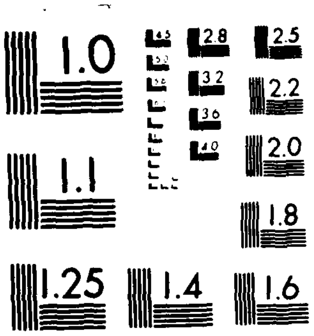
AD-A128 756 POTABLE WATER TREATMENT FOR DIEGO GARCIA(U) NAVAL CIVIL ENGINEERING LAB PORT HUENEME CA D B CHAN ET AL. JAN 83 1/1
NCEL-R-898

UNCLASSIFIED F/G 13/2 NL

END
DATE
FILMED
6 83
DTIC



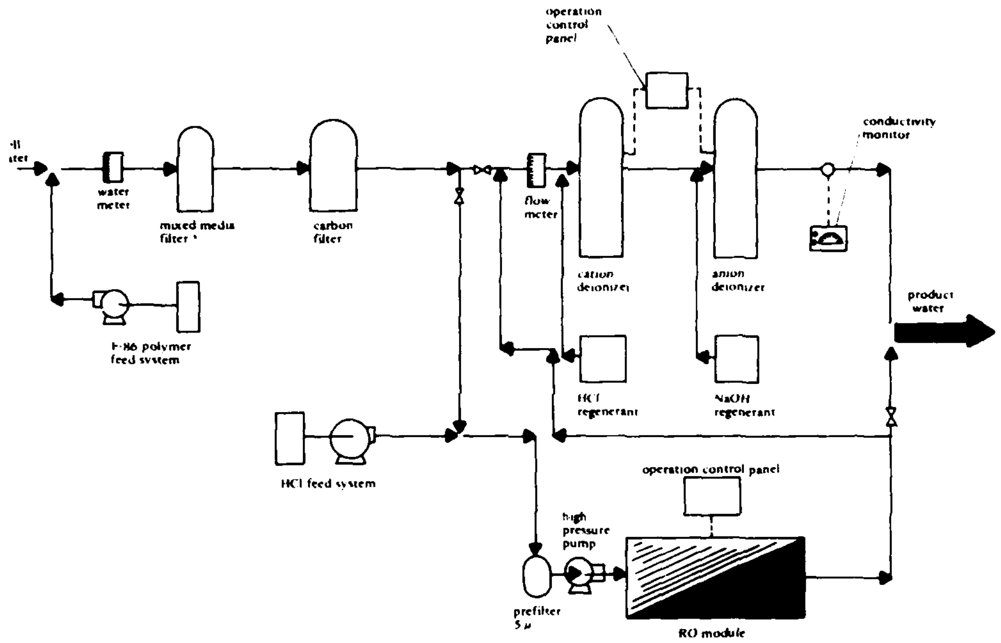
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

12

Potable Water Treatment for Diego Garcia

by D. B. Chan and J. S. Williams

January 1983



Technical Report R-898

Naval Civil Engineering Laboratory
Port Hueneme, California 93043

Sponsored by
Naval Facilities Engineering
Command
Pacific Division

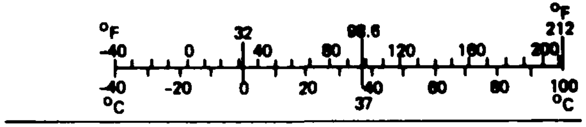
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



---

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

12

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-898	2. GOVT ACCESSION NO. DN087326	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) POTABLE WATER TREATMENT FOR DIEGO GARCIA		5. TYPE OF REPORT & PERIOD COVERED Final; May 80 - Sep 82
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) D. B. Chan and J. S. Williams		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVAL CIVIL ENGINEERING LABORATORY Port Hueneme, California 93043		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS OMN 54-013
11. CONTROLLING OFFICE NAME AND ADDRESS Pacific Division, Naval Facilities Engineering Command Pearl Harbor, HI 96860		12. REPORT DATE January 1983
		13. NUMBER OF PAGES 72
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document has been approved for public release and sale; its distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

Approved for public release; distribution unlimited

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Water treatment; drinking water; cost effectiveness; Diego Garcia; prototypes; reverse osmosis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents an engineering investigation for the development of a cost-effective water treatment system to be used at Diego Garcia. The system must effectively remove or reduce TDS, color, taste and odor, turbidity, and the excessive amounts of organics and microorganisms so that all EPA's drinking water standards can be met. A three-stage water treatment system consisting of a multi-media filter, a carbon filter and an RO system was tested at Diego Garcia and proved to be the most cost-effective treatment process.

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Library Card

Naval Civil Engineering Laboratory
POTABLE WATER TREATMENT FOR DIEGO GARCIA
(Final), by D. B. Chan and J. S. Williams
TR-898 72 pp illus January 1983 Unclassified
1. Water treatment 2. Drinking water I. 52-013

This report documents an engineering investigation for the development of a cost-effective water treatment system to be used at Diego Garcia. The system must effectively remove or reduce TDS, color, taste and odor, turbidity, and the excessive amounts of organics and microorganisms so that all EPA's drinking water standards can be met. A three-stage water treatment system consisting of a multi-media filter, a carbon filter and an RO system was tested at Diego Garcia and proved to be the most cost-effective treatment process.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

CONTENTS

A

Page

APPENDIXES

INTRODUCTION

The water supply at Diego Garcia and at many other Naval installations in CONUS and overseas is very hard and has poor palatability due to contaminants, such as total dissolved solids (TDS), turbidity, color, taste, and odor. Hard water causes scaling in pipelines, reduces the life of boilers, cooling towers, and other heat exchange elements. On the other hand, high TDS, turbidity, color, taste, and odor reduce water palatability and affect personnel morale.

The wells supplying water at Diego Garcia possess all the contaminants described above and some exceed the U.S. Environmental Protection Agency's (EPA) and the Navy Bureau of Medicine (BUMED) recommended secondary drinking water standards. In addition, excessive quantities of organics and microorganisms also exist in the raw well water.

The treated water quality now existing at Diego Garcia, however, does meet the primary (mandatory) drinking water standards and most of the recommended secondary drinking water standards. For the success of the Navy's mission and Fleet readiness, a high quality water that meets all of EPA secondary drinking water standards is desirable at Diego Garcia if it can be feasibly attained.

The objective of this engineering investigation, sponsored by Pacific Division, Naval Facilities Engineering Command (PACNAVFACENGCOM) (Ref 1), is to develop a cost-effective water treatment system that would effectively remove or reduce TDS, color, taste, odor, turbidity, and the excessive amounts of organics and microorganisms so that all EPA standards can be met. The developed water treatment system will also have to meet other critical criteria: (a) minimum logistic support requirement, (b) low level skill and manpower to operate and maintain the system, and (c) capable of treating water containing high concentrations of TDS and other contaminants due to anticipated population increase and overdraft of wells causing water quality to degrade.

A series of water treatment components was evaluated by the Naval Civil Engineering Laboratory (NCEL), and a three-stage process was selected for test and evaluation at Diego Garcia. The system, consisting of a multi-media filter with a chemical feeder; a carbon filter and the demineralizing component, a cation-anion deionizer and a reverse osmosis (RO) system was fabricated. The water treatment system had a design capacity of 20-gpm.

The water treatment system was installed at the Final Water Plant, Diego Garcia, on 13 March 1981, and was tested and evaluated during the period of 1 April and 5 August 1981. The water meters recorded that 570,000 gallons of water was produced by the deionizer and 1,033,000 gallons of water was produced by the RO system during the testing period. The product water possessed superior quality and far exceeded the EPA's standards. The results, conclusions, and recommendations of the water treatment system at Diego Garcia are summarized in this report.

BACKGROUND

The Navy's mission at Diego Garcia has expanded significantly during the last few years. This ever increasing military operation demands a larger quantity and a standard quality water supply for the personnel deployed on the island. At present the raw groundwater supply, which fulfills the larger quantity requirement, does not meet all of EPA's secondary drinking water standards.

Some simple treatment systems are currently being used or are under construction at Diego Garcia. These systems include ultraviolet disinfection at the well fields, and aeration and chlorination at the Final Water Plant. The aeration and chlorination systems are currently in operation. The ultraviolet disinfection has been installed in most areas and should be in operation shortly. These systems treating and producing a composite water supply on Diego Garcia are expected to meet all secondary drinking water standards except those for removing TDS. It should be noted, however, that the aquifer has been degraded by locally high pumping rates and periodic droughts, causing a number of wells to upcone.

The groundwater quality at Diego Garcia is compared to EPA's standards as follows:

Parameters	EPA Standards	Diego Garcia Wells (Range)	Composite[a] of Wells (Range)
TDS (mg/l)	500	270-1540	400-600
Turbidity (JTU)	1	3	1-3
Color	15	+20	20-30
Odor	3	3	3
Chloride (mg/l)	250	25-400[b]	75-130
Total Hardness (mg/l)[c]	No Std. 150-300 is Hardwater	160-480	160-200
Microorganisms[c] (SPC)	No Std.	10^4-10^5	---
Total Coliform (MFC)[c]	1 coliform/100 ml	---	<1
Organic Chemicals[c]	No Std.	---	---

[a] Water sample taken from the raw water tank at the Final Water Plant.

[b] Well pumping instruction requires that pumping be terminated when chloride concentration exceeds 250 mg/l.

[c] Additional contaminants that need to be removed. Total hardness is directly related to the TDS and turbidity problem, while organic chemicals are the major cause of color, taste, odor and excessive growth of microorganisms.

The three-stage treatment process for this project was designed to function as follows:

Stage	Unit Process[a]	Major Removal/Reduction Parameters
1	Multi-Media Filter with Chemical Feeder	Turbidity, microorganisms
2	Carbon Filter	Color, taste, odor, and organics
3A	RO System	TDS, hardness, chloride, organics, microorganisms, turbidity, color, taste, and odor.
3B	Cation-Anion Deionizer	TDS, hardness, chloride

[a] Stage 1 and 2 unit processes are considered to be pretreatments for the RO and deionizer systems.

The RO process was selected for test and evaluation based on criteria established by NCEL. The RO possesses many advantages over other water purification methods; e.g., low energy consumption, low maintenance, is not sensitive to TDS concentration, etc. The RO like other membrane processes may require pretreatment of the feed water to prevent the membrane from fouling. Therefore, additional treatments (including pretreatment requirements) membrane fouling characteristics, and membrane cleaning requirements had to be evaluated prior to being used at Diego Garcia.

The ion-exchange deionization process was selected for testing because of its better known, field-proven technology. However, the ion exchange process requires a large quantity of chemical regenerants that could create a logistic burden on the Navy. The ion-exchange process may be used in the future to furnish high quality water for such uses as: injection water for aircraft takeoff, batteries, as an engine coolant, and boiler feed.

As indicated in the comparison of water quality between the wells (current raw water supplied at Diego Garcia) and EPA standards, the primary objective of this project is to reduce the TDS content in the water. In addition, the pretreatment required for the use of an ion-exchange deionizer or RO demineralizer would aid in the final removal of turbidity, color, taste, odor, and excessive organics. More importantly, should the groundwater quality degrade further due to upconing, drought, or man-made pollution, the three-stage water treatment system tested will provide the treatment required.

Specific objectives for the test and evaluation of the water treatment system are:

1. Determine the capability of the three-stage water treatment system to meet EPA/BUMED drinking water standards.

2. Identify additional treatments including pretreatment requirements.

3. Define ion-exchange resin and RO membrane fouling characteristics and their regeneration and or membrane cleaning requirements.

4. Determine reliability and maintainability of the water treatment system components and evaluate their applicability at Diego Garcia.

5. Assess product water scaling and corrosion potential.

6. Analyze test data for preparation of design criteria for a feasible water treatment system.

7. Investigate* the total amount of trihalomethanes (TTHMs) in the well water, the water supply, and the product water of the water treatment system (before and after chlorination). The capability of the water treatment system to remove TTHMs and TTHMs' precursors must be determined.

TEST EQUIPMENT AND OPERATION**

Water Treatment System

Multi-Media Filter. The Culligan HD-20 Depth Filter, the tank on the right-hand side of Figure 1, has a design flow rate of 20 gpm, a loading rate of 10 gpm/ft^2, and a backwash rate of 30 gpm. The filter contains about 6 ft^3 of multi-media materials, and the bed is approximately 33 inches deep. The filter tank is 20 inches in diameter and 54 inches long excluding the height of the supporting legs. An automated control system panel is built in for the filter operation and backwash. A space of 20 inches wide by 36 inches deep by 66 inches high is required for the filter. The filter can stand up to 100 psi operational pressure and temperatures ranging from 40°F to 120°F. The saturated filter weighs 1,600 pounds.

Activated Carbon Adsorber (Filter). The Culligan HR-24 Carbon Filter, the left hand-side tank of Figure 1, has a design flow rate of 20 gpm, a loading rate of 7 gpm/ft^2, and a backwash rate of 30 gpm. The filter contains about 6.5 ft^3 of Cullar D carbon, and the bed is approximately 25 inches deep. The filter tank is 24-inches in diameter and 54 inches long excluding the supporting legs. An automated control system panel is built in for the filter operation and backwash. A space of 25 inches wide by 40 inches deep by 67 inches high is required for the filter. The filter can stand up to 100 psi operational pressure and temperatures ranging from 40°F to 120°F. The saturated filter weighs about 2,150 pounds.

Ion Exchange Deionizer. Two Culligan AC-20W deionizers, Figure 2, are hooked up in a series, one for cation and the other for anion removal. The deionizers have a design flow rate of 10 gpm. The cation

---

*This objective was added by Reference 2.

**Further described in Reference 3.

resin (right-hand side tank) has an exchange capacity of about 230,000 grains expressed as $CaCO_3$, and the anion resin (left-hand side tank) has a capacity of 64,100 grains expressed as $CaCO_3$ per each regeneration cycle. The cation deionizer has 10 ft^3 of exchange material (CH-1 resin), and requires 20 gallons of 20°Be (31.4%) HCl to regenerate. The anion deionizer has 8 ft^3 of exchange material (CW-4 resin), and requires 5 gallons of 50% NaOH to regenerate. Each of the resin tanks is 20 inches in diameter and 84 inches long excluding the supporting legs. An automated control system panel is attached for the deionizer operation and regeneration. A space of 78 inches wide by 32 inches deep by 102 inches high is required for the two deionizer resin tanks hooked up in a series. The deionizer can stand 100 psi operational pressure, and will tolerate a temperature range of 45°F to 100°F. The deionizers weigh about 3,500 pounds each in operation.

Figure 1. Multi-media filter (right) and activated carbon adsorber (left).

Reverse Osmosis System. The Culligan KD-20 RO unit, Figure 3, has a design flow rate of 18 to 20 gpm. Nominal product water recovery is 75% initially. After 3 years, the recovery will be approximately 60%, due to membrane compaction and fouling. Final product water will contain about 10% of TDS in the feed water. The RO unit, a two-stage process, contains one DuPont B-9 hollow-fiber module (9-1/2 inches in diameter by 48 inches long by 47 inches wide) and one DuPont B-9 hollow-fiber module (5-1/4 inches in diameter by 47 inches long). The two stages are used to produce the maximum amount of product water from a given amount of feed water (one pass). The RO system is also equipped with a 5 μ prefilter (cartridge) and a 15 hp motor-pump assembly. The RO unit can tolerate 400 psi operational pressure and temperatures ranging from 40°F to 95°F. A space of 120 inches by 36 inches deep by 80 inches high is required for installation of the RO unit. The unit weighs about 1,725 pounds (dry).

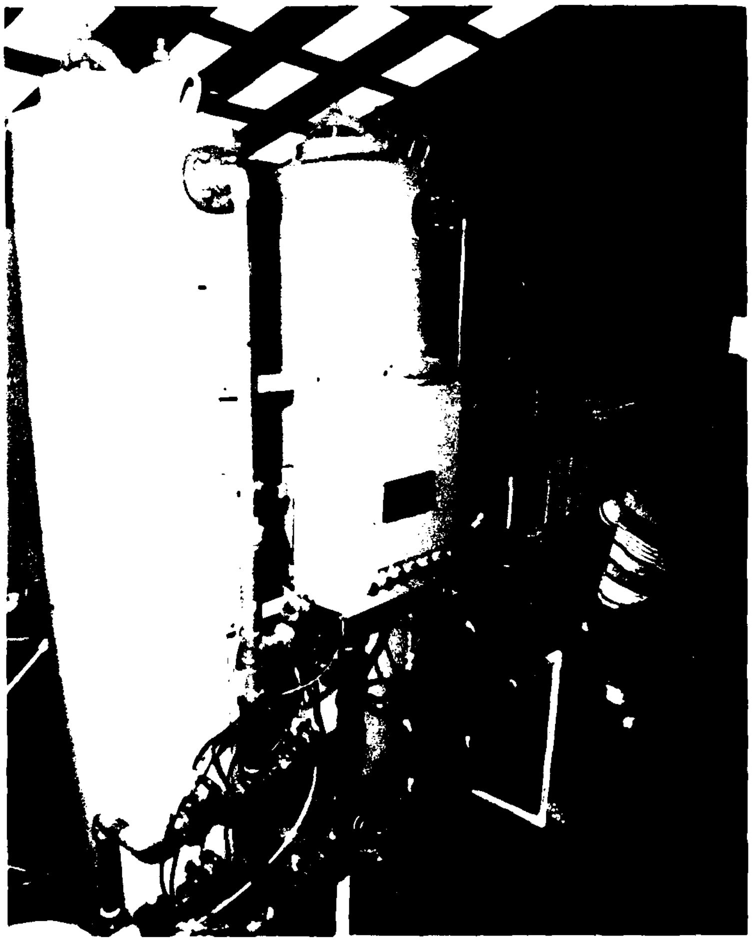


Figure 2. Ion exchange deionizer water treatment system

Accessories

Chemical Feeders and Feeder Systems. The Culligan DT-60A chemical feeder system was procured to feed F-86 into the feed water before RO treatment. F-86 is a highly active cationic liquid polyelectrolyte used in conjunction with the multi-media filter to remove a majority of the colloidal particles. The feeder system has a capacity of 60 gal/day and is equipped with a 40-gal chemical storage tank. A feed rate determination test procedure was provided by Culligan. A total of 90 gallons of F-86 concentrate was procured for field testing at Diego Garcia.

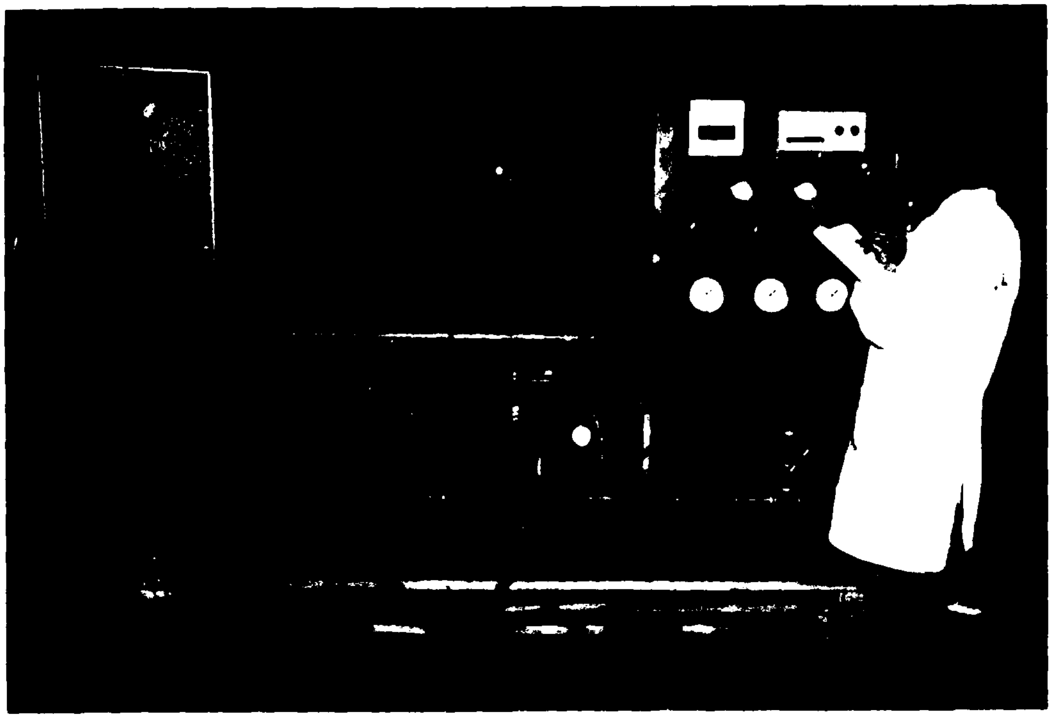


Figure 3. The reverse osmosis water treatment system.

Culligan Special pH Control. The Culligan pH monitor/controller was procured for use. The controller, with a shutdown feature, is designed to continuously feed 20°Be (31.4%) HCl at a preset rate, into the feed water of the RO unit. It will stop the acid feeder when the pH drops below a preset range of 5.2 to 5.6. The acid is used to control scale formation on the RO membrane.

Fouling Index Test Kit. Culligan supplied a fouling index test kit for determinating the quality of the feed water necessary to protect the RO membrane. Instructions for operating the test kit were provided by Culligan along with an RO unit operation manual.

Water Treatment System Installation and Operation

Installation and operation manuals for the water treatment system were provided by Culligan, and a list of these manuals can be found in Appendix A (a schematic of the water treatment system tested at Diego Garcia is shown in Figure 4).

TEST PROCEDURES, METHODOLOGY, AND RESULTS

Test and evaluation of the water treatment system at Diego Garcia was divided into six major parts. The test procedures, methodology, and sample collection and analysis are listed below and described in subsequent sections:

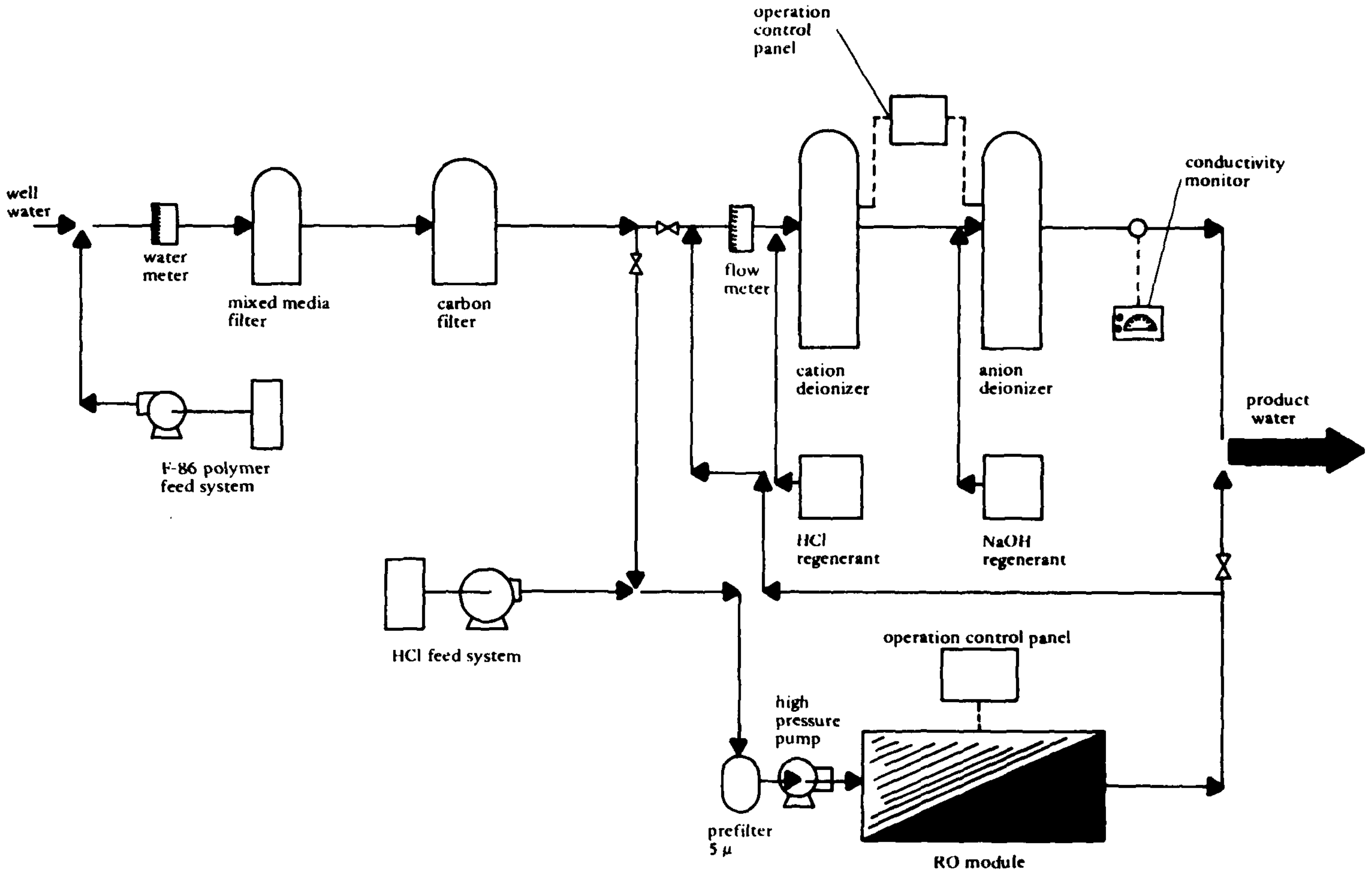


Figure 4. Water treatment system tested at Diego Garcia.

1. Monitoring the Well Water Quality
2. Identification of Pretreatment Requirements
3. Test of the Water Treatment System
4. Analysis of Water Samples for Total Trihalomethanes (TTHMs) Content
5. Sample Collection and Analysis
6. Milestones and Schedule

Monitoring the Well Water Quality

Individual wells were monitored daily to determine the amounts of TDS and chloride that were in the well water so that the impact on the water treatment system performance could be assessed. A sudden increase of TDS and/or chloride concentrations in well water means upconing and/or the intrusion of salt water. When chloride concentration was to exceed 250 mg/l, pumping would be terminated immediately in accordance with existing instructions.

The wells were monitored for additional water quality parameters at least once a week or as frequently as circumstances dictated. Grab water samples were considered satisfactory. The physical and chemical parameters tested and recorded are summarized and presented in Appendix B. A set of water quality field test kits was procured. They are listed below:

Test Kits and Parameters

Test Kits*	Parameters
P-5085/2119	pH
CWA/7611	Color
TTM/7519	Turbidity
WAT-DC/4491	Alkalinity
CC-PS/4630	Sulfide
MPSC-DR/7932	Chloride
EDO/7414	Dissolved oxygen (DO)
PHT-CM-DR/4824-DR	Total hardness, calcium hardness

*Procured from LaMotte Chemical Company.

Analytical procedures for using these kits were provided with each kit package. They are comparable to the HACH system and standard methods although their accuracies are somewhat lower. The kits were adequate for field use in terms of accuracy, time consumption, and manpower/skill requirements.

In addition, a TDS and dissolved solids (DS) test meter, made by Myron L. Meter Co., was used in the field. A Millipore Coli-Count Water Tester (MC 00 000 00) was used to test the coliform population in well and product water.

Identification of Pretreatment Requirements

The primary treatment objective is to reduce the TDS content from the current level of approximately 650 ppm to the EPA standard of below 500 ppm. In order to use the ion-exchange deionizer or the RO demineralizer effectively, preliminary pretreatment is necessary.

Several different pretreatment tests were conducted: two filters, a multi-media filter (first stage) and a carbon adsorption filter (second stage), were used in the water treatment system to provide the preliminary pretreatment of the raw water (or feed water) prior to its being processed through either an ion-exchange deionizer or RO demineralizer. The pretreatment of the feed water was designed to remove turbidity, suspended solids, color, taste, odor, excessive organics, and microorganisms in the water so that the product water would meet drinking water standards after deionization/demineralization. In the meantime, the ion-exchange resins and RO membrane would be protected through such pretreatment for a longer service time and useful life span.

Addition of acid to the RO system feed water was necessary in order to control scale formation on the RO membrane. As indicated previously, the pH of feed water must be maintained between 5.2 and 5.6, with 20°Be HCl.

Additional pretreatments were tested at the field site as alternatives and/or add-on processes for future applications. The pretreatments tested included addition of a polymer before filtration, an addition of NaOCl or H_2O_2, or a combination of these two chemicals to oxidize organics and kill microorganisms.

Another treatment process, which could be used in place of multimedia filtration, is slow sand filtration. This process has long been recognized in water treatment as an effective means of removing suspended solids and microorganisms. The Naval Facilities Engineering Command recommended that NCEL test the process in the field. Accordingly, a small bench scale set-up, using coral sand, was tested to determine its applicability.

All of the pretreatment alternative tests were conducted at Diego Garcia. The test results are presented in Appendix C.

Test of the Water Treatment System

The water treatment system consists of two mineral removal processes: a cation-anion ion-exchange deionizer and a RO demineralizer. Both components were tested for their effectiveness in removing TDS, chloride, hardness and other parameters. The reliability of operation and the requirements for maintenance were also evaluated. Test procedures for each of the water treatment systems are described as follows:

Ion-Exchange Deionizer. As indicated previously, a multi-media and a carbon adsorption filter was used for pretreatment of water to be fed into the ion-exchange deionizer. The deionizer has the capability of reducing mineral content (measured as TDS) in the feed water to 1 to 10 ppm. The ion-exchange capacity for the cation exchanger is about 230,000 grains expressed as $CaCO_3$ per regeneration cycle. A total of 30 regeneration cycles were run to determine the ion-exchanger capacity in the field situation. A mass balance was calculated to determine mineral removal effectiveness and efficiency of the ion exchanger. A Langelier Index (LI), for the ion-exchanger effluent, was calculated to assess the water's scaling or corrosion potential. Results of the deionizer operation are summarized and presented in Appendix D.

Reverse Osmosis Demineralizer. An RO demineralizer can remove not only the mineral content in the water but also other contaminants, such as organic chemicals and micro-organisms. During the test, the capability of the RO membrane to treat Diego Garcia water was thoroughly investigated. Fouling characteristics, the major concern for employing the RO process, was studied. To protect the membrane from fouling, pretreatment of the feed water was provided. A multi-media filter, a carbon adsorption filter, a polyelectrolyte feed an acid feed, and a 5 μ prefilter were the pretreatment components used in the RO water treatment system.

The polyelectrolyte F-86, a highly active cationic liquid polyelectrolyte, was used in conjunction with the multi-media filter to remove a majority of the colloidal particles (including microorganisms) in the water prior to using the RO system. These colloidal particles in the water were measured in terms of a fouling index (FI). Based on field experience and manufacturers' recommendation, the FI should be measured at the field operation site and be maintained below a value of 3 to avoid the frequent or premature cleaning of the RO membranes.

The pH control system, with a shutdown feature, was designed to continuously feed 20°Be HCl to the feed water of the RO system, and to shut off the acid feeder if the pH went below a designated preset range. By feeding acid to the feed water, the scale forming rate in the RO system was greatly reduced. The recommended pH setting ranges are between 5.2 and 5.6.

Methods and procedures for removing foulants from the RO membranes were provided in operational instructions. The modules were cleaned once during the entire test period to familiarize the operator with the cleaning procedure. A small amount of dirt appeared in the cleaning solution.

The RO system operated for more than 500 hours (cumulative time) during the test period. The recovery rate (ratio of total product water flow rate and feed water flow rate) was arbitrarily maintained at 70%. Definitions of operation parameters that should be noted on data sheets, such as recovery rate, salt passage rate, and pressure drop, were provided in the operating instructions manuals.

Data sheets for RO demineralizer's operations and water sample analysis are presented in Appendix E.

Data were recorded daily and evaluated on a continuous basis. This evaluation and comparison helped in determining the consistency of RO system performance and frequency of cleaning. Evaluation techniques were provided in the operating instruction manuals. A graphic analysis that relates three parameters: salt passage rate, average pressure drop, and total product flow, was maintained for a better understanding of the RO system performance.

Analysis of Water Samples for Total Trihalomethanes (TTHMs) Content

On 29 November 1979, the EPA promulgated regulations limiting the permissible levels for TTHMs in drinking water (Ref 4). Recently, the American Water Works Association reached an agreement with the EPA on the TTHMs rule. A summary of the TTHMs regulations is described in Appendix F.

Removal and/or reduction of TTHMs in water can be achieved by: (a) use of an oxidant disinfectant that does not generate trihalomethanes in water, or that generates less, (such oxidant disinfectants that can be used include: ozone, ozone-UV, chlorine dioxide, and chloramines); (b) treatment to reduce precursor concentrations prior to chlorination, such treatments include: off-line water storage, aeration, improved coagulation, ion exchange resins, granular-activated carbon (GAC), powdered-activated carbon (PAC), and ozone-enhanced biological activated carbon (BAC); or (c) treatment to remove TTHMs after formation, such treatments include: GAC, aeration, and macroreticular resins.

Impact of TTHM's Regulations to Diego Garcia. The regulations promulgated by EPA do not apply to Diego Garcia. BUMED does not provide any regulations or guidelines on TTHMs at this time (Ref 5). Nevertheless, the objective of the testing and monitoring of the TTHMs parameter during the test period was to ensure that TTHMs in the water is within the EPA limit and that the Fleet's readiness is adequately protected.

In the water treatment system, the second-stage carbon filter would remove the TTHMs and their precursors. The RO system provided has a molecular cuttoff weight of 200, therefore, any TTHMs with a molecular weight of more than 200 could be removed by the RO process.

Collecting water samples for TTHMs analysis required a special sampling bottle and sampling procedure. TTHMs analytical methodology and procedure were provided by EPA (Ref 4). A gas chromatopgraphy/mass spectroscopy instrument was used for quantitative and qualitative analysis of TTHMs in a water sample. The Chemistry Laboratory at the Public Works Center (PWC), Guam, has the capability and facility for TTHMs water sample analysis. Four series of water samples collected at Diego Garcia were sent to PWC, Guam, for TTHMs analysis. The results are presented in Appendix G.

Sample Collection and Analysis

Water samples were collected and analyzed as follows:

1. During system startup - daily.

2. During test period - twice weekly.

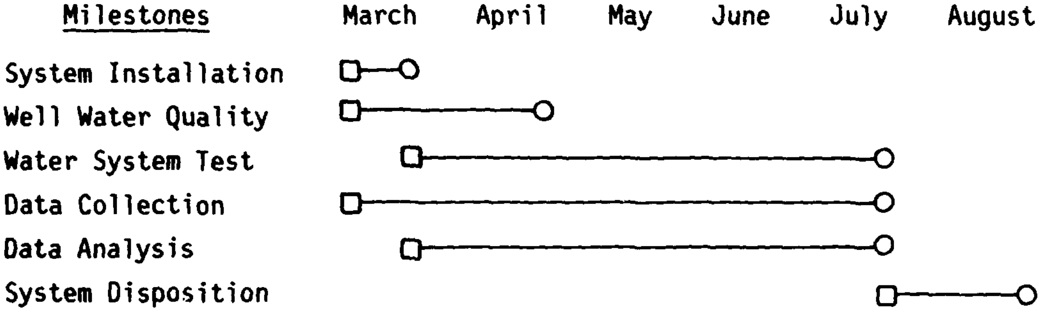
3. Occasionally, a coliform count for raw and product water was performed.

4. Every two weeks water samples were collected at Diego Garcia along with one of the biweekly sample collections, sent to PWC, Subic Bay, for analysis of all physical, chemical, and biological parameters. In addition, a chemical oxygen demand (COD) analysis was planned, but due to transportation problems, only one set of water samples was sent to PWC, Subic Bay. The test results have not been received from PWC, Subic Bay.

5. Four series of water samples were collected for TTHMs analysis. (The water samples were sent to PWC, Guam for analyzing.)

Milestones and Schedule

The milestones and test and evaluation schedule of the water treatment system at Diego Garcia for 1981 are shown below:



DISCUSSION OF TEST RESULTS

The test results on well water quality, pretreatment requirements, water treatment system operation, and TTHMs content analysis are presented in Appendixes B, C, D, E, and G. The results and findings are discussed below:

Well Water Quality

Blended well water from about 14 wells was used in the test and evaluation of the water treatment system. Because a parameter affecting the quality of the blended water was an average of all the individual wells, a slight increase could be due to a large increase of that parameter in a single well. Therefore, daily well water samples from each well were checked for TDS and chloride concentration. Any well with chloride exceeding 250 mg/l would be shut down or operated at a reduced pumping rate.

The values of other parameters previously discussed plus alkalinity, dissolved oxygen, sulfide, and pH were determined on a weekly basis or more frequently if needed. These additional parameters were measured for assessment of well water quality. The well water quality did not change much. However, a few wells, such as C-2 and C-3, in which C-2 had been secured for some time due to a high conductivity (or TDS) reading, did vary significantly in quality (see Appendix B).

In general, the pH values of the well water ranged from 6.8 to 7.7, the raw water had color and turbidity readings exceeding EPA standards and had a high alkalinity content (300 to 850 ppm of $CaCO_3$) due to high bicarbonate and associated hardness content. The chloride content ranged from 24 to 456 ppm (average composite was 100 ppm), while TDS concentrations ranged from 300 to 1400 ppm (average composite was 600 ppm). Alkalinity values were consistently higher than TDS.

As reported in the Background section, the composite well water quality generally met EPA's standards except for TDS, turbidity, and color. Among these parameters, the turbidity measurement might have been affected by the color content in the water. It is anticipated that ultraviolet radiation units now being installed, and existing aeration and chlorination are adequate to treat the composited well water for potable use.

Pretreatment Requirements

There were three components in the water treatment system that provide pretreatment of the well water to prevent fouling of the desalination unit, either the ion-exchange deionizer or the RO demineralizer. The components are a polyelectrolyte, a multi-media filter (first stage), and a carbon filter (second stage). The pretreatment not only prepared water suitable for desalination, but also provided a treatment for removing turbidity, microorganisms, color, taste, odor, and organics (including TTHMs formation precursors). These pretreatments produced water meeting a portion of EPA standards and made it more palatable. The efficiencies of these pretreatments are presented in the following sections together with the water treatment system.

The water fed into the RO system required two additional treatments to the pretreatments just mentioned. These treatments were a pH adjustment and a 5 μ cartridge filter. The pH adjustment, in terms of hydrochloric acid requirement, is discussed below. Titration data are shown in Appendix C.

pH Adjustment.

Titration experiments were conducted at Diego Garcia to determine what dosages of hydrochloric acid were needed to adjust pH in the feed water. The strength of the hydrochloric acid used was one-tenth of 20°Be (31.4%) HCl stock solution. It was found that in the laboratory titration experiment, an average of 0.045% (volume by volume, (v/v)) of hydrochloric acid was required to adjust the feed water's pH to 5.6. This correlated well with the RO operational data, in which 0.057% (v/v) was the average dosage required. Acids available for use in the RO process are described in Appendix H.

Slow Sand Filtration.

A slow sand filter, fabricated at Diego Garcia, was tested and evaluated to determine its capability to remove water contaminants. The filter had the following characteristics:

Filter size: 5 1/8 in. diam by 6 ft long
Sand depth: 42 in. (coral sand media)
Gravel depth: 6 in. (coral gravel)
Sand media: Effective size (0.5 mm), uniformity coefficient (1.5)
Filtration rate 0.07 gpm/ft^2

The results of 16 days of continuous operation indicated that the water's color was consistently reduced from 20-30 to 5 except the last 2 days (reduced to 10 only) and the turbidity from 3 to 0. The water quality would meet EPA standards for these two parameters. However, the flow rate of the filter dropped from 35 ml/min (0.07 gpm/ft^2 equivalent surface loading rate) controlled effluent flow rate to 15 ml/min (0.03 gpm/ft^2 equivalent surface loading rate) effluent flow rate uncontrolled, i.e., the valve was wide open. This reduced flow rate is an indication of clogging. Further investigation indicated that the sand filter had a limited capacity for removing the bacteria cells, even with the addition of disinfectants, i.e., H_2O_2 and/or $Ca(ClO)_2$.

<u>Fouling Index (FI)</u>

When water contains particulates smaller in size than can be removed by the available filter media, it is necessary to increase this particle size in some way. Coagulation is the most common method, and aluminum sulfate has been used as a coagulant for many years. The process requires large settling tanks and long retention times. Recently polyelectrolyte compounds have been introduced which accomplish the coagulation more rapidly. As mentioned earlier, long membrane life requires a water with minimum amounts of particulates. An indicator of filtration efficiency, FI, is used where high quality water is required. FI is defined as follows:

$$\text{FI} = \frac{\text{Final Time } (T_f) - \text{Initial Time } (T_i)}{T_f} \times 10$$

where T_i = time required to collect 500 ml of a water sample filtered through a Millipore filter at the beginning of test (sec)

T_f = time required to collect 500 ml of a water sample filtered through the same Millipore filter after the filter is continuously used for 10 min (sec)

Millipore filter used: 5HA 0.45 μ
Filtration pressure used: 30 psi

The manufacturer of the hollow-fiber membrane recommended an FI of 3.0 or less for good membrane performance and also recommended a cationic liquid polyelectrolyte (F-86) being used at Diego Garcia for controlling FI.

The amount of F-86 to use was arrived at by trial and error. The correct amount of F-86 to use was obtained by gradually increasing the F-86 feed until the FI reduction leveled off and then began to increase. At Diego Garcia the FI of the raw feed water was in excess of 8. The F-86 dosage was started at about 15 ppm (v/v) and increased incrementally with only a slight reduction of the FI; at 20 ppm the FI was 7.5.

Increasing the retention time between the point of F-86 injection and the filter was tried as a possible means of improving the FI. This was accomplished by adding a 100-gal. tank in the line, and also by reducing the flow to one-half and one-fourth the normal rate. No appreciable reduction in FI was obtained.

The high concentration of F-86 did clog the mixed media filter to the point that it could not be backwashed effectively. The entire anthracite portion of the filter was a solid mass with a few passages through it where the flow channeled. Physical breakup of the mass was not enough to assist in the backwash. Laboratory field tests indicated that NaOH would remove the clog, so 50% NaOH was added to the filter with enough water to make a 12.5% solution. A series of soakings and backwashes finally returned the filter to its original state. Fifteen days later the same condition was found and again the filter was cleaned with NaOH. At this time it was decided to discontinue using F-86. Some other electrolyte might work better at Diego Garcia.

Culligan commented on the FI results after the field test was completed. They recommended that the FI also be measured at the prefilter (5 μ cartridge filter) effluent. This was the final treatment that the water was subjected to before entering the RO system. This means that the prefilter would be used as a "sacrificer" to ensure that the membrane would be protected. This appeared to be the case at Diego Garcia because using F-86 and the multi-media filter treatment failed to reduce the FI value to 3.0 and below. However, the membrane appeared to be protected, because the membrane performed well according to the data (recovery rate and salt passage percentages) shown in Appendix E. Replacement of the prefilter toward the end of the field tests supports the assumption that the prefilter was sacrificed.

Even if a satisfactory solution can be found to control the FI, it is considered advisable to use a spiral wound membrane which is less liable to fouling, is easier to clean than the hollow-fiber filter, and will not increase the cost. One manufacturer of the spiral wound membrane claimed that fouling is not a serious problem. They have projected a 3-year life for their membrane, based on operating data and water analyses.

Chemical Additions

Two experiments were conducted at Diego Garcia to determine the feasibility of adding $Ca(OCl)_2$ and H_2O_2 for reducing color, odor, H_2S, and bacteria count and to increase dissolved oxygen. The results shown in Appendix C were not as good as had been anticipated. Logistic support for either treatment would not be justified for the limited benefit obtained.

Water Treatment System

As stated previously, the water treatment system consists of a three-stage process: multi-media filter, carbon filter, and desalination. The first and second stages of the treatment did remove or reduce the color, turbidity, taste, odor, and most organic chemicals in the well water so that a portion of the EPA standards were met. The third stage, desalination, either by ion-exchange or reverse osmosis, is discussed as follows:

Ion-Exchange Deionizer. As shown in Appendix D, the two-bed cation and anion exchanger effectively removed TDS down to 4 to 42 ppm range (measured by conductivity), total hardness to 0 to 16 ppm, calcium to 0 to 15 ppm, chloride to 7 to 76 ppm, and alkalinity to 100 to 300 ppm. The product water quality met the EPA requirement of 500 ppm TDS and 250 ppm chloride. The effluent water quality was measured continuously by a conductivity cell (measurement of TDS) connected to a meter with the capability of stopping the operation when a preset conductivity level was reached. Since the capacity of the resin beds is fixed with respect to the concentration in ppm of ion removal, the quantity of product made and the time of each cycle is indirectly proportional to the TDS of the feed water. For example, during the first hour or two of operation on a newly regenerated ion exchange resin on 500 ppm feed, the product was as low as 1 ppm TDS. For the major portion of the cycle, the TDS level was about 12 to 15 ppm. When the resin was exhausted, the TDS climbed very rapidly to the preset conductivity level, shutting down the unit. When the deionizer was operated on effluent water from the RO unit (40 ppm TDS), the product water was about 10 to 12 ppm during the major portion of the run. Cycle times were much longer, although the actual figures were not determined.

During the test period, 1,040 gallons of 20°Be HCl (31.4%) and 285 gallons of NaOH (50%) were used to regenerate the resins while producing 492,290 gallons of high quality water. This would require 2.11 gallons of HCl and 0.579 gallon of NaOH per 1,000 gallons of product water. It is estimated that a 450,000-gallon water treatment plant would require 950 gallons of HCl and 260 gallons of NaOH per day for resin regeneration. This would create a considerable logistic support problem.

The amount of chemicals would be drastically reduced, of course, if the deionized water was blended with the pretreated high TDS water to obtain a product having less than 500 ppm TDS. For example, if 1,000 gallons of 20 ppm TDS water were added to 4,800 gallons of 600 ppm TDS water this would provide 5,800 gallons of water at 500 ppm TDS. This would be equivalent to 0.364 gallons of HCl and 0.1 gallon of NaOH/1,000 gal product water at 500 ppm TDS. The 450,000-gallon plant would require 163 gallons of HCl and 45 gallons of NaOH; therefore, the minimum cost for chemicals would be approximately $1.00/1,000-gal product water (FOB Diego Garcia based on a price factor of 3). When H_2SO_4 is substituted for HCl the cost is reduced to $0.60/1,000-gal product water. For a 250 ppm TDS water product the above costs would be $3.50 and $2.10, respectively.

Reverse Osmosis Demineralizer. The RO demineralizer and its first and second stage filters were the major treatment processes tested and evaluated at Diego Garcia. The performance of the RO system was considered highly satisfactory. The product water quality far exceeded EPA standards.

In reviewing the data obtained during the RO operation (Appendix E), the RO membrane was capable of removing about 90% of TDS in the feed water, while maintaining a 70% recovery rate. Although the FI remained high because of the inability to control it with the polyelectrolyte, F-86, the RO system's performance did not appear to be affected. The prefilter apparently served as a "sacrificer" for assuring RO feed water quality in terms of FI value. The cost of a prefilter cartridge is $4.75 each. Using FOB Diego Garcia based on a price factor of 3, the prefilter will cost $71.25 (or 5 at $14.25 each), which is considered relatively inexpensive. Furthermore, in reviewing the percentage of salt passage (ratio between effluent TDS ppm to the total TDS ppm in feed water), the membrane performed well during the entire test period.

Towards the end of the field test, brackish water was simulated by adding seawater to bring the TDS to 1,000, 1,500 and 2,000 ppm (See Appendix E). A 70% recovery rate and a 6 to 8% salt passage rate (or 94 to 92% salt rejection rate) were maintained. Though the TDS concentration in the product water had increased, the EPA standards were still met. This finding indicates the RO system can operate on a high concentration of TDS without altering the operational procedure or sacrificing the production rate.

The acid (20°Be 31.4% HCl) consumption rate was estimated at Diego Garcia at 0.057% (v/v) for pH adjustment. This is equivalent to 0.81 gallon HCl (20°Be 31.4%)/1,000 gallons of product water at 70% recovery rate. For a 450,000-gallon water treatment plant, 366 gallons of HCl will be required. The logistic support for handling this much acid could be significant. As calculated in Appendix H, when 94% concentration H_2SO_4 is used, the volume of the acid can be significantly reduced to 103 gallons.

Chemical consumption rates between the ion-exchange deionizer and the RO demineralizer are compared as follows:

Process	Product Water		Raw Water (mix with)		Chem. Consump. Rates		
					Acids		NaOH
	Volume (K gal)	TDS (ppm)	Volume (K gal)	TDS (ppm)	HCl (gal)	H_2SO_4 (gal)	(gal)
Ion-Exchange Deionizer	77.59	20	372.41	600	164	46	45
RO Demineralizer	88.33	60	366.67	600	67	19	None

The 450,000 gallons of blended product water will contain 500 ppm TDS from original raw water containing 600 ppm TDS.

The concentration of chloride (when HCl is used) or sulfate (when H_2SO_4 is used) in product water must be monitored to assure that the EPA standards are met. Power requirement was estimated at 12.0 KWH per 1,000 gallons of product water.

A preliminary design of a 300,000-gpd (product water) RO system is illustrated in Appendix E. Better salt balance data (cation and anion analysis) shall be provided for a closer preliminary design of a full-scale RO system.

Total Trihalomethanes (TTHMs) Concentration in the Water

Four series of water samples were collected for TTHMs concentration analysis by PWC, Guam. The results (Appendix G), indicated that the TTHMs concentration in the water at Diego Garcia appeared insignificant. In the second and fourth series of samples, though, there were two samples, no. 2 multi-media effluent and no. 3 carbon filter effluent which exceeded the EPA primary standard of 100 ppb, yet with a follow-on treatment with either the ion-deionizer or the RO system the TTHMs concentration was reduced to below 10 ppb. The carbon filter supposedly would adsorb TTHMs and its precursors. That the carbon filter effluent contained higher TTHMs concentration than raw well water and multi-media filter effluent can only be explained by: (a) the activated carbon was exhausted in adsorbing TTHMs, (b) there was suddenly a release of TTHMs previously adsorbed on carbon, and/or (c) a bio-discharge occurred due to sloughing-off or biomass disintegration, and (d) laboratory analytical errors.

Low TTHMs concentration in the ion-exchange effluent appeared *strange*, unless the TTHMs precursors were in radical forms that could be temporarily ion-exchanged. As for the RO membrane, should there be a molecular weight cut-off at 200 (as claimed by the membrane manufacturers), then two of the TTHMs species, $CHClBr_2$, and $CHBr_3$ should have been removed. In natural well water, however, the formation of brominated compounds is less probable than chlorinated compounds. Therefore, it appears that there is a need to review the accuracy of the analytical procedure.

The first series of samples taken by a technician of PWC, Guam, appeared to have a high concentration of TTHMs, but no satisfactory explanation could be provided.

WATER QUALITY REQUIREMENT

The desirable characteristics of water vary with its intended use. Water for drinking and food preparation must be free from organisms capable of causing disease, and from minerals and organic substances producing adverse physiological effects. To encourage man to drink this health-promoting liquid, the water must also be aesthetically acceptable. For example, the water should be free from turbidity, color, taste, and odor. Drinking water should also have a reasonable temperature. The term "potable water," means that it can be consumed in any desired amount without concern for adverse effects on human health.

The water produced by the experimental water treatment system at Diego Garcia betters EPA's standards in terms of turbidity, color, taste, and odor, chloride, TDS, microorganisms, and organic substances. However, the water is not suitable for long term consumption primarily due to the low mineral content (TDS 50 ppm) and low pH value (about 5.5), i.e., the water is "too pure and too acidic." This type of water can cause severe corrosion problems in metal pipelines and is generally used in medical and general chemistry and certain industrial operations, e.g., electronics, photo labs, boiler/cooling towers. Blending the demineralized water with some of the raw well water processed from the two filters will provide a suitable potable water.

Langelier's Saturation Index

Langelier's Saturation Index (LI) is the most widely used method to measure the water quality for scaling or corrosion potential. Appendix I provides the LI calculation formula.

Using water quality data obtained at Diego Garcia, one can easily calculate the LI at which scale or corrosion can be predicted.

For example:

Date: May 11, 1981. Ion-Exchange Deionizer Operation, Temp = 28°C

	TDS	Total Hardness	Ca Hardness	Alk	pH
Well Water	460	180	104	550	7.7
Product Water	10	16	4	200	5.5

LI Well Water = (+) 0.65 (scale formation)
LI Product Water = (-) 3.28 (corrosion)

Date: May 9, 1981 Reverse Osmosis Operation, Temp = 28°C

	TDS	Total Hardness	Ca Hardness	Alk	pH
Well Water	440	184	112	650	7.6
Product Water	44	4	0	200	5.5

LI Well Water = (+) 0.6 (scale formation)
LI Product Water = (-) 2.22 (corrosion)

By using the same equation, one can also calculate an adequate pH level to be maintained (or adjusted) in the RO feed water so that calcium or magnesium carbonate (scale) deposits will not form on the RO membrane. For this purpose, LI is recommended by the membrane manufacturer to be about -0.2, which is slightly corrosive. A calculation is illustrated as follows (using May 9, 1981 well water quality data):

$LI = pH - pH_s = -0.2$

$pH = pH_s - 0.2$

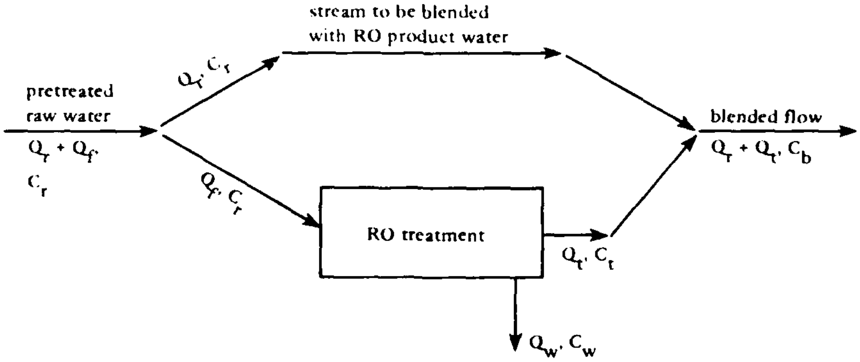
$pH_s = 6.94$ (previously calculated)

$pH = 6.74$

This theoretical pH value appeared to be quite different from the manufacturer's recommended actual field operation value of 5.6. This recommendation was made to compensate for any drastic changes in well water quality (e.g., a sudden increase in hardness). Additional testing will be required to determine what will be the most appropriate pH level. The acid required for pH adjustment can be reduced by two-thirds when pH 6.7 RO feed water is allowed, rather than 5.6 (refer to pH adjustment data, Appendix C (1)).

To use the RO system product water as drinking water, the pH must be readjusted to at least 6.5 and mineral content be increased to 250 ppm TDS (optimum). Sodium bicarbonate is the most commonly used chemical for such purposes. Other methods that can be used to solve the problem without any cost are (a) split treatment and blending, and (b) the use of a coarser and newer membrane that will require lower power/pressure and produce water with higher TDS.

Calculation of Split Treatment Requirement



Where:

Q_r = raw water flow rate, (to be blended with treated water), L^3/T

Q_f = feed water flow rate, (to be treated with RO), L^3/T

Q_t = treated water flow rate, (considering certain waste of feed water), L^3/T

Q_w = waste water stream from treatment process, L^3/T

C_r = total dissolved solids (TDS) concentration in raw water, M/L^3

C_b = total dissolved solids (TDS) concentration in blended water, M/L^3

C_t = total dissolved solids (TDS) concentration in treated water, M/L^3

C_w = total dissolved solids (TDS) concentration in waste stream, M/L^3

Define:

$R = Q_t/Q_f$ (RO treatment recovery rate) or $Q_t = RQ_f$

$r = Q_f/Q_f+Q_r$ or $Q_r = (1-r)/r\ Q_f$

$p = 1-C_t/C_r$ (TDS removal efficiency), or $C_t = C_r(1-p)$

Mass balance:

$$C_rQ_r = C_bQ_b - C_tQ_t$$

$$C_rQ_r = C_b(Q_r+Q_t) - C_f(1-P)(Q_fR)$$

$$Q_r = Q_fR\ [C_b - C_f\ (1-P)]/C_f - C_b) \qquad (1)$$

Blended Water Treatment

Equation (1) shows the flow rate of pretreated raw water to be blended with RO treated water.

For example, a demand of 450,000 gallons of 500 ppm TDS water for Diego Garcia would require 485,000 gallons of 600 ppm TDS well water fed into the pretreatment system. The pretreated water is then split into two streams: 118,000 gallons is processed through the RO system to produce 83,000 gallons of 60 ppm TDS water, assuming a 70% recovery rate. The other 367,000 gallons of water, with no further treatment, is blended with the 83,000 gallons of RO product water. This equation can be further developed to provide the relationship between TDS concentrations in raw water and blended water. For example:

$$(1-r)/r\ Q_f = Q_fR\ [C_r(1-p) - C_b]/(C_b-C_r)$$

$$(1-r)\ (C_b-C_r) = rR\ [C_r(1-p) - C_b]$$

$$(1-r)C_b - (1-r)C_r = rR\ (1-p)\ C_r - rRC_b$$

$$C_b = [(1-r) + rR(1-p)]C_r/(1-r) + rR \qquad (2)$$

Concentration of TDS in the waste stream can also be estimated as follows:

$$Q_f C_r = Q_t C_t + Q_w C_w$$

$$Q_t/R\ C_r = Q_t C_r\ (1-p) + (Q_t/R - Q_t)\ C_w$$

$$C_r = C_r R\ (1-p) + (1-R)\ C_w$$

$$C_w = [R\ (1-p) - 1]C_r/(1-R) \tag{3}$$

COST COMPARISON FOR DESALINATION PROCESSES

Desalination processes include distillation, reverse osmosis, electrodialysis, ion-exchange, and freezing. Distillation has been used for seawater conversion for many years, but is not economical to treat brackish water. Recent high energy and skilled personnel costs have made distillation also less economical for seawater. RO has been used successfully on brackish water for about 10 years and within the past 5 years the technology has been used to economically treat seawater for potable use. Electrodialysis (ED) and ion-exchange (IX) methods are generally used for treating brackish water only. The freezing method is still in the development stage; its applicability in the field still needs to be proved.

Economical comparison of the desalination processes is very difficult since they are generally site specific. Pretreatment requirements of feed water for these processes has a significant impact on the costs.

Based on studies published in AWWA journals (Ref 5 and 6), the RO process has become the least-cost option for demineralization of the bulk of brackish water supplies in the western United States.

The water supply capacity of the 15 communities studied (see Tables 1 through 4), ranged from 0.15 to 6.10 MGD. The TDS concentration in the feed water was between 941 to 3236 ppm. The demineralization cost in 1977 dollars ranged from \$0.37 per 1,000 gallons of water to \$1.56 per 1,000 gallons of water. The study revealed that in seven of the municipalities, RO is projected as the least-cost demineralizing system; in six, RO is combined with ion-exchange or zeolite deionizer (Z); and in the remaining two, RO and ED are considered an even choice. Recent developments in the RO membrane technology, as well as the mass production of the membranes, has not only reduced the RO system's capital investment and O&M cost, but has also made it more reliable and favorable for future applications. For instance, the RO manufacturers have lowered the feed water pressure requirements from 800 to 600 to 400 psi while maintaining membrane permeation rates.

Optimization of RO system designs to employ looser membranes - having somewhat lower salt-rejection characteristics, yet yielding potable water from high salinity feeds at lower pressures - is one objective of current RO manufacturers. Such opportunities do not appear to exist for lowering the energy requirements of ED systems.

Table 1
Projected Demineralization Costs for 15 Candidate Communities, 1970-1973

Municipality	Population 1970	Feedwater Quality—mg/l		Municipal Water Quality—mg/l		Demineralization Process	Demineralization Cost			
							70-73*		1977*	
		TDS	Hardness	TDS	Hardness		¢/m^3	¢/1000 gal	¢/m^3	¢/1000 gal
Lakota, N. D.	964	1754	816	195	100	IX-RO	41.5	157	45 2	171
Eureka, S. D.	1 547	2163	1248	430	5	Z-RO	20	75	30.1	114
Sibley, Iowa	2 747	2720	1547	481	100	IX-ED	38.3	145	50.4	191
Freer, Tex.	3 000	1242	77	500	49	ED	15	56	27 7	105
Towanda, Kan.	1 242	2417	1033	246	125	RO	36.2	137	55 2	209
Roundup, ~~Tex.~~ Mont.	2 010	1643	725	385	72	RO	20	77	34 3	130
Malta, Mont.	2 195	969	332	493	29	IX	11	42	19	71
Las Animas, Colo.	3 100	3236	1512	981	194	RO	15	57	25	96
Ft. Lupton, Colo.	2 500	1423	588	430	200	RO	11	41	18	69
Ft. Stockton, Tex.	7 500	1796	798	485	150	IX-ED	10	40	20	75
Kihei, Haw.	13 500	1100	207	500	90	ED	15	57	20	75
Casa Grande, Ariz.	10 500	945	380	500	205	ED	8.2	31	13	50
Midland, Tex.†	63 000	1135	503	400	100	IX-RO	6.9	26	11	42
Ark. City, Kan.	14 000	1658	565	500	65	ED	9.2	35	14	53
Artesia, N. M.	10 315	941	855	490	100	IX	9.0	34	15	57

*1970-1973 costs equated to 1977 dollar values
†For supplement to surface water supply

Table 2
Demineralization Plant Flows, 1970-1973

Municipality	Feed		Demineralization		Brine		Blend		Supply	
	m^3/day	mgd	m^3/day	mgd	m^3/day	mgd	m^3/day	mgd	m^3/day	mgd
Lakota, N. D.	790	0.21	570	0 15	200	0.06	0	0	570	0 15
Eureka, S D.	1 300	0.35	1 100	0 30	200	0 05	0	0	1 100	0 30
Sibley, Iowa	1 900	0.50	1 400	0.36	530	0 14	0	0	1 400	0 36
Freer, Tex.	1 800	0.47	1 500	0 40	300	0 07	0	0	1 500	0 40
Towanda, Kan.	2 700	0.71	1 900	0 49	790	0 21	40	0 01	1 900	0 50
Roundup, Mont.	2 700	0.71	2 400	0.64	300	0.07	0	0	2 400	0.64
Malta, Mont.	3 500	0.92	3 000	0.79	490	0 13	0	0	3 000	0.79
Las Animas, Colo.	8 330	2.20	5 300	1.40	3 000	0 80	0	0	5 300	1 40
Ft. Lupton, Colo.	7 190	1.90	6 060	1.60	1 100	0 30	0	0	6 060	1.60
Ft. Stockton, Tex.	10 600	2.80	9 460	2.50	1 100	0.30	0	0	9 460	2.50
Kihei, Haw.	13 000	3.45	11 400	3 00	1 700	0.45	0	0	11 400	3.00
Casa Grande, Ariz.	15 700	4.15	11 000	2 90	950	0.25	3 790	1.00	14 800	3.90
Midland, Tex.*	21 200	5.60	18 900	5 00	2 300	0 60	0	0	18 900	5 00
Arkansas City, Kan.	21 800	5.75	18 900	5 00	2 800	0.75	0	0	18 900	5.00
Artesia, N. M.	25 000	6.60	20 100	5.30	1 900	0.50	3 000	0.8	23 100	6.10

*For supplement to surface water supply

Table 3
Projected Demineralization Costs for Fifteen Candidate Communities, 1977

Municipality	Municipal Water Quality—mg/l		Demineralization Process	Demineralization Cost			
				1970-1973*		1977	
	TDS	Hardness		¢/m^3	¢/1000 gal	¢/m^3	¢/1000 gal
Lakota, N.D.	157	61	IX-RO	45.2	171	41.2	156
Eureka, S.D.	456	5	Z-RO	30.1	114	21	80
Sibley, Iowa	263	148	IX-RO	50.4	191	22	82
Freer, Tex.	341	21	RO	27.7	105	21	79
Towanda, Kan.	500	42	IX-RO	55.2	209	18	67
Roundup, Mont.	287	76	IX-RO	34.3	130	20	75
Malta, Mont.	281	90	RO	19	71	18	69
Las Animas, Colo.	363	145	IX-RO	25	96	17	63
Ft. Lupton, Colo.	258	107	RO	18	69	16	60
Ft. Stockton, Tex.	270	120	RO	20	75	17	66
Kihei, Haw.	500	94	RO	20	75	11	41
Casa Grande, Ariz.	220	89	ED or RO	13	50	13	49
Midland, Tex.†	370	100	IX-ED or IX-RO	11	42	9.8	37
Arkansas City, Kan.	323	91	RO	14	53	14	52
Artesia, N.M.	160	111	RO	15	57	13	48

*1970–1973 costs equated to 1977 dollar values

†*For supplement to surface water supply* at Midland

Table 4
Demineralization Plant Flows, 1977

Municipality	Feed		Demineralization		Brine		Blend		Supply	
	m^3/day	mgd	m^3/day	mgd	m^3/day	mgd	m^3/day	mgd	m^3/day	mgd
Lakota, N.D.	490	0.13	380	0.10	110	0.03	190	0.05	570	0.15
Eureka, S.D.	1 300	0.34	1 100	0.30	150	0.04	0	0	1 100	0.30
Sibley, Iowa	1 700	0.45	1 400	0.36	300	0.09	0	0	1 400	0.36
Freer, Tex.	1 700	0.44	1 500	0.40	150	0.04	0	0	1 500	0.40
Towanda, Kan.	2 200	0.58	1 900	0.50	300	0.08	0	0	1 900	0.50
Roundup, Mont.	2 700	0.71	2 400	0.64	260	0.07	0	0	2 400	0.64
Malta, Mont.	3 300	0.88	3 000	0.79	300	0.09	0	0	3 000	0.79
Las Animas, Colo.	6 700	1.77	5 300	1.40	1400	0.37	0	0	5 300	1.40
Ft. Lupton, Colo.	7 040	1.86	6 060	1.60	980	0.26	0	0	6 060	1.60
Ft. Stockton, Tex.	11 400	3.00	9 460	2.50	1900	0.50	0	0	9 460	2.50
Kihei, Haw.	12 300	3.24	8 330	2.20	910	0.24	3000	0.80	11 400	3.00
Casa Grande, Ariz.	16 600	4.38	14 800	3.90	1800	0.48	0	0	14 800	3.90
Midland, Tex.*	20 600	5.44	18 900	5.00	1700	0.44	0	0	18 900	5.00
Arkansas City, Kan.	21 800	5.75	18 900	5.00	2800	0.75	0	0	18 900	5.00
Artesia, N.M.	27 200	7.18	23 100	6.10	4000	1.08	0	0	23 100	6.10

*For supplement to surface water supply

The brackish water RO membrane can take feed water containing TDS up to 15,000 ppm. The saline water RO membrane, however, will treat from 15,000 up to 50,000 ppm TDS. Since the pressure required for an RO system is directly proportional to the TDS content in the water (about 10 ppm TDS/psi max), it will be cost effective to use brackish water rather than seawater. Generally, the cost for using the RO system for treating brackish water is about one-third the cost of treating seawater.

FINDINGS AND CONCLUSIONS

1. The water treatment system tested at Diego Garcia accomplished the objective of reducing TDS turbidity, hardness, chloride, color, taste, and odor.

2. Several tests made on synthetic brackish water indicated that similar reductions could be attained to meet the standards with little change in the production rate or chemical demand.

3. The applicability of a slow sand filter at Diego Garcia is limited in terms of pretreatment for minimizing fouling.

4. Adding $Ca(OCl)_2$ and H_2O_2 did reduce the amount of color, odor, H_2S, and did increase the amount of dissolved oxygen and bacteria killed, but the results obtained do not justify using this chemical treatment.

5. In spite of the problems with lowering the fouling index, the RO system performed well. Based on performance data, the membrane did not appear to have fouling problems. This was substantiated by the small amount of dirt removed during the trial cleaning operation. The use of a spiral-wound membrane, which is less sensitive to fouling, is a better choice than the hollow-fiber membrane.

6. Although the ion-exchange deionizer performed as well as the RO system, with respect to TDS removal, the amount of regenerating chemicals required would increase in direct proportion to the concentration of TDS in the feed water. Supply of such large quantity of regenerating chemicals will create severe logistic burden to the Navy. Based on performance data, resins fouling did not appear to be a problem.

7. The RO system has an added advantage over the ion-exchange deionizer: the RO system is capable of removing other contaminants, such as colloidal particles, organic chemicals, and micro-organisms not removed in the pretreatment components; the system also uses less chemicals.

8. Cost of the RO system has been reduced substantially during the last few years. The performance of the RO membranes has also improved. The RO system has been rated as the least cost desalination process and most feasible water treatment system for Diego Garcia.

9. The water produced by the water treatment system is too low in TDS and too acidic to be suitable for long-term human consumption. The product water must be blended with undemineralized water to provide water of potable quality.

10. The total TTHMs content in the well water and the present water supply appears to be low (below EPAs 100 ppb standard); there is no TTHMs health threat to the personnel. The water treatment systems tested were effective in removing TTHMs.

RECOMMENDATIONS

1. The RO water treatment system is recommended for use at Diego Garcia for treating brackish water as supplemental to the existing fresh water supply.

2. Should there be no adequate source and quantity of fresh/brackish water on the island available, seawater desalting RO system is recommended for use.

3. When RO water treatment system is in use, the addition of power recovery system to reduce power consumption is recommended.

4. One pretreatment alternative that should be strongly considered is an ultrafiltration (UF) membrane process. The UF membrane module is constructed with the same precision as RO modules. The UF module does not reject salts, but removes practically all organics over 1,000 molecular weight (e.g., polysaccharides, virus, bacteria, and colloids).

5. The waste stream from a demineralization plant processing brackish water in the 1,000 to 3,000 ppm TDS range will usually constitute from 10 to 30% of the water fed and will contain from 5,000 to 10,000 ppm TDS. At Diego Garcia, the RO system waste stream contained about 2,000 ppm TDS (from 550 ppm water fed). An appropriate disposal option must be provided for the waste; such as discharged to lagoon, ocean and/or injected to ground.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of the following people who contributed to the success of this engineering investigation. Without the cooperation of these persons and members of their organizations, it would have been impossible to complete the mission within the limited time and resources.

Mr. Edward F. C. Lau	Code 405	PACNAVFACENGCOM
Mr. Tom Arita	Code 405	PACNAVFACENGCOM
Mr. Ken Imada	Code 412	PACNAVFACENGCOM
Mr. Stephen W. Surface	Code 111	PACNAVFACENGCOM
Mr. Francis K. Y. Mau	Code 114	PACNAVFACENGCOM
Mr. Glenn H. Yoshinaga	Code 114	PACNAVFACENGCOM

Mr. L. M. Wernigg	Code 451 NAVFAC HQ
Mr. H. G. Dorsey	PWC, Guam
Capt. L. K. Donovan	CO, PWC, Subic Bay
Mr. J. K. Latham	PWC, Subic Bay
Mr. Eric Torngren	PWC, Subic Bay
Mr. Bob Jones	PWC, Subic Bay
Mr. E. D. Alviar	PWC, Subic Bay
CDR James Palmborg	PWO, Diego Garcia
CDR Jack Buffington	CO MCB 1, Diego Garcia

REFERENCES

1. Naval Facilities Engineering Command, Pacific Division, ltr 405/rd Ser: 40 of 3 Jan 1980 Subj: Potable water treatment for removal of hardness, total dissolved solids (TDS), color, taste and odor from the water supply at Diego Garcia and other Naval facilities.

2. _______________, Memo 405 lsm of 16 Mar 1981 Subj: Potable water treatment for removal of hardness, total dissolved solids (TDS), color, taste and odor from the water supply at Diego Garcia and other Naval facilities. (An internal memo from Code 405 to Code 114.)

3. Naval Civil Engineering Laboratory. Memorandum of Procedure (MOP): Test and evaluation of a potable water treatment system at Diego Garcia, by D. B. Chan. Port Hueneme, Calif., Dec 1980.

4. Environmental Protection Agency. "National interim primary drinking water regulations; control of trihalomethanes in drinking water," Federal Register, vol 44, no. 231, Nov 1979, pp 68624-68675.

5. Private communication with personnel at NEHC, April 1982.

6. E. F. Miller. "Demineralization of brackish municipal water supplies - comparative costs," American Water Works Association Journal, vol __, no.__, Journal, Jul 1977, pp 348-351.

7. H. J. Adams and W. H. Brant. "The reverse osmosis water-treatment plant at Minitonas, Mont.," American Water Works Association Journal, vol __ no. __, Jul 1977, pp 352-355.

BIBLIOGRAPHY

Disinfection

Capital Controls Co., Chlorination Guide.

Diamond Shamrock Corp. Disinfection by on-site sodium hypochlorite generation, equipment description and budget pricing of brine electrolysis systems, by Sanilec Systems, Electrolytic System Division, Chardon, Ohio 1980.

"Impacts of water chlorination," Environmental Science and Technology, 1974, pp. 20-21.

S. H. Gupta, K. B. and Sutton, "What's best for disinfection?," Water and Wastes Engineering, May 1976, pp. 52-56.

Livesey, R. J. "The ozonisation of potable water supplies," water services, Nov 1975, pp. 460-464.

Mitchell, R. "Destruction of Bacteria and Viruses in Seawater," in the American Society Civil Engineering Procedures, Journal of the Sanitary Engineering Division, vol. 97, no. SA4, Aug 1971, pp. 425-432.

O'Connor, J. T. and Kapoor, S. K. "*Small quantity field disinfection.*" American Water Works Association Journal, Feb 1970, pp. 80-84.

REFCO Purification Systems, Ultraviolet water purification system, Inc.: San Leandro, Calif., Dec 1976.

USAF Aerospace Medical Center: Microbiologic studies with ozone, quantitative lethality of ozone for escherichia coli, Brooks Air Force Base, Mar 1961.

U.S. Army Contract Report: Summary of the Harvard report on the disinfection of water, by J. T. O'Connor, and S. K. Kapoor, Aug 1969, Contract No. (DADA 17-67-C-7062).

U.S. Ozonair Corp. Ozonair, South San Francisco, Calif.

UV-OZONE Co.: A guide to ultrox water treatment, West Los Angeles, Calif.

Yapijakis, Costas. "Rx for H_2O," Water and Wastes Engineering, May 1978, pp. 33-37.

Ultrafiltration (UF) & Reverse Osmosis (RO)

Amicon Publication No. 413C. Technical Data: Micro-ultrafiltration system, Lexington, Mass.

Breslau, B. R., et al., "Hollow fiber ultrafiltration" Chemical Engineering Progress Journal, Dec 1975.

CH$_2$M Hill "A Desalination Project (RO Process) in South Florida" Portland, Ore., 1977.

Crabbe, D. C. M. "A double pass reverse osmosis system," Industrial Water Engineering Journal, Dec 1976 - Jan 1977, pp. 12-15.

Culligan International, Water treatment system, Northbrook, Ill.

Curtis, G. J. "Some characteristics of major types of reverse osmosis modules" Industrial Water Engineering Journal, Dec 1976 - Jan 1977, pp. 20-23.

Desai, A. M. "Performance of hydraunautics reverse osmosis (RO) test units at Yuma desalting test facility," paper presented at International Congress on Desalination and Water Reuse, Tokyo, Japan, 27 Nov - 3 Dec 1977.

Department of Interior, Office of Water Research and Technology, Contract Report OWRT/RU-80/3: Advanced pretreatment process for wastewater reuse using reverse osmosis, by Film Tec Corp., Sep 1980. (Contract No. 14-34-0001-8804.)

_______________. Contract Report: Development and demonstration of a reverse osmosis energy - recovery device," by G. B. Andeen. Menlo Park, Calif., SRI International, ___ (date) (Contract No. 14-34-0001-1403).

Dow Chemical Co., Reverse osmosis and/or ion exchange? Using them together for water demineralization, Midland, Mich.

Hydranautics, Military requirements for water supply, First Desalination Conference on the American Continent, October 1976.

Millipore Corp., Water treatment system, Bedford, Mass.

Naval Civil Engineering Laboratory. Contract Report: Demonstration of an energy recovery pump system for reverse osmosis desalination of seawater, by B. G. Keefer and M. Wall. British Columbia, Canada, Seagold Industries, Mar 1980. (Contract No. N62583-78-MR-313.)

_______________. Contract Report: Evaluation of pretreatment for field oriented reverse osmosis units" by D. R. Kasper and S. H. Ellis, Orange, Calif., PRC Toups, Aug 1980, (Contract No. N68305-79-C-0023.)

Osmonics, Inc., Ultrafiltration and reverse osmosis systems, Hopkins, Minn.

Seagold Ind., Ltd.: Fresh water from the sea, efficiently, Burnaby, British Columbia, Canada.

Technic Central Systems, Inc.; Reverse osmosis water treatment, Seattle, Wash.

Ultrafiltration, Abcor, Wilmington, Mass.

U. S. Army Mobility Equipment R&D Command. 600 gph reverse osmosis water purification unit, Ft. Belvoir, Va., July 1978.

Water Re-Use Promotion Center: Water-reuse and desalination technologies in Japan, Annual Report, Tokyo, Japan, 1980.

Ion Exchange

Barnstead Co. Get more out of water, Boston, Mass.

Cosa Corp., B No. 114: ELGA cartridge deionizers, Montvale, N.J.

Culligan, Ion exchange deionizer, Northbrook, Ill.

Cyclo Chemical Corp., Cyclose ion exchange celluloses, Santa Fe Springs, Calif.

Rohm and Haas., Deionization with amberlite MB-A, Philadelphia, Penn.

Appendix A

WATER TREATMENT SYSTEM OPERATION MANUALS

1. Cat. No. 8802-81, HI-FLO DEPTH & CULLAR FILTER MEDIA FILTERS, Model 20, Installation Instructions.

2. Cat. No. 8805-87, DT-60 FEEDERS, Installation Instructions.

3. Cat. No. 8176-86, CULLIGAN A SERIES TWO COLUMN INDUSTRIAL DEIONIZER.

4. Culligan. INSTALLATION AND OPERATING INSTRUCTIONS FOR A KD-20 REVERSE OSMOSIS SYSTEM.

5. Gould Pump, Model 3333, INSTALLATION, OPERATION AND MAINTENANCE.

Installation, Operation, and Maintenance Manuals for:

1. HI-FLO DEPTH FILTER - CULLIGAN MODEL HD-20
2. CULAR CARBON FILTER - CULLIGAN MODEL HR-24
3. POLYELECTROLYTE FEEDER - CULLIGAN MODEL CT-10
4. TWO COLUMN INDUSTRIAL DEIONIZER - CULLIGAN MODEL
5. REVERSE OSMOSIS UNIT - CULLIGAN MODEL KD-20
6. MULTI STAGE CENTRIFUGAL PUMP - GOULD MODEL 3333

Appendix B

WELL WATER QUALITY

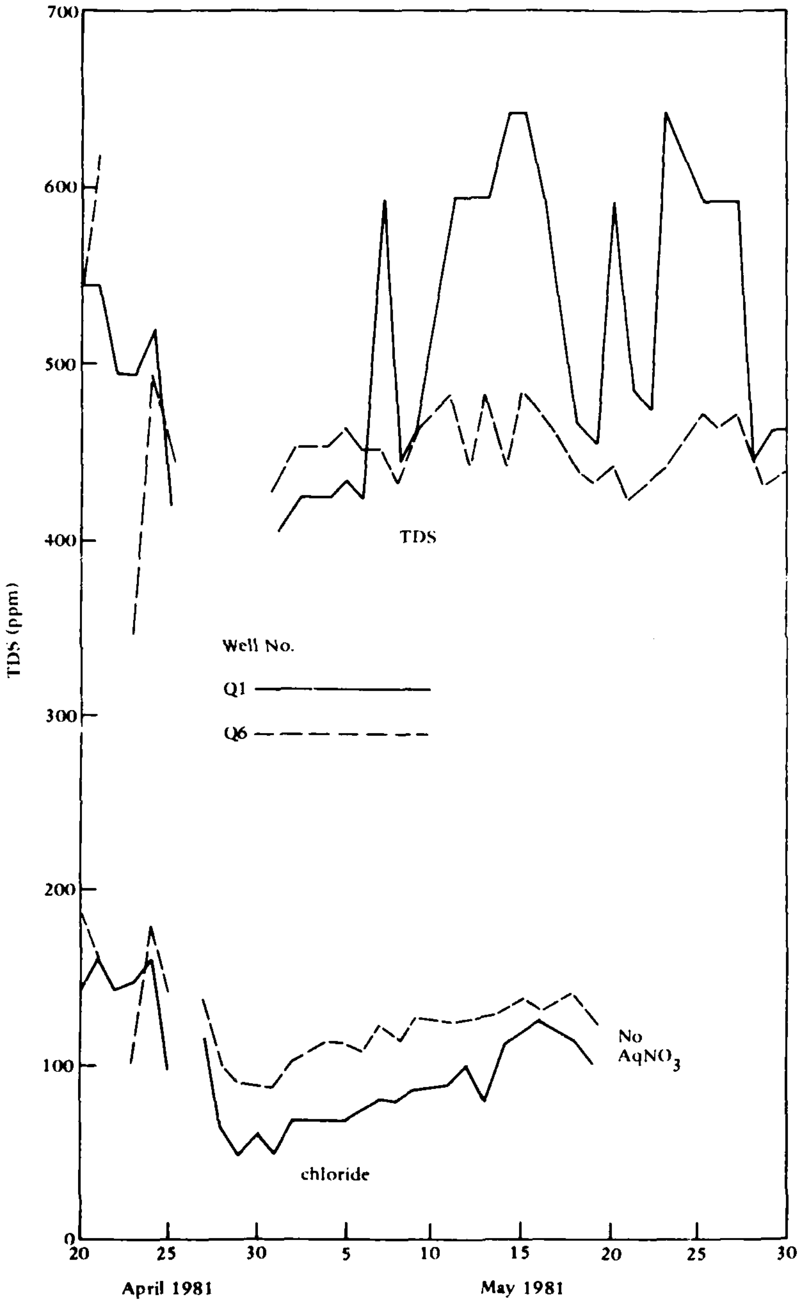


Figure B-1. TDS and chloride concentration correlation.

Table B-1. Well Water Quality, Characteristics, and TDS-Chloride Concentration Correlation

Well Number	Sampling Dates	pH	Color	Turbidity (JTU)	Water Quality		Total Hardness (ppm)	Ca Hardness (ppm)	DS/TDS (ppm)	D.O. (ppm)
					Alkalinity (ppm)	Chloride (ppm)				
Q-1	4/21/81	6.8	20	4	850	168	240	68	550	5.2
Q-3	4/21/81									
Q-4	4/21/81	7.2	20	3	850	120	200	44	600	3.2
Q-6	4/21/81	7.5	20	3	700	172	170	38	625	6.0
C-1	4/22/81	7.0	30	5	650	118	200	100	400	2.8
C-2	secured due to high conductivity									
C-3	4/22/81	6.8	20	3	650	228	264	100	600	1.8
C-4	4/22/81	7.0	30	3	750	233	246	72	625	1.6
C-5	4/22/81	7.2	10	4	550	175	186	60	600	3.6
C-6	4/22/81	7.0	30	3	700	125	200	84	575	3.6
C-7	4/22/81	7.0	20	4	600	72	186	84	375	6.6
C-8	4/22/81	6.8	20	3	700	60	200	84	375	4.8
C-9	4/22/81	7.5	20	5	550	199	192	56	500	6.8

(continued)

Table B-1. Continued

Well Number	Sampling Dates	pH	Color	Turbidity (JTU)	Water Quality		Total Hardness (ppm)	Ca Hardness (ppm)	DS/TDS (ppm)	D.O. (ppm)
					Alkalinity (ppm)	Chloride (ppm)				
Q-1	4/29/81	7.2	10	5	700	55	160	65	100	5.8
Q-4	4/29/81	7.0	30	10	550	72	155	100	125	4.0
Q-6	4/29/81	7.5	20	3	500	96	152	95	150	6.6
C-1	4/30/81	7.2	30	5	600	77	200	124	165	4.8
C-3	4/30/81	7.7	30	3	650	72	224	148	165	5.6
C-4	4/30/81	7.0	20	3	700	84	216	132	180	4.8
C-5	4/30/81	7.2	10	2	700	77	188	112	160	5.4
C-6	4/30/81	7.5	10	2	750	77	164	104	160	6.6
C-7	4/30/81	7.0	10	1	650	67	172	132	150	3.0
C-8	4/30/81	7.0	10	2	750	72	212	148	160	5.0
C-9	4/30/81	7.0	10	2	550	48	156	108	130	3.4
P1-13	4/30/81	7.5	10	1	500	43	140	88	100	6.2

(continued)

Table B-1. Continued

Well Number	Sampling Dates	pH	Color	Turbidity (JTU)	Water Quality		Total Hardness (ppm)	Ca Hardness (ppm)	DS/TDS (ppm)	D.O. (ppm)
					Alkalinity (ppm)	Chloride (ppm)				
Q-1	5/5/81	7.0	20	3	450	72	168	120	440	4.8
Q-4	5/5/81	7.0	20	5	450	82	168	100	440	3.4
Q-6	5/5/81	7.7	30	5	500	120	160	80	470	6.0
C-1	5/6/81	7.0	20	3	650	84	172	108	440	3.2
C-2	5/6/81	7.0	20	1	550	180	220	120	700	4.4
C-3	5/6/81	7.0	20	1	600	456	280	100	1,400	1.4
C-4	5/6/81	7.0	10	1	500	252	240	96	1,000	1.4
C-5	5/6/81	7.2	10	1	500	113	180	100	470	5.0
C-6	5/6/81	7.0	10	1	500	113	200	120	600	4.2
C-7	5/6/81	7.0	10	1	500	58	180	120	420	4.4
C-8	5/6/81	7.0	10	1	600	60	200	132	440	4.6
C-9	5/6/81	7.2	10	1	450	144	180	64	490	5.0
P1-13	5/6/81	7.5	10	0	350	24	120	80	300	6.6

(continued)

Table B-1. *Continued*

Well Number	Sampling Dates	pH	Color	Turbidity (JTU)	Water Quality		Total Hardness (ppm)	Ca Hardness (ppm)	DS/TDS (ppm)	D.O. (ppm)
					Alkalinity (ppm)	Chloride (ppm)				
Q-1	5/7/81	7.0	10	2	500	86	200	128	600	5.4
C-9	5/7/81	7.7	10	2	650	60	148	104	360	5.8
C-6	5/8/81	7.2	20	3	600	108	192	128	460	6.4
Q-1	5/12/81	7.2	30	3	550	108	156	120	500	5.4
Q-3	5/12/81	7.0	30	3	650	120	184	148	600	1.6
Q-4	5/12/81	7.0	30	3	500	91	144	112	470	4.8
Q-6	5/12/81	7.7	30	3	500	132	144	100	480	6.2
C-1	5/13/81	7.0	30	3	600	84	180	120	450	2.0
C-2	5/13/81	7.2	30	3	650	168	188	132	700	4.8
C-4	5/13/81	7.0	10	2	650	163	240	124	800	2.4
C-5	5/13/81	7.2	30	5	650	156	180	128	600	5.6
C-6	5/13/81	7.0	30	3	600	120	200	104	600	3.8
C-7	5/13/81	7.2	10	2	650	60	172	116	400	5.0
C-8	5/13/81	7.0	10	2	450	60	200	140	430	3.6
C-9	5/13/81	7.7	20	2	500	168	180	100	600	3.8
P1-13	5/13/81	7.7	20	2	400	29	120	96	250	6.2

(continued)

Table B-1. Continued

Well Number	Sampling Dates	pH	Color	Turbidity (JTU)	Water Quality		Total Hardness (ppm)	Ca Hardness (ppm)	DS/TDS (ppm)	D.O. (ppm)
					Alkalinity (ppm)	Chloride (ppm)				
Q-1	5/19/81	7.2	20	1	600	108	180	108	460	5.4
Q-3	5/19/81	6.8	30	3	750	139	240	136	700	1.4
Q-4	5/19/81	7.2	20	2	500	91	144	84	420	5.2
Q-6	5/19/81	7.7	30	5	500	137	156	64	440	6.0
C-1	5/20/81	7.2	30	3	650		176	44	400	1.6
C-4	5/20/81	7.2	30	3	600		200	20	700	1.4
C-5	5/20/81	7.5	30	3	450		160	100	470	3.8
C-6	5/20/81	7.2	30	3	600		196	100	500	4.2
C-7	5/20/81	7.2	30	3	500		172	108	380	3.2
C-8	5/20/81	7.0	30	3	600		192	128	400	3.8
C-9	5/20/81	7.2	30	3	450		172	80	600	3.0
P1-13	5/20/81	7.5	30	2	300		120	80	240	6.0

(continued)

Table B-1. Continued

Well Number	Sampling Dates	pH	Color	Turbidity (JTU)	Water Quality		Total Hardness (ppm)	Ca Hardness (ppm)	DS/TDS (ppm)	D.O. (ppm)
					Alkalinity (ppm)	Chloride (ppm)				
Q-1	5/26/81	7.2	20	2	750		200	120	600	6.6
Q-3	5/26/81	6.8	30	3	750		268	148	750	0.6
Q-4	5/26/81	7.2	20	3	600		192	116	460	4.6
Q-6	5/26/81	7.7	30	3	500		176	92	470	6.0
C-1	5/26/81	7.0	30	3	600		184	80	420	6.4
C-4	5/27/81	7.2	35	3	600		220	60	700	5.4
C-5	5/27/81	7.2	20	3	550		168	100	430	5.0
C-6	5/27/81	7.5	35	5	600		216	100	490	5.4
C-7	5/27/81	7.2	20	2	550		180	104	380	6.4
C-8	5/27/81	7.2	30	2	600		192	128	400	6.8
C-9	5/27/81	7.5	30	5	500		172	84	600	3.8
P1-13	5/27/81	7.7	30	2	500		116	88	240	6.8

Appendix C

PRETREATMENT TEST RESULTS

Table C-1. pH adjustment

Experiment 1. July 1, 1981. Well water alkalinity = 600 ppm as $CaCO_3$
pH initial = 7.05. Well water volume = 1,000 ml.

Experiment 2. July 2,1981. Well water alkalinity = 620 ppm as $CaCO_3$
pH initial = 7.6. Well water volume = 1,000 ml.

Acid strength used in Experiment 1 and 2, 1/10 of 20°Be HCl.

Experimental results:

Experiment 1		Experiment 2	
Acid Volume (ml)	ph Value	Acid Volume (ml)	pH Value
0	7.05	0	7.6
0.5	6.7	0.5	7.25
1.0	6.5	1.0	7.0
1.5	6.2	1.5	6.7
2.0	6.15	2.0	6.6
2.5	6.0	2.5	6.35
3.0	5.9	3.0	6.3
3.5	5.8	3.5	6.2
4.0	5.65	4.0	6.0
4.5	5.5	4.5	5.8
5.0	5.35	4.75	5.75
5.5	5.1	5.0	5.65
6.0	4.6	5.25	5.5
6.5	3.4	5.5	5.4
7.0	3.2	6.0	4.6
7.5	3.2	6.5	3.5
8.0	3.2	7.0	3.45
		7.5	3.45
		8.0	3.45
		10.0	3.2

Table C-2. Test Results of Slow Sand Filtration

Hour and Date		Color	Turbidity	TDS (ppm)	Total Hardness	Calcium Hardness	Dissolved Oxygen	Chloride	Alkalinity	pH	Bacteria Count	Flow Rate (ml/min)	Residual Chlorine	Remarks
0900	Influent	20	3	465	168	112	11.2	94	680	8.0	TNTO			H_2O_2 added
7-16-81	Effluent	5	0	450	152	96	7.0	92	630	7.7	TNTO	35		H_2O_2 added
1300	Influent	30	3	480	172	112	6.0	94	630	7.7	300			H_2O_2 added
7-16-81	Effluent	5	0	440	156	96	7.0	92	580	7.7	300	35		H_2O_2 added
0900 7-17-81	Influent	30	3	490	168	112	6.6	104	680	8.0	100			Added approx 10 ppm of $Ca(OCl)_2$
	Effluent	5	0	470	164	88	7.8	99	530	7.7	100	32.5		Measured immediately. Obtained 2 ppm Cl_2 residual. Reduce flow rate from 50 to 35 ml/min. Partial plug-up.
1230 7-17-81	Influent	30	3	480	176	128	6.4	104	630	8.0	600		0.0	Flow rate further reduces down to 30 ml/min (1300 H)
	Effluent	5	0	460	168	66	7.6	99	580	7.7	200	30	0.0	1350 - added 3 gm of HTH to about 40 gal of water; 1352 - residual Cl_2 = 6 ppm
0900	Influent	20	2	600	196	140	7.2	127	580	7.7	0		13.0	
7-18-81	Effluent	8	0	550	164	112	7.4	115	580	7.7	200	33.5	0.0	
1330	Influent	20	2	600	320	210				7.7			3.0	
7-18-81	Effluent	5	0	560								38	0.0	
0900	Influent	20	3	475	180	120	7.4	108	580	7.7				
7-20-81	Effluent	5	0	460	172	100	8.2	108	530	7.7		38		
0900	Influent	20	3	475	180	120	7.4	108	580	7.7				
7-20-81	Effluent	5	0	460	172	100	8.2	108	580	7.7		38		
0900	Influent	20	3	575	176	120	6.6	106	580	7.5				
7-21-81	Effluent	5	0	490	164	96	6.2	106	580	7.5		36		
0830	Influent	20	3	590	172	120	6.6	104	630	8.0				
7-22-81	Effluent	5	0	525	164	100	6.8	104	580	7.7		28		
0900	Influent	20	3	625	172	120	6.6	108	630	8.0				
7-23-81	Effluent	5	0	575	156	108	6.6	108	480	7.7		23		

Continued

Table C-2. Continued.

Hour and Date		Color	Turbidity	TDS (ppm)	Total Hardness	Calcium Hardness	Dissolved Oxygen	Chloride	Alkalinity	pH	Bacteria Count	Flow Rate (ml/min)	Residual Chlorine	Remarks
0900	Influent	20	3	590	176	120	6.6	115	630	8.0				Experimental set-up was transferred to another plant
7-24-81	Effluent	5	0	550	164	104	6.8	106	530	7.7		25		
0900	Influent	20	3	625	176	120	6.8	108	680	8.0				
7-25-81	Effluent	5	0	550	156	104	6.0	104	580	7.5		22		
0900	Influent	30	3	480	168	120	6.2	108	680	8.0				
7-27-81	Effluent	5	0	465	152	104	5.6	104	580	7.5		17		
1000	Influent	30	3	465	168	120	6.8	94	630	8.0				
7-28-81	Effluent	5	0	450	152	92	6.0	92	580	7.6		16		
1000	Influent	30	3	460	168	120	6.6	92	530	7.9				
7-29-81	Effluent	10	0	450	152	100	6.0	92	480	7.6		15		
1000	Influent	30	3	450	164	104	6.4	92	630	8.0				
7-30-81	Effluent	10	0	420	140	80	5.6	90	580	7.6		15		

Note: Initial flow rate = 50 ml/min.

Table C-3. Fouling Index

Date	Multi-Media Filter Effluent
05-01-81	3.10
05-02-81	2.70
05-07-81	6.10
05-08-81	6.10
05-09-81	5.70
05-14-81	4.50
05-15-81	4.50
05-16-81	4.80
05-21-81	4.80
05-22-81	4.80
05-23-81	5.00
07-15-81	4.20
07-24-81	7.46
07-25-81	6.71
07-28-81	5.69
07-29-81	6.14
07-30-81	6.59
07-31-81	7.50
08-01-81	6.31

Table C-4. Chemical Additions

Experiment No.1. Hydrogen peroxide added to raw well water

Sample	H_2O_2 Dosage (ppm)	Color	Sulfide	DO	Odor
Blank	0	30	0.3	4.2	Yes
1	2.5	30	0.1	5.4	Slight
2	5.0	30	0	6.0	No
3	7.5	25	0	8.5	No
4	10.0	25	0	8.6	No
5	12.5	20	0	11.0	No
6	15.0	20	0	11.0	No

Experiment No. 2. Calcium hypochlorite and hydrogen peroxide added to raw well water

Sample No.	$Ca(COl_2)$ (ppm)	H_2O_2 (ppm)	Odor	Color	Cl_2 Residual	Sulfide	Bacteria Count
B	0	0	Yes	30	0	0.4	45
1	2.5	0	No	30	0	0.1	30
2	5.0	0	No	30	0	0	25
3	0	2.5	No	30	0	0	3
4	0	5.0	No	30	0	0	0

Appendix D

ION-EXCHANGE DEIONIZER'S OPERATION DATA SUMMARY AND PERFORMANCE DATA SHEETS

Table D-1. Ion-Exchange Deionizer Operation Data Summary

Date	Product (gal)	Time			Product Performance		Chemicals	
		Total[a] (hrs)	On Line (hrs)	Regeneration (hrs)	Flow Rate (gpm)	Percentage of Input[b]	HCl (gal)	NaOH (gal)
	8,220	(Meter reading at start of test)						
3-15-81	10,885	24	20.5	3.5	8.9	87.9	20	5
3-16-81	10,795	24	20.5	3.5	8.8	87.9	20	5
3-17-81	10,320	24	20.5	3.5	8.4	87.3	20	5
3-18-81	6,900	21	14	7.0[c]	8.2	62.4	40	10
3-19-81	5,790	17	17	--	5.7	100	0	0
3-20-81	6,730	19	15.5	3.5	7.2	81.8	20	5
3-21-81	9,360	24	20.5	3.5	7.6	86.2	20	5
3-22-81	4,760	10.5	10.5	--	7.6	100	0	0
3-23-81	1,150	6	2.5	3.5	7.7	43.4	20	5
3-25-81	1,290	3	3	--	7.2	100	0	0
3-28-81	8,630	22	22	--	6.5	100	0	0
3-29-81	8,160	24	18	6.0	7.6	84.5	20	5
3-30-81	---	3.5	0	3.5	0	--	20	5
3-31-81	7,530	12	12	--	10.5[d]	83.4	0	0
4-1-81	5,130	20	12	8.0	7.1	63.1	40	10
4-2-81	12,510	20	16	4.0	13.0	89.3	20	5
4-3-81	7,140	5.5	5.5	--	21.6[e]	100	0	0
4-6-81	9,540	11	7.5	3.5	21.2	86.4	20	0
4-7-81 to 4-19-81	54,220	No operating data available for this period					120	30
4-20-81	18,750	24	17	7.0	18.4	70.8	40	10
4-21-81	20,270	24	20.5	3.5	16.5	85.4	20	5
4-22-81	16,390	24	17	7.0	16.1	70.8	40	10
4-27-81	17,470	23	16	7.0	18.2	69.6	40	10
4-28-81	16,470	24	20.5	3.5	13.4	85.4	20	5
4-29-81	12,930	24	17	7	12.7	70.8	40	10

(continued)

Table D-1. Continued

Date	Product (gal)	Time			Product Performance		Chemicals	
		Total[a] (hrs)	On Line (hrs)	Regeneration (hrs)	Flow Rate (gpm)	Percentage of Input[b]	HCl (gal)	NaOH (gal)
5-4-81	16,120	23.5	16.5	7.0	16.3	70.2	40	10
5-5-81	18,260	22	18.5	3.5	16.5	84.1	20	5
5-6-81	18,160	26	18.5	7.5	16.4	71.2	40	10
5-11-81	14,730	24	16.5	7.5	14.9	68.8	40	10
5-12-81	18,010	23.5	16.5	7.0	18.2	70.2	40	10
5-13-81	16,330	23.5	16.5	7.0	16.5	70.2	40	10
5-18-81	18,720	25	18	7	17.3	72	40	10
5-19-81	17,820	24	17	7	17.5	70.8	40	10
5-20-81	17,420	23	16	7	18.1	69.6	40	10
5-25-81	19,220	23.5	16	7.5	20	68.1	40	10
5-26-81	17,040	23	16	7	17.8	69.6	40	10
5-27-81	9,660	12.5	9	3.5	17.9	72	20	5
	500,510	Meter reading at conclusion of test						
Total	492,290	794	590.5	208.5	13.9	74.3	1040	160
							2.1 gal HCl per 1,000 gal water product	0.53 gal NaOH per 1,000 gal water product

---

[a] Time period = 0800 - 0800.

[b] Based on 1,500 gallons of water for regeneration.

[c] Regeneration cycle was started accidentally.

[d] Added booster pump to increase flow rate to the system.

[e] Increased flow rate to maximum.

Table D-2. Summary of Water Analyses of Feed to and Water Product from a Ion-Exchange Deionizer

Date	TDS (ppm)		Total Hardness (ppm)		Calcium Hardness (ppm)		Chloride (ppm)		Alkalinity (ppm)		pH		Color		Turbidity (JTU)	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
4-3-81	600	12	372	0	248	0	115	7	650	150	7.5	5.0	20	0	2	0
4-20-81	425	12	167	0	115	0	124	40	750	200	7.5	5.5	20	10	3	0
4-21-81	425	12	198	12	130	0	117	76	650	150	7.7	5.0	25	0	2	0
4-22-81	400	42	174	0	135	10	110	50	650	300	7.6	5.5	20	0	1	0
4-27-82	225[a]	10	185	12	107	8	105	64	700	150	7.5	5.0	20	0	2	0
4-28-81	175[a]	25	197	15	123	15	98	72	650	150	7.5	5.5	20	0	1	0
4-29-81	75[a]	12	178	10	115	15	76	28	550	200	7.5	5.5	30	0	3	0
5-4-81	430	9	168	0	104	0	96	19	450	100	7.5	5.0	20	0	3	0
5-5-81	430	7	172	10	100	0	84	19	500	200	7.7	5.2	20	0	2	0
5-11-81	460	10	180	16	104	4	86	24	550	200	7.7	5.5	30	0	3	0
5-12-81	400	10	180	0	120	0	96	24	650	150	7.7	5.0	30	0	2	0
5-13-81	460	9	172	0	108	0	96	10	500	200	7.7	5.0	30	0	2	0
5-18-81	370	9	169	0	100	0	84	12	600	250	7.7	5.0	30	0	2	0
5-19-82	300	9	172	0	108	0	--	--	600	100	7.2	5.0	30	0	2	0
5-20-81	370	9	172	0	96	0	--	--	450	200	7.5	5.0	30	0	3	0
5-25-81	400	4	168	0	96	0	--	--	600	150	7.7	5.5	30	0	3	0
5-26-81	410	8	180	0	100	0	--	--	600	200	7.7	5.0	20	0	3	0
5-27-81	400	8	180	0	84	0	--	--	550	150	7.7	5.0	30	0	2	0
							Out of chloride reagent									

[a] Meter was out of order on these dates.

Appendix E

RO DEMINERALIZER OPERATIONAL AND PERFORMANCE SUMMARY

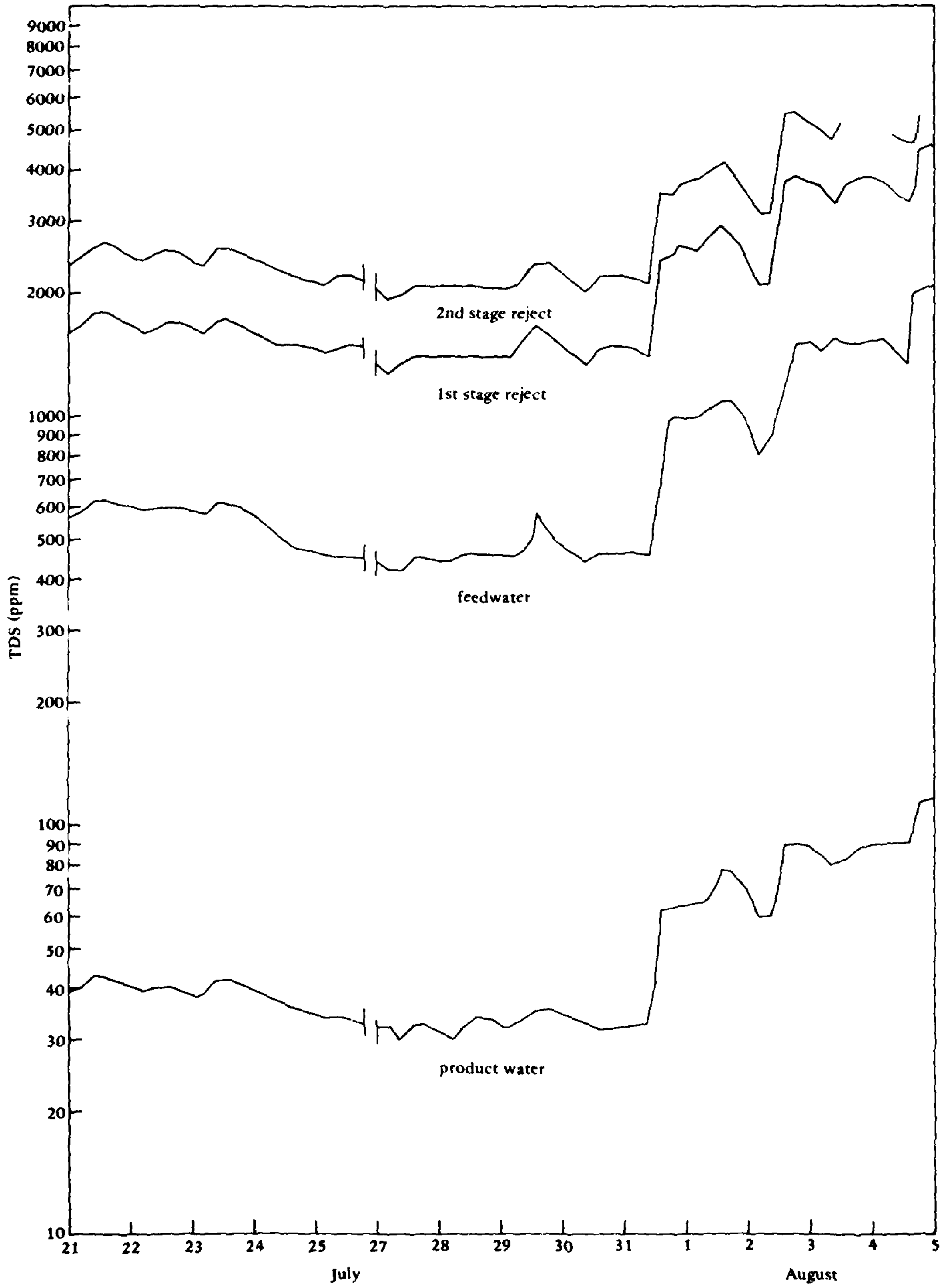


Figure E-1. Correlation of TDS in product water and feedwater; first- and second-stage rejects.

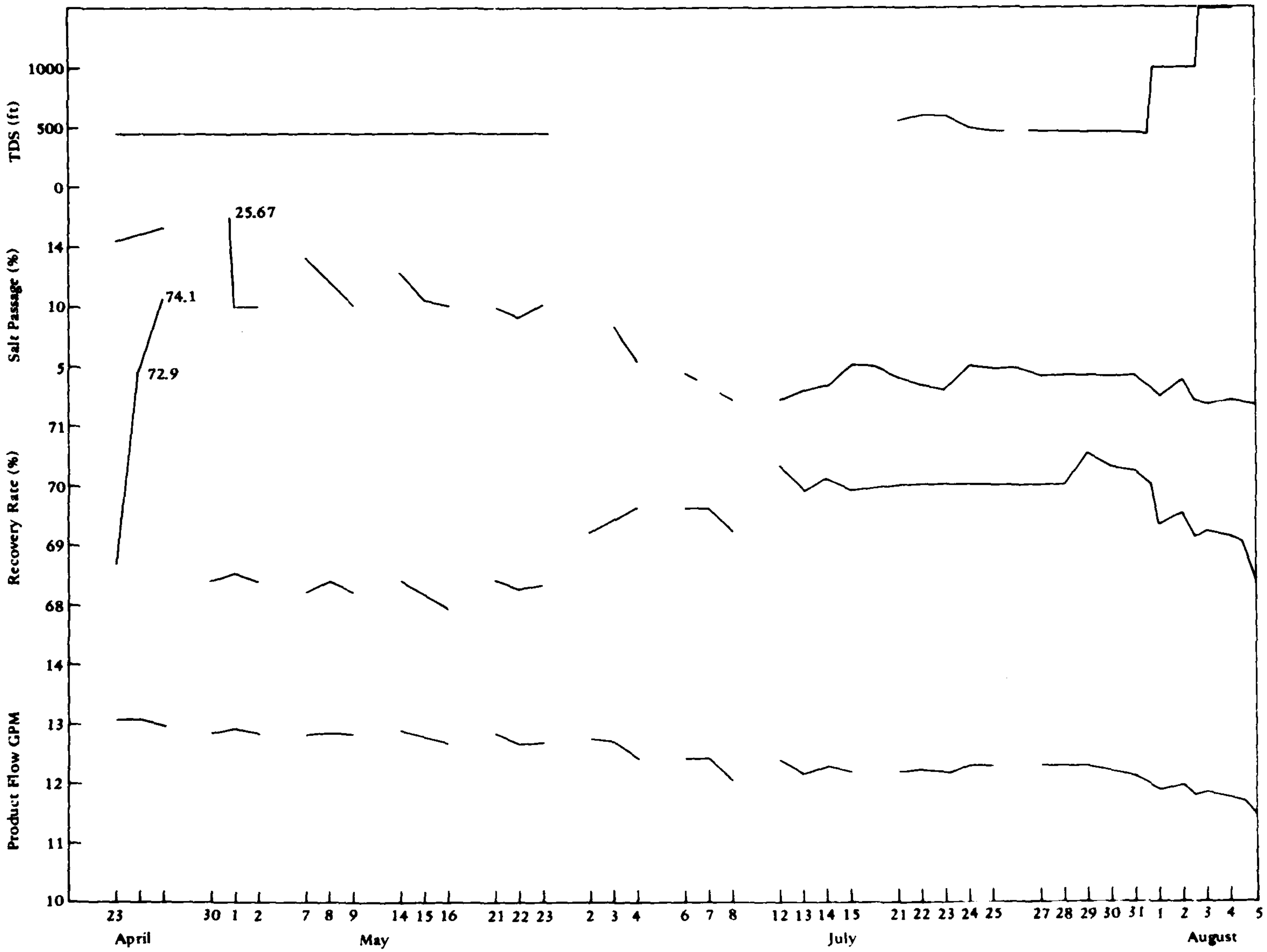


Figure E - 2. System performance curves for parameters, product flow, recovery rate, and salt passage.

Table E-1. Demineralizer Operational Summary

Date	Time on Line (hrs)	Flows			Inlet Pressure		Performance	
		Total Amount of Water (gals)	Product Water (gpm)	Waste Water (gpm)	First Stage (psig)	Second Stage (psig)	Recovery Rate (%)	Salt Passage (%)
4-23-81	4	4,800	13.8	6.0	400	370	69.7	12.75
4-24-81	24	27,900	13.8	5.1	400	370	72.9	12.97
4-25-81	24	26,700	13.7	4.7	400	370	74.1	13.32[a]
4-30-81	8	9,600	13.6	6.0	400	370	69.4	
5-1-81	24	25,500	13.7	6.0	400	370	69.5	9.90
5-2-81	24	28,400	13.6	6.0	400	370	69.4	9.92
5-7-81	8	9,500	13.5	6.0	400	370	69.2	12.03
5-8-81	24	23,000	13.6	6.0	400	370	69.4	10.82
5-9-81	24	27,500	13.5	6.0	400	370	69.2	10.0
5-14-81	8	8,300	13.6	6.0	400	370	69.4	11.4
5-15-81	24	28,300	13.4	6.0	400	370	69.1	10.23
5-16-81	24	27,500	13.3	6.0	400	370	68.9	10.05
5-21-81	8	5,350	13.6	6.0	400	370	69.4	9.86
5-22-81	24	32,050	13.3	5.9	400	370	69.3	9.45
5-23-81	24	27,500	13.3	5.9	400	370	69.3	10.0
7-2-81	8	9,200	13.4	5.7	400	370	70.2	---
7-3-81	24	17,100	13.3	5.6	400	370	70.2	9.1
7-4-81	24	33,500	13.0	5.4	400	370	70.6	7.61
7-6-81	24	26,800	13.0	5.4	400	38=70	70.6	7.09
7-7-81	14	15,500	13.0	5.4	400	370	70.6	---
8-8-81	36	34,900	12.5	5.3	400	370	70.2	6.0
7-12-81	10	5,370	12.9	5.2	400	372	70.2	5.97
7-13-81	18	20,870	12.7	5.2	400	375	71.3	6.45
7-14-81	24	23,900	12.8	5.2	400	372	71.1	6.61
7-15-81	24	24,970	12.7	5.2	400	370	70.9	7.51
7-21-81	24	25,780	12.7	5.2	400	372	71.0	6.8
7-22-81	23	24,840	12.8	5.2	400	375	71.0	6.5
7-23-81	14.5	15,575	12.7	5.2	400	375	71.0	7.5
7-24-81	11	11,880	12.8	5.2	400	375	71.0	7.4
7-25-81	23	24,840	12.8	5.2	400	375	71.0	7.1
7-27-81	24	25,920	12.8	5.2	400	375	71.0	7.2
7-28-81	21	22,680	12.8	5.2	400	375	71.0	7.2
7-29-81	24	25,920	12.8	5.1	400	375	71.5	7.2
7-30-81	20	21,360	12.7	5.1	400	375	71.3	7.1
7-31-81	14	14,870	12.6	5.1	400	375	71.2	7.1
	9[a]	9,450	12.4	5.1	400	375	71.0	6.7
8-1-81	23	24,150	12.3	5.1	400	375	70.3	6.2
8-2-81	18	19,010	12.4	5.2	400	375	70.5	5.8
	5[b]	5,720	12.2	5.2	400	375	70.1	6.0
8-3-81	20	20,940	12.25	5.2	400	375	70.2	5.8
8-4-81	16.5	17,225	12.2	5.2	400	375	70.1	6.0
	6.5[c]	6,750	12.1	5.2	400	375	70.0	5.8
8-5-81	9	9,180	11.8	5.2	400	375	69.4	5.7
	14[d]	14,700	12.3	5.2	400	375	70.3	8.0

[a] TDS increased to 1,000 ppm in feed stream.

[b] TDS increased to 1,500 ppm in feed stream.

[c] TDS increased to 2,000 ppm in feed stream.

[d] Return to normal TDS of 450 ppm.

Table E-2. Water Analyses Summary of Feed Water and Product Water from the RO Demineralizer

Date	TDS (ppm)		Total Hardness (ppm)		Calcium Hardness (ppm)		Chloride (ppm)		Alkalinity (ppm)		pH		Color		Turbidity (JTU)		TI Mixed Media Filter
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	
4-23-81	450	52	190	15	135	13	129	52	700	400	7.7	5.3	20	0	2	0	---
4-24-81	450	55	186	10	120	10	124	52	650	200	7.7	5.4	20	0	2		---
4-25-81	400	52	192	10	125	10	132	62	650	200	7.7	5.6	30		1		---
5-1-81	410	40	172	20	108	12	84	36	600	200	7.7	5.3	20		3		3.1
5-2-81	430	44	168	12	120	12	84	36	700	200	7.7	5.6	20	3			2.7
5-7-81	410	45	160	12	120	12	84	29	450	150	7.2	5.3	20		2		6.1
5-8-81	420	42	160	0	108	0	77	29	500	200	7.6	5.2	20		2		6.1
5-9-81	440	44	184	4	112	0			650	200	7.6	5.5	30		3		5.7
5-14-81	450	48	176	0	120	0	108	31	800	350	7.7	5.8	30		3		4.5
5-15-81	440	42	188	16	60	4	103	19	800	450	7.7	5.5	30		3		4.5
5-15-81	440	42	170	0	100	0	108	24	1,000	500	7.7	5.5	30		2		4.8
5-21-81	400	43	160	0	108	0			600	350	7.7	5.0	30		3		4.8
5-22-81	430	42	180	16	84	0			600	300	7.7	5.5	30		3		4.8
5-23-81	400	40	160	0	104	4			500	150	7.7	5.5	30		3		5.0
7-2-81[a]																	
7-3-81																	
7-4-81																	
7-6-81																	
7-7-81																	
7-8-81																	
7-15-81	575	37	176	0	124	0	110	34	700	200	7.7	5.5	30		3		4.2
7-21-81	625	42	188	0	124	8	131	7	630	230	7.5	5.5	20		3		---
7-22-81	600	40	172	4	124	4	110	16	700	280	7.5	5.5	30				---
7-23-81	625	41	180	0	132	4	108	14	530	230	7.7	5.5					---
7-24-81							No Data										7.46
7-25-81	460	34	172	4	112	0	87	18	680	130	7.7	5.2					6.71
7-27-81	420	30	176	4	120	4	89	21	530	180	7.7	5.5					---
7-28-81	444	30	176	4	124	4	85	23	530	230	7.7	5.3					5.69
7-29-81	455	32	172	4	124	4	83	23	580	180	7.7	5.5					6.14
7-30-81	460	34	164	4	124	0	83	23	580	230	7.7	5.6					6.59
7-31-81	450	33	172	4	120	4	92	18	630	180	7.7	5.3	30	0	3	0	7.5
	1,000	63															
8-1-81	1,050	65	224	12	128	8	347	35	680	230	7.6	5.5			5		6.31
8-2-81	1,500	100															
8-3-81	1,550	80	228	8	120	8	437	35	580	180	7.7	5.5			3		---
8-4-81	1,550	80	224	12	128	8	420	32	580	190	7.7	5.5	30	0	3	0	---
8-5-81	2,100	119															
	450	38															

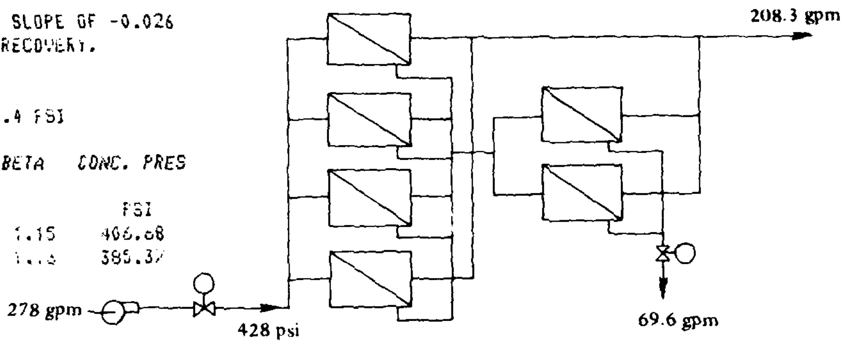
[a] Operator not available for simple analyses during 2 thru 8 July 1981.

Table E-3. Preliminary design of a 300,000-gpd RO system.

```
THIS IS ROSYS.FOR VERSION 005                                                        10-SEP-81    12:13:20
NAVY                                                                             CALCULATION NUMBER  7774
THIS CALCULATION WAS MADE BY: ROBERT BLEVITT
USING 8540 A ELEMENTS

FEED WATER TEMPERATURE WAS ASSUMED TO BE  82.0 F.
THE ELEMENTS WERE 0.00 YEARS OLD WITH A FLUX DECLINE SLOPE OF -0.026
TOTAL PRODUCT =  300,000 GPD OR  208.33 GPM AT 75.0 RECOVERY.
THE ARRAY WAS    4   2
TOTAL NUMBER OF ELEMENTS IN THIS SYSTEM IS    36.
FEED PRESSURE =    428.7 PSI   CONC. PRESSURE =   385.4 PSI

BANK              FEED FLOW          CONC. FLOW         BETA   CONC. PRES
               TOTAL     VESSEL     TOTAL       VESSEL
                GPM        GPM        GPM         GPM                PSI
  1           277.78     69.44     134.39       33.60      1.15     406.68
  2           134.39     67.19      69.62       34.81      [illegible]   385.37
```



```
|------------------FEED-----------------|----------------PERMEATE---------------|------------------CONCENTRATE-------------|
|                                        |                                       |                                          |
|  ION      MG/L     MEQ/L      PPM*     |    ION      MG/L     MEQ/L     PPM*   |    ION      MG/L     MEQ/L      PPM*      |
|                                        |                                       |                                          |
|  CA       52.0       2.6     129.4     |    CA        0.9       0.0      2.1   |    CA      204.9      10.2     509.7      |
|  MG       24.0       2.0      98.4     |    MG        0.4       0.0      1.6   |    MG       94.6       7.8     387.6      |
|  NA      439.0      19.1     954.3     |    NA       37.4       1.6     81.4   |    NA     1640.3      71.3    3565.8      |
|  K         0.0       0.0       0.0     |    K         0.0       0.0      0.0   |    K         0.0       0.0       0.0      |
|  NH4       0.0       0.0       0.0     |    NH4       0.0       0.0      0.0   |    NH4       0.0       0.0       0.0      |
|  HCO3    106.0       1.7      86.9     |    HCO3      6.3       0.1      5.1   |    HCO3    404.2       6.6     331.4      |
|  SO4     484.0      10.1     504.2     |    SO4       5.6       0.1      5.8   |    SO4    1914.4      39.9    1994.2      |
|  CL      420.0      11.8     591.5     |    CL       52.7       1.5     74.2   |    CL     1519.2      42.8    2139.7      |
|  NO3       0.0       0.0       0.0     |    NO3       0.0       0.0      0.0   |    NO3       0.0       0.0       0.0      |
|  F         0.0       0.0       0.0     |    F         0.0       0.0      0.0   |    F         0.0       0.0       0.0      |
|  SIO2      5.0       0.0       0.0     |    SIO2      0.9       0.0      0.0   |    SIO2     17.2       0.0       0.0      |
|          ----------------------------  |           --------------------------|            ------------------------      |
|  TDS    1530.0                         |    TDS     104.1                      |    TDS    5794.8                          |
|---------------------------------------------------------------------------------------------------------------------------|
|   NOTES:  *  PPM AS CACO3      --  THESE PERMEATE AND CONCENTRATE PREDICTIONS ARE ACCURATE TO ONLY + OR - 10%             |
|---------------------------------------------------------------------------------------------------------------------------|
```

continued

Table E-3. Continued.

```
THIS IS ROSYS.FOR VERSION 005
NAVY                                                              10-SEP-81    12:16:20
THIS CALCULATION WAS MADE BY: ROBERT BLEVITT                      CALCULATION NUMBER 7775
USING 8540 A ELEMENTS

FEED WATER TEMPERATURE WAS ASSUMED TO BE  82.0 F.
THE ELEMENTS WERE 3.00 YEARS OLD WITH A FLUX DECLINE SLOPE OF -0.026
TOTAL PRODUCT =  300,000 GPD OR  208.33 GPM AT 75.0 RECOVERY.
THE ARRAY WAS    4   2
TOTAL NUMBER OF ELEMENTS IN THIS SYSTEM IS    36.
FEED PRESSURE =   503.6 PSI   CONC. PRESSURE =   460.9 PSI

BANK          FEED FLOW          CONC. FLOW        BETA   CONC. PRES
           TOTAL     VESSEL    TOTAL     VESSEL
            GPM       GPM       GPM       GPM                PSI
  1        277.78    69.44    135.08     33.77      1.15    482.31
  2        135.08    67.54     69.27     34.64      1.14    460.91


:-----------------FEED------------------:----------------PERMEATE---------------:---------------CONCENTRATE--------------:
:                                       :                                       :                                        :
: ION      MG/L     MEQ/L     PPM*      :  ION      MG/L     MEQ/L     PPM*     :  ION      MG/L     MEQ/L     PPM*        :
:                                       :                                       :                                        :
: CA       52.0      2.6     129.4      :  CA        1.2      0.1       2.9     :  CA      205.0      10.2     509.9       :
: MG       24.0      2.0      98.4      :  MG        0.5      0.0       2.2     :  MG       94.6       7.8     387.7       :
: NA      439.0     19.1     954.3      :  NA       65.2      2.8     141.8     :  NA     1565.1      68.0    3402.4       :
: K         0.0      0.0       0.0      :  K         0.0      0.0       0.0     :  K         0.0       0.0       0.0       :
: NH4       0.0      0.0       0.0      :  NH4       0.0      0.0       0.0     :  NH4       0.0       0.0       0.0       :
: HCO3    106.0      1.7      86.9      :  HCO3     11.2      0.2       9.2     :  HCO3    391.6       6.4     321.0       :
: SO4     484.0     10.1     504.2      :  SO4       6.2      0.1       6.5     :  SO4    1922.2      40.0    2002.3       :
: CL      420.0     11.8     591.5      :  CL       93.2      2.6     131.3     :  CL     1405.0      39.6    1978.9       :
: NO3       0.0      0.0       0.0      :  NO3       0.0      0.0       0.0     :  NO3       0.0       0.0       0.0       :
: F         0.0      0.0       0.0      :  F         0.0      0.0       0.0     :  F         0.0       0.0       0.0       :
: SIO2      5.0      0.0       0.0      :  SIO2      1.5      0.0       0.0     :  SIO2     15.4       0.0       0.0       :
:                                       :                                       :                                        :
:         -----------------------------  :          ---------------------------- :         ------------------------------ :
: TDS    1530.0                         :  TDS     179.1                        :  TDS    5599.0                          :
:---------------------------------------------------------------------------------------------------------------------------:
:   NOTES:  * PPM AS CACO3      --  THESE PERMEATE AND CONCENTRATE PREDICTIONS ARE ACCURATE TO ONLY + OR - 10%             :
:---------------------------------------------------------------------------------------------------------------------------:
```

continued

Table E-3. Continued.

```
NAVY                                                                                    10-SEP-81   12:04:06
SAMPLE DATE:  81                                                                        SERIAL NUMBER:   859

THE IONS WERE ASSUMED TO BE REPORTED AS THE IONS.
SUM OF THE CATIONS IS      5.00 MEQ/L
SUM OF THE ANIONS IS     -23.66 MEQ/L


THE ORIGINAL ANALYSIS DID NOT BALANCE BY -65.08 %
A CORRECTION OF 18.65 MEQ/L WAS ADDED TO THE NA  CONC.

-------------------RAW WATER--PH OF 7.2-------------------------------------------------ACIDIFIED TO PH 5.6 WITH H2SO4------------------
   ION       CONCENTRATION        CONCENTRATION             :    ION                   CONCENTRATION
               REPORTED     --------CALCULATED------------ :                  ---------------CALCULATED---------------
                  MG/L          MG/L      MEQ/L PPM AS CACO3 :                       MG/L           MEQ/L       PPM AS CACO3
   CA             52.00         52.00      2.59    129.74   :    CA                52.00            2.59          129.74
   MG             24.00         24.00      1.97     98.68   :    MG                24.00            1.97           98.68
   NA             10.00        438.99     19.09    954.34   :    NA               438.99           19.09          954.34
   HCO3          708.00        708.00     11.60    580.14   :    HCO3             105.75            1.73           86.65
   SO4            10.00         10.00      0.21     10.41   .    SO4              484.14           10.08          503.90
   CL            420.00        420.00     11.84    592.22   :    CL               420.00           11.84          592.22
---------------------------------------------------------------------------------------------------------------------------------
   TDS          1550.00       1657.99                            TDS             1529.89
---------------------------------------------------------------------------------------------------------------------------------

T-ALKALINITY    580.00--PPM AS CACO3            580.14                                                             86.65
T-HARDNESS      224.00--PPM AS CACO3            228.42                                                             228.42

RAW WATER IONIC STRENGTH WAS  0.02604 MOLE/LITER              THE IONIC STRENGTH AFTER ACID IS  0.03098 MOLES/LITER

THE OSMOTIC PRESSURE IS ESTIMATED TO BE  13.2 PSI  AT 25 DEGREES C.
IT WOULD REQUIRE  367.60 MG/L OF HCL, OR  493.49 MG/L OF H2SO4. TO GIVE A PH OF 5.60

THIS WATER AS IS, OR PH ADJUSTED WITH HCL, WOULD BE SATURATED WITH CASO4 WHEN CONCENTRATED BY A FACTOR OF223.50
IF H2SO4 IS USED, THE FACTOR IS  10.96
```

Appendix F

SUMMARY OF TTHMs REGULATIONS

THE MAXIMUM CONTAMINANT LEVEL (MCL)

0.10 mg/l total trihalomethanes.

APPLICABILITY

Community water systems that add disinfectant to the treatment process (ground and surface).

EFFECTIVE DATES

Systems ≥75,000: 2 years after promulgation (29 Nov 1981)

Systems 10,000 to 75,000: 4 years after promulgation (29 Nov 1983)

Systems <10,000: State's discretion

MONITORING REQUIREMENTS

Analyze an annual average of a minimum of 4 samples per quarter per plant taken on same day. Systems using multiple wells drawing raw water from a single aquifer may, with state approval, be considered one treatment plant for determining the required number of samples.

EFFECTIVE DATES

Systems ≥75,000: 1 year after promulgation (29 Nov 1980)

Systems 10-75,000: 3 years after promulgation (29 Nov 1982)

Systems <10,000: State's discretion

SAMPLES LOCATIONS

25% at extreme of distribution system, 75% at location representative of population distribution.

FREQUENCY

For groundwater systems, reduced monitoring may be appropriate for certain systems; states may reduce the requirements through consideration of appropriate data including demonstration by the system that the maximum total trihalomethane potential (MTP) is less than 0.10 mg/l; the minimum frequency would be one sample per year for MTP. For groundwater systems not meeting the above MTP and for surface water systems, states may reduce the monitoring requirements if after 1 year of data collection, TTHMs levels are consistently below 0.10 mg/l; the minimum frequency would be one sample per quarter for TTHMs. The original frequency would be reinstated if the levels exceed 0.10 mg/l or if the treatment or source is modified.

REPORTING REQUIREMENTS TO STATE

Average of each quarterly analysis, within 30 days; until states have adopted the regulations, reporting will be to EPA unless the state requests receipt of data from the public water systems.

REPORTING REQUIREMENTS TO PUBLIC AND STATE

Running annual average of each quarterly sample if it exceeds MCL as prescribed by the public notification provisions.

OTHER REQUIREMENTS

To ensure microbiological quality, state approval of significant modifications in the treatment process to meet MCL.

AGREEMENT REACHED ON TRIHALOMETHANE RULE

The American Water Works Association (AWWA) and the Environmental Protection Agency (EPA) have agreed to settle a lawsuit challenging EPA's standard of 100 parts per billion (0.10 mg/l) for total trihalomethanes (TTHMs) in drinking water.

Under the agreement, EPA will propose a new rule that responds to many of AWWA's concerns. The new rule would set procedures for obtaining and maintaining a variance from the TTHMs standard, and specify control measures a water system may be required to consider.

AWWA said the treatment techniques known as granular activated carbon (GAC) filtration and biologically activated carbon (BAC) filtration for TTHMs control will not be required by EPA. A community would not need to consider those techniques in order to obtain a variance under the proposed rule.

In addition, EPA has clarified its suggestion that a lower standard of 0.010 to 0.025 mg/l is a goal. The agency's original TTHMs proposal left water systems unsure of what control measures eventually would be necessary. In the proposed rule, EPA says it did not mean "to suggest a status for the 0.10 mg/l of short duration."

The proposed new rule lists two groups of technologies for water utilities. The first group is deemed to be widely recognized technologies that are relatively low cost and within the technical capability of most water systems. The second group is considered to be technologies not generally available, but which a system granted a variance could be required to study, and perhaps install, under a compliance schedule.

Group One technologies are: (1) use of chloramines as alternate disinfectant; (2) use of chlorine dioxide as alternate disinfectant; (3) improving existing clarification; (4) alternating the point of chlorination; (5) intermittent or seasonal use of powdered activated carbon and dosages not to exceed 10 mg/l on an annual average basis.

Group Two technologies are: (1) introduction of off-line water storage; (2) aeration where geographically and environmentally appropriate; (3) introduction of clarification where not currently practiced; (4) con sideration of alternative sources of raw water; (5) use of ozone.

EPA or a state exercising enforcement authority could require any Group One item as a condition for granting and maintaining a variance to the TTHM maximums contaminant level of 0.10 mg/l. A water system could challenge such a ruling by demonstrating that the treatment method was not technically appropriate and feasible, or would result in only a marginal reduction of TTHMs for that system.

Group Two technologies could only be required to be installed if EPA or a state demonstrated that for the affected system, the treatment was technically feasible, economically reasonable and would achieve TTHMs reduction at least equal in value to the cost of obtaining the treatment.

AWWA said it believes the proposed rule will minimize potentially disruptive economic and technological effects of the TTHMs standard on water systems. AWWA said it supports adoption of the new rule.

If EPA adopts the proposal as it now stands, AWWA said it will dismiss its pending petition for review of the TTHMs standard, subject to court approval.

The legal action was filed in January 1980. AWWA argued that EPA had not properly determined what control measures were "generally available" and effective for achieving the standard, and that EPA had not properly taken costs into account. AWWA also questioned EPA's stated goal on lowering the standard substantially in the future.

Appendix G

TTHMs ANALYSIS AND ANALYTICAL RESULTS

Table G-1. Diego Garcia's TTHMs Analysis by PWC, Guam.

Samples Taken 12 June 1981

Sampling Point	Time	Type Sample	Free Cl_2 Residual	(ug/l) $CHCl_3$	(ug/l) $CHCl_2Br$	(ug/l) $CHClBr_2$	(ug/l) $CHBr_3$	(ug/l) TTHM
Effluent of Carbon Filter	0845	100 ml w/o*	0.0	20	<1	< 1	< 2	21
		100 ml w/o		17	1	<1	< 2	19
		30 ml w/ *		NT*				
		30 ml w/		NT				
		100 ml blank w/o		17	1	<1	< 2	19
		60 ml blank w/		NT				
Effluent of Reverse Osmosis	0900	100 ml w/o	0.0	17	<1	<1	<2	18
		100 ml w/o		17	1	<1	<2	19
		30 ml w/		NT				
		30 ml w/		NT				
		100 ml blank w/o		18	1	<1	<2	20
		60 ml blank w/		NT				
Effluent of Deionizer	0915	100 ml w/o	0.0	15	<1	<1	<2	16
		100 ml w/o		17	1	<1	<2	19
		30 ml w/		NT				
		30 ml w/		NT	-			
		100 ml blank w/o		20	1	<1	<2	22
		60 ml blank w/		NT				
Lab Faucet of Treated Water	0715	100 ml w/o	3.0	117	125	130	30	402
		100 ml w/o		127	124	132	30	413
		30 ml w/		49	44	52	15	160
		30 ml w/		78	88	100	15	281
		100 ml blank w/o		20	1	<1	<2	
		60 ml blank w/		17	1	<1	<2	
Food Services Cold Storage Area, S-Site most remote point south-east	1040	100 ml w/o	2.0	332	174	124	15	645
		100 ml w/o		283	156	108	15	562
		30 ml w/		234	141	112	15	502
		30 ml w/		239	144	112	15	510
		100 ml blank w/o		17	1	<1	<2	
		60 ml blank w/		20	1	<1	<2	
Officer's Mess Building, most remote point north	1115	100 ml w/o	2.5	146	144	144	30	464
		100 ml w/o		146	147	148	30	471
		30 ml w/		83	90	102	22	297
		30 ml w/		83	85	96	22	286
		100 ml blank w/o		17	1	<1	<2	
		60 ml blank w/		18	4	<1	<2	
Air Operations Raw Water Tank	1010	100 ml w/o	0.0	16	1	<1	<2	
		100 ml w/o		16	1	<1	<2	
		100 ml blank w/o		21	1	<1	<2	
MAC Air Terminal Restroom	1000	100 ml w/o	1.8	156	118	104	15	393
		100 ml w/o		166	126	112	15	419
		30 ml w/		137	115	112	15	379
		30 ml w/		122	103	100	< 2	325
		100 ml blank w/o		18	1	<1	<2	
		60 ml blank w/		20	2	2	<2	

* w/o - without thiosulfate   w/ - with thiosulfate   NT - not tested

Table G-2. TTHMs Analytical Results

[Samples received 9 July 1981; date in ppb]

Pretreatment	Sample Number																	
	1A	1B	C4	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
$CHCl_3$	5	37	13	2	25	18	2	28	12	1	4	5	2	1	1	1	2	1
$CHCl_2Br$	2	17	14	2	46	22	2	84	21	<1	4	1	3	3	1	1	4	1
$CHClBr_2$	<1	4	10	<1	33	13	<1	74	17	<1	<1	1	<1	<1	<1	<1	<1	<1
$CHBr_3$	<1	<1	3	<1	14	6	<1	29	9	<1	<1	<1	<1	<1	<1	<1	<1	<1
TTHM	7	58	40	4	118	59	4	215	59	1	7	5	9	5	2	2	6	2
Cl_2 (ppm) added	0	3.0	3.0	0	3.0	3.0	0	3.0	3.0	0	3.0	3.0	0	3.0	3.0	0	3.0	3.0
$Na_2S_2O_3$ added	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes

Note: (1) "B" and "C" sample results are averages of duplicate analyses of the same sample. "A" samples are single samples.

(2) Analyses performed 13-15 July 1981.

Table G-3. TTHMs Analytical Results

[Samples received 22 July, data in ppb]

Pretreatment	Sample Number																	
	1A	1B	C4	2A	2B	2C	3A	3B	3C	4A	4B	4C	5A	5B	5C	6A	6B	6C
$CHCl_3$	1	2	3	<1	2	<1	3	2	2	<1	1	2	3	3	3	<1	11	6
$CHCl_2Br$	1	1	1	<1	1	1	1	2	1	<1	<1	<1	<1	<1	<1	<1	1	<1
$CHClBr_2$	<1	<1	<1	<1	<1	<1	3	<1	1	<1	<1	<1	<1	<1	2	<1	<1	<1
$CHBr_3$	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total THM	2	3	4	<1	3	1	8	4	4	<1	1	2	3	3	5	<1	12	6

Note: Analyses performed 23-25 July 1981.
A, B, C, samples were respectively pretreated with 0, 3, 3 ppm of chlorine and no, no, yes of $Na_2S_2O_3$ (addition).

Table G-4. TTHMs Analytical Results

[Samples received 9 September 1981, data in ppb]

Pretreatment	Sample Number																			
	1A	1B	1C	2A	2B	2C	3A	3B	3C	4A	4B*	4C	5A	5B	5C	6A	6B**	6C	Blank	Toluene
$CHCl_3$	<1	7.2	6.4	1.0	9.2	7.2	<1	12.5	6.7	1.0	2.8	2.2	1.0	2.9	2.4	<1	3.9	2.1	<1	<1
$CHCl_2Br$	<1	10.8	6.7	<1	13.5	7.7	<1	46.0	14.0	<1	3.3	<1	<1	<1	<1	<1	2.3	<1	<1	<1
$CHClBr_2$	<1	6.8	4.1	<1	7.9	4.3	<1	48.6	15.0	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
$CHBr_3$	<1	2.0	1.0	<1	2.0	1.0	<1	15.0	6.5	<1	4.5	<1	<1	<1	<1	<1	4.9	<1	<1	<1
Total TTHMs	<1	26.8	18.2	1.0	32.6	20.2	<1	121.8	42.2	1.0	10.6	2.2	1.0	2.9	2.4	<1	11.1	2.1		
Cl_2 added, ppm	0	4	4	0	4	4	0	4	4	0	4	4	0	4	4	0	4	4		

Note: * Set 4B samples-11 unidentified peaks.
**Set 6B-10 unidentified peaks.

Appendix H

ACIDS FOR pH CONTROL IN RO PROCESS

Two acids readily available in commercial quantities (55-gallon drums or bulk) are hydrochloric acid and sulfuric acid. Hydrochloric acid is usually sold as 20° Baumé or about 31.4% HCl. Sulfuric acid can be obtained in several different concentrations, the most common being battery electrolyte (33.3%), concentrated (94%), and oleum (100%).

In calculating the amount of each acid required to neutralize a given alkalinity, the following chemical reactions apply:

$$\underset{0.45\ \mathrm{lb}}{\overset{2(36.5)}{2\mathrm{HCl}}} + \underset{1\ \mathrm{lb}}{\overset{162}{\mathrm{Ca(HCO_3)_2}}} = 2\mathrm{H_2O} + \mathrm{CaCl_2} + 2\mathrm{CO_2} \qquad (1)$$

$$\underset{0.6\ \mathrm{lb}}{\overset{98}{\mathrm{H_2SO_4}}} + \underset{1\ \mathrm{lb}}{\overset{162}{\mathrm{Ca(HCO_3)_2}}} = 2\mathrm{H_2O} + \mathrm{CaSO_4} + 2\mathrm{CO_2} \qquad (2)$$

The specific gravity of 20°Be HCl is 1.16 *and* that of concentrated H_2SO_4 is 1.83 or 9.6 lb/gal for HCl and 15.2 lb/gal for H_2SO_4.

Therefore, it would require 0.15 gallons of HCl (31.4%) *and/or* 0.042 gallons of H_2SO_4 (94%) to neutralize 1 pound alkalinity as $Ca(HCO_3)_2$.

For a 450,000-gallon per day water treatment system, assuming alkalinity concentration of 500 ppm as $CaCO_3$ (equivalent to 810 ppm as $Ca(HCO_3)_2$), the total alkalinity content is 3,025 pounds. This alkalinity will require 454 gallons of HCl (31.4%) and/or 127 gallons of H_2SO_4 (94%) to neutralize. The HCl requirement found in the actual field test was 15 gallons HCl/26,000 gallons of feed water or 0.057% (v/v) that was equivalent to 0.081% (v/v) for product water at 70% recovery rate. Based on this figure, 366 gallons of 20°Be HCl will be needed for obtaining 450,000 gallons of product water per day at a 70% recovery rate. The difference between 454 and 366 gallons is a result of the assumption that alkalinity is all in $Ca(HCO_3)_2$ form rather than in many other forms.

Appendix I

LANGLIER'S SATURATION INDEX (LI)

$$LI = pH - pH_s \qquad (1)$$

$$pH_s = pK_2 - pK_s + p[Ca] + p[Alk] + 6.301 + S \qquad (2)$$

$$S = 2.5\ (\mu)^{0.5}/[1 + 5.3\ (\mu)^{0.5} + 5.5\mu] \qquad (3)$$

pH = pH value of the water sample

where pH_s = pH of saturation

p = common logarithm

K_2 = the second ionization constant for carbonic acid

K_s = the solubility product constant

[Ca] = calcium hardness in ppm as $CaCO_3/50$

[Alk] = alkalinity in ppm as $CaCO_3/50$

S = 2.5×10^{-5}Sd; Sd = TDS in ppm (when less than 500)

S = 4H-A when Sd >500 ppm(TDS)

H = total hardness in moles/l

A = alkalinity in eq/l

The carbonate solution equilibrium constants vary with temperature as follows:

Temperature (°C)	5	10	15	20	25	40	60
Log (K_s/K_2)	+2.47	+2.34	+2.21	+2.10	+1.99	+1.71	+1.40

A linear regression of these values can be expressed as:

$$\text{Log}\ (K_s/K_2) = 2.55 - 0.0216T \qquad (4)$$

There is no corrosion and scaling when LI=0: LI with a positive value indicates scaling tendency, while LI with a negative value indicates corrosion tendency.

DISTRIBUTION LIST

ARMY Fal Engr, Letterkenny Army Depot, Chambersburg, PA
AFB (AFIT/LDE), Wright Patterson OH; AF Tech Office (Mgt & Ops), Tyndall, FL; CESCH, Wright-Patterson; HQ Tactical Air Cmd/DEMM (Schmidt) Langley, VA; MAC/DET, Scott, IL; SAMSO/MNND, Norton AFB CA; Stinfo Library, Offutt NE
AFESC DEB, Tyndall, FL
NATL ACADEMY OF ENG. Alexandria, VA
ARMY ARRADCOM, Dover, NJ; BMDSC-RE (H. McClellan) Huntsville AL; Contracts - Facs Engr Directorate, Fort Ord, CA; DAEN-CWE-M, Washington DC; DAEN-MPE-D Washington DC; DAEN-MPU, Washington DC; Engr District (Memphis) Library, Memphis TN; Tech. Ref. Div., Fort Huachuca, AZ
ARMY - CERL Library, Champaign IL
ARMY COASTAL ENGR RSCH CEN Fort Belvoir VA
ARMY COE Philadelphia Dist. (LIBRARY) Philadelphia, PA
ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA
ARMY CRREL Library, Hanover NH
ARMY ENG DIV HNDED-CS, Huntsville AL; HNDED-FD, Huntsville, AL
ARMY ENG WATERWAYS EXP STA Library, Vicksburg MS
ARMY ENGR DIST. Library, Portland OR
ARMY ENVIRON. HYGIENE AGCY Dir Env Qual Aberdeen Proving Ground MD; HSE-EW Water Qual Eng Div Aberdeen Prov Grnd MD; HSE-RP-HG/Pest Coord, Arberdeen Proving Ground, MD; Librarian, Aberdeen Proving Ground MD
ARMY MATERIALS & MECHANICS RESEARCH CENTER Dr. Lenoe, Watertown MA
BUREAU OF RECLAMATION Code 1512 (C. Selander) Denver CO
CINCPAC Fac Engrng Div (J44) Makalapa, HI
CNAVRES Code 13 (Dir. Facilities) New Orleans, LA
CNM NMAT - 044, Washington DC
CNO Code NOP-964, Washington DC
COMNAVMARIANAS Code N4, Guam
COMOCEANSYSLANT PW-FAC MGMNT Off Norfolk, VA
DEFFUELSUPPCEN DFSC-OWE (Term Engrng) Alexandria, VA
DOD Staff Spec. Chem. Tech. Washington DC
DTIC Defense Technical Info Ctr/Alexandria, VA
DTNSRDC Code 42, Bethesda MD
DTNSRDC Code 522 (Library), Annapolis MD
ENVIRONMENTAL PROTECTION AGENCY Reg. III Library, Philadelphia PA; Reg. VIII, 8M-ASL, Denver CO; Reg. X Lib. (M/S 541), Seattle WA
FLTCOMBATTRACENLANT PWO, Virginia Bch VA
GSA Assist Comm Des & Cnst (FAIA) D R Dibner Washington, DC ; Fed. Sup. Serv. (FMBP), Washington DC; Off of Des & Const-PCDP (D Eakin) Washington, DC
HCU ONE CO, Bishops Point, HI
KWAJALEIN MISRAN BMDSC-RKL-C
LIBRARY OF CONGRESS Washington, DC (Sciences & Tech Div)
MARINE CORPS BASE Code 406, Camp Lejeune, NC; M & R Division, Camp Lejeune NC; Maint Off Camp Pendleton, CA; PWD - Maint. Control Div. Camp Butler, Kawasaki, Japan; PWO Camp Lejeune NC; PWO, Camp Pendleton CA; PWO, Camp S. D. Butler, Kawasaki Japan
MARINE CORPS HQS Code LFF-2, Washington DC
MCAS Facil. Engr. Div. Cherry Point NC; CO, Kaneohe Bay HI; Code S4, Quantico VA; Facs Maint Dept - Operations Div, Cherry Point; PWD - Utilities Div, Iwakuni, Japan; PWD, Dir. Maint. Control Div., Iwakuni Japan; PWO, Iwakuni, Japan; PWO, Yuma AZ
MCDEC NSAP REP, Quantico VA
MCLB B520, Barstow CA
MILITARY SEALIFT COMMAND Washington DC
NAF PWD - Engr Div, Atsugi, Japan; PWO, Atsugi Japan
NALF OINC, San Diego, CA
NARF Code 612, Jax, FL; Code 640, Pensacola FL; SCE Norfolk, VA
NAS CO, Guantanamo Bay Cuba; Code 114, Alameda CA; Code 183 (Fac. Plan BR MGR); Code 187, Jacksonville FL; Code 18700, Brunswick ME; Code 18U (ENS P.J. Hickey), Corpus Christi TX; Code 70, Atlanta, Marietta GA; Code 8E, Patuxent Riv., MD; Dir of Engrng, PWD, Corpus Christi, TX; Dir. Util. Div., Bermuda; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div Dir, Millington, TN; PWD - Engr Div, Gtmo, Cuba; PWD - Engr Div, Oak Harbor, WA; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Willow Grove PA; PWO Belle Chasse, LA; PWO Chase Field Beeville, TX; PWO Key West FL;

PWO Lakehurst, NJ; PWO Sigonella Sicily; PWO Whiting Fld, Milton FL; PWO, Dallas TX; PWO, Glenview IL; PWO, Kingsville TX; PWO, Millington TN; SCE Norfolk, VA; SCE, Barbers Point HI
NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
NAVAEROSPREGMEDCEN SCE, Pensacola FL
NAVAIRDEVCEN PWD, Engr Div Mgr, Warminster, PA
NAVAIRPROPTESTCEN CO, Trenton, NJ
NAVAIRTESTCEN PATUXENT RIVER PWD (F. McGrath), Patuxent Riv.,MD
NAVAVIONICFAC PWD Deputy Dir. D/701, Indianapolis, IN
NAVCOASTSYSCEN Library Panama City, FL; PWO Panama City, FL
NAVCOMMAREAMSTRSTA PWO, Norfolk VA; SCE Unit 1 Naples Italy
NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia; SCE, Balboa, CZ
NAVCONSTRACEN Code 00U15, Port Hueneme CA
NAVEDTRAPRODEVCEN Technical Library, Pensacola, FL
NAVEDUTRACEN Engr Dept (Code 42) Newport, RI
NAVEODTECHCEN Code 605, Indian Head MD
NAVFAC PWO, Point Sur, Big Sur CA
NAVFACENGCOM Alexandria, VA; Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 0451 (P W Brewer) Alexandria, Va; Code 0451, Alexandria, VA; Code 0454B Alexandria, Va; Code 04A1 Alexandria, VA; Code 051A Alexandria, VA; Code 09M54, Tech Lib, Alexandria, VA; Code 1113, Alexandria, VA; code 08T Alexandria, VA
NAVFACENGCOM - CHES DIV. Code 405 Wash, DC; Library, Washington, D.C.
NAVFACENGCOM - LANT DIV. Code 403, Norfolk, VA; Code 405 Civil Engr BR Norfolk VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA
NAVFACENGCOM - NORTH DIV. (Boretsky) Philadelphia, PA; CO; Code 04 Philadelphia, PA; Code 1028, RDT&ELO, Philadelphia PA; Code 111 Philadelphia, PA; Code 114 (A. Rhoads); Library, Philadelphia, PA; ROICC, Contracts, Crane IN
NAVFACENGCOM - PAC DIV. CODE 09P PEARL HARBOR HI; Code 402, RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI
NAVFACENGCOM - SOUTH DIV. Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC
NAVFACENGCOM - WEST DIV. AROICC, Contracts, Twentynine Palms CA; Code 04B San Bruno, CA; Code 114C, San Diego CA; Library, San Bruno, CA; O9P/20 San Bruno, CA; RDT&ELO Code 2011 San Bruno, CA
NAVFACENGCOM CONTRACTS AROICC, Quantico, VA; Dir, Eng. Div., Exmouth, Australia; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC-ROICC, NAS Oceana, Virginia Beach, VA; OICC/ROICC, Balboa Panama Canal; ROICC AF Guam; ROICC Code 495 Portsmouth VA; ROICC Key West FL; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Point Mugu, CA; ROICC, Yap; ROICC-OICC-SPA, Norfolk, VA
NAVFORCARIB Commander (N42), Puerto Rico
NAVMAG PWD - Engr Div, Guam
NAVOCEANO Library Bay St. Louis, MS
NAVORDSTA PWO, Louisville KY
NAVPETOFF Code 30, Alexandria VA
NAVPETRES Director, Washington DC
NAVPGSCOL E. Thornton, Monterey CA
NAVPHIBASE CO, ACB 2 Norfolk, VA; Code S3T, Norfolk VA; SCE Coronado, SD,CA
NAVRADRECFAC PWO, Kami Seya Japan
NAVREGMEDCEN Code 29, Env. Health Serv. (Al Bryson) San Diego, CA
NAVREGMEDCEN PWO, Okinawa, Japan
NAVREGMEDCEN SCE; SCE San Diego, CA; SCE, Camp Pendleton CA; SCE, Newport, RI; SCE, Oakland CA
NAVREGMEDCEN SCE, Yokosuka, Japan
NAVREGMEDCLINIC A. Watanabe, Pearl Harbor, HI
NAVSCOLCECOFF C35 Port Hueneme, CA; CO, Code C44A Port Hueneme, CA
NAVSEASYSCOM SEA 04E (L Kess) Washington, DC
NAVSECGRUACT Facil. Off., Galeta Is. Panama Canal; PWO, Adak AK; PWO, Edzell Scotland; PWO, Puerto Rico
NAVSHIPYD Bremerton, WA (Carr Inlet Acoustic Range); Code 202.5 (Library) Puget Sound, Bremerton WA; Code 380, Portsmouth, VA; Code 400, Puget Sound; Code 410, Mare Is., Vallejo CA; Code 440 Portsmouth NH; Code 440, Norfolk; Code 440, Puget Sound, Bremerton WA; L.D. Vivian; Library, Portsmouth NH; PW Dept, Long Beach, CA; PWD (Code 420) Dir Portsmouth, VA; PWD (Code 450-HD) Portsmouth, VA; PWO, Bremerton, WA; PWO, Mare Is.; PWO, Puget Sound; SCE, Pearl Harbor HI; Tech Library, Vallejo, CA
NAVSTA CO Roosevelt Roads P.R. Puerto Rico; CO, Brooklyn NY; Dir Engr Div, PWD, Mayport FL; Dir Mech Engr 37WC93 Norfolk, VA; Engr. Dir., Rota Spain; Long Beach, CA; Maint. Cont. Div.,

Guantanamo Bay Cuba; Maint. Div. Dir/Code 531, Rodman Panama Canal; PWD - Engr Dept, Adak, AK; PWD - Engr Div, Midway Is.; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam; SCE, Pearl Harbor HI; Security Offr, San Francisco, CA
NAVSUBASE SCE, Pearl Harbor HI
NAVSUPPFAC PWD - Maint. Control Div, Thurmont, MD
NAVTECHTRACEN SCE, Pensacola FL
NAVWPNCEN Code 2636 China Lake; Code 3803 China Lake, CA; PWO (Code 266) China Lake, CA
NAVWPNSTA Code 092, Colts Neck NJ; Maint. Control Dir., Yorktown VA
NAVWPNSTA PW Office Yorktown, VA
NAVWPNSTA PWD - Maint Control Div, Charleston, SC; PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO, Charleston, SC; PWO, Seal Beach CA
NAVWPNSUPPCEN Code 09 Crane IN
NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port Hueneme, CA; Code 25111 Port Hueneme, CA; Code 400, Gulfport MS; Code 430 (PW Engrng) Gulfport, MS; Code 470.2, Gulfport, MS; NEESA Code 252 (P Winters) Port Hueneme, CA; PWO (Code 80) Port Hueneme, CA; PWO, Gulfport, MS
NCR 20, Code R70
NMCB FIVE, Operations Dept; Forty, CO
NOAA Library Rockville, MD
NORDA Code 410 Bay St. Louis, MS; Code 440 (Ocean Rsch Off) Bay St. Louis MS
NSC Code 54.1 Norfolk, VA
NSD SCE, Subic Bay, R.P.
NSWSES Code 0150 Port Hueneme, CA
NTC OICC, CBU-401, Great Lakes IL
NUCLEAR REGULATORY COMMISSION T.C. Johnson, Washington, DC
NUSC Code 131 New London, CT; Code EA123 (R.S. Munn), New London CT
ONR Code 700F Arlington VA
PHIBCB 1 P&E, San Diego, CA
PMTC Pat. Counsel, Point Mugu CA
PWC ACE Office Norfolk, VA; CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10, Great Lakes, IL; Code 105 Oakland, CA; Code 120, Oakland CA; Code 128, Guam; Code 200, Great Lakes IL; Code 30V, Norfolk, VA; Code 400, Great Lakes, IL; Code 400, Oakland, CA; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 505A Oakland, CA; Code 600, Great Lakes, IL; Code 610, San Diego Ca; Code 700, Great Lakes, IL; Code 700, San Diego, CA; Library, Code 120C, San Diego, CA; Library, Code 154, Great Lakes, IL; Library, Guam; Library, Norfolk, VA; Library, Oakland, CA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic Bay, R.P.; Library, Yokosuka, JA; Util Dept (R Pascua) Pearl Harbor, HI; Utilities Officer, Guam
SUPANX PWO, Williamsburg VA
TVA Solar Group, Arnold, Knoxville, TN
U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
US DEPT OF COMMERCE NOAA, Pacific Marine Center, Seattle WA
US DEPT OF HEALTH, ED., & WELFARE Food & Drug Admin, (A. Story), Dauphin Is. AL
US GEOLOGICAL SURVEY Off. Marine Geology, Piteleki, Reston VA
US NATIONAL MARINE FISHERIES SERVICE Highlands NY (Sandy Hook Lab-Library)
USAF REGIONAL HOSPITAL Fairchild AFB, WA
USCG (Smith), Washington, DC
USDA Forest Service Reg 3 (R. Brown) Albuquerque, NM; Forest Service, Bowers, Atlanta, GA; Forest Service, San Dimas, CA
USNA ENGRNG Div, PWD, Annapolis MD; Energy-Environ Study Grp, Annapolis, MD; Environ. Prot. R&D Prog. (J. Williams), Annapolis MD; PWO Annapolis MD; USNA/Sys Eng Dept, Annapolis, MD
BERKELEY PW Engr Div, Harrison, Berkeley, CA
BROOKHAVEN NATL LAB M. Steinberg, Upton NY
CALIF. DEPT OF FISH & GAME Long Beach CA (Marine Tech Info Ctr)
CALIF. DEPT OF NAVIGATION & OCEAN DEV. Sacramento, CA (G. Armstrong)
CALIFORNIA INSTITUTE OF TECHNOLOGY Pasadena CA (Keck Ref. Rm)
CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.)
DAMES & MOORE LIBRARY LOS ANGELES, CA
FOREST INST. FOR OCEAN & MOUNTAIN Carson City NV (Studies - Library)
GEORGIA INSTITUTE OF TECHNOLOGY (LT R. Johnson) Atlanta, GA
HARVARD UNIV. Dept. of Architecture, Dr. Kim, Cambridge, MA
INSTITUTE OF MARINE SCIENCES Morehead City NC (Director)
KEENE STATE COLLEGE Keene NH (Cunningham)
LEHIGH UNIVERSITY Bethlehem PA (Fritz Engr. Lab No. 13, Beedle); Bethlehem PA (Linderman Lib. No.30, Flecksteiner)

MIT Cambridge MA; Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge, MA (Harleman)
NATL ACADEMY OF ENG. ALEXANDRIA, VA (SEARLE, JR.)
NEW MEXICO SOLAR ENERGY INST. Dr. Zwibel Las Cruces NM
NY CITY COMMUNITY COLLEGE BROOKLYN, NY (LIBRARY)
OREGON STATE UNIVERSITY (CE Dept Grace) Corvallis, OR
POLLUTION ABATEMENT ASSOC. Graham
PURDUE UNIVERSITY Lafayette, IN (CE Engr. Lib)
SEATTLE U Prof Schwaegler Seattle WA
SRI INTL Phillips, Chem Engr Lab, Menlo Park, CA
STATE UNIV. OF NEW YORK Buffalo, NY; Fort Schuyler, NY (Longobardi)
UNIVERSITY OF CALIFORNIA Berkeley CA (E. Pearson); La Jolla CA (Acq. Dept, Lib. C-075A)
UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.)
UNIVERSITY OF ILLINOIS Metz Ref Rm, Urbana IL; URBANA, IL (LIBRARY)
UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)
UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX
UNIVERSITY OF WASHINGTON (FH-10, D. Carlson) Seattle, WA; Seattle WA (E. Linger)
UNIVERSITY OF WISCONSIN Milwaukee WI (Ctr of Great Lakes Studies)
VIRGINIA INST. OF MARINE SCI. Gloucester Point VA (Library)
ANALYTICAL TECH Lawrence, Port Hueneme, CA
ARVID GRANT OLYMPIA, WA
AWWA RSCH FOUNDATION R. Heaton, Denver CO
BRITISH EMBASSY M A Wilkins (Sci & Tech Dept) Washington, DC
CHEMED CORP Lake Zurich IL (Dearborn Chem. Div.Lib.)
COLUMBIA GULF TRANSMISSION CO. HOUSTON, TX (ENG. LIB.)
DIXIE DIVING CENTER Decatur, GA
DRAVO CORP Pittsburgh PA (Wright)
DURLACH, O'NEAL, JENKINS & ASSOC. Columbia SC
FURGO INC. Library, Houston, TX
GARD INC. Dr. L. Holmes, Niles, IL
GENERAL DYNAMICS Elec. Boat Div., Environ. Engr (H. Wallman), Groton CT
GRUMMAN AEROSPACE CORP. Bethpage NY (Tech. Info. Ctr)
MATRECON Oakland, CA (Haxo)
NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ
SEAFOOD LABORATORY MOREHEAD CITY, NC (LIBRARY)
SHANNON & WILLSON INC. Librarian Seattle, WA
THE AM. WATERWAYS OPERATIONS, INC. Arlington, VA (Schuster)
UNITED TECHNOLOGIES Windsor Locks CT (Hamilton Std Div., Library)
WM CLAPP LABS - BATTELLE DUXBURY, MA (LIBRARY)
BRAHTZ La Jolla, CA
BULLOCK La Canada
ERVIN, DOUG Belmont, CA
KRUZIC, T.P. Silver Spring, MD
LAFKIN Seattle, WA
LAYTON Redmond, WA
CAPT MURPHY Sunnyvale, CA
BROWN & CALDWELL Saunders, E.M./Oakland, CA
WALTZ Livermore, CA