MVC with a seeded slurry. This comparison indicates that the RO process has capital and annual costs that are approximately half those of the MVC systems. Therefore, the RO based system was selected for further study.

For the RO process train, the preliminary cost estimate indicate the cost (in 1996 dollars) is between $2,000 and $2,500 per acre-ft for a 1.8 mgd treatment plant operating at capacity. This compares with estimates of $500 ???? per acre-ft for developing new brackish (~1,000 mg/l TDS) groundwater water sources in California in a non-adjudicated basin (Kennedy/Jenks 1997). In adjudicated groundwater basins the cost of developing a new groundwater source could be much higher.. As a point of reference, the wholesale price of treated water from the Metropolitan Water District in southern California was $406 per acre-ft for fiscal year 1995-96 (Metropolitan Water District 1996); however, these costs are expected to rise in the future.

Table 4 provides a breakdown of the costs for the RO treatment train by process. Inspection of this table makes it is obvious that the warm softening process (39 to 51 percent) and the RO (26 to 32 percent) processes are the most expensive parts of the total treatment costs. The pilot study will investigate ways that these costs might be reduced, such as using less chemicals and producing less sludge in the warm precipitative softening process.

CONCLUSIONS

If this project is successful, it will benefit water utilities located near an oil field that need additional water resources, oil companies that currently dispose of produced water through costly underground injection, and water users in general that will benefit from having a new, drought-resistant water supply.

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Table 1
Oil, Gas, and Produced Water Quantities in California for 1995

County Name	Oil Production (bbl)*	Nat. Gas Production (Mcf)†	Water Production (bbl)	Water Production (acre-ft)
Kern	207,606,727	105,424,313	1,085,398,711	139,880
Los Angeles	34,012,835	11,673,343	502,995,438	64,823
Fresno	10,409,518	27,699,375	95,146,538	12,262
Santa Barbara	4,723,804	3,033,534	76,597,412	9,823
Orange	6,729,990	3,225,742	74,886,944	9,651
Monterey	4,336,275	220,618	61,275,558	7,897
Ventura	10,163,569	10,796,438	50,726,087	6,537
San Luis Obispo	639,829	119,807	4,827,874	622
Tulare	30,638	31,976	2,576,648	332
Kings	175,409	939,086	1,090,505	140
Others	69,988	76,675,170	2,252,279	290
State Totals	278,898,582	239,839,402	1,957,773,994	252,305

Source: California Div. Oil, Gas, & Geothermal Resources 1996
*bbl = barrel = 42 gallons
Mcf = millions of standard cubic feet of gas
acre-ft = 325,900 gallons = 7760 barrels

Table 2
Typical Placerita Produced Water Quality and Treatment Goals

Water quality parameter	Typical produced water value	Treatment goal
Temperature (° F)	170	75
pH (s.u.)	7.0	6.5 - 8.5
Ammonia (mg/l-N)	15	<1.0
Total organic carbon (mg/l)	120	1-2
Total hardness (mg/l as $CaCO_3$)	1,500	70
Total dissolved solids (mg/l)	6,000	350
Silica (mg/l)	200^+	20 - 40
Boron (mg/l - B)	20	0.5 - 2.0

Table 3
Comparison of Planning Level Cost Estimates for 1.8 MGD Reverse Osmosis and Vapor Compression Systems

Evaluation Parameter	Reverse Osmosis, with pretreatment	Mechanical Vapor Compression, with pretreatment	Mechanical Vapor Compression, Seeded Slurry
Treated water recovery (percent)	80%	90%	98%
Total capital costs (Millions of 1996 dollars)	$115	$1,029	$1,528
Annual Operating Costs (millions of 1996 dollars)	$2.1 - $2.9	$6.1	$6.5 - $7.7
Total annual costs (millions of 1996 dollars)	$3.1 - $3.9	$8.8	$10.3
Total unit cost (dollars/acre-ft)	$2,000 - $2,500	$5,800	$5,400

Table 4
Cost Breakdown for Reverse Osmosis Alternative

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Cost (Thousand 1996 $)	Total Unit Cost (1996 $/AF of water produced)
Warm Softening*	2.3	1,000 - 1,800	1,200 -2,000	800 - 1,300
Cooling	0.6	60	120	75
Fixed-Film Organics Removal	1.0	50	150	100
Sand Filtration	1.3	130	250	150
Ion Exchange Softening	1.3	150	280	160
Reverse Osmosis	4.1	600	1,000	700
Stabilization	0.1	20	30	20
Disinfection	0.1	40	50	30
Total	11	2,100 - 2,900	3,100 - 3,900	2,000 - 2,500

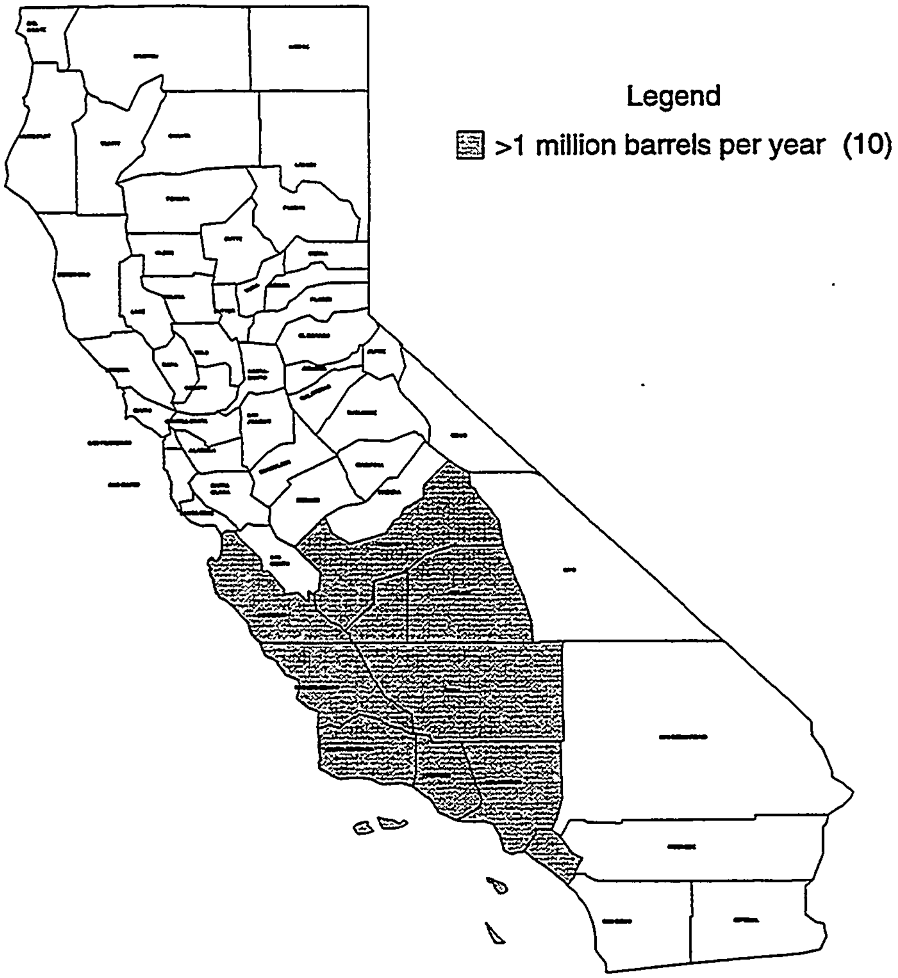

Figure 1
Counties with Greater than 1 Million Barrels Per Year of Produced Water

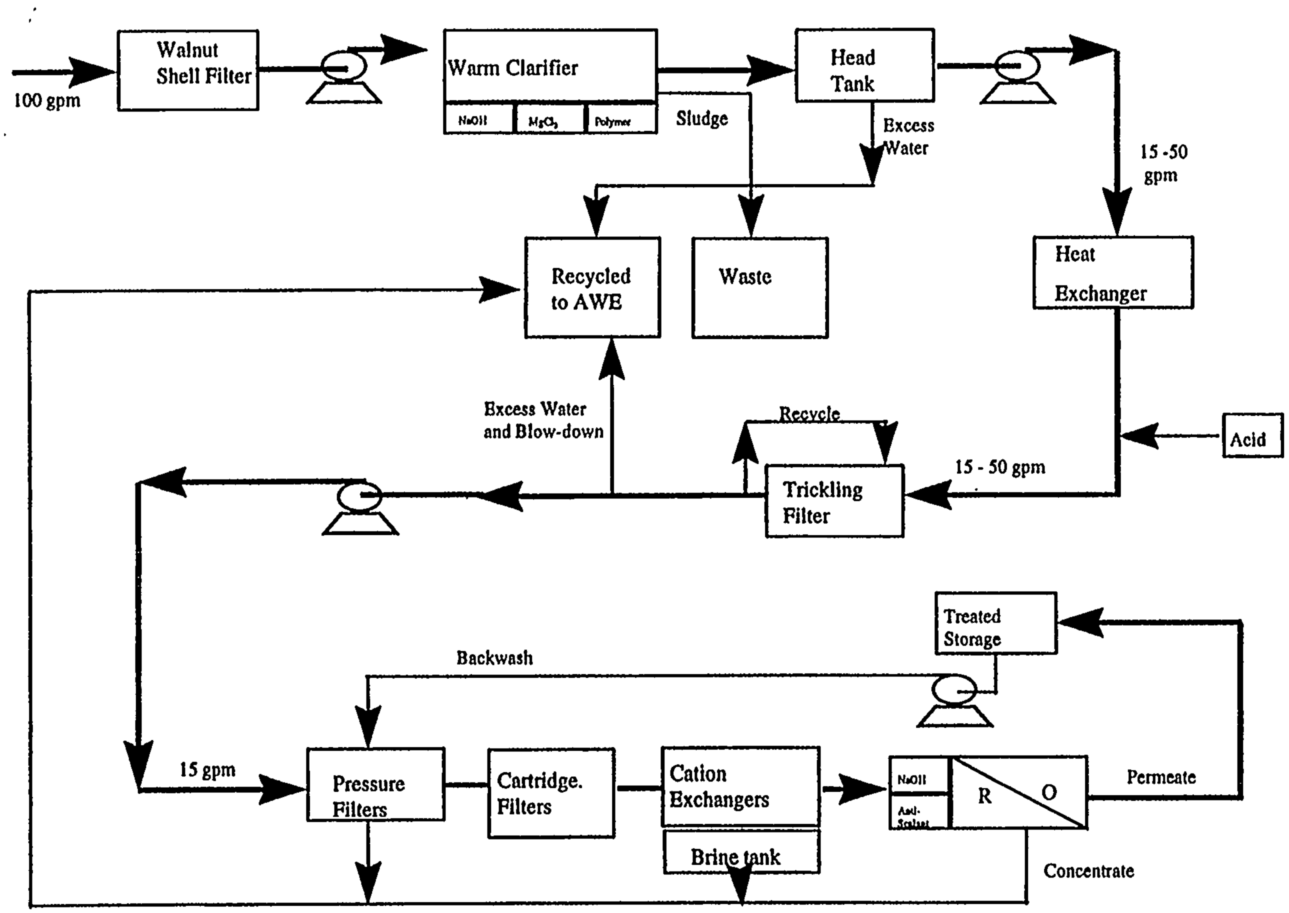

Figure 2. Schematic of Pilot Plant

Table 1
Typical Placerita Produced Water Quality and Treatment Goals

Water quality parameter	Typical produced water value	Treatment goal
Temperature (° F)	170	75
pH (s.u.)	7.0	6.5 - 8.5
Total dissolved solids (mg/l)	6,000	350
Total organic carbon (mg/l)	120	1-2
Ammonia (mg/l-N)	15	<1.0
Boron (mg/l - B)	20	0.5 - 2.0
Silica (mg/l)	> 200	20 - 40
Total hardness (mg/l as $CaCO_3$)	1,500	70
Oil and Grease (mg/l)	20	< 0.1

Table 2
Comparison of Reported Silica Removal from Produced Water Using Warm-Lime and Hot-Lime Softening

Source (Size) Warm/Hot	Temperature (°C) / (°F)	SiO_2 Influent	SiO_2 Effluent	SiO_2 Perc. Removal	Operating pH
Ref. 3 (5,824 gpm) **Hot**	80 - 90 / 176-194	203	28	86	9.5
Ref. 4 (5 gpm) **Warm**	up to 78 / up to 172	250	<30	88	11.0
Ref. 5 (1,200 gpm) **Warm**	38 / 100	63	23	63.5	11.2
Ref. 6 (6,900 gpm) **Warm**	60-75 / 140-167	290	45	85	9.1 - 9.4

Table 3
One Set of Results from Phase I Bench-Scale Warm Softening Experiments

$MgCl_2$ Dosage (mg/l)	Effluent Silica (mg/l SiO_2)	Effluent Boron (mg/l B)	Effluent Total Hardness (mg/l $CaCO_3$)	pH
0	23	12	80	9.7
400	13	10	108	9.7
800	6	8	100	9.8
1,200	6	7	150	9.7
1,600	6	5	160	9.7

*Influent concentrations were: 174 mg/l SiO_2, 17 mg/l B, 1,210 mg/l $CaCO_3$

Table 4
Planning Level Cost Estimates for 43,000 bpd Reverse Osmosis and Vapor Compression Systems

Desalting Technology	Treated Water Recovery (Percent of 43,000 bpd)	Total Capital Cost (Million 1996 Dollars)	Annual Operating Costs (Million 1996 Dollars/yr)	Annual Operating Costs (1996 cents/barrel of water treated)
Reverse Osmosis, including pretreatment	80	11	2.1 - 2.9	13- 18
Mechanical Vapor Compression, including pretreatment	90	29	6.1	39
Mechanical Vapor Compression, Seeded Slurry	98	28	7.7	49

Table 5
Cost Breakdown for Reverse Osmosis System

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Operating Cost (1996 cents/ barrel of water treated)
Warm Softening*	2.3	1,000 (B) - 1,800 (A)	6.4 - 11.5
Cooling	0.6	60	0.4
Fixed-Film Organics Removal	1.0	50	0.3
Sand Filtration	1.3	130	0.8
Ion Exchange Softening	1.3	150	1.0
Reverse Osmosis	4.1	600	3.8
Stabilization	0.1	20	0.1
Disinfection	0.1	40	0.3
Total	**11**	**2,100 - 2,900**	**13 - 18**

Costs assume:

indirect capital costs included
inlet water temperature 160 - 170 °F
design capacity 43,000 barrels/day
NaOH $0.125 / lb
$MgCl_2$ $0.26 / lb
sludge disposal $50 / dry ton
500 RO membranes replaced every 18 months at $800/element

* Range of operating costs based on higher chemical usage, Scenario A, and lower chemical usage, Scenario B.

Table 6
Cost Breakdown for Vapor Compression System with Pretreatment

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Operating Cost (1996 cents/ barrel of water treated)
Warm Softening	2.3	1,000	6.4
Sand Filtration	1.3	125	0.8
Vapor Compression	23.6	4,800	30.6
Cooling and Stripping	0.5	50	0.3
Carbon Filtration	1.3	100	0.5
Stabilization	0.1	20	0.1
Disinfection	0.1	40	0.3
Total	**29**	**6,100**	**39**

Costs assume:

indirect capital costs included

energy usage of 140 kWh/1000 gallons treated for MVC

Table 7
Cost Breakdown for Seeded-Slurry Vapor Compression System without Pretreatment

Process	Total Capital Cost (Million 1996 $)	Annual Operations Cost (Thousand 1996 $)	Total Annual Operating Cost (1996 cents/ barrel of water treated)
Vapor Compression	25.7	7,500	47.8
Cooling and Ammonia Stripping	0.6	60	0.4
Carbon Filtration	1.4	100	0.5
Stabilization	0.1	20	0.1
Disinfection	0.1	40	0.3
Total	**28**	**7,700**	**49**

Costs assume:

indirect capital costs included
energy usage of 140 kWh/1000 gallons treated for MVC

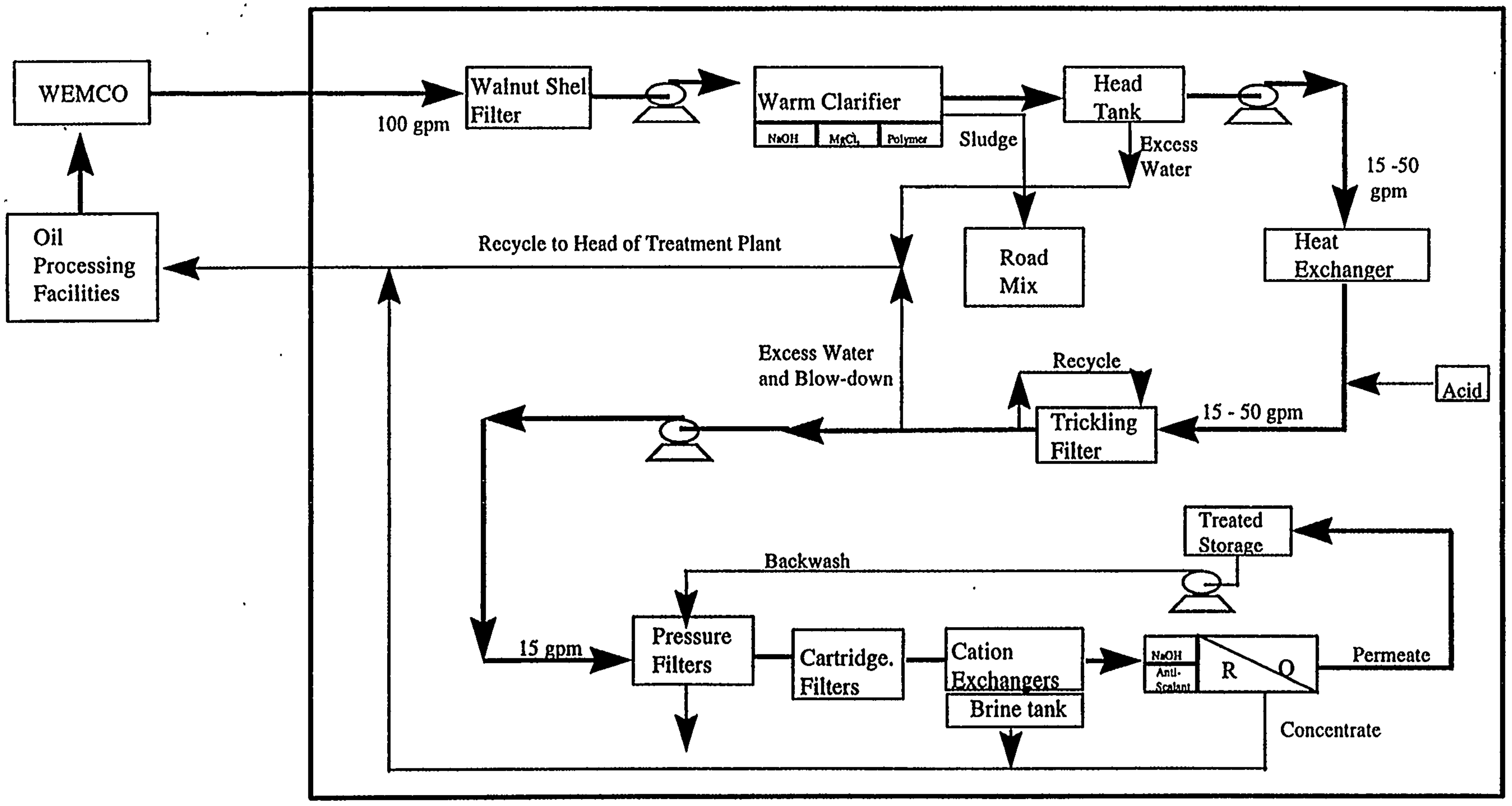

Fig. 1-- Schematic of Pilot Plant

SPE 38830

Evaluation of Technologies to Treat Oil Field Produced Water to Drinking Water or Reuse Quality

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his paper was prepared for presentation at the 1997 SPE Annual Technical Conference and xhibition held in San Antonio, Texas, 5 8 October 1997.

Abstract

Treatment technologies for reclaiming oil field produced ater for beneficial reuse were evaluated, including thermal and membrane processes for salinity removal. Warm precipitative softening and high-pH reverse osmosis were selected for pilot testing based on a literature review of reatment technologies and results from bench-scale softening ests that indicated hardness, boron and silica removal could be simultaneously optimized.

Introduction

The goal of this project is to convert a currently unusable by-product of oil production, produced water, into a valuable drinking water resource. To accomplish the project goal, the project team has built a pilot plant to treat oil field produced water to current and anticipated California potable and reuse water standards. The project site is the Placerita Oil Field which is located in the County of Los Angeles near the City of Santa Clarita, California. The project is divided into two phases: Phase I (research and planning) and Phase II (pilot testing). This paper summarizes the results of Phase I, including a literature-based review of treatment technologies applicable for produced water, planning level cost estimates of recommended technologies, and results from bench-scale precipitation studies. The paper also identifies the treatment train that is currently being tested as part of Phase II of this project. The paper was adapted from Ref. 1, which provides a more detailed summary of this project.

Several entities with diverse interests are contributing funds to this project. They include the U.S. Department of Energy, ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company, Castaic Lake Water Agency, Electric Power Research Institute Chemicals and Petroleum Office, Southern California Edison, the National Water Research Institute and Kennedy/Jenks Consultants.

The diverse sources of funding for the project reflect the wide range of potential beneficiaries that have an interest in the success of the project, including:

1) Oil companies that dispose of the produced water through costly underground injection at high pressures;

2) Oil refineries that may be able to use these technologies to recycle water at their facilities;

3) Water utilities that need additional water resources and are located near a producing oil field;

4) Water users with projects such as housing developments and industrial manufacturing complexes that require additional potable water resources before they can build their projects.

Project Approach

This project is structured to solicit input from members of the drinking water treatment and reclamation community, including staff of state regulatory agencies. The approach is intended to identify and address concerns early enough to obtain agency approval of the proof of concept process train similar to the wastewater reclamation reuse regulations in California s Title 22. The result would be a set of guidelines and design criteria that are applicable throughout California for reclaiming produced water, substantially decreasing the cost of future produced water reclamation projects. If the project obtains Department of Health Services approval, a 43,000 barrel per day [1.8 million gallon per day (mgd)] treatment plant may be built in Santa Clarita, California.

Supporting this project is a technical review panel, an dependent panel organized under the auspices of the National Water Research Institute. The responsibility of the panel is to provide a scientific critique of the work plans and products to assist the regulatory agencies in determining the scientific merits of the collected data. In addition, there is a project advisory committee composed of interested parties. These members have contributed research funds or bring special expertise or experience to assist the conduct of this study. The project team is also working closely with staff from regional and state regulatory agencies.

The project team has met with the technical review panel, project advisory committee, and regulatory staff on two occasions. First, in September of 1996, a meeting was held to familiarize participants with the project and solicit input for bench-scale testing. Next, in March 1997, a second meeting was held to review results from bench-scale testing and finalize a pilot-scale treatment plan.

Methodology

Technology evaluation was composed of four tasks: compiling water quality measurements and treatment goals, conducting a literature search of applicable treatment technologies, performing bench-scale softening experiments, and selecting a pilot treatment train.

Produced water quality measurements from the Placerita l field were compiled and compared to potential water quality standards in the first task.

In the second task, the project team conducted a literature search to identify potential treatment technologies and develop preliminary treatment cost estimates.

Bench-scale softening experiments were conducted in the third task to develop an operating strategy for the pilot study and refine chemical dosages that comprise a large fraction of estimated treatment costs. Standard jar tests were performed to measure softening efficiency at a variety of chemical combinations and pH values by varying dosages of calcium hydroxide, sodium hydroxide, ferric chloride, and magnesium chloride. Experiments were conducted in 2 liter square jars using a standard Phipps and Bird jar testing apparatus. The jars were placed in a water bath to regulate the temperature of their contents, with the water bath temperature regulated by coil-immersion heaters and sterno burners. After chemicals were added, the jars were mixed at 150 rpm for two minutes, then mixed at 20 rpm for 20 minutes for flocculation, and allowed to settle quiessently for 30 minutes.

Selecting a treatment train to pilot test was the fourth task. The selection was based primarily on estimated costs, though operating ease and potential for regulatory acceptance were also considered.

Costs for treatment technologies were obtained by requesting planning-level costs estimates from vendors and sing cost-estimating computer models. Costs were compared based on estimated capital costs, annual operating cost, and unit (cents/barrel) costs.

Results

The results of these technology evaluation and selection tasks are presented below.

Produced Water Quality and Treatment Goals

Produced water requires treatment for a number of water quality constituents depending on the intended water use. In California, there are no current drinking water regulations covering the use of treated produced water. There are reclamation standards and design criteria for treatment of domestic wastewater for a direct beneficial use or a controlled use that would not otherwise occur. There are also extensive federal and state regulations for drinking water. For planning and evaluating potential technologies, the most stringent water quality goals have been identified to provide the greatest flexibility for potential uses of the produced water. Drinking water standards, with few exceptions, are the most stringent.

Table 1 summarizes the key water quality goals to be met through treatment for this project. The major water quality concerns are the removal of dissolved salts (4,000 - 6,000 mg/l TDS), ammonia (>10 mg/l - N), boron (~18 mg/l B), and organics (TOC ~100+). The concentrations of silica (~200+ mg/l $SiO2$), hardness (600 - 1,500 mg/l), and oil and grease (up to 50 mg/l) present well-known problems as potential foulants for TDS removal technologies. In addition, confirmation that residual TOC does not present a disinfection by-product formation issue is necessary to meet future drinking water regulations.

Salinity

TDS of produced water must be reduced to below 500 mg/l for potable use.

Organics

The TOC goal is in the 1 - 2 mg/l range to satisfy future drinking water regulations and potential regulatory concerns. The removal of organics will be a major challenge because produced water from heavy oil fields are high in low molecular weight aromatic compounds and naphthenic acids.

Ammonia

Ammonia levels need to be controlled below 1 mg/l to preclude a number of operational problems including increased corrosion in copper and copper alloys, additional chlorine demand, and increased biological activity in potable distribution systems that can lead to nitrification and enhanced biofilm formation.

Boron

Boron removal is particularly important for water used for irrigation (typical goals of 0.5 - 0.7 mg/l), and a project treatment goal of 1 - 2 mg/l is being evaluated.

Oil and Grease

Oil and grease levels are a concern because of the potential for fouling in membrane processes. RO membrane anufacturers recommend a treatment goal close to 0.0 mg/l suspended oil and grease.

Silica

Although there is no silica drinking water standard, low silica concentrations (80 to 150 mg/l) are desirable for steam production and other industrial uses, and a project goal of 30 mg/l has been set to avoid fouling in salinity removal processes.

Review of Treatment Technologies

Technology selection was driven by salinity removal and appropriate pre- and post-treatments. The following sections identify potential treatment technologies for the concerns identified in the previous section.

Salinity Removal

Treatment technologies to remove dissolved salt from water include thermal distillation and membrane processes. Thermal processes that were screened include multi-stage flash distillation, multiple effect distillation, and vapor compression. Membrane processes that were screened for this project include reverse osmosis, nanofiltration, and electrodialysis / electrodialysis reversal. Within the desalination industry, membrane technologies such as reverse osmosis (RO) are generally the technology of choice for brackish applications, while both distillation and membrane processes are considered competitive for higher salinity aters such as sea water. Selecting the appropriate desalting echnology for a particular project depends to a large extent on specific conditions and requirements of the project. In the case of brackish produced water, the high influent temperature and the need for extensive pre-treatment prior to membrane desalting suggests that thermal processes be considered.

The two desalting processes that were evaluated for this project are mechanical vapor compression (MVC) and reverse osmosis. Both of these proven technologies are capable of removing a large fraction (but not all) of the organics and boron under certain pH conditions. Thus, supplemental TOC removal will likely be required. Silica removal, generally achieved by precipitative softening, is required for both processes, although some MVC systems incorporate silica removal as part of the main process, using a seeded silica slurry.

Mechanical Vapor Compression

Mechanical vapor compression is the most energy efficient distillation process for desalting brackish water. The desalting equipment consists of a vessel with a tube bundle, mechanical compressor, heat exchanger, and pumps.

Incoming filtered produced water is dosed with a scale inhibitor and preheated if necessary in the heat exchanger by the exiting product and brine. The preheated produced water ixes with recirculating brine inside the shell and is sprayed nto the outside of the tubes. Vacuum created on the suction side of the compressor lowers the boiling point of the salt water mixture allowing vapor to evaporate from the produced water. This vapor is compressed and returned inside the tubes where it condenses. The latent heat released is transferred to the influent assisting in the evaporation process. Additional vacuum is provided by a vacuum pump, which draws off non-condensable gases, and vents outside the system.

The recovery (hydraulic recovery) of MVC and other desalting processes is the ratio of the product water to the feedwater. The MVC units evaluated for this project had recoveries between 90 and 98 percent. A recovery of 90 percent means that for every 100 gallons of feedwater 90 gallons of product water and 10 gallons of concentrate are produced.

MVC systems have been installed in the United States and abroad, with the majority designed as zero-discharge brine concentrators and treatment systems for steam-water makeup. A promising evaporator for recovering produced waters is the vertical tube, falling film evaporator, operated with seeded slurry to reduce or eliminate pre-treatment requirements. Extensive pre-treatment, including silica removal, is required for evaporators to treat produced water operated in the un-seeded mode. The amount of treatment is similar to pre-treatment required for RO systems.

Reverse Osmosis

The reverse osmosis (RO) process uses hydraulic pressure to force pure water from the feedwater through a membrane. The energy required to overcome natural osmotic forces depends on the quantity of salts to be removed.

A typical RO membrane is a film under pressure in the 150 - 600 psi range. The membrane acts like a filter to retain ions such as sodium and chloride on the brackish water side, while permitting pure or nearly pure water to pass through the membrane.

Most brackish water RO systems operate at recoveries between 65 and 90 percent depending upon the composition of the feedwater and the size of the system. For this project, a recovery of 80 percent was estimated based on feed water characteristics.

The recovery, or level of concentration in the brine, in part determines the amount of pre-treatment necessary to prevent fouling of inorganic constituents. When compounds such as silica and calcium carbonate are concentrated in the brine, they may exceed their respective solubility concentrations.

Organics Removal

Both fixed-film biological oxidation and granular activated carbon (GAC) are candidate processes for organics removal. Because many of these organics are refractory, pilot tests are necessary to determine the efficacy of these processes.

Ammonia Removal

Some of the ammonia may be removed in the biological oxidation process and perhaps the RO process, but the remainder will have to be removed by air stripping. This may be accomplished in the cooling process or in separate strippers at high pH.

Boron Removal

A large portion of the boron can be removed concurrently with silica in the warm softening process if sufficient magnesium is added. Boron can also be removed by RO at high pH or by ion exchange using special anion exchange resins.

Oil and Grease Removal

A WEMCO induced gas flotation unit is currently used by AWE to remove oil and grease from produced water. A walnut shell filter is being tested downstream of the WEMCO in Phase II to remove additional oil during normal operating conditions and to provide protection during upset conditions.

Silica Removal for Scale Control

As discussed previously, both membrane and thermal desalting processes require pre-treatment to prevent inorganic scaling. Inorganic scaling occurs when the concentration of inorganic compounds such as silica exceed their solubility limits in the concentrated brine. Calcium and magnesium hardness, as well as silica, are the primary compounds of concern for inorganic scaling.

The most prevalent approach to address scaling in RO and thermal processes is to decrease the pH of the feed water to less than 7 and add an anti-scalant. The solubility of calcium and magnesium increases at a lower pH, and anti-scalants help prevent silica and other compounds from precipitating as solids.

Reverse osmosis also requires pre-treatment to avoid organic fouling that occurs when dissolved organics are adsorbed and provide nutrients for biological activity within the pores of the RO membrane or on the membrane surface as a biofilm. Experience treating produced water with RO has shown that reducing feed water pH is not a practical operating strategy because it increases organic fouling (Ref 2). The efficiency of boron removal also decreases with a lower pH because boron exists primarily in an unionized form of boric acid at pH below 9.5. Thus hardness and silica are usually removed from source water prior to treatment with either an RO membrane or thermal process. The most common processes used to remove hardness and silica are precipitative softening and/or ion exchange.

In precipitative softening, hydrated lime ($Ca(OH)_2$) or caustic soda (NaOH) is added to the feed water to raise the pH and convert bicarbonate alkalinity into carbonate and hydroxide alkalinity. Soda ash, Na_2CO_3 may also be added as a source of carbonate if insufficient inorganic carbon is available in the raw water. Calcium then precipitates with carbonate and magnesium precipitates with hydroxide. Silica precipitates directly with magnesium or calcium, depending on pH conditions. Silica also co-precipitates with magnesium hydroxide, so additional magnesium or lime is sometimes added to increase silica removal.

Produced water is typically warm when extracted, and precipitative processes can be more effectively operated at either warm (90 to 175 F; 32 to 80 C) or hot (215 to 230 F; 102 to 110 C) temperatures rather than ambient temperatures (40 to 90 F; 4 to 32 C). At the hot temperatures, the solubility of calcium carbonate is lower, the solubility of magnesium salts is higher, chemical kinetics are faster, and precipitates settle more quickly.

The primary difference between a hot process and the colder processes is that hot softening process operates in closed vessels under pressure, while warm and ambient softening processes operate at atmospheric pressure. In hot processes, carbon dioxide is generally flashed off prior to chemical addition as the water is heated above boiling. This effect reduces the doses of lime or caustic soda required.

Table 2 compares reported removal effectiveness of hot and warm lime softening processes at pilot-scale or full-scale produced water installations(Ref. 3-6). The data indicate that both warm and hot lime processes are capable of removing up to 85 percent of influent silica to levels below 30 mg/l SiO_2. Bench studies, including those reported below, indicate that effluent silica concentrations can be reduced to less than 10 mg/l SiO_2 (Ref. 5).

To minimize the quantity of sludge produced from the precipitative softening process, partial softening without soda ash would likely be used for the Placerita produced water. In this operating scenario, the potential advantage of a lower effluent hardness concentration from a hot process operated with excess soda ash would not be utilized.

Hardness Removal

Total hardness, including calcium and magnesium can also be removed concurrently with silica in the warm softening process. In addition, residual hardness remaining in the softened water can be removed by cation exchange. This is important if salinity removal is carried out at high pH.

Bench Scale Softening Experiments

A preliminary estimate of treatment costs suggested that pre-treatment with precipitative softening would incur large operating costs. Bench-scale softening experiments were conducted to investigate the potential for simultaneous silica and boron removal, and develop more accurate chemical dosages to refine cost estimates.

Results from the bench scale tests, summarized in Table 3. indicate that warm precipitative softening with caustic soda at pH values between 9.5 and 10, with the addition of magnesium chloride, can simultaneously reduce both silica and boron levels. Under these conditions, effluent silica levels were consistently below the project goal of 30 mg/l and effluent boron concentrations were under 10 mg/l. Results indicate that increasing magnesium chloride dosages between 0 and 800 mg/l provide higher removal percentages for boron and silica. For magnesium chloride dosages above 800 mg/l, residual boron concentrations decrease, residual silica ncentrations remain constant, and residual hardness levels crease.

The magnesium dosage is important for determining treatment costs in several ways. As the magnesium dosage increases, more magnesium and caustic soda is consumed, and more sludge is produced because solids production increases and settleability generally decreases. Based on these considerations, two operating strategies were selected for cost estimation. The higher cost estimate, Scenario A, is optimized for boron and silica removal in the precipitative warm softener, with a magnesium dosage equivalent to 400 mg/l of magnesium chloride and 1,000 mg/l of caustic soda. The lower cost estimate, Scenario B, assumes less boron removal will be required in the precipitative softener, with warm softening chemical dosages of 40 mg/l of magnesium chloride and 700 mg/l of caustic soda.

Comparison of Costs

The following discussion compares the capital and operating costs for a 43,000 barrel per day (bpd) [1.8 million gallon per day (mgd)] treatment plant that utilize reverse osmosis or mechanical vapor compression. Table 4 presents planning level cost comparison of the treatment options, reverse osmosis with pre-treatment, MVC with pre-treatment, and seeded-slurry MVC that does not require extensive pre-treatment. All costs are presented in 1996 dollars. The cost timates have an accuracy of approximately -30 to + 50 percent.

Total capital costs listed include equipment and direct constructions costs (50 percent of equipment) such as installation costs, as well as indirect costs (38 percent of equipment and construction costs) such as engineering, legal fees and administration. Operating costs include chemicals, sludge disposal, membrane replacement, energy, and labor. Operating costs do not include concentrate disposal or other maintenance and materials.

For the brackish water in this project, the RO process has capital and operating costs that are less than half of a MVC plant designed to meet drinking water standards.

The estimated planning-level capital cost for a 43,000 bpd facility based on the above treatment train, including construction and indirect costs, is $11 million, not including effluent storage. The estimated annual operating cost is approximately $2.1 to $2.9 million per year, or 13 to 18 cents per barrel of water treated. The range of estimated treatment costs correspond to Scenario A, higher chemical usage, and Scenario B, lower chemical usage, that were developed for precipitative softening.

The estimated planning level cost estimate for a 43,000 bpd facility incorporating vapor compression is $28-29 million total capital, including construction and indirect osts, not including effluent storage. This technology was the ost competitive thermal process for this particular site. The estimated operating cost is approximately $6.1 to 7.7 million per year, corresponding to approximately 39 to 49 cents per barrel of water treated. The variation in capital costs and unit water costs arise from different MVC arrangements with water recoveries ranging from 90 to 98 percent.

Table 5 through 7 list the components of capital and annual costs for the three treatment trains evaluated.

The current cost for disposing produced water from the Placerita field is approximately 10 cents per barrel for underground injection. Although the wholesale price of treated water from the Metropolitan Water District in southern California was 5.2 cents per barrel for fiscal year 1995-96 (Ref. 7), the incremental cost of developing new water resources is expected to be higher due to difficulties in securing water rights and the cost of developing new infrastructure to convey water to the area. Based on the current water rate and an assumed hydraulic recovery of 80 percent, the economic benefit of treating produced water to drinking water quality is 12.2 cents per barrel. This value accounts for disposal costs that are avoided by treating produced water and the value of the treated product, but these benefits only apply to the fraction of the water that is recovered (80 percent assumed).

Technology Selection for Phase II Pilot Testing

Warm precipitative softening was selected over hot precipitative softening for the following reasons:

- Warm softening has lower anticipated capital costs than hot softening
- Warm softening is less energy intensive than hot softening
- Warm softening is easier to operate than hot softening
- Warm softening requires less cooling to protect RO membranes or ion exchange resins

RO was selected as the process to desalt produced water for this project for the following reasons:

- RO capital costs are less than 40 percent of the MVC costs
- RO operating costs are less than 45 percent of MVC costs
- RO has greater acceptance in U.S., especially for drinking water applications.

The project team selected a high-pH reverse osmosis process for the pilot study that included the following components:

- Warm precipitative softening with caustic soda and magnesium chloride at pH 9.7
- Cooling
- Fixed-Film Biological Organics Oxidation
- Pressure Filtration
- Ion-exchange softening
- Reverse Osmosis

Fig. 1 illustrates this treatment train.

Conclusions

reating produced water to drinking water or reuse quality can be accomplished through a number of treatment trains. The least expensive treatment train evaluated for the brackish produced water at the Placerita oil field utilizes high-pH RO with warm precipitative softening in addition to other pre- and post-treatments. The estimated unit operating costs for this treatment train are slightly higher than the combined unit costs for injecting produced water underground and purchasing treated surface water at current water rates. When compared to the incremental cost of developing new water resources, treating produced water will likely be economically viable.

Acknowledgments

The authors thank the DOE project manager Nancy Holt; members of the Technical Review Panel: Robert Carnahan, Harvey Collins, Mike Kavanaugh, Yosif Kharaka, Stanley Ponce, Harry F. Ridgway, George Tchobanoglous, and Walter J. Weber; members of the project Technical Advisory Committee: Lory Larson, Michael Dubrovsky, Mike Rightmire, Dick Schmeal; Regulatory agency participants: Bob Hulquist, Gary Yamamoto, Hubert Kang; and the project sponsors: U.S. Department of Energy, ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company, Castaic Lake Water Agency, Electric Power esearch Institute Chemicals and Petroleum Office, Southern alifornia Edison, the National Water Research Institute and Kennedy/Jenks Consultants.

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SIMULTANEOUS REMOVAL OF SILICA AND BORON FROM PRODUCED WATER BY CHEMICAL PRECIPITATION

IWC 97-31

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Presented at
1997 International Water Conference
Engineer's Society of Western Pennsylvania
Pittsburgh, PA
November 3-5, 1997

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IWC-97-31

Keywords: produced water, silica removal, boron removal, magnesium, warm precipitative softening

Summary: This paper discusses the results of bench-scale softening experiments conducted at warm temperatures of approximately 150 °F (65 °C) to evaluate effectiveness in removing silica, boron, and hardness from oil field produced water. Simultaneous removal of silica and boron by magnesium was optimized at pH 9.6 - 9.8.

INTRODUCTION

Oil production generates a significant by-product, commonly known as "produced water". As the oil is extracted from an oil field, produced water can reach 90 percent or more of the fluids pumped from an oil well. In fact, heavy oil fields in California produce 10 to 15 barrels of water for every barrel of oil. In 1990 approximately 14.5 billion gallons per day of produced water were generated through hydrocarbon production (oil, natural gas, and coal) in the US, including production within the three mile coastal water limits.

In 1996, the authors began work on a project to demonstrate the feasibility of treating produced water to various water quality criteria for reuse. To accomplish the project goal, the project team is currently operating a pilot plant to treat oil field produced water to present and anticipated California potable and reuse criteria. The project site is the Placerita Oil Field which is located in the County of Los Angeles near the City of Santa Clarita, California.

Table 1 summarizes the typical produced water quality at the Placerita site and key water quality goals to be met through treatment for this project. The major water quality concerns are the removal of dissolved salts, ammonia, boron , and organics. The concentrations of silica, hardness, and oil and grease present well-known problems as potential foulants for salinity removal processes such as reverse osmosis. Because warm precipitative softening had been previously used for removal of silica from produced waters,(1)(2) it was selected as an important pre-treatment step for removing silica and hardness in a process train that may also include ammonia stripping and cooling, biological treatment, and reverse osmosis. Boron removal with reverse osmosis requires operating at high pH conditions which may increase RO treatment costs. Therefore, concurrent removal of boron in the warm softening process is of interest.

TABLE 1- Typical Placerita Produced Water Quality and Treatment Goals

Water quality parameter	Typical produced water value	Treatment goal
Temperature (° F)	170	75
pH (s.u.)	7.0	6.5 - 8.5
Total dissolved solids (mg/L)	6,000	350
Total organic carbon (mg/L)	120	1-2
Ammonia (mg/L-N)	15	<1.0
Boron (mg/L - B)	20	0.5 - 2.0
Silica (mg/L)	> 200	20 - 40
Total hardness (mg/L as $CaCO_3$)	1,500	70
Oil and Grease (mg/L)	20	< 0.1

The objective of this paper is to examine the feasibility of simultaneously removing hardness, silica, and boron with warm precipitative softening. The results discussed here were used to define the pilot plant train and test program for the second phase of this project.

SILICA AND BORON REMOVAL

Silica removal in precipitative softening has been described in literature considering hot or cold softening with the addition of magnesium or other metals under alkaline conditions, but the removal mechanisms have not been completely resolved. Powell (3) characterized silica removal with magnesium as an adsorptive process that can be best modeled with a Freundlich isotherm. Nordell (4) agreed that the Freundlich isotherm predicts silica removal with magnesium, but argued that silica is removed as magnesium silicate in a direct chemical reaction.

Mujeriego(5) found that silica removal by magnesium and calcium is controlled by silica species present; namely, his research indicated that silica removal by magnesium was controlled by $H_3SiO_4^-$ while silica removal by calcium is controlled by $H_2SiO_4^{2-}$. Table 2 shows the first two dissociation reactions for orthosilicic acid and their corresponding pK_N values (where K_n represents the nth dissociation constant) at 25 °C.

TABLE 2. Dissociation Reactions and pK values for Orthosilicic Acid and Boric Acid at 25 °C

Reaction	Value at 25 ° C
$H_4SiO_4 = H_3SiO_4^- + H^+$	$pK_1 = 9.93$ (5)
$H_3SiO_4^- = H_2SiO_4^{2-} + H^+$	$pK_2 = 11.69$ (5)
$H_3BO_3 = H_2BO_3^- + H^+$	$pK_1 = 9.20$ (6)
$H_2BO_3^- = HBO_3^{2-} + H^+$	$pK_2 = 12.73$ (6)

The optimum removals occurred at the pH level where the concentration of these controlling species are maximized. For example, $H_3SiO_4^-$, which controls silica removal with magnesium is greatest, dominates at pH = $(pK_1 + p_{K2})/2$. Table 3 indicates that at 65°C (149°F), these conditions occur at pH ~ 9.7. Likewise, silica removal with calcium occurs at pH above 11.5 where $H_2SiO_4^{2-}$ would dominate at this temperature.

Mujeriego also hypothesized that silica is removed by forming metal silicates. His research indicated that a magnesium silica similar in structure to sepiolite ($Mg_2Si_3O_8(H_2O)_n$) and a calcium silicate corresponding to $CaH_2SiO_4(H_20)_n$ explained his experimental results.

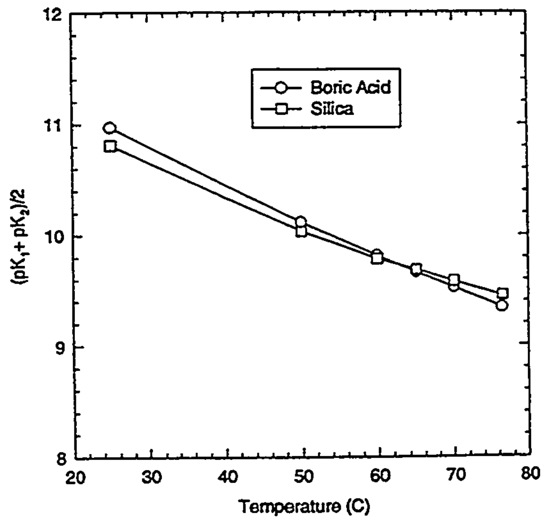
TABLE 3- Comparison of Dissociation Constants for Orthosilicic Acid and Boric Acid at 65 ° C

Element	pK_1	pK_2	$(pK_1 + pK_2)/2$
Silica	9.25	10.15	9.70
Boron	8.11	11.21	9.66

Precipitative processes have also been commercially used for boron removal.(7)-(10) This includes co-precipitation with and/or adsorption on magnesium hydroxides and precipitation as calcium borates under alkaline conditions.

Latimer and Hildebrand(11) suggested that borate may behave similarly to silica. Tables 2 and 3 also compare the first two dissociation reactions and corresponding pK values for orthosilicic and boric acids. Thus, boron removal with magnesium may be greatest at pH where $H_2BO_3^-$ dominates (midway between pK_1 and pK_2 for boric acid). For warm softening temperatures, this optimum pH occurs at pH ~ 9.7, which is similar to the optimum pH values for orthosilicic acid as illustrated in Figure 1. If boron is removed through a mechanism similar to silica, then removal with magnesium should both be optimized at the same pH.

FIGURE 1. Impact of Temperature on $(pK_1 + pK_2)/2$ for Boron and Silica



METHODS AND MATERIALS

Standard jar tests were performed to evaluate the effectiveness of removing silica, boron, and hardness at a variety of chemical combinations and pH values by varying dosages of sodium hydroxide, calcium hydroxide, and magnesium chloride (Ferric chloride was also screened as precipitant; however, it did not perform as well as magnesium chloride and is not discussed further in this paper).

Raw sample water from the Placerita site was shipped in sealed 5-gallon plastic containers to the Kennedy/Jenks laboratory in San Francisco. Table 4 lists analytical results for the raw water used in this bench study.

TABLE 4- Water Quality for Raw Water, mg/L

Constituent	Med.	Min	Max	N*
pH**	7.8	7.3	8.1	3
Tot Alk (CaCO3)	420	352	480	7
Tot Hard (CaCO3)	1180	1110	1290	9
Ca	302	180	392	8
Mg	105	69	122	8
Silica	177	110	202	9
Boron	18	17	20	9

* N= number of observations

** standard units

Experiments were conducted in 2 liter square jars using a standard Phipps and Bird jar testing apparatus. The jars were placed in a water bath to regulate the temperature of their contents, with the water bath temperature regulated by coil-immersion heaters and sterno burners. After chemicals were added, the jars were mixed at 150 rpm for two minutes, then mixed at 20 rpm for 20 minutes for flocculation, and allowed to settle quiessently for 30 minutes. For each experiment, initial and residual concentrations of total hardness, calcium hardness, alkalinity, silica, and boron were measured. Temperature and pH were measured *in situ* during the tests. Most jar tests were performed at warm temperatures of approximately 140 - 155 F (60 - 68 C).

After settling, a 200 mL portion of supernatant from each jar was removed and filtered through Whatman 541 filter paper into a flask. A 50 mL portion was immediately withdrawn from the flask to measure alkalininty. The remaining sample was stored and allowed to cool to room temperature for subsequent analysis of silica, calcium, hardness, and boron. Sample bottles were covered, and no preservatives were used.

RESULTS

Initial bench scale tests were performed by adding caustic soda (NaOH) or lime ($Ca(OH)_2$) to raw water samples and observing changes in solution pH and in the efficacy for total hardness, silica, and boron removal. Figure 2 illustrates how the pH changes with the addition of NaOH or lime dose, while Figures 3 and 4 show the residual total hardness, silica, and boron vs. pH for the corresponding NaOH and lime doses, respectively.

Figure 2. Impact of Caustic Soda and Lime Addition on Solution pH

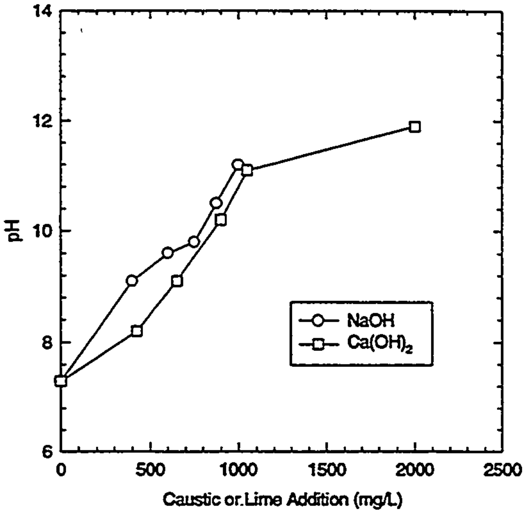
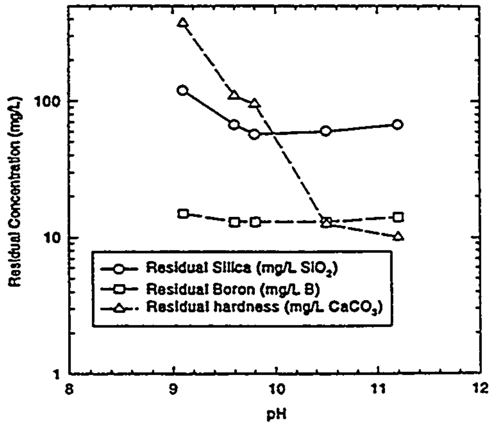
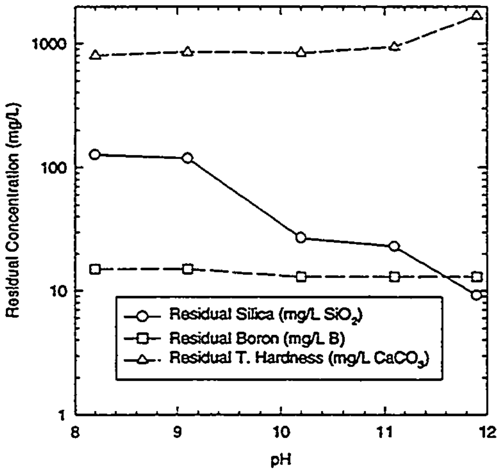


FIGURE 3- Residual Silica, Boron and Total Hardness as function of pH with Caustic Soda Addition



(Initial Conditions: SiO_2=232 mg/L, B=19 mg/L, Mg= 96 mg/L, Total Hardness= 1200 mg/L)

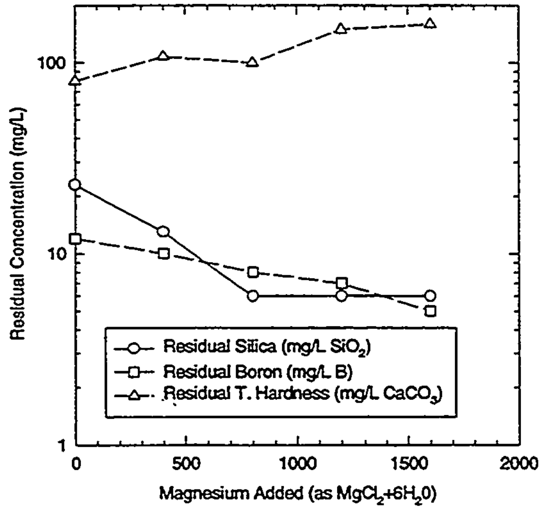
FIGURE 4- Residual Silica, Boron, and Total Hardness as a Function of pH with Lime Addition



(Initial Conditions: SiO_2= 202 mg/L, B=19 mg/L, Mg=106 mg/L, Total Hardness=1200 mg/L)

The addition of magnesium chloride was shown to provide further, simultaneously reduction of both silica and boron levels in the optimum pH range of 9.6 and 9.8. Results presented in Figure 5 indicate that increasing magnesium chloride dosages between 0 (influent magnesium concentrations represented a magnesium chloride dosage of approximately 350 to 450 mg/L) and 800 mg/L provide higher removal percentages for boron and silica.

FIGURE 5. Residual Silica, Boron, and Hardness as a Function of Magnesium Dosage at pH =9.7



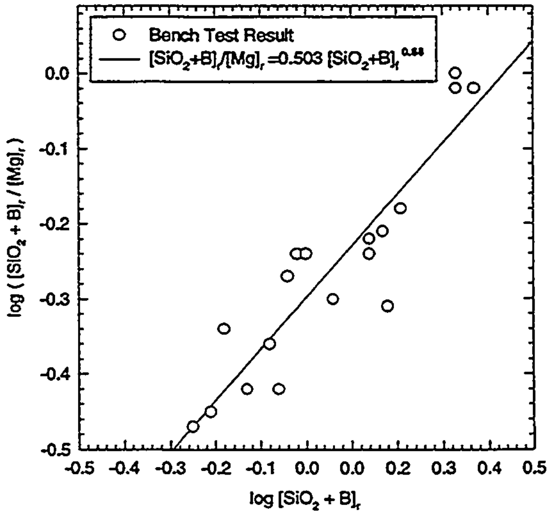
(Initial Conditions: SiO_2=174 mg/L, B=17 mg/L, Mg=130 mg/L, Total Hardness=1200 mg/L)

DISCUSSION

The bench scale results suggest that silica and boron levels in produced water can be simultaneously reduced with a magnesium - NaOH warm precipitative softening treatment at an optimum pH range of 9.6 to 9.8 at a temperature around 65 °C. This condition corresponds to the pH range where the $(pK_1 + pK_2)/2$ values for both silica and boric acid coincide. This observation appears to be consistent with Mjeriego s work, where an optimum was found for silica removal by magnesium. There appears to be a preference for silica over boron removal, and sufficient magnesium must be present before substantial amounts of boron removal occur.

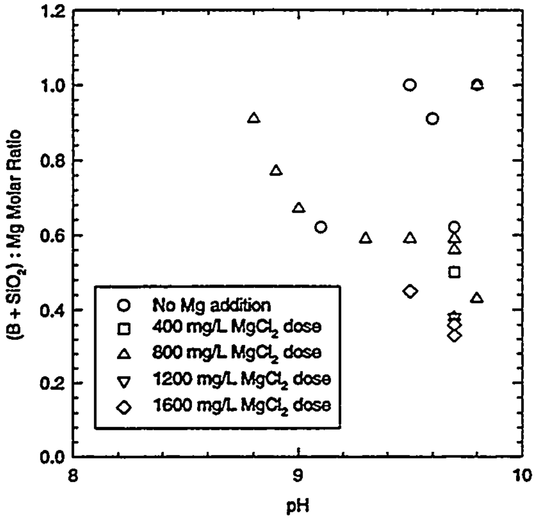
The bench scale test results do not clearly indicate whether the removal mechanism is adsorption of silica and boron on a magnesium hydroxide floc or co-precipitation as magnesium silicates and borates, or a combination of both. Data from bench scale tests in the pH 9 - 10 range were used to construct a Fruendlich isotherm plot of log silica plus boron to magnesium removed molar ratio vs. log residual silica plus boron concentrations (in mMols/L) after warm precipitative softening, as shown on Figure 6. These results indicate a reasonably good correlation ($r^2 = 0.833$) for this isotherm model.

FIGURE 6- Freundlich Isotherm Plot for Simultaneous Silica and Boron Removal



The molar ratio of silica plus boron $(SiO_2 + B)_r$ removed to magnesium $(Mg)_r$ removed was also examined as a function of magnesium chloride dosage added over the pH range of 8.8 to 9.8. As shown by Figure 7, there is some scatter in the data, with ratios ranging from 0.33:1 to 1.0:1. The data at pH 9.7 indicate that the ratio generally decreased as the magnesium addition increased, while the data for the 800 mg/L dose indicate that the ratio decreased with pH increase over this range. In general, the lower molar ratios were associated with higher percent removals.

FIGURE 7- Molar Ratios for Combined Silica and Boron Removal by Magnesium



Controlling pH between 9.6 and 9.8 with caustic soda and adding approximately 400-600 mg/L of magnesium chloride appears to be the most promising strategy to operate a pilot precipitative softening process to remove silica and boron simultaneously. In jar tests, this combination consistently led to residual silica levels of 20 mg/L or lower and boron concentrations of 10 mg/L or lower. Higher dosages of magnesium reduce residual boron concentrations but also require higher dosages of caustic soda, produce more sludge, and increase magnesium hardness levels of the effluent. Additional process optimization is currently being tested in a pilot plant demonstration.

ACKNOWLEDGMENTS

Several entities with diverse interests are contributing funds to this project. They include the U.S. Department of Energy, ARCO Western Energy, a unit of the Atlantic Richfield Company (ARCO), Castaic Lake Water Agency, Electric Power Research Institute Chemicals and Petroleum Office, Southern California Edison, the National Water Research Institute and Kennedy/Jenks Consultants.

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Developing a Cost Effective Environmental Solution for Produced Water and Creating a "New" Water Resource

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The 4th International Petroleum Environmental Conference
September 9-12, 1997
San Antonio, TX

ABSTRACT

The most prevalent method of handling oil field produced water is through underground injection. The authors will report on a DOE-sponsored project whose goal is to convert this currently unusable by-product of oil production into a valuable water resource that is cost competitive with other new water resources.

This paper will present results from a four-month pilot study that assesses the technical feasibility and economics of treating produced water to current and anticipated California potable and reclaimed water standards. Key pilot study goals include the removal of salinity, silica, ammonia, boron, and organics by warm precipitative softening and reverse osmosis, with and without biological treatment.

A successful project will benefit oil companies by reducing produced water disposal costs and by improving the quality, and reducing the quantity, of steam used for tertiary hydrocarbon recovery. Water users in arid regions will also benefit from having a new, drought-resistant water supply.

INTRODUCTION

Background

The goal of this project is to convert a currently unusable by-product of oil production, produced water, into a valuable drinking water resource. To accomplish the project goal, the project team has built a pilot plant to treat oil field produced water to current and anticipated California potable and reuse water standards. Earlier studies (1,2,3) have had the same objective, but the drinking water regulations have significantly changed(4).

The project site is the Placerita Oil Field which is located in the County of Los Angeles near the City of Santa Clarita, California (see Figure 1). The project was divided into two phases: Phase I (research and planning) and Phase II (pilot testing). Table 1 summarizes the key water quality goals to be met through treatment for this project. After a literature review and a planning level cost estimate, a membrane based desalting system was selected. A detailed description of this effort is presented elsewhere (5). Table 2 summarizes the pilot study that was designed to meet three potential water resource uses, industrial, irrigation, and unrestricted potable water. The three treatment goals were to: 1) determine the optimal chemical dose of the warm softening unit that resulted in <600 mg/L hardness and <100 mg/L silica; 2) determine an operating scenario for irrigation water (removing boron from ~15 ppm to ~1 ppm); and 3) determine an operating scenario for potable water by reducing the total organic carbon (TOC) to 1 ppm from ~120 ppm. This paper reports only on the result of the first object that only requires the warm softening and sludge handling equipment.

Several entities with diverse interests are contributing funds to this project. They include the US Department of Energy, ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company, Castaic Lake Water Agency, Electric Power Research Institute Chemicals and Petroleum Office, Southern California Edison, the National Water Research Institute and Kennedy/Jenks Consultants.

The diverse sources of funding for the project reflect the wide range of potential beneficiaries that have an interest in the success of the project, including:

1) Oil companies that dispose of produced water through costly underground injection at high pressures or use produced water with poor steam quality due to high silica and total hardness for tertiary recovery;

2) Oil refineries that may be able to use these technologies to recycle water at their facilities;

3) Water utilities that need additional water resources and are located near a producing oil field;

4) Large housing developer and industrial manufacturing complexes that must identify their own sustainable water resources before they can build their projects.

Project Structure

This project is intended to develop regulatory guidelines and design criteria that are applicable throughout California for conversion of produced water to a water resource. The development of state-wide criteria would substantially decrease the future permitting time and cost for similar projects in California. As a result, the project is structured to solicit input from members of the drinking water treatment and reclamation community, including staff of state regulatory agencies. If the project is successful, a 43,000 barrel per day [1.8 million gallon per day (mgd)] treatment plant may be built in Santa Clarita, California.

Supporting this project is a technical review panel, an independent panel organized under the auspices of the National Water Research Institute. The responsibility of the panel is to provide a scientific critique of the work plans and products to assist the regulatory agencies in determining the scientific merits of the data. In addition, there is a project advisory committee composed of interested parties who have contributed research funds or bring special expertise or experience to assist the conduct of this study.

PRODUCED WATER QUALITY, TREATMENT GOALS, PROCESS DESCRIPTION

Produced water requires treatment for a number of water quality constituents depending on the intended water use. In California, there are no current regulations covering the use of treated produced water for drinking or reclamation. There are extensive federal and state regulations for drinking water using traditional potable water resources. California has extensive reclamation standards and design criteria for treatment of domestic wastewater for a direct beneficial or controlled use augmenting the potable water resource. For planning and evaluating potential technologies, the most stringent water quality goals have been identified to provide the greatest flexibility and economic value of the produced water. As a result, potable drinking water became the goal for this project. Figure 2 is a summary schematic of the pilot plant treatment process that was constructed at the Placerita Oil Field.

Influent

Influent for the pilot plant comes from ARCO Western Energy s WEMCO induced gas flotation cell WF-2. The unit s is designed to deliver water with 0-5 ppm oil and grease. Water is taken from a recirculation line with approximately 20 psig of pressure and a temperature of approximately 160 F.

Warm Softening

Warm precipitative softening for silica and hardness removal was the first step in the treatment process. Sodium hydroxide (caustic soda), magnesium chloride, and polymer was added to the water to induce precipitation and aid in flocculation. The polymer was ChemTreat P-813E which is an anionic polyacryamide polymer in a water-in-oil emulsion manufactured by ChemTreat. The polymer dosage ranged from 3 to 6 ppm (liquid volume basis). This polymer is. a concentrated solution of 35% dry weight polymer. Based on field trials shown in Figure 3, the target pH for softening was set at 8.6.

The warm softening is accomplished with a DensaDeg unit provided by Infilco Degremont, Inc. The unit includes a reaction tank and upflow clarifier with lamella separators. Sludge thickening is accomplished as a sludge bed develops in the upflow clarifier. The unit is a 20-100 gpm prototype that can operated at approximately 100 gpm to provide a rise rate of 10 gpm/ft^2 in the clarifier. Sludge was periodically blown-down manually.

Cooling

Cooling was necessary to protect components of treatment processes such as plastic packing media and thin-film composite RO membranes. The highest allowable temperatures for these processes is approximately 100 F, and a design cooled water temperature of 90 F was used. The pilot study utilizes fin-fan heat exchangers.

pH Control

A chemical feed pump provides the ability to lower the pH of the water, if required. When the operational pH of the DensaDeg is > 9.5, the pH was lowered to this level to protect the biological process.

Trickling Filter

Biological oxidation of organics was the next step in the full treatment train. Based on the literature (6,7), it was hypothesized that a large fraction of the organics would be organic acids. A trickling filter was selected to evaluate biological organic oxidation at a range of loading rates. The goal for organics removal was 80 to 90 percent removal of soluble BOD to lessen organic fouling of membranes and achieve an RO permeate with less than 2 mg/L TOC.

Preliminary evaluation using a non-acclimated seed, the bio-chemical oxygen demand (BOD) of the produced water was approximately 20 mg/L. The total organic carbon (TOC) was approximately 120 mg/L and chemical oxygen demand (COD) measurements ranged between 350-450 mg/L. Based on these findings, the trickling filter was not expected to remove a large fraction of the organic content because of the low ratio of BOD to TOC or COD.

The trickling filter was 5 feet in diameter with 20 feet of Q-PAC from Lantec Products, Inc. Q-PAC is made of polypropylene, has a nominal diameter of seven inches, there are six pieces per cubic foot, 30 square feet of surface area per cubic foot of media, and a void fraction of 97.5 %. There was approximately 400 cubic feet of packing material in the trickling filter. Hydraulic and organic loading could vary between 0.5 - 2.5 gpm/ft^2 and 6 to 300 lbs/1000 ft^3 of media per day. For this study the trickling filter was operated at a hydraulic loading rate of 2.5 gpm/ft^2 and an organic loading rate of 20 lbs/1000 ft^3 of media per day.

During the first two phases, this unit process was bypassed to acclimate the bacteria to the produced water substrate. The unit was operated on a batch mode with weekly changes of the warm softened water. Continuous operation of this unit process in a flow through mode was completed on August 29, 1997, but results are not currently available.

Pressure Filtration

Two multimedia pressure filters were operated in parallel. The filters are 22 inches in diameter and have approximately 4 feet of multimedia filter material consisting of anthracite, sand, and garnet. With approximately 2.5 ft^2 of area per filter, the hydraulic loading rate for the filters are approximately 2.5 gpm/ft^2. During some of the trials a filter aid, ChemTreat P-822L, a cationic polyamine polymer manufactured by ChemTreat. was added at rates from 1.5 to 8.6 ppm (volume/volume basis). The filters were backwashed with RO permeate manually with down stream units (ion exchange and RO) off line.

Ion Exchange

Two cation exchange columns in parallel were used to remove divalent cations that might cause scaling in high-pH RO for half of the testing period. Each column contained approximately 5 ft^3 of Ionac C-249 resin with a rated capacity approximately 25-30 kilo-grains per ft^3. The high TDS of the water is expected to reduce the capacity of the resins by approximately 20 percent, so the expected capacity is approximately 20 kilo-grains per ft^3. Regeneration is performed using a RO permeate for washing and making up the brine solution.

For a half of the test period the hardness from the DensaDeg was low enough (<15 mg/L CaCO3 Total Hardness) that the ion exchange units were bypassed.

Reverse Osmosis

A scale inhibitor PreTreat Plus 0100 Inorganic scale inhibitor/antifoulant manufactured by King Lee Technologies was added at 1 mg dry powder/L feed water to the RO unit. When operating the RO unit at pH < 9.6 and without the trickling filter on-line, an antifoulant, Protec RO Organic antifoulant, manufactured by King Lee Technologies was added at a 5 mg dry powder/L rate to minimize potential residual oil fouling. Adjustment of pH followed with caustic or sulfuric acid as required. The elevated pH was to examine the rejection of boron that was reported by Dyke *et al* (8). The reverse osmosis unit contained twelve 4 x 40 brackish water spiral wound elements, housed in 4 pressure vessels that were arranged in a 3-stage (2 x 1 x 1) array. The membranes were Fluid Systems XR extra-high rejection polyamide elements. The three stages and a concentrate recycle line facilitate tests at water recovery rates of 75 percent at inlet pressures as high as 600 psig.

PILOT TESTING RESULTS

The pilot plant was operated to meet three different water quality scenarios to refine the cost estimate of this water resource and are summarized in the Table 2. Although the field work has been completed, results are only available for developing an industrial water resource. To generate an industrial water with <600 mg/L hardness and <100 mg/L silica the only process required would be the warm softening precipitating unit and associated sludge handling equipment. The operating conditions and resultant water quality for this portion of the study are summarized in Table 3.

Water Quality

The first step in this portion of the study was to vary the pH of the DensaDeg unit. These results are presented in Figure 3 which also presents titration performed in the field and during the Phase I bench study. These results indicate that a higher than anticipated dose has been required to raise the pH to the target level as indicated in Figure 3. We hypothesis that this is due primarily to carbon dioxide reacting with the caustic in the rapid mix of the DensaDeg. The carbon dioxide was probably off-gassed during handling and titration of the field and bench-scale samples. The impact of this hypothesis is dramatic. For example, 250 mg/l of NaOH was required to titrate the produced water to a pH of 8.7 whether it was tritated in the field or at the bench, up to four days later. Approximately 750 mg/l was required to reach the same pH in the DensaDeg (See Figure 3). Assuming that this caustic requirement difference was only due to carbon dioxide, as much as 200 mg/l carbon dioxide was estimated to be in the produced water.

Mujeriego(9) found that silica removal by magnesium and calcium is controlled by silica species present; namely, his research indicated that silica removal by magnesium was controlled by $H_3SiO_4^-$ while silica removal by calcium is controlled by $H_2SiO_4^{2-}$. Table 4 shows the first two dissociation reactions for orthosilicic acid and their corresponding pKN values (where Kn represents the nth dissociation constant) at 25 and 65(C.

The optimum removals occurred at the pH level where the concentration of these controlling species are maximized. For example, $H_3SiO_4^-$, which controls silica removal with magnesium is greatest, dominates at pH = (pK1 + pK2)/2. Table 4 indicates that at 65(C (149(F), these conditions occur at pH ~ 9.7. Likewise, silica removal with calcium occurs at pH above 11.5 where $H_2SiO_4^{2-}$ would dominate at this temperature. Figure 4 shows that effluent silica and total hardness concentrations decreased as pH increased between 7.6 and 10.8. The expected silica minimum was pH 9.7 based on the average between the two pK s for silica as previously mentioned. The observed minimum for silica in Figure 4 was ~ pH 9.8 (See arrow in Figure 4) as predicted. At higher pH, silica concentrations increased as expected due to the role of the second pK. This suggests that the silica behavior under low magnesium conditions a solubility/precipitation mechanism controlling the concentrations observed in the DensaDeg effluent.

Mujeriego also hypothesized that silica is removed by forming metal silicates. His research indicated that a magnesium silica similar in structure to sepiolite ($Mg_2Si_3O_8(H_2O)n$) and a calcium silicate corresponding to $CaH_2SiO_4(H_20)n$ explained his experimental results.

Precipitative processes have also been commercially used for boron removal (10)-(13). This includes co-precipitation with and/or adsorption on magnesium hydroxides and precipitation as calcium borates under alkaline conditions. Latimer and Hildebrand(14) suggested that borate may behave similarly to silica. Table 4 also compare the first two dissociation reactions and corresponding pK values for orthosilicic and boric acids. Thus, boron removal with magnesium may be greatest at pH where H2BO3- dominates (midway between pK1 and pK2 for boric acid). For warm softening temperatures, this optimum pH occurs at pH ~ 9.7, which is similar to the optimum pH values for orthosilicic acid as illustrated in Figure 4. If boron is removed through a mechanism similar to silica, then removal with magnesium should both be optimized at the same pH. However, the pilot results indicated that the boron removals, 12 percent, were dramatically less than the silica implying that either that the mechanisms or kinetics are different. Results from the bench scale portion of this work would tend to suggest an adsorptive mechanism(15).

The DensaDeg effluent (pH 9.7, 10 ppm total hardness as CaCO3) had almost 10 times less total hardness than observed in the bench scale testing (pH 9.7, 100 ppm total hardness as CaCO3). This would suggest that the carbon dioxide-calcium precipitation reaction and the recirculation features of this reactor/clarifier are significant features over the traditional precipitation and clarification, i.e., no recirculation of the sludge.

Sludge

Sludge generation ranged from 3-6 percent on a volume basis. The wet solids on a weight basis ranged between 5-10 percent. The sludge was a non-hazardous waste based on California and US EPA standards. The sludge from the pilot operation was air dried, mixed with tank bottoms, and used as road mix at the oil field.

Final Results

The results for the two other pilot study objectives will be available in December 1997. The results will include the following operating scenarios: 1) to meet the boron treatment goal of < 1 mg/L two techniques were used (increasing the magnesium dose to 400-800 mg/L in the DensaDeg or increasing the pH of the RO influent to 10.8); and 2) to meet the TOC treatment goal of 1 mg/L, the trickling filter was placed in service in combination with a pH 8.5 (low pH).

ESTIMATED COSTS

For this study, several cost estimates were done. The initial cost estimate was done to screen alternative technology. A final cost estimate will be completed in December 1997 using information gained from operating the pilot plant.

Planning Level Estimates

During the technology selection phase of this project an estimate for the capital and operating costs was done for a 43,000 barrel per day (bpd) [1.8 million gallon per day (mgd)] treatment plant for three prototypes, reverse osmosis with pretreatment, vapor compression with pretreatment, and vapor compression slurry seed. Table 6 presents planning level cost in 1996 dollars that have an accuracy of approximately -30 to + 50 percent comparing these technologies. Table 7 summarizes the individual processes for the RO option and table 6 summarizes the underlying cost assumptions for the cost estimates.

Total capital costs listed include equipment and direct constructions costs (50 percent of equipment) such as installation costs, as well as indirect costs (38 percent of equipment and construction costs) such as engineering, legal fees and administration. Operating costs include chemicals, sludge disposal, membrane replacement, energy, and labor. Operating costs do not include concentrate disposal or other maintenance and materials. For this project, the RO process has capital and operating costs that are less than half of a MVC plant designed to meet drinking water standards.

Current Disposal and Water Costs

The current cost for disposing produced water from the Placerita field is approximately 10 ¢ per barrel for underground injection. Although the wholesale price of treated water from the Metropolitan Water District in southern California was 5.2 ¢ per barrel for fiscal year 1995-96(16), the incremental cost of developing new water resources is expected to be higher. In water short southern California, there are difficulties in securing water rights not dependent on above average rainfall years. Additionally, the cost of developing new infrastructure such as pumping and storage facilities to convey new water to an area can be two to three times that of the water rights.

Industrial Water

As noted earlier in this paper, the only required unit process to meet the industrial water quality goals of silica and hardness is the warm softening and associated sludge treatment facilities. Table 6 identifies that the capital cost for this treatment is $2.3 million. The estimated operating and maintenance costs is 7 ¢ per treated barrel of water which included the sludge handling using a filter belt press and disposal at a nearby landfill that is less than 10 miles away.

CONCLUSIONS

Using a warm softening process to treat produced water, a treated water was generated that could become an industrial water resource. The treated water met the treatment goal of <600 mg/l of total hardness as CaCO3 and <100 mg/l of silica as SiO2. The silica removal involved a solubility/precipitation mechanism controlling the concentrations observed in the DensaDeg effluent. Less than 10 percent of the organic carbon and 12 percent of the boron was removed in this unit process. Although the pK's for silica and boron are similar, the pilot results indicate that the boron removals were dramatically less than the silica indicating that either that the mechanisms or kinetics are different. The sludge generated at this site was nonhazardous by both EPA and California Hazardous Waste definitions. A DensaDeg unit with a capital cost for a 43,000 bpd unit of $2.3 million and an operational and maintenance cost of 7 ¢ per barrel was the only unit process required to generate this industrial grade water. The treated water would improve the steam quality and lower the maintenance cost of water and steam infrastructure systems at the Placerita Oil Field.

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TABLES

Table 1. Summary of Produce Water and Water Quality Goals

Parameter	Raw Water	Goal	Average Percent Removal
Total Dissolved Solids	~6,000 mg/L	≤ 500 mg/L	92
Temp	150-175 F	≤85 F	47
Boron	~15 mg/L	≤ 1 mg/L	93
Ammonia	~13 mg/L	≤ 1 mg/L	92
Sulfide	~10 mg/L	< 0.05 mg/L	99.5
Iron	1-5 mg/L	< 0.3 mg/L	90
Total Organic Carbon	~120 mg/L	≤ 1 mg/L	99

Table 2: Summary of Pilot Testing Plan

Pilot Phase	Water Quality Objective	Controlling Water Quality Goal	Pilot Plant Operational Testing Strategy
1	Improve steam quality and deep well injectability of produced water	Hardness <600 mg/L as CaCO3; Silica <100 mg/LWith DensaDeg only on-line,	Vary pH up to 10.8
2	Treat produced water so it meets irrigation discharge criteria	Boron is < 1 mg/LTo minimize DensaDeg sludge	Run RO at pH 9.6-10.8
3	Treat produced water so it meets potable water criteria	TOC is < 1 mg/L	Lower pH of RO to 8.0; Use Trickling Filter to reduce organic load

Table 3. Summary of Industrial Water Operating Scenario for DensaDeg Effluent

Parameter	Observations	Range	Median	Percent Removal
pH	5	8.34 - 8.76	8.6	N/A
Silica (mg/l SiO2)	4	66 - 101	87.5	64
Total Hardness (mg/l CaCO3)	4	164 - 226	194	83
Turbidity (NTU)	2	1.3 - 1.5	1.4	N/A
Oil and Grease (mg/l as per Nalco method)	4	5.3 - 8.6	6.6	56
Boron (mg/l B)	4	12.4 - 17	14.5	12

Table 4. Dissociation Reactions and pK values for Orthosilicic Acid and Boric Acid at 25 °C

Reaction	Value at 25 ° C	Value at 65 ° C	$(pK_1 + pK_2)/2$ at 65 ° C
$H_4SiO_4 = H_3SiO_4^- + H^+$	$pK_1 = 9.93$ (5)	$pK_1 = 9.95$	
$H_3SiO_4^- = H_2SiO_4^{2-} + H^+$	$pK_2 = 11.69$ (5)	$pK_2 = 10.15$	Silica = 9.70
$H_3BO_3 = H_2BO_3^- + H^+$	$pK_1 = 9.20$ (6)	$pK_1 = 8.11$	
$H_2BO_3^- = HBO_3^{2-} + H^+$	$pK_2 = 12.73$ (6)	$pK_2 = 11.21$	Boron = 9.66

Table 5. Planning Level Cost Estimates for 43,000 Barrel per Day Reverse Osmosis and Vapor Compression Systems

Desalting Technology	Percent Treated Water Recovery	Total Capital Cost (Million 1996 $)	Annual Operating Costs (Million 1996 $/yr)	Operating Cost (1996 ¢/treated barrel)
Reverse Osmosis, including pretreatment	80	11	2.1 - 2.9	15-21
Mechanical Vapor Compression, including pretreatment	90	29	6.1	43
Mechanical Vapor Compression, Seeded Slurry	98	28	7.7	54

Table 6. Cost Breakdown for Reverse Osmosis System

Process	**Total Capital Cost (Million 1996 $)**	**Annual Operations Cost (Thousand 1996 $)**	**O & M Cost (1996 ¢/ barrel treated)**
Warm Softening*	2.3	1,000 - 1,800	7-13
Cooling	0.6	60	0.4
Fixed-Film Organics Removal	1.0	50	04
Sand Filtration	1.3	130	0.9
Ion Exchange Softening	1.3	150	1
Reverse Osmosis	4.1	600	4
Stabilization/Disinfection	0.2	60	0.4
Total	**11**	**2,100 - 2,900**	**15-21**

* Operating costs depend on operational strategy.

Table 7. Values Assigned to Generic Cost Factor

Parameter	Value	Unit
Capital		
Dollar	1996	index year
Mobilization and Bonding,	50	percent of facilities costs
Site Preparation, Contractor s Overhead and Profit, and Contingencies		
Indirect Costs, including Legal and Administrative	38	percent of construction bid costs
O&M		
Electricity Rate	0.05	$ per kW hr
Labor Rate	30	$ per hr

FIGURES

Figure 1. Location of project, Placerita Oil Field in the coastal basin in southern California.

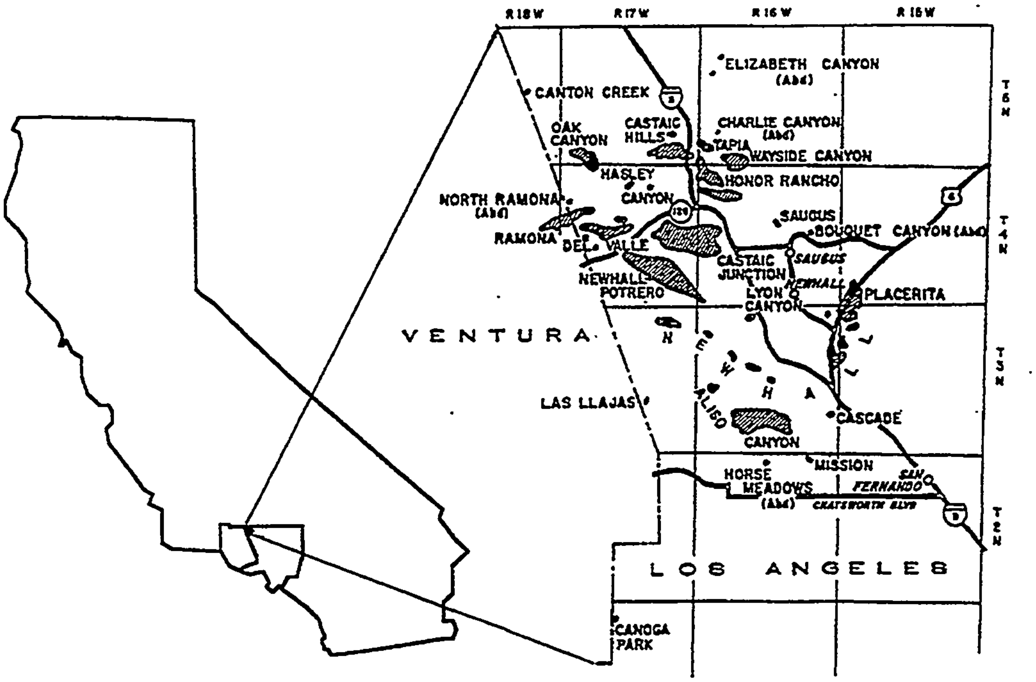


Figure 2. Pilot plant process schematic.

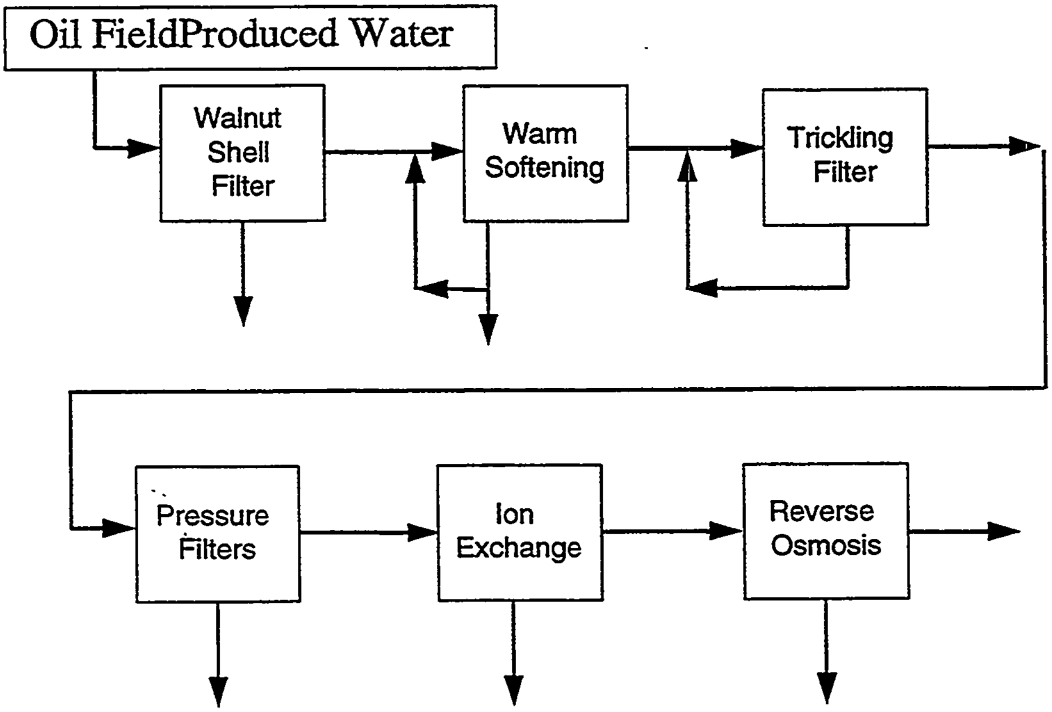


Figure 3. Comparison of pilot scale versus bench or field titration of caustic to obtain a target pH.

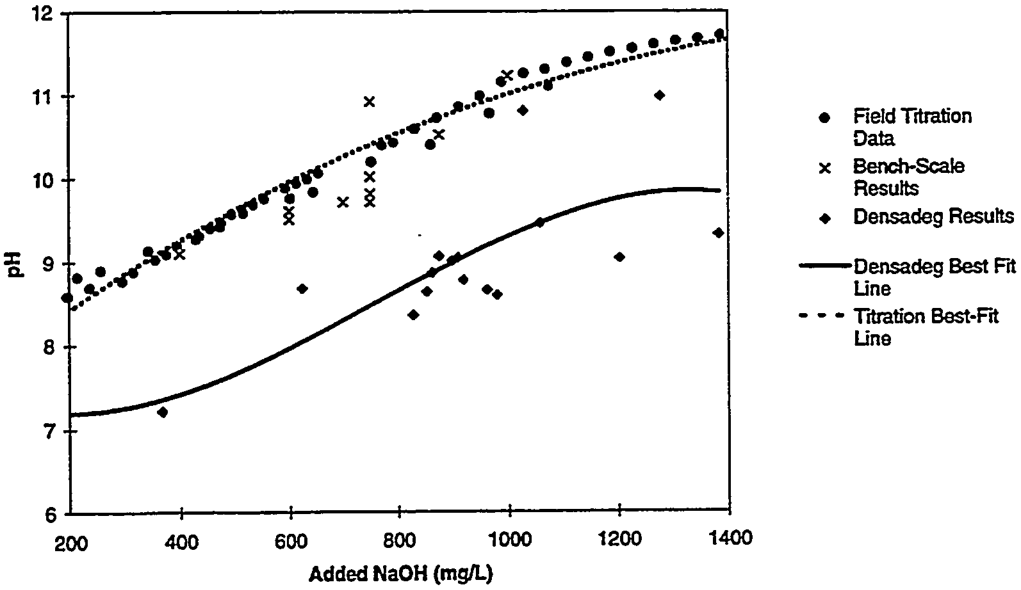
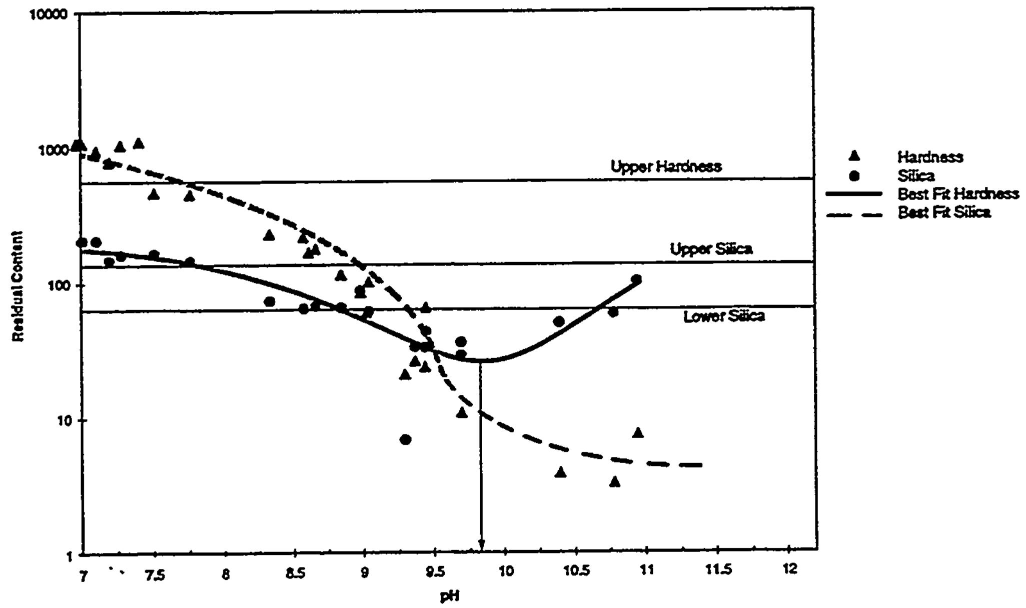


Figure 4. Residual DensaDeg clarifier effluent concentration of total hardness and silica after warm softening treatment at different pH s.



TREATING OIL FIELD PRODUCED WATER TO DRINKING WATER STANDARDS: PILOT-SCALE EVALUATION

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American Water Works Association
Water Quality Technology Conference
November 9-12, 1997
Denver, CO

INTRODUCTION

This paper presents preliminary results from a recently completed pilot plant study to help demonstrate the feasibility of treating oil field produced water to present and anticipated California potable and reclaimed water quality standards. Key pilot study goals include the removal of total dissolved solids (TDS), total hardness, silica, boron, ammonia, and total organic carbon (TOC) by a membrane based desalting system. Pretreatment included warm precipitative softening, biological treatment, filtration, and ion exchange. If this project is successful, it will benefit water utilities located near oil fields that need additional water resources and water users in general that will benefit from having a new, drought-resistant water supply.

BACKGROUND

The goal of this project is to convert a currently unusable by-product of oil production, produced water, into a valuable drinking water resource. To accomplish the project goal, the project team has built a pilot plant to treat oil field produced water to current and anticipated California potable and reuse water standards. Earlier studies (1,2,3) have had similar objectives, but the drinking water regulations have significantly changed(4).

The project site is the Placerita Oil Field which is located in the County of Los Angeles near the City of Santa Clarita, California (Figure 1). The project was divided into two phases: Phase I (research and planning) and Phase II (pilot testing). Table 1 summarizes the key water quality goals to be met through treatment for this project. After a literature review and a planning level cost estimate, a membrane based desalting system was selected. A detailed description of this effort is presented elsewhere (5). Table 2 summarizes the pilot study that was designed to meet three potential water resource uses, industrial, irrigation, and unrestricted potable water. The three treatment goals were to: 1) determine the optimal chemical dose of the warm softening unit that resulted in <600 mg/L hardness and <100 mg/L silica; 2) determine an operating scenario for irrigation water (removing boron from ~15 mg/L to ~1 mg/L); and 3) determine an operating scenario for potable water by reducing the TOC to 1 mg/L from ~120 mg/L. This paper reports only on the result of the second two objectives. The first objective has been reported elsewhere(6).

Several entities with diverse interests are contributing funds to this project. They include the US Department of Energy, ARCO Western Energy, a wholly owned subsidiary of Atlantic Richfield Company, Castaic Lake Water Agency, Electric Power Research Institute Chemicals and Petroleum Office, Southern California Edison, the National Water Research Institute and Kennedy/Jenks Consultants.

The diverse sources of funding for the project reflect the wide range of potential beneficiaries that have an interest in the success of the project, including:

1) Oil companies that dispose of produced water through costly underground injection at high pressures or use produced water with poor steam quality due to high silica and total hardness for tertiary recovery;

2) Oil refineries that may be able to use these technologies to recycle water at their facilities;

3) Water utilities that need additional water resources and are located near a producing oil field;

4) Large housing developer and industrial manufacturing complexes that must identify their own sustainable water resources before they can build their projects.

PROJECT STRUCTURE

This project is intended to develop regulatory guidelines and design criteria that are applicable throughout California for conversion of produced water to a water resource. The development of state-wide criteria would substantially decrease the future permitting time and cost for similar projects in California. As a result, the project is structured to solicit input from members of the drinking water treatment and reclamation community, including staff of state regulatory agencies. If the project is successful, a 1.8 million gallon per day (mgd) [43,000 barrel per day] treatment plant may be built in Santa Clarita, California.

Supporting this project is a technical review panel, an independent panel organized under the auspices of the National Water Research Institute. The responsibility of the panel is to provide a scientific critique of the work plans and products to assist the regulatory agencies in determining the scientific merits of the data. In addition, there is a project advisory committee composed of interested parties who have contributed research funds or bring special expertise or experience to assist the conduct of this study.

PILOT PLANT DESCRIPTION AND OPERATION

Produced water requires treatment for a number of water quality constituents depending on the intended water use. In California, there are no current regulations covering the use of treated produced water for drinking or reclamation. There are extensive federal and state regulations for drinking water using traditional potable water resources. California has extensive reclamation standards and design criteria for treatment of domestic wastewater for a direct beneficial or controlled use augmenting the potable water resource. For planning and evaluating potential technologies, the most stringent water quality goals have been identified to provide the greatest flexibility and economic value of the produced water. As a result, potable drinking water became the goal for this project. Figure 2 is a summary schematic of the pilot plant treatment process that was constructed at the Placerita Oil Field.

Influent

Influent for the pilot plant comes from ARCO Western Energy s WEMCO induced gas flotation cell WF-2. The unit's is designed to deliver water with 0-5 ppm oil and grease. Water is taken from a recirculation line with approximately 20 psig of pressure and a temperature of approximately 160 ¡F.

Warm Softening

Warm precipitative softening for silica and hardness removal was the first step in the treatment process. Sodium hydroxide (caustic soda), magnesium chloride, and an anionic polymer were added to the water to induce precipitation and aid in flocculation. The polymer was ChemTreat P-813E which is an anionic polyacryamide polymer in a water-in-oil emulsion manufactured by ChemTreat. The polymer dosage ranged from 3 to 6 ppm (liquid volume basis). This polymer is a concentrated solution of 35% dry weight polymer.

The caustic soda dosage was varied to achieve the desired pH. During pilot phases 2 and 3, the pH of the warming precipitative softening process was targeted for a range of 9.6 to 9.8, where the process can be optimized for silica precipitation as magnesium silicates (9). Bench scale tests performed for the first phase of this project suggested that boron could also be removed at this pH with the magnesium silicates if sufficient magnesium chloride (over 800 mg/L) is added (7).

The warm softening was accomplished with a DensaDeg unit provided by Infilco Degremont, Inc. The unit includes a reaction tank and upflow clarifier with lamella separators. Sludge thickening was accomplished as a sludge blanket developed in the upflow clarifier. The unit is a 20-100 gpm prototype that can operated at approximately 100 gpm to provide a rise rate of 10 gpm/ft2 in the clarifier. Sludge was periodically blown-down manually.

Cooling

Cooling was necessary to protect components of treatment processes such as plastic packing media and thin-film composite reverse osmosis (RO) membranes. The highest allowable temperatures for these processes is approximately 100 ¡F, and a design cooled water temperature of 90 ¡F was used. The pilot study utilizes fin-fan heat exchangers.

pH Control

A chemical feed pump provides the ability to lower the pH of the water, if required. When the operational pH of the DensaDeg is > 9.5, the pH was lowered to this level to protect the biological process.

Trickling Filter

Biological oxidation of organics was the next step in the full treatment train. Based on the literature (8,9), it was hypothesized that a large fraction of the organics would be organic acids. A trickling filter was selected to evaluate biological organic oxidation at a range of loading rates. The goal for organics removal was 80 to 90 percent removal of soluble BOD to lessen organic fouling of membranes and achieve an RO permeate with less than 2 mg/L TOC.

Preliminary evaluation using a non-acclimated seed, the bio-chemical oxygen demand (BOD) of the produced water was approximately 20 mg/L. The total organic carbon (TOC) was approximately 120 mg/L and chemical oxygen demand (COD) measurements ranged between 350-450 mg/L. Based on these findings, the trickling filter was not expected to remove a large fraction of the organic content because of the low ratio of BOD to TOC or COD.

The trickling filter was 5 feet in diameter with 20 feet of Q-PAC from Lantec Products, Inc. Q-PAC is made of polypropylene, has a nominal diameter of seven inches, there are six pieces per cubic foot, 30 square feet of surface area per cubic foot of media, and a void fraction of 97.5 %. There was approximately 400 cubic feet of packing material in the trickling filter. Hydraulic and organic loadings could vary between 0.5 - 2.5 gpm/ft2 and 6 to 300 lbs/1000 ft3 of media per day. For this study the trickling filter was operated at a hydraulic loading rate of 2.5 gpm/ft2 and an organic loading rate of 20 lbs/1000 ft3 of media per day.

During the first two phases, this unit process was bypassed to acclimate the bacteria to the produced water substrate. The unit was operated on a batch mode with weekly changes of the warm softened water. Continuous operation of this unit process in a flow through mode was completed on August 29, 1997, but results are not currently available.

Pressure Filtration

Two multimedia pressure filters were operated in parallel. The filters were 22 inches in diameter and have approximately 4 feet of multimedia filter material consisting of anthracite, sand, and garnet. With approximately 2.5 ft2 of area per filter, the hydraulic loading rate for the filters are approximately 2.5 gpm/ft2. During some of the trials a filter aid, ChemTreat P-822L, a cationic polyamine polymer manufactured by ChemTreat. was added at rates from 1.5 to 8.6 ppm (volume/volume basis). The filters were backwashed with RO permeate manually with down stream units (ion exchange and RO) off line.

Ion Exchange

Two cation exchange columns in parallel were used to remove divalent cations that might cause scaling in high-pH RO for half of the testing period. Each column contained approximately 5 ft3 of Ionac C-249 resin with a rated capacity approximately 25-30 kilo-grains per ft3. The high TDS of the water is expected to reduce the capacity of the resins by approximately 20 percent, so the expected capacity is approximately 20 kilo-grains per ft3. Regeneration is performed using a RO permeate for washing and making up the brine solution.

For a half of the test period the hardness from the DensaDeg was low enough (<15 mg/L CaCO3 Total Hardness) that the ion exchange units were bypassed.

Reverse Osmosis

A scale inhibitor PreTreat Plus 0100 Inorganic scale inhibitor/antifoulant manufactured by King Lee Technologies was added at 1 mg dry powder/L feed water to the RO unit. When operating the RO unit at pH < 9.6 and without the trickling filter on-line, an antifoulant, Protec RO Organic antifoulant, manufactured by King Lee Technologies was added at a 5 mg dry powder/L rate to minimize potential residual oil fouling. Adjustment of pH followed with caustic or sulfuric acid as required. The elevated pH was to examine the rejection of boron that was reported by Dyke et al (10). The reverse osmosis unit contained twelve 4 x 40 brackish water spiral wound elements, housed in 4 pressure vessels that were arranged in a 3-stage (2 x 1 x 1) array. The membranes were Fluid Systems XR extra-high rejection polyamide elements. The three stages and a concentrate recycle line facilitate tests at water recovery rates of 75 percent at inlet pressures as high as 600 psig.

Cleaning was performed when a pressure drop of 20 percent was observed. DIAMITE AFT RO cleaning solution manufactured by King Lee Technologies was used. Fifty gallons were made up by diluting 1:40 cleaner to water. For each cleaning the solution was circulated through system at 7 gpm and 60 psig for 1 hour.

PRELIMINARY PILOT PLANT RESULTS

The pilot plant was operated to meet three different water quality scenarios to refine the cost estimate of this water resource and are summarized in the Table 2. Although the field work has been completed, results only preliminary results for pilot phases 2 and 3 (portion without the trickling filter on line) are presented here. The phase 1 pilot phase work, involving use as an industrial water resource, is presented elsewhere (6).

Warm Precipitative Softening

During pilot phases 2 and 3, the DensaDeg clarifier was operated with a targeted pH of 9.6 to 9.8 and a magnesium chloride dose of approximately 99 mg/L (1 millimole/L). For data evaluated for this paper, the flow rate ranged from 24.3 gpm to 27.9 gpm (median of 27.0 gpm) and the softening pH ranged from 9.5 to 10.0 (median of 9.8), with caustic soda dose ranged from 739 mg/L to 1,0044 mg/L (median of 882 mg/L) and the magnesium chloride dose ranged from 81 mg/L to 117 mg/L (median of 98 mg/L).

The performance of the clarifier was based primarily on its ability to remove hardness and silica, and to a lesser degree, boron, as a pretreatment to reverse osmosis. Table 3 summarizes the raw water and clarifier effluent for total hardness, calcium, magnesium, silica, and boron during this operating period. Figure 3 shows the residual total hardness, silica, and boron as a function of warm softening pH during this period.

Hardness Removal. The warm softening process is very effective in removing total hardness, with removal ranging 96 to over 99 percent. The residual total hardness ranged from 10.8 mg/L to 53.8 mg/L as CaCO3, with most of the residual hardness represented by magnesium. The low hardness observed indicates that it may be handled by an anti-scalant rather than polishing with a cation softening for the full scale facility.

Silica Removal. During this period, silica removal ranged from 75.8 to 91.1 percent, with residual silica ranging from 16 mg/L to 42.1 mg/L. Thus, the project goal of silica in the 20 mg/L to 40 mg/L is achievable with the warm softening process.

Boron Removal. Boron removal ranged from about 16 to 32 percent, with residual boron levels ranging from 10.3 mg/L to 13.3 mg/L. Based on previous bench scale tests, modest boron removals were anticipated. The magnesium chloride dose would have to be increased substantially (400 mg/L to 800 mg/L), resulting in a significant quantity of sludge before additional removal would be expected.

Sludge. Sludge generation ranged from 3-6 percent on a volume basis. The wet solids on a weight basis ranged between 5-10 percent. The sludge was a non-hazardous waste based on California and US EPA standards. The sludge from the pilot operation was air dried, mixed with tank bottoms, and used as road mix at the oil field.

Reverse Osmosis Demineralization

During pilot phases 2 and 3, the reverse osmosis unit was operated at a feed rate of approximately 9.3 gpm, with a recycle flow rate of 4.7 gpm. The total permeate and reject flow rates were approximately 7.0 gpm and 2.3 gpm, with a product recovery of 75 percent. There were four operating conditions tested to evaluate the effect of pH on RO performance; namely, baseline condition without pH adjustment (pH 9.5(target), moderate pH increase (pH 10.0(target), high pH increase (pH 10.5(target), and reduced pH (pH 8.3(target). The primary purpose of varying the pH was to determine its impact on boron, silica, TOC, and ammonia removal, since all of these constituents would potentially be impacted by pH selection. Specifically, boron and silica removal would be better removed at higher pH (above 10.5) where they are more ionized, while ammonia and TOC would be better removed at lower pH's (below 9.0) where they are more ionized.

Table 4 provides a summary of the RO feed and permeate water quality during these four RO operating conditions. Figure 4 illustrates the impact of influent pH on boron, TOC, and TDS removal over the pH range of 8.0 to 10.7. The RO unit performance for removing individual constituents are briefly discussed below.

Boron Removal. Boron removal was as expected. Its removal is highly dependent on the RO feed pH, as shown by Figure 3 and Table 4. The best boron removal (over 80 percent) was achieved at pH 10.6 to 10.8, with corresponding permeate boron concentrations of 1.5 to 2.3 mg/L. This indicates that the RO unit would need to be operated at pH greater than 10.6 which was above the manufacturer's recommendation for the membranes to approach the project goal of 1 mg/L boron. Under the best removal scenario with these membranes, the treated water might have to be blended with a low boron water source for irrigation of sensitive plants.

TDS Removal. TDS removal ranged 96 to over 98 percent, with permeate TDS ranging from 78 mg/L to 219 mg/L. TDS removals decrease with increasing pH, but was well below the treatment goal of 500 mg/L. Thus, the permeate may be suitable for blending with moderately high TDS (around 1,00 mg/L) water sources with low boron levels.

TOC Removal. TOC removal ranged from approximately 93 to over 98 percent, with permeate TOC ranging from 1.3 mg/L to 6.7 mg/L. The TOC goal of 1 mg/L was approached only at pH below 9.0. However, Figure 3 indicates that TOC removal would suffer at the optimum boron removal condition (pH >10.6), with permeate TOC levels of 2.1 to 6.7 mg/L. Thus, either additional removal through a biological process or polishing with granular activated carbon may be required to achieve this treatment goal.

Ammonia Removal. Based on the limited ammonia data available to date, the ammonia removal achieved by the RO unit was quite variable, ranging from approximately 2 to 76 percent, with permeate ammonia levels ranging from 0.9 to 5.6 mg/L. Ammonia removal was also influenced by the pH of the RO feed, with better removals at pH below 9.0, where the ammonium ion predominates.

Disinfection By-Product (DBP) Formation Potential. Tests with the permeate to determine the potential for forming DBPs such as trihalomethanes and haloacetic acids upon chlorination have not yet been performed. However, the relatively low TOC and the presence of residual ammonia, which would form chloramines, suggest that the DBP formation potential of the permeate should be low.

FINAL RESULTS

The complete results for the entire pilot study will be available in December 1997. Additional results to be evaluated include the following operating scenarios: 1) increasing the magnesium dose to 400-800 mg/L in the DensaDeg to meet the boron treatment goal of < 1 mg/L and 2) placing the trickling filter in service in combination with a pH 8.5 (low pH) to meet the TOC treatment goal of 1 mg/L.

CONCLUSIONS

The preliminary pilot plant results indicate that the TDS goal can be met and that hardness and silica can be readily controlled. Blending RO permeate with a moderately high ((1,000 mg/L) TDS water may be necessary to achieve other reuse or unrestricted potable water goals. The tradeoffs between boron and TOC removal appear to be the area of greatest technological challenge where future efforts must be focused. If this project is successful, it will benefit water utilities located near an oil field that need additional water resources, oil companies that currently dispose of produced water through costly underground injection, and water users in general that will benefit from having a new, drought-resistant water supply.

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Table 1
Typical Placerita Produced Water Quality and Treatment Goals

Water quality parameter	Typical produced water value	Treatment goal
Temperature (° F)	170	75
pH (s.u.)	6.5	6.5 - 8.5
Ammonia (mg/l-N)	<13	£1
Total organic carbon (mg/l)	~120	<1
Total hardness (mg/l as $CaCO_3$)	~1,200	70±
Total dissolved solids (mg/l)	~6,000	£500
Silica (mg/l)	200^+	20 - 40
Boron (mg/l - B)	~15	£1

Table 2
Summary of Pilot Testing Plan

Study Parameter	Pilot Phase 1	Pilot Phase 2	Pilot Phase 3
Water Quality Objective	Improve steam quality and deep well injectability of produced water	Treat produced water so it meets irrigation discharge criteria	Treat produced water so it meets potable water criteria
Controlling Water Quality Goals	T. hardness <600 mg/L as $CaCO_3$ Silica<100 mg/L with DensaDeg only on line	Boron<1 mg/L to minimize DensaDeg sludge	TOC<1 mg/L
Pilot Plant Operational Testing Strategy	Vary pH up to 10.8	Run RO at pH 9.6 to 10.8	Lower pH of RO to 8.0 Use trickling filter to reduce organic load

Table 3
Warm Softening Results

Process parameter	Minimum	Maximum	Median
Process pH*	9.51	10.02	9.68
Total hardness*			
influent (mg/L as $CaCO_3$)	860	1470	1160
effluent (mg/L as $CaCO_3$)	10.8	53.8	22.2
% removal	96.0	99.1	98.0
Calcium*			
influent (mg/L)	25.7	478	299
effluent (mg/L)	1.4	5.9	3.3
% removal	97.8	99.5	99.0
Magnesium*			
influent (mg/L)	13.0	167	99.0
effluent (mg/L)	1.3	9.8	3.2
% removal	51.3	98.6	97.1
Silica*			
influent (mg/L)	136	260	189
effluent (mg/L)	16.0	42.1	23.2
% removal	75.8	91.1	87.7
Boron			
influent (mg/L)	14.3	17.6	16.3
effluent (mg/L)	10.3	13.3	12.6
% removal	16.1	32.2	22.4

*Field measurement
Laboratory analysis

Table 4
Performance of Reverse Osmosis Unit

Process parameter	Baseline (no pH adjustment)	Moderately high pH adjustment	High pH adjustment	Low pH adjustment
Process pH				
RO feed	8.6 - 9.5 (9.1)*	9.4 - 10.1 (10.0)	10.6 - 10.8 (10.7)	8.2 - 9.0 (8.3)
permeate	9.4 - 10.8 (10.5)	10.06 - 11.08 (11.0)	10.7 - 11.3 (11.0)	8.2 - 10.0 (8.9)
TDS				
RO feed, mg/L	5,000 - 5,695 (5,297)	5,548 - 5,700 (5,700)	5,113 - 5,876 (5,773)	5,894 - 6,184 (6,000)
permeate, mg/L	78 - 158 (114)	70 - 197 (127)	108 - 182	122 - 219
% removal	97.1 - 98.6 (97.6)	96.8 - 98.8 (98.3)	96.4 - 97.3 (97.1)	96.4 - 97.9 (97.5)
Boron				
RO feed, mg/L	11.8 - 13.1 (12.5)	10.7 - 12.7 (12.1)	13.3 - 15.1 (13.8)	12.8 - 13.3 (13.1)
permeate, mg/L	3.2 - 6.8 (4.3)	3.0 - 5.2 (4.6)	1.5 - 2.3 (2.2)	5.4 - 8.5 (6.4)
% removal	45.6 - 73.3 (66.4)	51.4 - 75.6 (63.8)	83.3 - 88.7 (85.0)	36.1 - 57.8 (50.7)
TOC				
RO feed, mg/L	88 - 115 (97)	101 - 117 (109)	66 - 95 (83)	74 - 100 (87)
permeate, mg/L	1.3 - 2.0 (1.9)	2.0 - 3.7 (2.4)	2.1 - 6.7 (2.6)	1.8 - 2.7 (2.4)
% removal	97.9 - 98.5 (98.2)	96.3 - 97.9 (97.9)	92.9 - 97.5 (96.6)	96.5 - 98.1 (97.2)
Ammonia				
RO feed, mg/L	3.6 - 6.0 (5.6)	3.7 - 5.4 (5.3)	n.a.**	n.a.**
permeate, mg/L	0.9 - 5.6 (3.0)	2.5 - 5.6 (5.0)	n.a.**	n.a.**
% removal	1.8 - 75.5 (49.1)	0 - 32.4 (4.7)	n.a.**	n.a.**

*( ) = median value for range shown

**Data not available yet

Figure 1. Placerita Oil Field Location

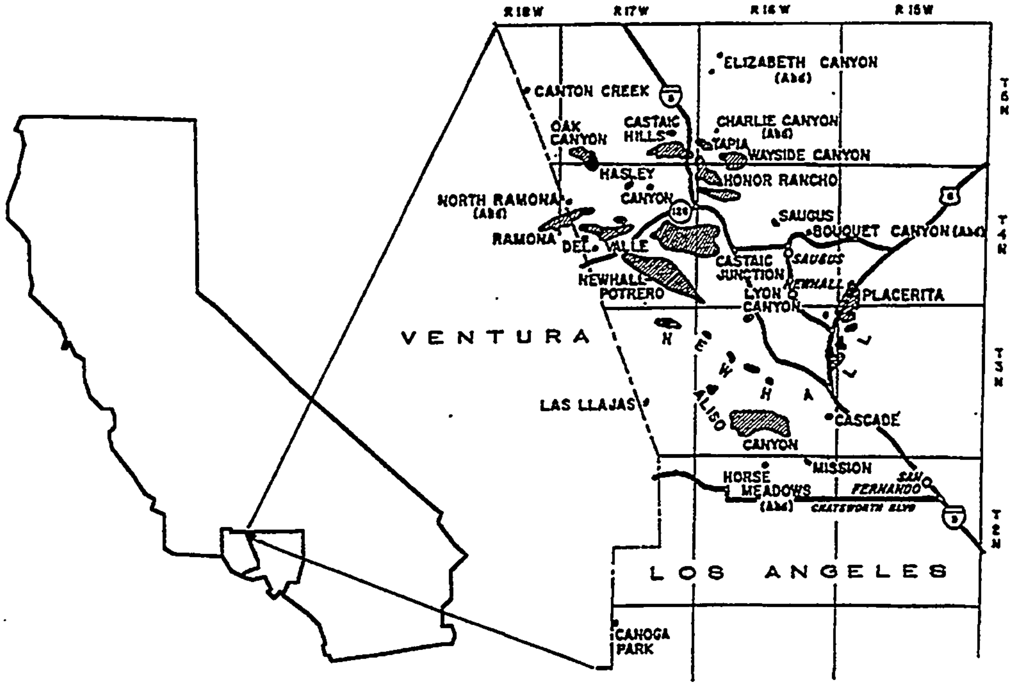

Figure 2. Pilot Plant Schematic

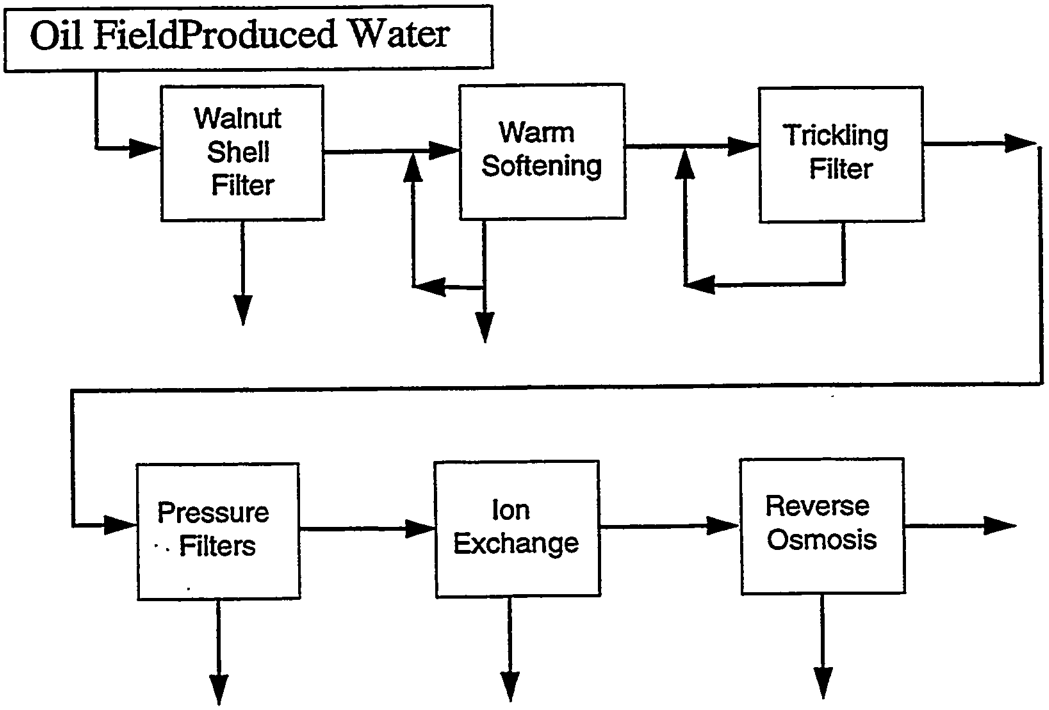

Figure 3. Effect of pH on Clarifier Effluent Quality

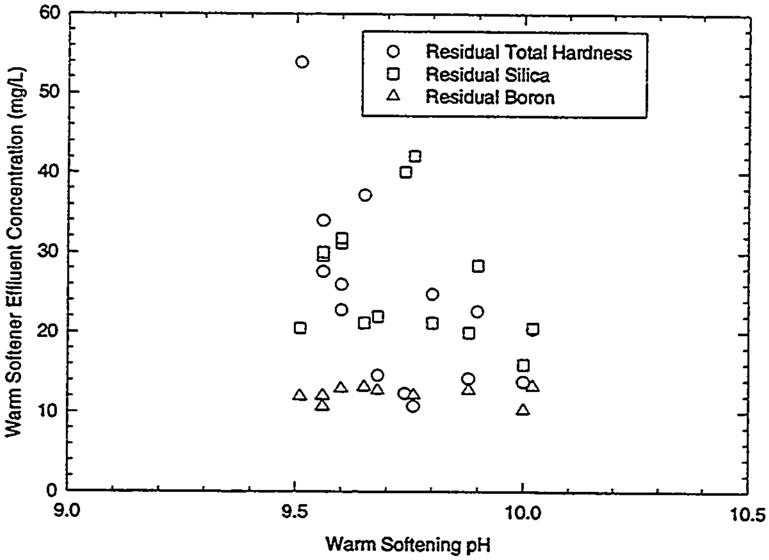

Figure 4. Effect of pH on Reverse Osmosis Unit Performance