BLACK & VEATCH

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7/30/93

County of Dare
THM Study

B&V Project 23464.200
B&V File B
July 28, 1993

Dare County Desalination Plant
600 Mustian Street
Kill Devil Hills, North Carolina 27948

Attention: Mr. Bob Oreskovich

Gentlemen:

Black & Veatch is pleased to forward our final report on "Evaluation of Disinfection Byproduct Reduction Alternatives" prepared for the Dare County Regional Water Supply System.

We offer our appreciation to Bob Oreskovich, John Richeson, Darrell Merrill and their respective staff's for all the assistance provided during the preparation of this study.

Black & Veatch appreciates the opportunity to have been involved in this study and is always available to address any questions you may have.

Very truly yours,

BLACK & VEATCH

William P. Bizzell, P.E.

jyp
Enclosure

cc: w/enclosures
John Richeson, Nags Head
Darrell Merrill, Kill Devil Hills
Fred Hill, NC DEHNR
Doug Elder, Black & Veatch

RECEIVED 12/9/94

BLACK & VEATCH

110 West Walker Avenue, Asheboro, North Carolina 27204-0728, (919) 672-3600, Fax: (919) 672-3640

December 7, 1994

Mr. Bob Oreskovich
Dare County
PO Box 1000
Manteo, NC 27954

Dear Mr. Oreskovich:

As you know, a number of different regulations have been and continue to be developed under the Safe Drinking Water Act Amendments of 1986. Two important regulations which will affect most water suppliers in the United States are the Disinfectant/Disinfection Byproducts Rule (D/DBPR) and the Enhanced Surface Water Treatment Rule (ESWTR). The proposed D/DBPR and interim ESWTR, which were published by the USEPA in July of this year, were developed through a process known as Reg-Neg. In this process, input from representatives of many interest groups helped develop a rule which accommodated most of their concerns. The D/DBPR is expected to become law in December 1996 with very few changes. The interim ESWTR is scheduled for promulgation in 1998 after considerable public comment and consideration of monitoring results under the Information Collection Rule (ICR). Requirements of both rules will be effective 18 months after their promulgations.

Because of the wide impact on water providers across the country, Black & Veatch has prepared a summary document to clarify and promote awareness of the D/DBPR and interim ESWTR requirements. A copy of this document and a summary of comments made by USEPA officials at the 1994 Annual Meeting of the Association of Metropolitan Water Agencies regarding the impacts of these regulations on water suppliers are enclosed. I hope they will be useful references.

If you have questions about the D/DBPR, interim ESWTR, or other Safe Drinking Water Act regulations or if you would like additional copies of this document, please give me a call.

Very truly yours,

BLACK & VEATCH

John R Hendrick

John R. Hendrick

Enclosure

Summary of Regulatory Comments from the 1994 Annual Meeting of the Association of Metropolitan Water Agencies (AMWA)

A major focus of the 1994 Annual Meeting of the Association of Metropolitan Water Agencies (AMWA) was the impact on utilities of the upcoming Information Collection Rule (ICR), Enhanced Surface Water Treatment Rule (ESWTR), and Disinfectants and Disinfection Byproducts Rule (D/DBPR). Several key USEPA staff members spoke about the proposed regulations, potential changes, and estimated cost impacts for utilities.

Stig Regli, ICR Regulation Manager, presented an overview regarding the efforts to overcome the challenges in finalizing the ICR, as well as developing laboratory approval, laboratory quality assurance/quality control measures, and laboratory data base software. Originally, the ICR finalization date was October 1994, with laboratory testing to start no later than October 1995. However, the regulation has been delayed until spring of 1995, but testing requirements are still anticipated to begin in October 1995.

Regli also reported that laboratory approval will be handled by USEPA--it will not be delegated to the states. He said that in addition to using an approved laboratory to perform testing, the personnel performing the tests must also be USEPA approved. USEPA anticipates between 10 and 15 laboratories will be approved, and this number should be sufficient to handle the testing. USEPA's Pat Fair, chair of the Analytical Methods Task Force, presented an update on the plans for laboratory approval and monitoring. Fair said laboratories will not be approved until the ICR is finalized in the spring of 1995.

Coliphage and clestridium perfringen will be added to the microbials list for testing under the ICR, according to Regli. They will be possible indicator organisms for animal and agricultural sources of *Cryptosporidium*. In addition, Regli indicated that some cases will require sending a sample to USEPA for archiving. USEPA anticipates bench-scale and pilot testing required under the ICR will cost $150,000 and $750,000 per facility. Even with the exclusion criteria, Regli said he thought most systems will have to perform bench-scale and/or pilot testing for each of their facilities.

Larry Weiner, USEPA systems analyst, gave a preview of the Windows-based software that will be required for reporting testing results to USEPA. It will be available early in 1995.

John Cromwell, Apogee Research, presented estimated cost information on the impact of these proposed regulations for 300 of the largest utilities with facilities of 100 mgd or larger (approximately 440 plants total). Apogee Research is working for the American Water Works Association (AWWA) in compiling estimated cost impacts of these regulations on utilities. It is estimated that data collection required under the ICR will cost utilities upwards of $130 million. In addition, Apogee Research estimates the interim ESWTR, scheduled for promulgation by December 1996, will have a capital cost of $5.8 billion for approximately one half of the public water systems serving populations greater than 100,000. The D/DBPR, which will be promulgated in two stages, is anticipated to cost utilities $4.4 billion for capital improvement and $1 billion annually for Stage I of the D/DBPR. Stage II of the D/DBPR will cost about $6.8 billion in capital improvements and $1.6 billion annually.

Evaluation of Disinfection Byproduct Reduction Alternatives

Prepared for
Dare Regional Water Supply System
Dare County, North Carolina

Black & Veatch
Project No. 23464.150
June 1993

I HEREBY CERTIFY THAT THIS REPORT WAS PREPARED BY ME OR UNDER MY SUPERVISION.

SIGNED SEALED, AND DATED THIS 14th DAY OF July, 1993.

BY William P. Bizzell

TITLE Project Manager

NORTH CAROLINA
PROFESSIONAL
SEAL
4473
ENGINEER
WILLIAM P. BIZZELL

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I. Introduction

The Dare Regional Water Supply System encompasses an extensive system of water treatment, storage, and distribution facilities which serve various public water systems within Dare County. The treatment facilities produce a high-quality finished water which typically meets all current state and federal water quality standards. However, total trihalomethane concentrations within the distribution system serving Kill Devil Hills recently exceeded the Maximum Contaminant Level of 100 ug/L. In addition, impending regulations being promulgated under the 1986 Amendments to the Safe Drinking Water Act will include more stringent standards for total trihalomethanes, and new standards for other disinfection byproducts. Reductions in the current level of disinfection byproducts within the systems served by the Dare Regional Water Supply System are therefore required to comply with both current regulations and the more stringent future regulations.

A. Purpose

The purpose of this study is to identify and evaluate potential methods for reducing current levels of disinfection byproducts within the distribution systems served by the Dare Regional Water Supply System.

B. Scope

The study area for this project includes the areas currently served by the Dare Regional Water Supply System's three water treatment facilities. The principal elements of the study are the following:

1. Review historical trihalomethane monitoring data for areas served by the RO, Skyco, and Fresh Pond water treatment facilities.
2. Evaluate the level and speciation of trihalomethanes formed upon chlorination of treated waters from the RO, Skyco, and Fresh Pond plants for a variety of chlorine contact periods and simulated distribution system conditions.
3. Review current water treatment practices, and identify practices which may contribute to excessive formation of disinfection byproducts.
4. Identify and evaluate potential treatment methods for reducing current disinfection byproduct levels within the systems served by the Dare Regional Water Supply System to ensure compliance with impending regulations.

Conduct laboratory and bench-scale testing as necessary to confirm critical assumptions and/or to generate required data for evaluation of treatment alternatives.

5. Develop opinions of probable costs for the construction and annual operation and maintenance of treatment modifications or facilities required to comply with disinfection byproduct regulations.
6. Prepare a report summarizing the findings and recommendations of the study.

C. Abbreviations

Abbreviations used in this report are as follows:

C	Celcius
$CaCO_3$	Calcium carbonate
cm	Centimeter
DBP(s)	Disinfection byproduct(s)
D/DBP(s)	Disinfectant/disinfection byproduct(s)
DEH	North Carolina Division of Environmental Health
EPA	United States Environmental Protection Agency
F	Fahrenheit
GAC	Granular activated carbon
gpd	Gallons per day
gpm	Gallons per minute
GWDR	Groundwater Disinfection Rule
HAA(s)	Haloacetic acid(s)
HPC	Heterotrophic bacteria
IX	Ion exchange
lb	Pound
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MG	Million gallons
mgd	Million gallons per day
mg/L	Milligrams per liter
NTU	Nephelometric turbidity unit
O&M	Operation and maintenance

PAC	Powdered activated carbon
psi	Pounds per square inch
RO	Reverse osmosis
SDWA	Safe Drinking Water Act
sq ft	Square foot
SWTR	Surface Water Treatment Rule
TDS	Total dissolved solids
THAA(s)	Total haloacetic acid(s)
THM(s)	Trihalomethane(s)
THMFP	Trihalomethane formation potential
TTHM(s)	Total trihalomethane(s)
TOC	Total organic carbon
ug/L	Micrograms per liter
umhos/cm	Micromhos per centimeter (conductivity)
UV	Ultraviolet (light)
WTP	Water treatment plant

II. Summary of Findings and Recommendations

A. Findings

1. Under the impending Disinfectant/Disinfection Byproducts (D/DBP) Rule, the Maximum Contaminant Level (MCL) for total trihalomethanes (TTHMs) will likely be reduced from the current 0.10 mg/L (100 ug/L) to 80 ug/L by 1997, and may be further reduced to 40 ug/L during year 2002 under Stage 2 of the regulation. Systems served by the Dare Regional Water Supply System will be unable to comply with these revised MCLs unless treatment modifications to reduce TTHM formation are implemented.

2. During April 1993, the Kill Devil Hills system exceeded the current TTHM MCL of 100 ug/L, and the four-quarter running TTHM average (the current basis for assessing compliance with the regulation) for the Nags Head system was 99.3 ug/L.

3. Water Production Department staff have implemented measures to reduce treated water disinfection byproduct (DBP) levels. However, these measures have not reduced TTHM concentrations to levels which comply with either the current MCL or the probable future MCLs.

4. Proposed increases in the amounts of Fresh Pond and Skyco treated water delivered to the regional distribution system will likely increase the severity of current TTHM compliance problems, as water from these plants has significantly higher TTHM formation potential than treated water produced at the RO plant.

5. An MCL of 60 ug/L for total haloacetic acids (THAAs) will likely be included in the impending D/DBP Rule; the MCL may be reduced to 30 ug/L during year 2002 under Stage 2 of the regulation. Monitoring of system THAA levels conducted during this study at eight locations showed an average system THAA concentration of 37.3 ug/L; individual sample concentrations ranged from 20 to 49 ug/L. Reductions in system TTHM levels to achieve compliance with impending regulations should also result in compliance with impending MCLs for THAAs.

6. 7-day TTHM formation for RO plant treated water at blended water conductivities ranging from 300 to 700 umhos/cm was less than 20 ug/L in all cases. This suggests that current problems with high TTHM concentrations in portions of the system served primarily by the RO plant can be attributed to intermixing of waters from the RO and Skyco/Fresh Pond plants. Reaction of organic precursor compounds present in the Skyco/Fresh Pond treated waters with bromine in the RO treated water results in increased levels of both TTHMs and bromoform when these waters are combined in the distribution system.

7. Evaluation of TTHM formation potentials (7-day, pH 9.0) conducted by two independent laboratories for individual wells serving the Skyco plant confirmed previous testing data which indicate that the wells exhibit high formation potentials (average TTHM formation potential for all wells was 260 ug/L; maximum formation potential for a single well was 344 ug/L).

8. TTHM formation potential testing for the Skyco wells indicates that selective blending would not yield any significant reductions in system DBP levels.

9. Ozonation of softened water from the Skyco plant did not reduce TTHM formation at extended chlorine contact times to levels that would permit continued use of free chlorine as the secondary disinfectant within the distribution system.

10. Based on the potential for formation of excessive bromate concentrations, use of ozone, followed by chloramines as the secondary disinfectant at the RO plant is not considered a viable alternative to free chlorine for reducing DBP formation. (Allowable treated water bromate concentration will likely be 10 ug/L under the impending Disinfectant/Disinfection Byproducts Rule.) While limited testing conducted by other utilities indicates that addition of ammonia prior to ozonation may reduce bromate formation, effectiveness of this treatment technique is apparently site-specific. Pilot-scale testing would therefore be required to assess process effectiveness.

11. Treated water TTHM formation potential (272 ug/L at 7 days, pH 9.0) and total organic carbon concentration (4.62 mg/L) for the Fresh Pond plant suggest that

this plant may have significant influence on DBP levels within the systems served by the Dare Regional Water Supply System.

12. TTHM formation for treated water produced by the RO, Skyco, and Fresh Pond plants following 30 minutes of contact time with free chlorine was less than 25 ug/L in all cases. This data suggests that use of chloramines as a secondary disinfectant, following primary disinfection with free chlorine, would reduce TTHM concentrations within the distribution systems served by the Dare Regional Water Supply System to less than the probable future TTHM MCLs of 80 ug/L and 40 ug/L.

13. Evaluation of TTHM rate-of-formation for treated water from each of the Regional Water Supply System's three treatment facilities indicates that TTHM concentration reaches 50 ug/L (the goal established for this study for evaluation of DBP reduction alternatives) after approximately 9 hours of chlorine contact time for the Skyco treated water, and after approximately 8-10 hours for Fresh Pond treated water. TTHM concentration for the RO treated water never exceeded 20 ug/L at blended water conductivities ranging from 300 to 700 umhos/cm.

14. Treatment of Skyco raw water using the existing membranes currently stored at the RO plant would not reduce treated water DBP concentrations to levels which would result in compliance with impending regulations under most operating conditions due to inadequate membrane production capacity. (Projected capacity of the existing membranes is approximately 500 gpm (0.72 mgd), based on 75 percent raw-to-product conversion.)

15. TTHM monitoring data for the Dare County regional water distribution system suggest that compliance with the current TTHM MCL of 0.10 mg/L (and possibly the impending MCL of 80 ug/L) could potentially be achieved by increasing RO plant production rates to approximately 70 percent of the total system production. However, problems with high TTHM levels may still be experienced at Manteo and within the Nags Head system when the Fresh Pond plant supplies the majority of the Nags Head treated water.

16. Feasibility of increased RO plant production for meeting TTHM MCLs could be readily evaluated through adjustment of plant production rates (i.e., increase RO production to supply approximately 70 percent of the total system demand) approximately one to two weeks prior to collection of the next group of TTHM monitoring samples.

17. It is unlikely that expanded RO plant production would result in compliance with the impending future TTHM MCL of 40 ug/L.

18. Construction of ion exchange systems utilizing macroporous anion resins to remove DBP precursors cannot be recommended at this time due to limited full-scale operating experience. However, preliminary opinions of probable cost for this treatment alternative indicate that it could provide a cost-effective means of reducing current treated water DBP levels. Pilot testing of these resins currently being conducted at Cape Hatteras should yield valuable information regarding process effectiveness and costs.

19. Opinions of probable project costs (the total of probable construction cost and contingencies/engineering/administrative costs) and annual operation and maintenance costs were developed for six DBP reduction alternatives. The alternatives were evaluated using present worth analysis. Present worth costs for each alternative (i.e., the sum of the project cost and the present worth of the annual O&M over 20 years at an interest rate of 7.5 percent) are summarized in Table 1. Unit water production costs for the DBP reduction alternatives are summarized in Table 2. All costs reflect May 1993 price levels.

20. A weighted matrix evaluation which considers both total cost and "non-cost" related criteria was used to compare the five DBP reduction alternatives. The alternatives were ranked based on the following criteria:
    - Total Project Cost
    - Annual Operation and Maintenance Cost
    - Risk / Reliability
    - Quality of Water Produced
    - Control/Flexibility
    - Ability to Meet Current/Future Regulatory Requirements

Table II-1
Present Worth Costs for
DBP Control Alternatives

Alternative	Total Project Cost $	Present Worth of Annual O&M $	Total Present Worth $
Chloramination	390,000	281,000	671,000
Increased RO Plant Production	0	2,249,200	2,249,200
Skyco Anion Exchange Plant; Reduced RO Bypass	3,505,000	1,218,000	4,723,000
Skyco Ozonation/ Filtration; Reduced RO Bypass	4,555,000	1,125,000	5,680,000
Skyco Nanofiltration Plant; Reduced RO Bypass	6,715,000	3,626,000	10,341,000
Skyco GAC Plant; Reduced RO Bypass	4,535,000	12,343,000	16,878,000

- Waste Disposal Requirements
- Ease of Implementation / Compatibility with Existing Facilities

Based on the results of the matrix evaluation, alternative rankings are as follows (in decreasing order of desirability, when all factors are considered):

- Increase RO plant production to approximately 70 percent of the total system production, on an annual basis (matrix evaluation rating: 81 points).
- Add provisions for chloramination at the RO, Skyco, and Fresh Pond plants (matrix evaluation rating: 77 points).
- Construct nanofiltration facility to replace existing Skyco treatment plant; reduce amount of raw water blended with RO plant membrane permeate (matrix evaluation rating: 72 points).

Table II-2
Unit Water Costs for
DBP Control Alternatives

Alternative	Total Project Cost $	Annual O&M $/year	Unit Water Cost* $/1000 gals
Current WTP Operation	0	1,176,600	1.00
Chloramination	390,000	1,204,200	1.06
Increased RO Plant Production	0	1,397,200	1.19
Skyco Anion Exchange Plant; Reduced RO Bypass	3,505,000	1,296,100	1.39
Skyco Ozonation/ Filtration; Reduced RO Bypass	4,555,000	1,287,000	1.48
Skyco Nanofiltration Plant; Reduced RO Bypass	6,715,000	1,532,300	1.87
Skyco GAC Plant; Reduced RO Bypass	4,535,000	2,387,400	2.42

*Includes total project cost amortized over 20 years at 7.5% interest rate.

- Construct granular activated carbon adsorption facilities at Skyco plant; reduce amount of raw water blended with RO plant membrane permeate (matrix evaluation rating: 66 points).
- Construct anion ion exchange facility at Skyco plant; reduce amount of raw water blended with RO plant membrane permeate (matrix evaluation rating: 49 points).
- Construct ozonation/pressure filtration facilities at Skyco plant; reduce amount of raw water blended with RO plant membrane permeate (matrix evaluation rating: 48 points).

21. Systemwide implementation of chloramination is the most cost-effective DBP reduction alternative. Provisions for continued use of free chlorine as the primary disinfectant at the individual treatment plants (prior to adding ammonia to form chloramines) can be easily added.

22. A comprehensive public notification program should be conducted prior to implementing chloramination. Based on the seasonal nature of a significant portion of Dare County's population, this program should ideally be initiated approximately one year before converting to chloramines. An aggressive program utilizing electronic media (radio/television), newspaper advertisements, and monthly notices in consumer bills could reduce the duration of the notification period to three to six months.

23. The risks associated with use of chloramines (potential for nitrification within the distribution system; adverse impacts on kidney dialysis patients and fish-rearing operations) are not considered excessive and can be minimized/eliminated by maintaining proper chlorine/ammonia ratios at the treatment plants and by conducting the public notification program prior to implementation.

24. Should Dare County feel that the risks associated with use of chloramines in the distribution system are unacceptable (and assuming that increased RO plant production does not yield compliance with current and impending TTHM MCLs), the most desirable alternative would be to (1) reduce the amount of raw water bypassing the RO process and install provisions for stabilization of treated water (i.e., carbon dioxide feed facilities), and (2) construct a 4.5 mgd nanofiltration membrane treatment plant to replace the existing Skyco treatment facility. This would result in compliance with current and impending DBP regulations, while allowing continued use of free chlorine within the distribution system.

B. Recommendations

1. In light of current TTHM compliance difficulties, the County may want to reconsider (on a short-term basis) its decision to maximize use of the Skyco and Fresh Pond plants and to reduce production at the RO plant. As treated water from the Skyco and Fresh Pond plants exhibits significantly higher TTHM

formation potential than the RO treated water, increases in the relative amounts of Skyco/Fresh Pond delivered to the regional distribution system may result in increases in the severity of current TTHM compliance problems.

2. Feasibility of complying with current and impending TTHM MCLs by increasing RO plant production rates should be evaluated by adjusting the amount of RO treated water delivered to the system to approximately 70 percent of the total system demand. This increase in RO plant production should be initiated approximately one to two weeks prior to collection of the next group of TTHM monitoring samples (currently scheduled for September 1993), and maintained until the samples are collected.

3. Water Production Department staff are encouraged to contact other North Carolina utilities currently using chloramines in the distribution system (these utilities are summarized in Appendix B) regarding implementation procedures and overall effectiveness of the chloramination process.

4. The County should monitor results of pilot testing currently being conducted at Cape Hatteras using macroporous anion exchange resins for removal of DBP precursor compounds. Should results indicate that this process can successfully reduce DBP formation to acceptable levels, Dare County should consider conducting a similar pilot study using softened water from the Skyco plant to assess feasibility and site-specific operating requirements.

5. The County should implement the selected DBP reduction alternative as soon as possible in order to avoid further regulatory noncompliance. Should chloramination be selected, development and implementation of the public notification program should begin immediately, and Water Production Department staff should work closely with North Carolina DEH officials to ensure that a smooth transition to the chloramination process is achieved.

III. Existing Facilities and Operating Practices

The Dare Regional Water Supply System operates three water treatment facilities; a 3.0 mgd reverse osmosis facility treating water from the Yorktown aquifer, a 5.0 mgd ion exchange softening plant (the "Skyco" plant) on Roanoke Island, which treats water from 10 wells, and a 1.4 mgd conventional surface water plant at Nags Head which treats water from Fresh Pond. Treatment and operating practices for the three plants are discussed below.

A. Reverse Osmosis Water Treatment Plant

The 3 mgd reverse osmosis (RO) plant began service in 1989. Eight wells supply brackish water to the plant. Well depth is 425 feet, with the bottom 100 feet screened. Capacity of each well is 500 gpm.

RO system feedwater pretreatment consists of acidification, addition of a proprietary antiscalent (AF600), and 5-micron cartridge filtration. Vertical turbine pumps increase RO feedwater pressure to an average of 270 psi. The RO system consists of three independent trains, each with a design permeate production capacity of 850,000 gallons per day. Raw well water is blended with RO permeate to provide approximately 1,000,000 gallons of finished water per day per treatment train. Each RO train consists of 31 pressure vessels, each containing six spiral-wound membrane elements. Pressure vessels are arranged in a two-stage configuration (22 first-stage vessels, 9 second-stage vessels), and overall RO raw-to-product conversion is 75 percent. All membrane elements were originally UOP/Fluid Systems Model 8821 LP TFC units; however, the second-stage elements were replaced during June 1991 with Hydranautics Model 8040-LSZ CPA2 elements. This change was recommended by the County's membrane consultant to compensate for gradual increases in feedwater TDS/conductivity levels since plant startup. The 144 Fluid Systems elements removed from the second stage are currently being stored at the RO plant.

Posttreatment consists of blending of RO permeate with raw well water, and addition of chlorine for disinfection, sodium hydroxide for adjustment of pH to approximately 8.2, fluoride (hydrofluosilicic acid) for dental benefits, and a polyphosphate-based corrosion inhibitor (Virchem 950). In the past, the typical RO bypass flow rate was 10 to 15 percent of the total treated water produced; bypass flows have recently been reduced in order to reduce the levels of DBP precursors at the point of chlorine addition. Treated water flows to a 5 million gallon ground-level storage reservoir, and high service pumps deliver the treated water from the reservoir to the regional transmission main. The treated water typically has a TDS concentration of about 400 mg/L, and a total hardness of 40 to 50 mg/L (as $CaCO_3$).

The concentrate stream from the RO process is discharged to a tributary to the Atlantic Ocean under an NPDES permit.

The RO process is controlled by a programmable logic controller, which provides automated control of pre- and posttreatment chemical feed rates and RO feedwater pressures, and monitoring of all critical functions involved in the treatment process.

Monthly water quality records for July 1990 through March 1993 were reviewed to evaluate performance and to identify typical operating practices. Data used in this evaluation are summarized in Table III-1. (Note that the data represent a compilation of monitoring results for one day each month, and therefore may not reflect short-term variations in water quality.)

B. Skyco Water Treatment Plant

The 5 mgd Skyco plant, located on Roanoke Island, began service in 1979. Raw water is pumped to the plant from 10 wells ranging in depth from 120 to 220 feet. Eight of the wells were constructed along with the plant; two of the wells (well 12 and 13) were constructed during 1984. Rated capacity for eight of the wells is 500 gpm; rated capacity of wells 11 and 13 is 600 gpm.

Treatment consists of ion exchange softening using four pressure cation-exchange vessels. Provisions for blending of raw well water with the softened water are in place but are not currently used; the softeners are operated in a "staggered exhaustion" mode, which yields an average treated water hardness of approximately 80 mg/L (as $CaCO_3$). One softener is currently out of service, and resin was recently replaced in two of the four softeners. Regeneration of the resin is accomplished by passing a sodium chloride solution through the resin bed. Regeneration brine discharges to an onsite lagoon, which in turn overflows to Croaton Sound by way of a drainage canal.

Zinc metaphosphate (Virchem 937) is added to the softened water, primarily to sequester iron. Following addition of the zinc metaphosphate, chlorine is added for disinfection, and fluoride (hydrofluosilicic acid) is added for dental benefits. The treated water then flows to a 2 million gallon ground-level storage reservoir. A chlorine residual of 0.1 to 0.5 mg/L is maintained at the reservoir discharge.

Table III-1
Raw & Treated Water Quality
for Reverse Osmosis Plant
(July 1990 - March 1993)

Constituent	Average	Range
Total Alkalinity, mg/L as $CaCO_3$		
Raw	252	190-284
Treated	47	30-66
Total Hardness, mg/L as $CaCO_3$		
Raw	409	340-484
Treated	37	22-60
Calcium Hardness, mg/L as $CaCO_3$		
Raw	128	106-160
Treated	13	2-40
Total Dissolved Solids, mg/L		
Raw	3050	2520-3310
Treated	400	300-450
Conductivity, µmhos/cm		
Raw	6104	5270-6700
Treated	795	682-870
pH, Units		
Raw	7.96	7.60-8.09
Treated	8.06	7.41-8.43
Color, units		
Raw	14	4-27
Treated	1	0-4
Turbidity, NTU		
Raw	0.81	0.14-1.61
Treated	0.13	0.03-0.28
Sodium, mg/L		
Raw	682	570-880
Treated	91	63-142
Sulfate, mg/L		
Raw	122	48-177
Treated	14.6	8.3-18.2
Chloride, mg/L		
Raw	1760	1500-2000
Treated	185	170-210
Silica, mg/L as SiO_2		
Raw	13.2	5.2-16
Treated	1.9	1.4-2.3
Iron, mg/L		
Raw	0.45	0.34-0.52
Treated	0.05	0.03-0.08
Free Chlorine Residual, mg/L		
Raw	1.56	0.96-2.34
Treated	0.77	0.16-1.54
Fluoride, mg/L*		
Treated	1.02	0.91-1.17

*Fluoridation began September 1991.

Additional chlorine is fed at the high service pump suction. Four pumps deliver treated water to the regional transmission main, while two pumps deliver treated water directly to the town of Manteo.

Monthly water quality records for July 1990 through February 1993 were reviewed to evaluate performance and to identify typical operating practices. Data used in this evaluation are summarized in Table III-1. (Note that the data represent a compilation of monitoring results for one day each month, and therefore may not reflect short-term variations in water quality.)

C. Fresh Pond Water Treatment Plant

The Fresh Pond plant, located in the town of Nags Head, began providing water for the regional water system during 1985. The raw water supply is Fresh Pond, a surficial aquifer. Powdered activated carbon is added at the intake, and alum is added in a flash-mixing chamber at the inlet to a 1 million gallon flocculation/sedimentation tank. The tank is equipped with wooden baffles to affect flocculation. Settled water flows to two dual-media filters. Chlorine is added at the filter inlet to yield a residual of approximately 0.5 mg/L, and additional chlorine, fluoride (hydrofluosilicic acid) and sodium hydroxide (for pH adjustment) are added at the filter discharge. Filtered water enters a 40,000 gallon clearwell beneath the filters, and is then pumped directly to the regional distribution main and/or to the 0.5 million gallon Nags Head storage reservoir (located adjacent to the treatment plant).

The Fresh Pond plant can operate at rates of up to 1.5 mgd for several weeks. Production is limited by the need to maintain withdrawal rates from Fresh Pond at 900,000 gallons per day or less during June through September.

Tracer testing to assess disinfectant contact times has been conducted to satisfy the requirements of the impending Surface Water Treatment Rule. The North Carolina Division of Environmental Health (DEH) has assigned removal credits of 2.07-log cyst/1.66-log virus, based on its evaluation of plant facilities and operating practices (see Section IV, "Regulatory Requirements" for a discussion of Surface Water Treatment Rule requirements).

The Fresh Pond plant operates only on an "as needed" basis. Over the last several years, the plant has typically operated from May through September (during 1992, however, the plant operated until December).

Table III-2
Raw & Treated Water Quality
for Skyco Water Treatment Plant
(July 1990 - February 1993)

Constituent	Average	Range
Total Alkalinity, mg/L as $CaCO_3$		
Raw	91	55-148
Treated	91	50-155
Total Hardness, mg/L as $CaCO_3$		
Raw	170	156-188
Treated	81	40-166
Calcium Hardness, mg/L as $CaCO_3$		
Raw	126	114-154
Treated	55	20-88
Total Dissolved Solids, mg/L		
Raw	300	230-317
Treated	319	224-450
pH, units		
Raw	7.5	7.1-7.9
Treated	7.3	7.0-8.1
Color, units		
Raw	14	7-22
Treated	11	4-21
Turbidity, NTU		
Raw	0.67	0.37-1.0
Treated	0.67	0.21-1.80
Chloride, mg/L		
Raw	48	43-57
Treated	70	53-154
Silica, mg/L as SiO_2		
Raw	34.4	27.9-42.3
Treated	33.5	28.8-37.2
Iron, mg/L		
Raw	0.29	0.17-0.47
Treated	0.11	0.04-0.34
Free Chlorine Residual, mg/L		
Treated	0.61	0.05-1.36
Distributed	0.61	0.16-1.26
Fluoride, mg/L*		
Treated	1.03	0.84-1.17

*Fluoridation began August 1991.

D. Treated Water Transmission and Storage

The three treatment plants deliver treated water to a transmission system consisting of approximately 15 miles of 16- and 24-inch ductile iron main. The transmission main originates at the Skyco plant, passes under Roanoke Sound, and extends north to the Kitty Hawk reservoir and pumping station. The towns of Nags Head and Kill Devil Hills operate their own water distribution systems that are supplied from metered connections to the transmission main at several locations. Dare County owns and operates a distribution system west and north of Manteo on Roanoke Island, which is served by an elevated tank at the Skyco plant site. The town of Manteo owns and operates its own distribution system on Roanoke Island, and receives water from a metered connection to the Skyco plant. The distribution systems serving Kitty Hawk and Southern Shores, and unincorporated areas north of Southern Shores (Duck, Sanderling) are owned and operated by Dare County. A schematic representation of the regional transmission system, including plant and storage reservoir capacities, is presented on Figure III-1.

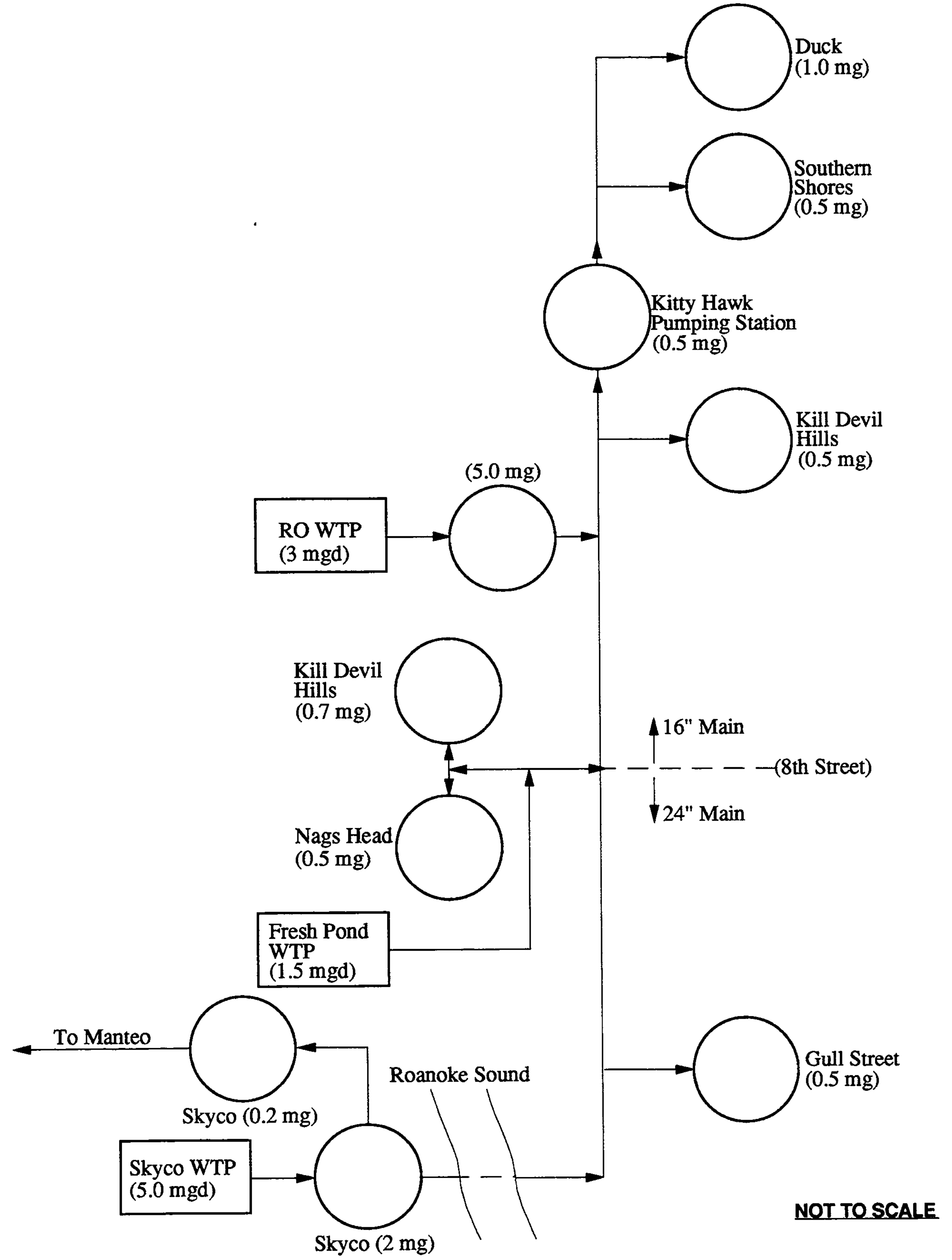
Water Production Department staff indicate that the "average" population served is approximately 13,000 (note that the total population served varies considerably over the year due to the County's popularity as a summer resort area).

E. Future Treated Water Production Considerations

Based on the high quality of water produced and the ease of plant operation, Water Production Department staff would prefer to maximize use of the RO plant, while reducing reliance on the Skyco and Fresh Pond facilities. However, several factors preclude operation in this manner:

- The higher cost of water production, attributable to the high RO process feedwater pressure requirements.
- County management policy that the RO plant serve as a "supplement" to the Skyco and Fresh Pond plants.
- Restrictions on power usage patterns and consumption imposed by North Carolina Power.

Water Production Department staff indicate that use of the RO facility will likely be scaled back over the next several years. Based on information presented in the Regional Water Supply System's "Third Annual Report", the RO plant supplied 56 percent of the total system demand during 1991; the Skyco and Fresh Pond plants supplied the remaining 38 percent and 6 percent, respectively. The staff predicts that that the RO plant will supply "30 to 40 percent" of the total system demand over the next two years, with the Skyco/Fresh Pond plants supplying the remaining 60-70 percent. No significant growth in treated water demand is predicted over the next several years.



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PROGRESS BY DESIGN

DARE COUNTY WATER TREATMENT AND STORAGE FACILITIES

Figure III-1

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Based on Water Production Department staff projections, treated water production for each plant over the next several years will be as follows:

RO WTP..........................361.77 MG/year (average 1.0 mgd)
Skyco WTP.......................677.71 MG/year (average 1.9 mgd)
Fresh Pond WTP............133.68 MG/year

The above treated water production figures were used during this study as the basis for development and evaluation of DBP reduction alternatives.

IV. Regulatory Requirements

Aspects of several current or impending regulations under the 1986 Amendments to the Safe Drinking Water Act (SDWA) which may affect current Dare Regional Water Supply System treatment practices are discussed below. The EPA is continuously modifying and revising these regulations in response to public comments and results of new research regarding the potential toxicity of the compounds to be regulated. The discussion which follows reflects current EPA positions on the various water quality issues, or the opinions of personnel currently involved in the development of the regulations. Major changes prior to final promulgation of the regulations may therefore require revision of the conclusions and opinions presented in this report.

A. Surface Water Treatment Rule

EPA published the final Surface Water Treatment Rule (SWTR) in June 1989. The SWTR specifies mandatory performance requirements for filtration and disinfection of surface water supplies and groundwater supplies "under the direct influence" of surface water. As the Fresh Pond plant treats a surface supply, the impact of any modification of current disinfection practices on compliance with this regulation must therefore be considered.

As directed under the 1986 SDWA Amendments, EPA has established new criteria for regulation of five microbial contaminants in drinking water derived from surface supplies; *Giardia lamblia* cysts (*Giardia*), enteric (intestinal) viruses, *Legionella*, heterotrophic bacteria (HPC), and coliforms. EPA has recognized that it is neither economically nor technically feasible to measure the levels of these contaminants on a regular basis. The Agency has therefore promulgated treatment techniques which will result in removal and/or inactivation of these contaminants, with primary focus on controlling *Giardia* cysts and enteric viruses. When these two contaminants are effectively inactivated, the remaining three are also reduced to acceptable levels. The treatment techniques for control of these microbial contaminants are specified in the SWTR, such that a minimum of 99.9 percent (3-log) and 99.99 percent (4-log) removal and/or inactivation is achieved for *Giardia* cysts and enteric viruses, respectively.

EPA has recognized that *Giardia* cysts and enteric viruses are readily removed by efficiently-operated conventional treatment facilities using granular media filtration. Therefore, credit for 99.7 percent (2.5-log) cyst removal and 99 percent (2-log) virus removal by conventional treatment (coagulation, sedimentation, and filtration) is recommended in EPA's SWTR "Guidance Manual". The State of North Carolina has adopted more stringent guidelines, which reduce the allowable credits in most cases. The actual credit received is determined on a case-by-case basis, based on results of an onsite plant inspection and review of operating practices. Plant staff indicate that DEH has assigned removal credits of 2.07-log cyst and 1.66-log virus. Provisions for a minimum additional 0.93-log inactivation of cysts and 2.34-log inactivation of viruses must therefore be made by disinfection to achieve the total required 3-log cyst and 4-log virus removal and/or inactivation. (Virus removal/inactivation well in excess of 99.99 percent is typically achieved when conditions for 99.9 percent removal/inactivation of *Giardia* cysts are maintained.)..

North Carolina DEH has adopted the use of CT values to assess the level of disinfection achieved. CT values are the product of the disinfectant concentration, C (in mg/L), and the contact time, T (in minutes), at the point of disinfectant residual measurement. Disinfectant contact times used in calculating CT values are determined by field studies using tracer compounds. Contact time is defined by EPA and DEH as the T_{10} detention time, or the period in which 10 percent of the water entering a specific unit process (settling basin, filter, clearwell) has passed through the unit. This definition of T_{10} ensures that a minimum of 90 percent of the water being treated is in contact with the disinfectant for the reported length of time. EPA has published CT values for various disinfectants in its SWTR "Guidance Manual". For disinfection using free chlorine, CT values are dependent upon water temperature, pH, and chlorine residual. CT values for free chlorine increase as water temperature decreases and as pH values increase.

Under the SWTR, DEH must determine whether a groundwater source is under the direct influence of surface water. This determination must be completed by June 1994. If a groundwater source is determined to be under the direct influence of surface water, the utility must comply with the turbidity and disinfection requirements of the SWTR. While DEH has not completed this determination for the wells serving the RO and Skyco plants, it is considered unlikely that these wells will be classified as "under the direct influence of surface water", based on well depths and construction methods. It is therefore assumed that the SWTR turbidity and disinfection requirements will not apply to the RO and Skyco plants.

One aspect of the SWTR which will likely be incorporated into the impending Groundwater Disinfection Rule in some form is the use of treatment techniques to ensure that protection from microbial contaminants is continuously maintained. The use of CT values to monitor disinfection efficiency is currently being considered for inclusion in the Groundwater Disinfection Rule.

B. Groundwater Disinfection Rule

Under the 1986 SDWA Amendments, EPA must propose and promulgate disinfection requirements for groundwater supplies not under the direct influence of surface water. A draft version of the Groundwater Disinfection Rule (GWDR) was made available for public comment during July 1992. The draft rule presents possible regulatory requirements and the rationale behind the rule, in addition to requesting comment on issues related to development of the rule. EPA's original intention was to publish the proposed GWDR during June 1993. However, this proposal has been delayed until August 1994 due to resource limitations within the Agency and to the current emphasis within EPA on development of the Disinfectant/Disinfection Byproducts Rule.

The GWDR will apply to all community water systems. It will likely include requirements for disinfection of source water, distribution system disinfection, use of qualified plant operators, treatment techniques for control of microbial contaminants, maximum contaminant level goals (MCLGs), and provisions for variances and exemptions. A treatment technique will probably be specified for viruses, heterotrophic bacteria, and *Legionella*, rather than specific maximum contaminant levels (disinfection will likely be proposed as the treatment technique). EPA has selected viruses as the target organism for this rule, as pathogens such as *Giardia* and *Cryptosporidium* are not normally found in groundwaters not under the direct influence of surface water. The minimum level of virus inactivation required has not yet been decided. However, it is expected that the level of inactivation to be required will not exceed the value specified in the Surface Water Treatment Rule (99.99 percent, or 4-log), and may in fact be lower (2-log or 3-log inactivation), based on removal of viruses by "natural disinfection" processes during passage of the water through subsurface strata.

EPA intends to provide guidance to state regulatory agencies for specifying design and operating conditions for systems using groundwater supplies. The Agency plans to include the application of the CT concept (as developed for the SWTR) in this guidance, but is also considering other methods that would also indicate adequacy of the disinfection provided. Unlike systems treating surface water supplies, the use of ultraviolet light (UV) for disinfection will probably be allowed for systems treating groundwater not under the influence of surface water. A discussion of UV disinfection requirements (light intensities, need for equipment redundancy, and factors that impact the overall process efficiency) is presented in the draft GWDR.

The draft rule also discusses the concept of "natural disinfection". A wellfield or well that is not vulnerable to virus contamination would be considered to meet the criteria for "natural disinfection", and may therefore be eligible to receive an exemption from (or a reduction in) the minimum disinfection requirements.

Based on an assumed GWDR promulgation date of June 1995, the regulation would become effective during December 1996 (18 months after promulgation). Under the schedule being considered by EPA, all community water systems which disinfect would have to be complying with the performance requirements specified within the rule by December 1997.

C. Disinfectant / Disinfection Byproducts Rule

The current Interim Primary Drinking Water Regulations provide standards for four disinfection byproducts (chloroform, chlorodibromomethane, bromodichloromethane, and bromoform), all of which are regulated under the MCL for total trihalomethanes (TTHMs). Consideration is also being given to regulating not only TTHM, but also many other disinfection byproducts. The current MCL for TTHMs (0.10 mg/L) is expected to be revised by 1995.

One of the primary difficulties EPA faces in developing this regulation is the need to simultaneously minimize the chronic cancer threat associated with disinfectants/disinfection byproducts (D/DBPs) and the acute threat of waterborne disease. The Agency recognizes that disinfection practices which may reduce the formation of undesirable byproducts may, in some cases, also reduce the levels of microbial contaminant inactivation achieved. Based on the anticipated difficulties in achieving the desired goals, and on the lack of extensive health effects data for the various disinfectants and their byproducts, EPA recommended that the rulemaking proceed as a negotiated rulemaking, or "Reg Neg". This procedure involves representatives of the affected industry (i.e., water utilities), academicians, State regulatory agency personnel, treatment equipment manufacturers, EPA, and various consultants and citizens organizations. The working group is to develop and analyze the alternative rulemaking options available to EPA for the D/DBP regulation, with the ultimate outcome being consensus on the requirements of the final rule. EPA is under a court-ordered deadline to issue the proposed regulation by June 1993. It is likely that EPA will seek a six-month extension of this deadline, with promulgation of the final rule during December 1995.

It is likely that the D/DBP rule will be proposed as a "staged" regulation. Conversations with officials involved in the Reg Neg process indicate that the following will be recommended under Stage 1 of the regulation:

- A revised MCL for total trihalomethanes of 80 ug/L.
- A new MCL for total haloacetic acids of 40 ug/L.
- MCLs of 4 mg/L for free chlorine and monochloramine.
- An MCL of 10 ug/L for bromate (a byproduct of disinfection using ozone).
- An MCL for chlorite (a byproduct of disinfection using chlorine dioxide) of 0.8 mg/L.
- An "enhanced coagulation" requirement for systems with total organic carbon (TOC) content at the point of disinfectant addition exceeding 2 mg/L; treatment option/pilot studies would be required for systems with TOC exceeding 4 mg/L.
- Beginning in 1994, monitoring of DBPs and microbial contaminants would be required for utilities serving more than 100,000 consumers to develop a data base to be used in the development of Stage 2 of the regulation.

Reduction of TOC prior to disinfectant addition is based on the desire to reduce the levels of both "known and unknown" DBPs in the treated water, and compliance would be determined based on an annual running TOC average (similar to the current procedure for monitoring compliance with the TTHM MCL). MCLs for individual THM compounds will not be recommended, and earlier plans to recommend an MCL for dichloroacetic acid have been dropped. Under the Stage 1 proposal, the compliance date for surface water systems serving more than 10,000 consumers would be December 1997; the deadline would be extended to December 1999 for groundwater systems serving more than 10,000 consumers and for all remaining surface water systems. (It is not clear at this time if the compliance date for Dare County will be 1997 or 1999 because both groundwater and surface water supplies are used.)

Under Stage 2 of the regulation, MCLs for TTHMs and THAAs may be lowered to 40 ug/L and 30 ug/L, respectively. Development of Stage 2 will require another round of negotiations; should these negotiations be unsuccessful, MCLs of 40 ug/L for TTHMs and 30 ug/L for THAAs would be promulgated. The Stage 2 requirements would become effective in year 2002.

While the Reg Neg committee has agreed in principle on the recommendations to be included under Stage 1 of the regulation, a consensus has not yet been reached on the Stage 2 recommendations.

D. North Carolina DEH Requirements

The Division of Environmental Health has adopted the following policies regarding the use of chloramines for disinfection of public drinking water supplies:

- Utilities must maintain a minimum total chlorine residual of 2.0 mg/L throughout the distribution system.
- All routine coliform monitoring samples must also be analyzed for the heterotrophic bacteria (HPC).
- Utilities must revert back to use of free chlorine within the distribution system once per year for a short period of time to ensure that development of excessive levels of biofilm does not occur within the system.

V. Disinfection Byproduct Formation and Control Techniques

A. DBP Formation and Occurrence

As discussed in Section IV, current regulations include standards for four disinfection byproducts (chloroform, chlorodibromomethane, bromodichloromethane, and bromoform), all of which are regulated under the MCL for total trihalomethanes (TTHMs). THMs are regulated because of their potential carcinogenicity to humans. Based on discussions with officials involved in the development of the impending Disinfectant/Disinfection Byproducts Rule (D/DBPR), it is likely that a new MCL for total haloacetic acids (THAAs) will be included in the rule. THAAs encompass five specific DBPs: monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid. These two categories of DBPs were therefore utilized during this study as the basis for evaluating DBP reduction alternatives.

Both TTHMs and THAAs are formed through reaction of free chlorine with natural organic materials (typically humic and fulvic acids) which are present in essentially all surface water supplies and in many groundwater supplies. The rate of formation and the ultimate concentration of DBPs within a water system are dependent upon a number of factors, including water temperature and pH, applied chlorine dosage, chlorine contact time, and the concentration of DBP precursor materials in the raw water supply. DBP rate-of-formation increases rapidly as pH increases, although ultimate DBP concentrations (as typically measured after 7 days of contact time with free chlorine) are not significantly affected by pH. The presence of bromide in the raw water supply (a common occurrence in systems located in coastal areas) can affect both the species of DBPs formed and ultimate DBP formation levels. Bromide is oxidized in the presence of free chlorine to bromine, which can then participate in the formation of brominated THM compounds (chlorodibromomethane, bromodichloromethane, bromoform).

Information on the relationship between TTHMs and THAAs in U.S. water systems is limited. However, existing data indicate that TTHMs are typically the predominant DBP, with THAAs present in most systems at concentrations less than for TTHMs. Analysis of distribution system samples for 35 water utilities throughout the U.S. conducted during 1987 and 1988 by the Association of Metropolitan Water Agencies and the State of California Department of Health Services revealed a median THAA value equal to approximately 50 percent of the median TTHM concentration. Limited pilot- and full-scale operating data also indicate that treatment to reduce TTHM levels yields reductions in THAA levels which are typically proportional to, or (in many cases), which exceed the level of TTHM reduction achieved (on a percent reduction basis). Therefore, treatment to achieve compliance with the MCL for THMs should, in most cases, result in compliance with the impending MCL for THAAs.

B. Historical Trihalomethane Monitoring Data

Trihalomethane monitoring data was reviewed for the Dare County distribution system, and for the systems serving the Towns of Nags Head and Kill Devil Hills. (A detailed summary of the THM monitoring data reviewed is presented in Appendix A). Monitoring results for the three systems are discussed below.

1. *Dare County Distribution System*

TTHM data for the Dare County system for November 1990 through April 1993 (11 monitoring periods) is presented in Table V-1. TTHM concentrations on a "quarterly running average" basis (the current basis for assessing compliance) ranged from 63.2 ug/L to 92.3 ug/L for the period reviewed. While compliance with the current MCL of 0.10 mg/L (100 ug/L) is being achieved, reductions in TTHM levels will be required to comply with the impending reduced MCL of 80 ug/L, and an ultimate future MCL of 40 ug/L.

TTHM concentrations for areas of the Dare County system served primarily by the RO plant and the Skyco plant are summarized in Table V-2. While there is no physical segregation of the treated water transmission system with respect to individual treatment facilities, system hydraulics and plant locations result in two distinct zones; (1) north of 8th street, served primarily by the RO plant, and (2) south of 8th Street, served primarily by the Skyco plant. The primary differences in the waters in each system are the THM species present. Bromoform is the predominant THM species in the system served by the RO plant (approximately 50 percent of the average total THM is bromoform), while chloroform is the predominant THM species in the system served by the Skyco plant (approximately 40 percent of the total average THM is chloroform). As shown on Table V-2, average TTHM levels for each of the two system zones are approximately equivalent (75.8 ug/L for the RO system vs. 80.6 ug/L for the Skyco system). Treated water trihalomethane formation

Table V-1
Trihalomethane Monitoring Data Summary for Dare County Regional Distribution System

Month/Year	Total Trihalomethane Concentration		
	Average µg/L	Range µg/L	Four-Quarter Running Average µg/L
11/90	65.5	25.8-123.9	--
02/91	79.5	23.9-146.4	--
05/91	93.5	23.3-141.1	--
09/91	90.0	35.6-120.1	82.1
11/91	62.1	15.4-101.4	81.3
02/92	50.1	19.1-48.1	73.9
04/92	50.1	16.7-89.3	63.1
07/92	94.5	50.9-162.7	64.2
11/92	90.5	55.8-140.1	71.3
01/93	90.9	20.2-129.3	81.5
04/93	93.3	70.4-119.2	92.3

levels for both the RO and Skyco plants must therefore be considered in the evaluation of TTHM reduction alternatives.

2. *Nags Head System*

Total THM concentrations within the Nags Head distribution system between March 1992 and April 1993 (5 monitoring periods) ranged from 64.3 ug/L to 124.9 ug/L on a quarterly average basis, with a maximum single-sample TTHM concentration of 152.3 ug/L at Oregon Inlet Marina. The four-quarter running TTHM average for the period reviewed ranged from 84.1 ug/L to 99.3 ug/L, with approximately equal concentrations of chloroform, bromoform, bromodichloromethane, and chlorodibromomethane present. While compliance with the current MCL of 0.10 mg/L (100 ug/L) is being achieved, reductions in TTHM levels will be required to comply with the impending reduced MCL of 80 ug/L, and an ultimate future MCL of 40 ug/L.

Table V-2
Dare County Regional Distribution System
Total Trihalomethane Levels for Areas Served by RO, Skyco Plants

Month/Year	Quarterly Sample Result		Four-Quarter Running Average	
	RO Plant µg/L	Skyco Plant µg/L	RO Plant µg/L	Skyco Plant µg/L
11/90	37.8	93.2	--	--
02/91	50.8	108.2	--	--
05/91	83.0	104.0	--	--
09/91	96.1	83.9	66.9	97.3
11/91	54.3	69.9	71.1	91.5
02/92	33.6	66.7	66.8	81.1
04/92	44.6	55.5	57.2	69.0
07/92	121.2	67.7	63.4	65.0
11/92	101.3	79.8	75.2	67.4
01/93	116.1	65.7	95.8	67.2
04/93	94.9	91.7	108.4	76.2
Average	75.8	80.6	75.6	76.8

3. Kill Devil Hills System

Total THM concentrations within the Kill Devil Hills distribution system between February 1992 and April 1993 (six monitoring periods) ranged from 57.6 ug/L to 130.6 ug/L on a quarterly average basis, with a maximum single-sample TTHM concentration of 163.5 ug/L at East Arch Street. The four-quarter running TTHM average for the period reviewed ranged from 91.8 ug/L to 104.6 ug/L, with bromoform the predominant THM species present (bromoform comprised approximately 45 percent of the running average TTHM concentration). The 4-quarter running TTHM average exceeded the current MCL of 0.10 mg/L (100 ug/L) during the April 1993 monitoring period. Reductions in current TTHM levels are therefore required to comply with the current MCL of 100 ug/L and the impending reduced MCL of 80 ug/L. Additional monitoring conducted during June 1992 at five locations within a housing development at the hydraulic end of the Kill Devil Hills distribution system showed an average TTHM concentration of 134.3 ug/L, with a range of 93.4 ug/L to 154.4 ug/L.

C. DBP Reduction Procedures Implemented at Dare County

Water Production Department staff have implemented measures to reduce DBP levels within the systems served by the Regional Water Supply System. These measures include: (1) reductions in chlorine residuals maintained across treated water storage facilities, (2) reducing water levels within storage facilities to reduce contact time of the water with free chlorine prior to distribution, and (3) most recently, reducing the pH of the treated water and the amount of raw water bypassing the RO treatment process. While all of these measures should reduce DBP levels in the distribution system to a limited extent, TTHM monitoring conducted during April 1993 indicates that TTHM concentrations, on a four-quarter running average basis, still approach (or exceed, in the case of Kill Devil Hills) the current MCL of 0.10 mg/L.

D. DBP Control Techniques

Three basic treatment approaches can be used to reduce/minimize the formation of DBPs:

- Limit the contact time of free chlorine with the process stream to the shortest period required to accomplish disinfection. Use combined chlorine (chloramine) as the secondary disinfectant within the distribution system.
- Use an alternative primary disinfectant which does not form unacceptable levels of DBPs. Use chloramine as the secondary disinfectant within the distribution system.
- Remove the organic precursor compounds which form DBPs prior to addition of chlorine.

Another approach to DBP control is to remove the DBPs after they are formed, rather than to prevent their formation. Adsorption using granular activated carbon contactors and air stripping using packed-tower aerators are typically considered for removal of TTHM compounds; however, data on efficiency of removal of THAAs by these treatment processes is limited. While both aeration and carbon adsorption can be used to reduce treated water chloroform levels, removal of brominated THM compounds (chlorodibromomethane, bromodichloromethane, bromoform) is relatively inefficient. Therefore, for systems exhibiting significant formation of brominated

THM compounds (as for the Dare County system), this treatment approach would not provide adequate control of DBP formation, and was therefore not evaluated during this study.

Each of the three applicable treatment approaches listed above are discussed in detail below.

1. Reduced Chlorine Contact Times.

As the formation of DBPs are time-dependent, ultimate DBP levels can often be reduced by limiting chlorine contact times. This is accomplished by adding ammonia to the water following the chlorine contact period required for disinfection. Ammonia reacts with free chlorine to form chloramines, stable disinfectant compounds which, unlike free chlorine, do not react with organic precursors to form TTHMs and THAAs. The term "chloramines" refers to any of three compounds formed during the free chlorine/ammonia reaction; monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine, or nitrogen trichloride (NCl_3). The species of chloramine formed is dependent primarily upon the pH of the water being treated and the ratio (by weight) of chlorine to ammonia added. Under normal pH conditions, monochloramine is the predominant chloramine species formed. Monchloramine is generally the preferred species within the distribution system, because of its biocidal properties and minimal potential for causing undesirable tastes and odors. Chloramines have been used successfully by several utilities in eastern North Carolina to control TTHM formation. (Comments from North Carolina utilities currently using chloramines are summarized in Appendix B.) Benefits and potential drawbacks associated with use of chloramines to limit DBP formation are summarized below.

a. Benefits. Because chloramines are less reactive and more stable than free chlorine, a persistent residual is more easily maintained throughout the distribution system. This is particularly beneficial for utilities with systems containing significant low-flow areas or many dead-end mains. The need for remote booster chlorination systems to maintain disinfectant residual is eliminated in most cases.

Research has shown that chloramines can apparently penetrate deeper into biofilm layers within the distribution system than free chlorine, thereby providing superior control of microorganism regrowth. Chloramines have also been shown to be effective at reducing heterotrophic plate counts within the system.

When the residual is maintained in the monochloramine form, chloramines generally have less tendency than free chlorine to impart undesirable chlorinous tastes and odors to the treated water. Finally, use of chloramines to limit free chlorine contact time typically will be the least expensive DBP control option to implement and operate. Chloramination can typically be easily adapted to existing plants (new chemical feeders for application of ammonia are required, however).

b. Potential Drawbacks. The primary drawbacks associated with use of chloramines are (1) lower disinfection capabilities than for free chlorine, (2) potential adverse impacts on special use groups, such as kidney dialysis patients, and commercial agencies and hobbyists involved in fish-rearing, (3) the potential for nitrification within the distribution system, and (4) degradation of elastomeric materials used in distribution system appurtenances and plumbing fixtures. Other drawbacks are increased system water quality monitoring requirements and the need to revert back to a free chlorine residual once per year to minimize potential nitrification problems.

Potential problems associated with chloramine's reduced disinfection effectiveness can typically be eliminated by providing facilities to ensure that disinfection is accomplished with free chlorine (or an alternative disinfectant such as ozone) prior to ammonia application. Under this mode of operation, a free chlorine residual is maintained for the period required to ensure positive inactivation of microbial contaminants, and then ammonia (and additional chlorine if necessary) are added to halt the formation of DBPs.

Chloramines must be removed from waters used in kidney dialysis units. Failure to remove the chloramine residual can result in hemolytic anemia and/or methemoglobinemia in dialysis patients. Chloramines are also toxic to fish and other aquatic life. Procedures are readily available which will remove the chloramine residual; a comprehensive public notification program must be conducted prior to implementing the chloramination process to ensure that these problems are not experienced.

A concern for utilities treating warm waters (above 10C to 15C) is the potential for nitrification within the distribution system. Nitrification is a microbial process in which residual ammonia is oxidized to nitrate and nitrite. Nitrification results in rapid depletion of the chloramine residual and (typically) increased frequency of positive coliform samples and enhanced growth of heterotrophic bacteria. Control measures include maintenance of adequate chloramine residuals (1 to 2 mg/L minimum) throughout the system, operation to minimize free ammonia in the treated water (i.e., use of higher chlorine-to-ammonia ratios), and periodic (typically annual) reversion to a free chlorine residual within the system for a short period. Other North Carolina utilities which currently use chloramines report that nitrification problems have not been experienced.

Chloramines are suspected of causing accelerated deterioration of elastomeric (rubber) components within the distribution system and residential plumbing and fixtures. As this deterioration is further accelerated at increasing water temperatures, utilities located in warmer climates are more likely to experience problems with elastomer deterioration than utilities located in colder climates.

Current North Carolina Division of Environmental Health policies require that utilities using chloramines analyze each routine distribution system coliform sample for heterotrophic bacteria, which will increase the workload on plant laboratory staff. DEH also requires reversion to a free chlorine residual in the system once per year. Other North Carolina utilities using chloramines indicate that no significant problems or consumer complaints have been experienced during this annual change in disinfection residual within the distribution system.

2. *Alternative Disinfectants*

A second alternative for reducing TTHM and THAA formation is the use of disinfectants which do not react with organic precursors to form the undesirable DBPs. Ozone and chlorine dioxide are typically considered for primary disinfection when use of free chlorine results in unacceptable DBP concentrations. However, continuing concerns regarding the potential long-term health impacts of chlorine dioxide byproducts (chlorite/chlorate ions), and lack of full-scale demonstrated techniques for removing these byproducts may reduce (or eliminate) future use of this compound. Based on the current uncertainties surrounding use of chlorine dioxide, it was not evaluated during this study.

3. *Removal of DBP Precursor Compounds*

A third DBP control alternative is to remove the organic precursor compounds which react with free chlorine to form TTHMs and THAAs prior to adding chlorine. Treatment processes which have demonstrated the ability to remove these precursors include (1) conventional coagulation/sedimentation/filtration using multi-valent metal salts, such as aluminum or iron, (2) adsorption using granular activated carbon, (3) ion exchange using anion exchange resins, and (4) membrane treatment (reverse osmosis or nanofiltration). The primary advantage associated with precursor removal for DBP control is the ability to continue to use free chlorine as a disinfectant within the distribution system.

TTHM formation potentials for the Skyco and RO plant raw water supplies exceed levels typically considered applicable to treatment using conventional coagulation/ sedimentation/filtration. Implementation of this alternative also is not considered practical because of the large site areas required for the treatment facilities. Use of conventional treatment to reduce DBP concentrations is therefore not considered feasible, and was not evaluated during this study.

VI. Analytical Testing Summary

Laboratory and bench-scale testing was conducted during this study to: (1) develop baseline data on water quality and TTHM formation rates for the Regional Water Supply System's three treatment facilities, (2) assist in the identification of potential DBP control alternatives, and (3) to confirm critical assumptions used in the evaluation of the DBP control alternatives. Testing procedures and results are summarized in this section.

A. Distribution System TTHM / THAA Levels

As discussed in Section V, no historical data exists on (1) THAA levels in the distribution systems served by the Regional Water Supply System, and (2) the relationship between TTHM concentrations and THAA concentrations within the system. As a new MCL for THAAs will be included in the impending Disinfectant/Disinfection Byproducts Rule, monitoring was conducted to assess current THAA levels within the distribution system, and to develop information on the relationship between TTHM and THAA concentrations.

Samples were taken on April 22, 1993 by Water Production Department staff at the eight locations currently used for the County's quarterly TTHM compliance monitoring, and at the RO and Skyco plant discharge. These samples were shipped to Montgomery Laboratories in Pasadena, California for analysis of TTHM and THAA concentrations. Quarterly TTHM compliance samples were also taken at this time and shipped to Oxford Laboratories. Results of these analyses are summarized in Table VI-1 (data on THM and HAA species for individual sample locations are presented in Appendix C).

While significant differences in the Montgomery and Oxford TTHM data were observed for several of the sample locations, the overall TTHM average for the eight sample locations exhibit acceptable correlation (the average of the TTHM values reported by Oxford is 13.6 percent less than for the Montgomery data). Average THAA concentration for the four sample locations served primarily by the RO and Skyco plants were 34.8 ug/L and 39.9 ug/L, respectively. The ratio of average THAA concentrations to average TTHM concentrations (based on the Montgomery TTHM data) was approximately 34.5 percent for the eight distribution system sample locations, with higher ratios for the system served primarily by the Skyco plant (40.7 percent for the Skyco system samples, vs. 29.7 percent for the RO system samples).

Table VI-1
Comparative TTHM, THAA Concentrations
for Dare County Distribution System

Sample Location	Total Trihalomethanes		THAA
	Montgomery µg/L	Oxford µg/L	Montgomery µg/L
Sanderling	128	119.2	38.9
Kitty Hawk Elem. School	114	98.0	36.0
Murray's Auto Supply	124	91.9	38.4
Kitty Hawk Fire Station	103	70.4	25.7
8th Street	92	90.6	43.4
Gull Street	100	86.7	49.0
Detention Center	105	98.7	20
Manteo WTP	96	90.8	47.2
RO WTP Discharge	23	--	2.5
Skyco WTP Discharge	102	--	31.9
Distribution System Average	108	93.3	37.3

While firm conclusions should not be drawn based on results from this limited monitoring period, the data suggest that reductions in system TTHM levels to achieve compliance with impending regulations would also result in compliance with impending MCLs for THAAs.

B. Reverse Osmosis Plant Testing

Testing was conducted to assess the impact of reduced raw water/membrane permeate blending rates on treated water TTHM formation levels and speciation under various simulated distribution system residence times, and to identify potential treated water stabilization requirements at the reduced blending rates. Additional testing was conducted to evaluate TTHM formation levels at reduced free chlorine contact times in order to assess feasibility of using chloramines as a secondary disinfectant to limit TTHM formation. Total organic carbon concentrations for the raw water and membrane permeate were analyzed to evaluate plant performance with respect to TOC removal and to assess the ability to comply with the TOC limitations to be included in the impending D/DBP Rule.

1. Procedures

As raw water bypass flow rates can be easily adjusted, plant staff recommended that samples for TTHM formation analyses be generated through operation of the plant at varying blended water conductivities. Testing was conducted on April 26th, 1993, and the plant was operated to produce raw/permeate blended conductivities ranging from 300 to 700 umhos/cm. Raw water conductivity at the time of sample collection was 6400 umhos/cm, and permeate conductivity (single train operating) was 200 umhos/cm. Blended raw/permeate samples were collected downstream from the static mixer. To ensure that no free chlorine was present in the samples, the chlorine feed system was turned off approximately 5 minutes prior to collection of each sample. (As a free chlorine residual is maintained in the 5 million gallon treated water reservoir, this procedure did not present any potential health threat, as the water with no chlorine residual is blended with the chlorinated water within the reservoir; chlorine feed was restored immediately after collection of each sample.) Samples were shipped to Oxford Laboratories in Wilmington, North Carolina in containers supplied by the laboratory.

2. Results

TTHM rate-of-formation for the various blended water conductivities is shown on Figure VI-1, and TTHM formation potentials (7-day, pH 9.0) are summarized in Table VI-2. This data agrees with testing results obtained previously, which indicated that TTHM concentrations at the RO plant discharge were approximately 20 ug/L to 30 ug/L. In all cases, the predominant THM species formed was bromoform (THM speciation data are presented in Appendix D). However, maximum bromform concentrations following 7 days of chlorine contact time were still significantly less than bromoform concentrations typically observed within the distribution system. For a blended water conductivity of 700 umhos/cm, the 7-day bromoform concentration was 8.9 ug/L; recorded bromoform levels for the portion of the distribution system served primarily by the RO plant range from 20.4 ug/L to 73.2 ug/L for November 1990 through April 1993. Seven-day TTHM formation potentials are also significantly

Table VI-2
TTHM Formation Potentials
for RO Plant Treated Water

Sample	THMFP* μg/L
Membrane Permeate	7.4
Blended Water	
300 Conductivity	17.2
400 Conductivity	25.9
500 Conductivity	30.6
600 Conductivity	37.2
700 Conductivity	48.3

* 7-day, pH 9.0.

less than levels typically found in the distribution system. Potential causes for these differences are discussed later in this section.

Monitoring data for raw/permeate pH, alkalinity, bromide, and total organic carbon are presented in Table VI-3. While the RO membranes are achieving approximately 97 percent rejection of bromide, permeate (and blended water) bromide levels are sufficient to promote formation of brominated THM compounds.

Table VI-3
Water Analysis Results
for RO Plant Raw, Treated Water

Parameter	Raw Water	RO Permeate
pH, units	7.75	6.25
Total Alkalinity, mg/L $CaCO_3$	280	8
Bromide, mg/L as Br	6.15	0.175
Total Organic Carbon, mg/L	7.4	0.8

C. Skyco Water Treatment Plant Testing

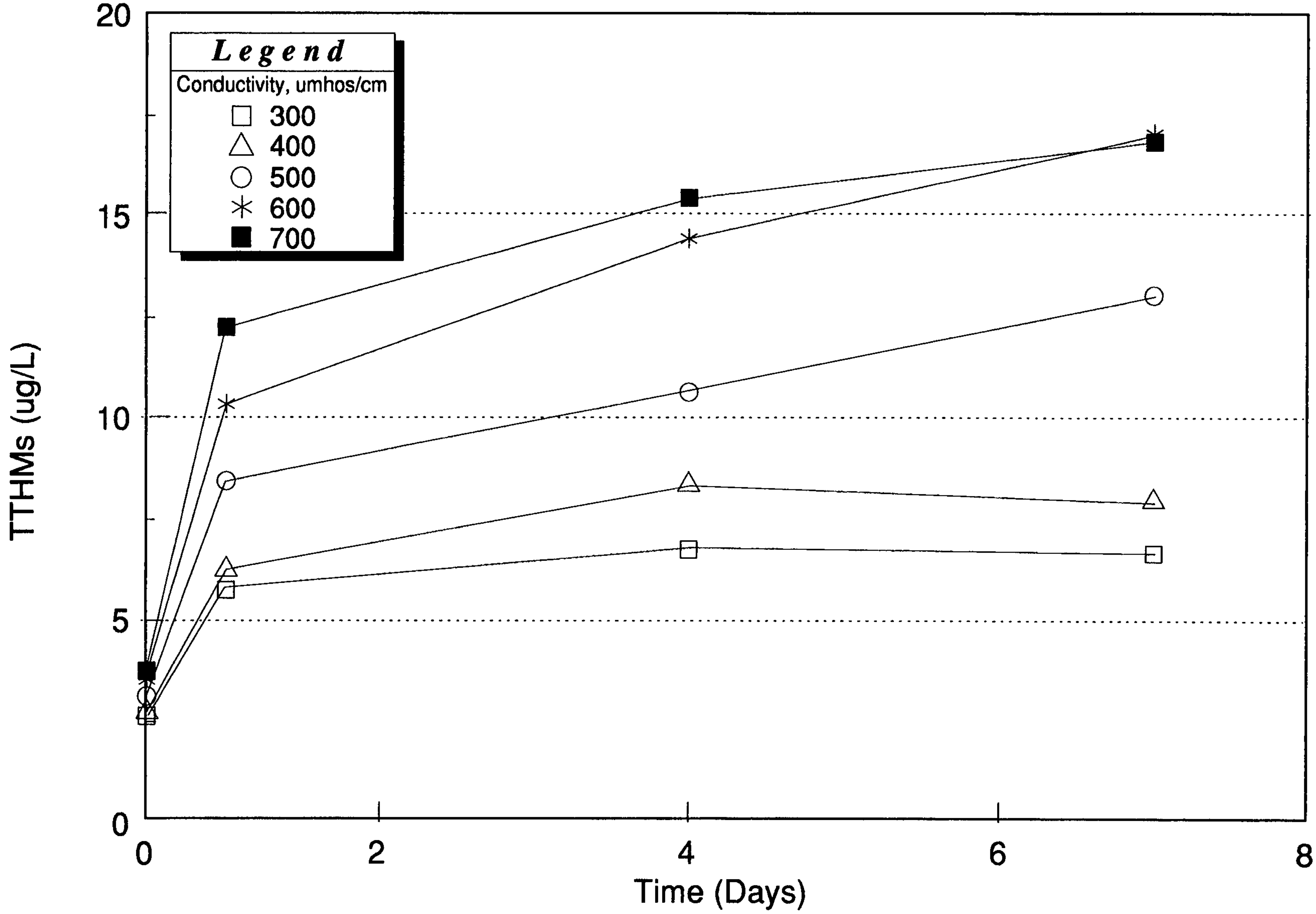
Testing was conducted to assess total organic carbon concentrations and maximum TTHM formation potentials for the individual Skyco wells, and to evaluate TTHM formation levels and speciation for the treated Skyco water under a variety of simulated distribution system residence times. Total organic carbon concentration was determined at the Skyco plant influent to assess the ability to comply with the TOC limitations to be included in the impending D/DBP Rule (ion exchange softening typically provides negligible removal of TOC). Ozone demand of the softened water was also determined.

1. Skyco Well THMFP

Sampling and analysis to determine maximum THMFP for the individual Skyco wells was conducted during April 1991 and October 1992 (prior to initiation of this study). THMFP was determined by Oxford Laboratories in accordance with standardized testing procedures and conditions (pH buffered to 9.0, incubation period 7 days at 25 C). Results for these two monitoring periods are summarized in Table VI-4. As significant differences exist in the results of these analyses, concerns were expressed regarding the validity of the data. Because of the importance of this information in the development and evaluation of DBP control alternatives, a third round of sampling and analysis was conducted, with samples collected on April 27, 1993 and split to Oxford Laboratories and to Industrial and Environmental Analysts, Inc., in Florida. Results for this monitoring period are summarized in Table VI-5. (Data on THM speciation for each well are summarized in Appendix E.)

Reported THMFP values for wells 1-5 and 9-12 exhibit good agreement (average difference in the reported THMFP values was approximately 8 percent, with a maximum difference of approximately 15 percent for well no. 10). Average THMFP for these wells is 256 ug/L, based on the Oxford analyses, and 276 ug/L, based on the IEA analyses. THMFP values for the composite sample (plant influent with all wells running) also show good correlation (difference is approximately 10 percent, using the average of the plant influent and softener discharge THMFP values reported by Oxford); the average of the reported values is 272 ug/L.

Significant differences in reported THMFP values exist for wells 7, 8, and 13. Values reported by IEA for wells 7 and 8 are substantially less than reported by Oxford, both for this monitoring period and for the October 1992 monitoring period. The significant differences between the Oxford and IEA results, and variations in results reported by IEA for wells 7 and 8 and for the remaining wells suggest that the IEA results for wells 7 and 8 may not accurately reflect actual THMFP conditions. IEA's reported THMFP value for well 13 (341 ug/L) is also significantly higher than



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TTHM RATE-OF-FORMATION FOR RO TREATED WATER

Figure VI-1

Table VI-4
TTHM Formation Potentials for
Skyco Wells: Historical Monitoring Data

Well No.	THMFP (4/25/91) μg/L	THMFP (10/16/92) μg/L	TOC (11/5/91) mg/L
1	143.2	237.2	2.49
4	30.4	237.3	1.85
5	37.5	238.0	2.17
7	11.0	399.1	2.81
8	14.4	395.5	2.97
9	29.9	--	3.13
10	35.5	240.5	2.49
11	203.4	244.1	2.17
12	216.3	297.2	2.49
13	37.9	253.6	2.17
Composite	--	362.1	--

Table VI-5
TTHM Formation Potentials for
Skyco Wells: April 1993 Monitoring Period

Well No.	THM Formation Potential		TOC μg/L
	Oxford μg/L	IEA μg/L	
1	229	265	2.41
4	284	274	2.87
5	250	268	4.10
7	344	113	9.54
8	333	94	4.49
9	283	299	13.3
10	227	268	2.74
11	243	266	3.32
12	274	289	5.65
13	246	341	3.00
Composite	237/278*	286	3.13

* Plant influent/softener discharge THMFP values.

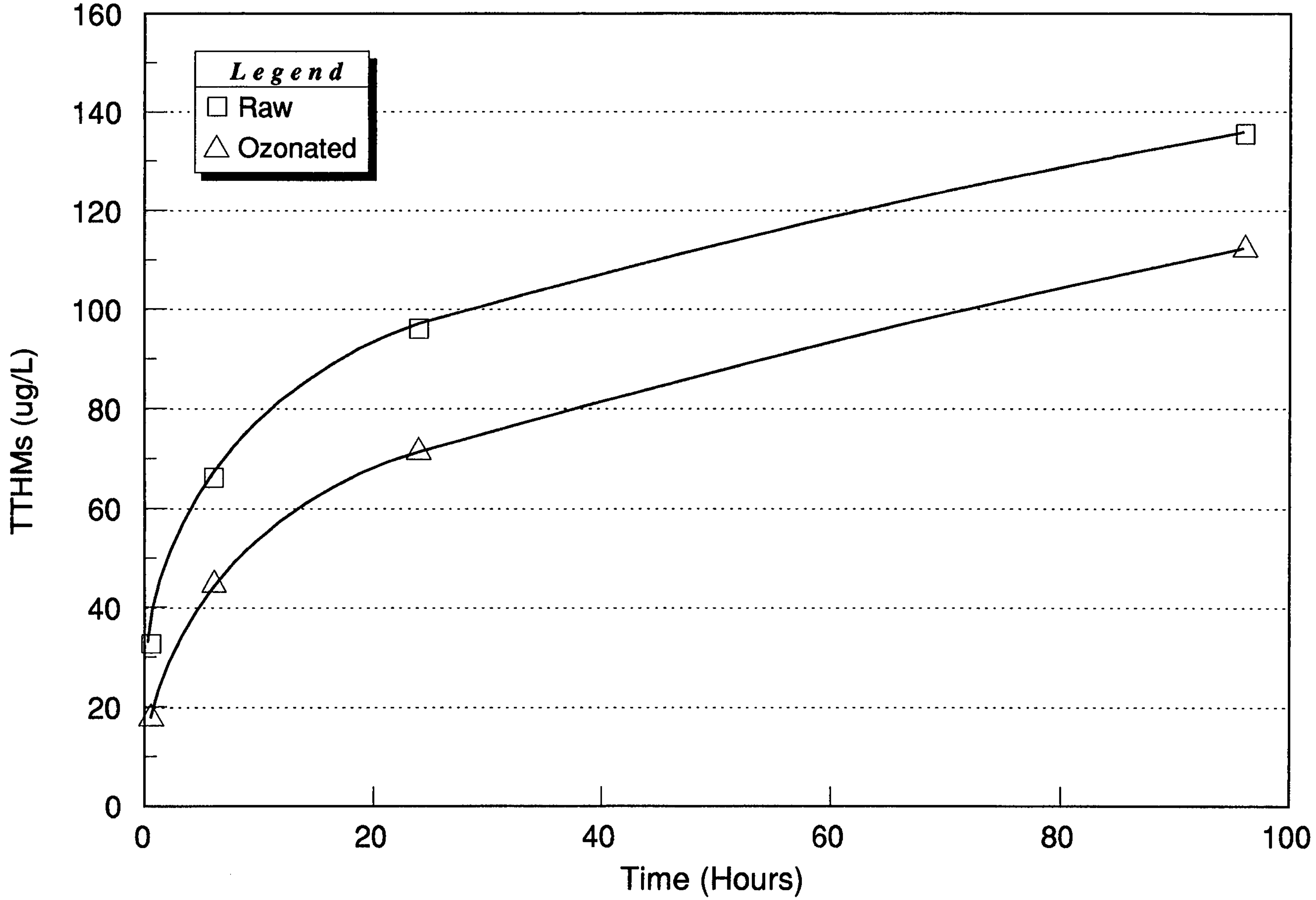
the values reported by Oxford for this monitoring period (246 ug/L) and for the October 1992 monitoring period (254 ug/L).

Based on review of the historical and current THMFP data for the individual wells and the plant influent, an average raw water THMFP concentration of 300 ug/L has been assumed in the evaluation of DBP reduction alternatives for the Skyco plant. The data do not support a conclusion that reductions in treated water TTHM concentrations would be realized by minimizing use of wells 7, 8, and 13.

2. Ozone Testing

To assess the ozone demand of the Skyco softened water, a sample of the water was shipped to the Black & Veatch Mobile Water Research Facility while the unit was located at the Nelson Water Treatment Plant in Winston-Salem, North Carolina. Ozone was applied to the water in a batch reaction vessel, with the ozone residual continuously monitored. An ozone residual (0.01 mg/L) was first observed at an applied dosage of approximately 2.6 mg/L. Higher applied ozone dosages yielded increased ozone residual levels (residual increased to 0.12 mg/L at 4.15 mg/L applied ozone dosage, and 0.23 mg/L at 5.9 mg/L applied ozone dosage). Based on this preliminary bench-scale data, an average applied ozone dosage of approximately 2.5 to 3 mg/L is projected for disinfection of the Skyco softened water. While pilot-scale testing is typically recommended to assess ozone requirements, results of this bench-scale test can be used to develop probable construction and operating costs for a full-scale ozonation facility at the Skyco plant.

Ozonation reduced color from the initial value of 20 units to approximately 14 units (note that the ozonated sample was not filtered prior to color analysis), and no increase in turbidity was observed. 7-day TTHM formation potential (at pH 9.0) for the raw (non-ozonated) sample was 345 ug/L, and total organic carbon concentration was 2.70 mg/L. TTHM concentrations were determined for both the raw and ozonated Skyco water samples for free chlorine contact periods ranging from 30 minutes to 96 hours. Results of these analyses are shown on Figure VI-2. Ozonation reduced TTHM formation potential by approximately 46 percent at a chlorine contact time of 30 minutes, and by approximately 33 percent at 6 hours' contact time. No significant increase in the levels of brominated THM species was observed for the ozonated sample following chlorination. Ozonation did not, however, reduce TTHM formation at extended chlorine contact times to levels that would permit use of free chlorine as the secondary disinfectant within the distribution system. TTHM rate-of-



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TTHM RATE-OF-FORMATION FOR OZONATED SKYCO WATER Figure VI-2

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formation data indicate that TTHM concentration reaches 50 ug/L after approximately 9 hours.

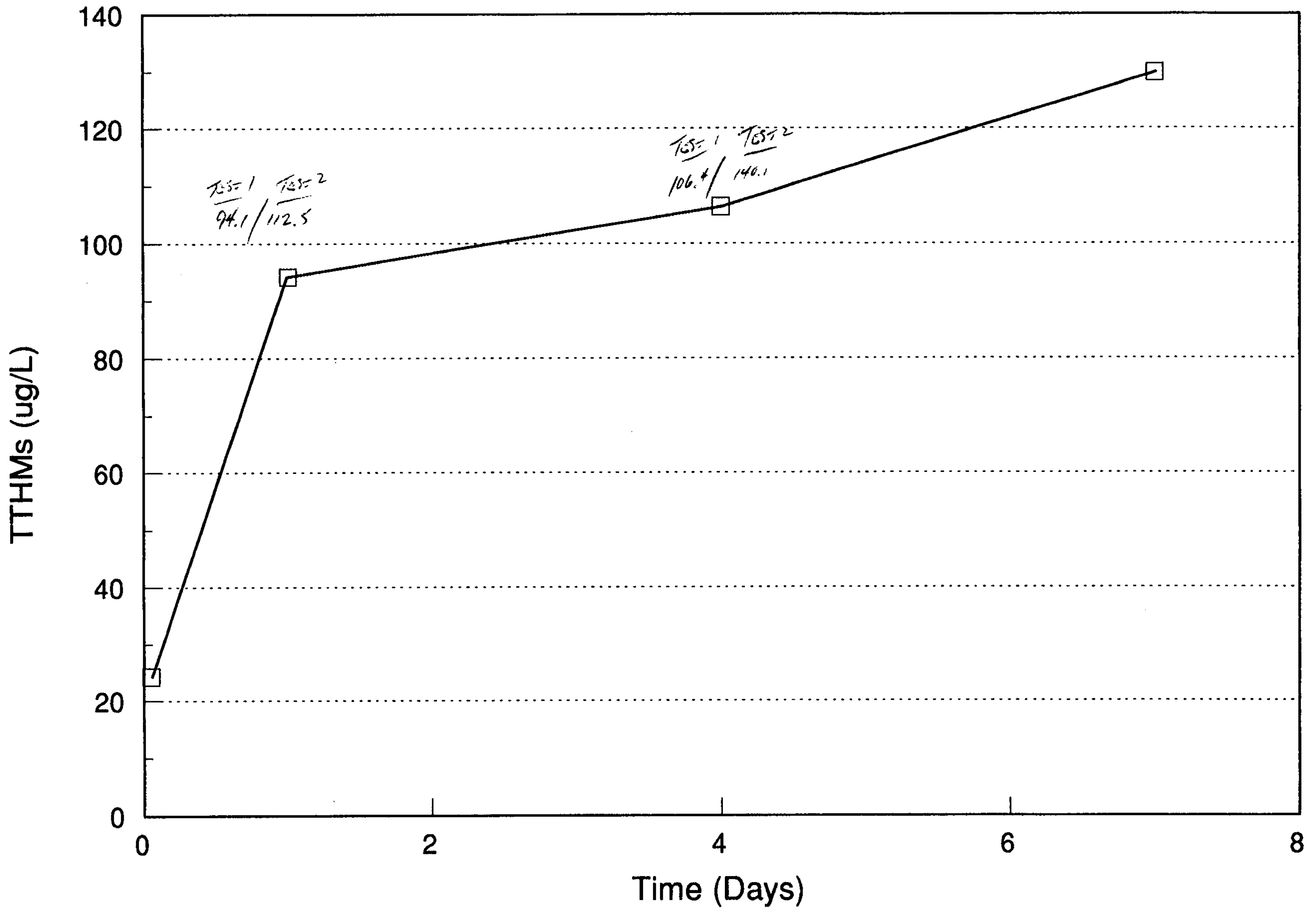
3. Testing at Skyco WTP

TTHM formation levels and speciation were determined for the softened Skyco water at free chlorine contact times of 15 and 30 minutes in order to assess feasibility of using chloramines as a secondary disinfectant to limit TTHM formation. TTHM formation levels and speciation for the softened water at free chlorine contact times of 1, 4, and 7 days (no pH adjustment), and 7-day maximum TTHM formation potential (sample pH buffered to 9.0) were also determined. As raw water silica levels could potentially limit raw-to-product conversion rates for membrane treatment systems, silica concentration at the plant influent was determined to confirm the accuracy of historical monitoring data. Results of this testing are summarized in Table VI-6 and on Figure VI-3 (laboratory data are presented in Appendix G).

Table VI-6
Water Analysis Results for Skyco WTP

Parameter	Value
Raw Water (Composite Well Sample)	
Bromide, mg/L	0.180
Silica, mg/L	27.4
Softened Water	
Total Organic Carbon, mg/L	3.30
TTHM Formation (15 minutes), μg/L	18.7
TTHM Formation (30 minutes), μg/L	24.3
THMFP (7-day, pH 9.0), μg/L	278

In all cases, the predominant THM compound formed was chloroform (chloroform comprises approximately 50 percent of the total THM concentration for the softened water following a chlorine contact period of 7 days). TTHM rate-of-formation data (Figure VI-3) also correlates fairly well with monitoring data for this same monitoring period on TTHM concentration at the Skyco plant discharge (treated water TTHM concentration at the plant discharge was 102 ug/L). TTHM rate-of-formation data (Figure VI-3) indicate that softened water TTHM concentration reaches 50 ug/L after approximately 9-10 hours.



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TTHM RATE-OF-FORMATION FOR SKYCO SOFTENED WATER

Figure VI-3

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D. Fresh Pond Water Treatment Plant Testing

As no historical data on TTHM rate-of-formation for the water produced by the Fresh Pond plant was available, testing was conducted to assess TTHM formation levels and speciation for the filtered water under a variety of simulated distribution system residence times. Maximum TTHM formation potential (7 days, pH 9.0) and total organic carbon concentration were also determined for the filtered water. TTHM formation levels for the settled (unfiltered) water at free chlorine contact times of 15 and 30 minutes, and for the filtered water (following pH adjustment to 7.5) at a free chlorine contact time of 30 minutes were also determined in order to assess feasibility of using chloramines as a secondary disinfectant to limit TTHM formation. Total organic carbon concentrations for the raw and filtered water were analyzed to evaluate plant performance with respect to TOC removal and to assess the ability to comply with the TOC limitations to be included in the impending D/DBP Rule.

1. Sample Preparation

As the plant was not operating during the preparation of this study, it was necessary to simulate plant performance through bench-scale treatment of the raw water supply. Treatment procedures are summarized below.

Samples of raw water from Fresh Pond were collected by plant staff and shipped to Black & Veatch's Kansas City regional office, where the samples were prepared for analysis. Coagulation/flocculation/sedimentation was simulated through jar testing, using 2-liter square beakers on a Phipps and Bird Model 7790-400 six-paddle stirrer. The 2-liter beakers include sample withdrawal taps located 10 cm below the water surface. Alum and powdered activated carbon (PAC was supplied by plant staff) were added at dosage rates typically used in the full-scale plant (50 mg/L alum, 7.5 mg/L PAC). Following alum/PAC addition, the samples were mixed for 30 seconds at maximum speed (approximately 300 rpm). Mixer speed was then reduced, and flocculation was carried out at 30 rpm for 10 minutes and 10 rpm for 10 minutes. Floc particles were allowed to settle for 5 minutes, after which supernatant samples were withdrawn from the individual beaker taps. The 5-minute settling period corresponds to an "equivalent" settling basin hydraulic loading rate of 0.5 gpm/sq ft (720 gpd per square foot).

Settled water was filtered by gravity through Whatman No. 40 filter paper. Previous experience has shown good correlation between the quality of filtrate produced using this procedure and that of a well-operated conventional dual-media filter. Filtered water pH was adjusted to approximately 7.5 using sodium hydroxide. Settled and filtered water samples were then shipped to Oxford Laboratories in containers supplied by Oxford.

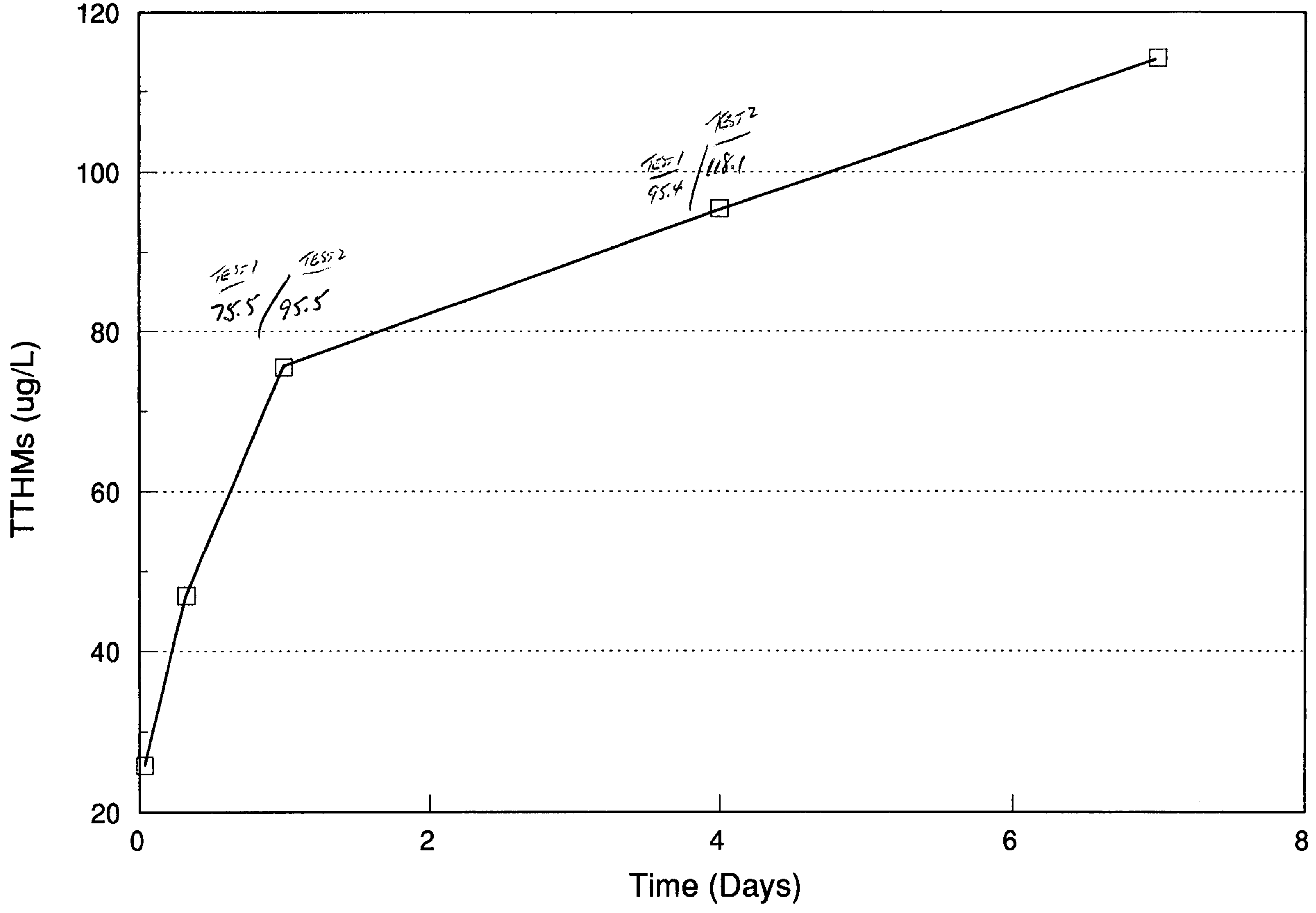
2. *Results*

TTHM rate-of-formation for the filtered water is shown on Figure VI-4, and results of total organic carbon and TTHM formation analyses are summarized in Table VI-7. (THM speciation data are presented in Appendix H.) The coagulation/sedimentation/filtration process provided a reduction in TOC concentration of approximately 7 percent, and a reduction in TTHM formation potential (7-day, pH 9.0) of approximately 35 percent. While TOC removal for the full-scale plant may exceed the level achieved during bench-scale testing, it is considered unlikely that the plant can achieve the 2 mg/L limit required to avoid having to implement "enhanced coagulation" under the impending D/DBP rule. (Note that if the TOC concentration at the point of disinfectant addition exceeds 4 mg/L, treatment optimization/pilot studies would be required under the impending D/DBP rule.)

Table VI-7
Water Analysis Results for Fresh Pond WTP

Parameter	Value
Raw Water	
Bromide, mg/L	0.115
Total Organic Carbon, mg/L	4.98
THMFP (7-day, pH 9.0), μg/L	416
Settled Water	
pH	6.70
TTHM Formation (15 minutes), μg/L	7.2
TTHM Formation (30 minutes), μg/L	9.4
Filtered Water	
pH	7.1
Total Organic Carbon, mg/L	4.62
TTHM Formation (30 minutes), μg/L	23.4
THMFP (7-day, pH 9.0), μg/L	271.5

In all cases, the predominant THM species formed upon chlorination is chloroform. Chloroform comprises approximately 78 percent (326 ug/L) of the raw



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TTHM RATE-OF-FORMATION FOR FRESH POND FILTERED WATER

Figure VI-4

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water THMFP, and approximately 68 percent (185 ug/L) of the filtered water THMFP. While treatment provided a significant reduction in chloroform formation potential (43 percent for the 7-day, pH 9.0 analyses), formation potentials for the remaining three THM species were not reduced. TTHM rate-of-formation data (Figure VI-4) indicate that filtered water TTHM concentration reaches 50 ug/L after approximately 8 - 10 hours.

E. Conclusions

Based on the testing discussed above, the following conclusions can be drawn:

- TTHM formation for treated water produced by the RO, Skyco, and Fresh Pond plants following 30 minutes of contact time with free chlorine was less than 25 ug/L in all cases. This suggests that use of chloramines as a secondary disinfectant, following primary disinfection with free chlorine, would reduce TTHM concentrations within the distribution systems served by the Dare Regional Water Supply System to less than the probable future TTHM MCL of 40 ug/L.
- 7-day TTHM formation for RO plant treated water at blended water conductivities ranging from 300 to 700 umhos/cm was less than 20 ug/L in all cases. This suggests that current problems with high TTHM levels in portions of the system served "primarily" by the RO plant can be attributed to intermixing of waters from the RO and Skyco/Fresh Pond plants. The presence of organic precursor compounds in the Skyco/Fresh Pond treated waters, in conjunction with bromine in the RO-treated water, result in increased levels of both TTHMs and bromoform when these waters are intermixed (this is discussed in further detail below).
- TTHM formation potential data for individual wells serving the Skyco plant indicate that selective blending would not yield any significant reductions in DBPs within the distribution system.
- Ozonation of softened water from the Skyco plant did not reduce TTHM formation at extended chlorine contact times to levels that would permit use of free chlorine as the secondary disinfectant within the distribution system.
- Treated water TTHM formation potential (272 ug/L at 7 days, pH 9.0) and total organic carbon concentration (4.62 mg/L) for the Fresh Pond plant suggest that this plant may have significant influence on DBP levels within the systems served by the Dare Regional Water Supply System.

- The Skyco and Fresh Pond treatment plants will likely experience difficulties in meeting the impending total organic carbon limit of 2 mg/L at the point of chlorine addition.
- Reductions in TTHM concentrations to achieve compliance with impending regulations should also result in compliance with impending MCLs for total haloacetic acids (THAAs).

As discussed above, TTHM formation potential (7-day, pH 9.0) for RO-treated water at all blended water conductivities evaluated was less than 50 ug/L in all cases; TTHM formation following 7 days of free chlorine contact time at typical treated water pH was less than 20 ug/L for all blended water conductivities evaluated. Bromoform concentrations were also significantly less than typically observed in portions of the distribution system served "primarily" by the RO plant. (Maximum bromoform formation of 9.0 ug/L occurred for 600 conductivity blended water following 7 days of free chlorine contact time.) These data suggest that intermixing of waters from the RO and Skyco/Fresh Pond plant is the primary cause of the high TTHM levels within this portion of the distribution system.

Increased TTHM/bromoform formation following blending of RO-treated groundwater and groundwater not treated by RO has been reported by other utilities. The chemistry and kinetics of TTHM formation in the presence of bromide ions are complex and not readily predictable. During chlorination of water containing bromide ions, chlorine oxidizes the bromide to free bromine, and this reaction continues as long as bromide and a free chlorine residual are present. For the RO-treated water, free bromine reacts with organic precursor compounds to form low concentrations of bromoform. However, as treated water precursor levels are relatively low following membrane treatment, all of the free bromine present does not combine with organic precursors; an excess of free bromine therefore exists in the treated water at the plant discharge. Intermixing of treated water from the RO and Skyco/Fresh Pond plants exposes this free bromine to additional organic precursors present in the Skyco/Fresh Pond waters, thereby increasing bromoform concentrations following mixing, and producing a shift in THM distribution toward the brominated species.

VII. Disinfection Byproduct Control Alternatives

Treatment methodologies to reduce current levels of disinfection byproducts in the distribution systems served by the Dare Regional Water Supply System are discussed below. Based on consideration of impending DBP regulations and discussions with Water Production Department staff, a treated water THMFP goal of 50 ug/L was established as the basis for evaluating the DBP control alternatives. Water Production Department staff indicate that theoretical detention time of the treated water within the distribution systems served by the Dare Regional Water Supply System exceeds seven days at some locations. Use of 7-day THMFP for evaluating treatment alternatives is therefore considered a reasonable approach. Production of treated water with a 7-day THMFP of 50 ug/L will ensure compliance with both the impending TTHM MCL of 80 ug/L and the potential future MCL of 40 ug/L. (Alternatives utilizing chloramines as a secondary disinfectant within the distribution system would need to limit free chlorine contact times at the treatment facilities to yield TTHM formation levels of 40 ug/L or less at the point of ammonia addition in order to achieve equivalent results.)

A. Limit Free Chlorine Contact Times

For this alternative, free chlorine would continue to be used as the primary disinfectant at each of the three treatment facilities operated by the Dare Regional Water Supply System. Following disinfection, however, ammonia would be added to form chloramines, thereby halting further formation of DBPs. A chloramine residual would be maintained within the treated water storage facilities at the individual treatment plants, and throughout the distribution system to maintain the microbial quality of the treated water. As DBP formation increases with time when free chlorine is used as the disinfectant, conversion of the free chlorine residual to the chloramine form prior to the treated water storage facilities is required to limit DBP formation. To ensure compatibility of the disinfectant residuals within the system, provisions for adding ammonia at each of the three treatment facilities would be required. Implementation requirements for each of the three treatment plants are discussed below.

1. Disinfection Requirements

As discussed in Section IV, the Groundwater Disinfection Rule will not be proposed until mid-1994, and therefore specific disinfection requirements under this this regulation cannot be determined at this time. However, preliminary indications are that the rule will use the CT concept to assess levels of disinfection achieved (see Section IV for a discussion of CT criteria), and virus inactivation will most likely form the basis for determining minimum disinfection requirements. Using CT values for virus inactivation as the basis for projecting disinfection requirements, required CTs range from 2 mg-min/L for 2-log inactivation at 15 C to 6 mg-min/L for 4-log inactivation at 10 C. As EPA's intentions regarding credits for removal/inactivation of viruses by "natural disinfection" processes during passage of water through subsurface strata are not yet defined, the more conservative 4-log virus inactivation criteria has been used to evaluate disinfection requirements for the RO and Skyco water treatment facilities.

As the Fresh Pond plant treats a surface supply, it is subject to the requirements of the Surface Water Treatment Rule. Any modification of current disinfection practices must therefore consider impacts on compliance with this regulation.

2. Reverse Osmosis Plant

Chlorine is currently added following blending of raw well water and RO permeate. The treated water then flows to the 5 million gallon storage reservoir through approximately 500 feet of 30-inch diameter pipeline. As the detention time of the treated water within the pipeline (approximately 8.8 minutes at 3 mgd) provides a significant amount of free chlorine contact time, addition of ammonia within the pipeline just prior to the reservoir was evaluated. At a minimum water temperature of 10 C (50 F) and a pH of 6 to 9, a CT of 6 mg-min/L is required to achieve a 4-log inactivation of viruses. Assuming a minimum treated water chloramine residual of 2 mg/L, a free chlorine residual of about 2 mg/L would be required at the point of ammonia addition to yield the desired chloramine residual. At 2 mg/L free chlorine residual, a T_{10} detention time of 3 minutes would be required to achieve a CT of 6 mg-min/L (2 mg/L chlorine residual x 3 minutes T_{10} = 6 mg min/L). As discussed in EPA's Surface Water Treatment Rule "Guidance Manual", pipelines can be considered to exhibit plug-flow hydraulic conditions, and therefore the T_{10} detention time can be assumed to be equal to the theoretical detention time of 8.8 minutes (as determined by dividing the pipe volume in gallons by the flow rate in gpm). Therefore, the treated water pipeline between the point of chlorine application and the storage reservoir would provide a CT of 17.6 at 2 mg/L free chlorine residual. This level of disinfection exceeds the minimum requirements for 4-log virus inactivation at both the current plant production capacity and at the ultimate expanded capacity of 8 mgd.

Ammonia would be added through a diffuser in the treated water pipeline near the storage reservoir influent. Ammonia can be received either in gaseous (anhydrous) form in 150 lb cylinders, or in aqueous form (aqua ammonia) in 55 gallon drums. (All of the North Carolina utilities which were contacted during this study to discuss their experience with chloramination are currently using aqua ammonia.) Each type of ammonia has both advantages and disadvantages. Anhydrous ammonia is fed using a solution feeder similar to a conventional chlorine feeder, while aqua ammonia is fed directly from storage to the point of application using metering pumps. While most utilities currently purchase aqua ammonia with an effective ammonia concentration of 25-30 percent (by weight), problems with emission of ammonia odors during hookup/changeout of drums can be minimized by using the more dilute 15 percent ammonia form. Use of anhydrous ammonia generally reduces problems with odor emissions, and chemical cost on a pounds-of-ammonia-purchased basis is typically less than for aqua ammonia. However, feed equipment for ammonia in anhydrous form is also more costly and somewhat more complex than for aqua ammonia. From a safety standpoint, the potential for injury associated with failure of a cylinder of anhydrous ammonia is generally considered greater than would be associated with spilling of a 55-gallon drum of aqua ammonia, due to the greater amount of ammonia released and the nature of the chemical. (When proper safety precautions are observed, however, neither compound is considered any more hazardous than other chemicals currently used at the Regional Water Supply System's three treatment facilities.) The decision as to which form of ammonia will best suit the needs of a particular utility is generally based on cost considerations and the level of familiarity and comfort that the operating staff have with a particular chemical form.

Both anhydrous and aqua ammonia feed systems were considered for the RO plant, and probable costs for each system are summarized in Section VIII. Ammonia storage requirements are based on 30 days' storage at an average ammonia dosage of 1 mg/L at the maximum plant operating rate of 3 mgd. The anhydrous ammonia feed system would consist of space for six 150 lb ammonia cylinders, two twin-cylinder scales, one ammonia supply manifold with auto switchover capability, two cabinet-type ammonia solution feeders, and a separate enclosure for the ammonia feed equipment and cylinder storage. The aqua ammonia feed system would consist of storage for approximately fifteen 55-gallon drums of 15 percent aqua ammonia (1.12 lb ammonia per gallon), two drum scales, two metering pumps, and a separate enclosure for the feed equipment and storage of the drums.

3. *Skyco Water Treatment Plant*

Chlorine is currently added at the discharge from the ion exchange softeners, and the treated water then flows to the 2 million gallon ground storage tank through approximately 100 feet of 16-inch pipeline. Available free chlorine contact time in the pipeline, assuming addition of ammonia at the storage tank inlet (prior to the point at which the pipeline enters the tank), would be inadequate to achieve conditions for 4-log virus inactivation at flow rates exceeding 0.75 - 1.25 mgd. Additional free chlorine contact time must therefore be provided prior to ammonia addition at the storage tank inlet. This can be accomplished by constructing a small chlorine contact basin between the softeners and the storage tank, or by extending the existing treated water pipeline, using larger-diameter pipe, to increase available detention times.

Any modification of the existing facilities must consider both implementability with respect to required plant "down time" to accomplish the modifications, and the need to minimize hydraulic headloss through the facilities. (Addition of facilities which increase hydraulic losses between the softeners and the storage tank would reduce the maximum tank level, thereby reducing its effective storage capacity). While construction of a chlorine contact basin is assumed for evaluation of this alternative, extension of the existing pipeline would also be a viable treatment option. Addition of approximately 300 feet of 24-inch diameter pipeline, or 90 feet of 30-inch diameter pipeline would provide a T_{10} detention time of 2 minutes at 5 mgd, which would be adequate to achieve 2-log virus inactivation conditions at the minimum water temperature of 15 C and a minimum free chlorine residual of 2 mg/L. (Required CT is 4 mg-min/L at a temperature of 10 C; (2 mg/L residual)(2 min T_{10}) = 4 mg-min/L.)

A chlorine contact basin with a theoretical detention time of 8 to 10 minutes at the plant capacity of 5 mgd would provide a T_{10} detention time of 2 to 3 minutes, which would be adequate to achieve 4-log virus inactivation at a minimum chlorine residual of 2 mg/L. Baffles would be installed in the contact basin to provide the necessary T_{10} detention period, but would be held to a minimum in order to avoid imparting excessive hydraulic headloss across the basin. The basin inlet and outlet would also be designed to minimize headlosses. The contact basin would be located adjacent to the treated water storage tank, and could be designed and constructed such that plant "down time" during tie-in of the contact basin to the existing facilities would be minimized.

Ammonia would be fed at the chlorine contact basin discharge prior to the treated water storage tank. Advantages/disadvantages of anhydrous and aqua ammonia systems were discussed above for the RO plant. Both anhydrous and aqua ammonia feed systems were considered for the Skyco plant, and probable costs for each system are summarized in Section VIII. Ammonia storage requirements are based on 30 days' storage at an average ammonia dosage of 1 mg/L at the maximum plant operating rate of 5 mgd. The anhydrous ammonia feed system would consist of space for nine 150 lb ammonia cylinders, two twin-cylinder scales, one ammonia supply manifold with auto switchover capability, two cabinet-type ammonia solution feeders, and a separate enclosure for the ammonia feed equipment and cylinder storage. The aqua ammonia feed system would consist of storage for approximately 24 55-gallon drums of 15 percent aqua ammonia (1.12 lb ammonia per gallon), two drum scales, two metering pumps, and a separate enclosure for the feed equipment and storage of the drums.

Problems can be experienced in feeding anhydrous ammonia if the hardness of the dilution water exceeds approximately 50 mg/L. As ammonia is a strongly alkaline compound, addition of dilution water with hardness exceeding this level will result in precipitation of calcium carbonate scale. Feed piping, diffusers, and other equipment exposed to the ammonia solution will become heavily scaled, and possibly clogged. This can be prevented by passing the dilution water through a cation exchange softener prior to the ammonia feeder. When feeding anhydrous ammonia with vacuum operated equipment, all of the injector water must be softened. The ratio of injector water to anhydrous ammonia should be approximately 15 gallons of water per pound of ammonia. As hardness of the treated water at the Skyco plant typically exceeds 50 mg/L as $CaCO_3$, provisions for softening of the ammonia dilution water should be provided. Costs for this equipment are included in the opinion of probable cost presented in Section VIII.

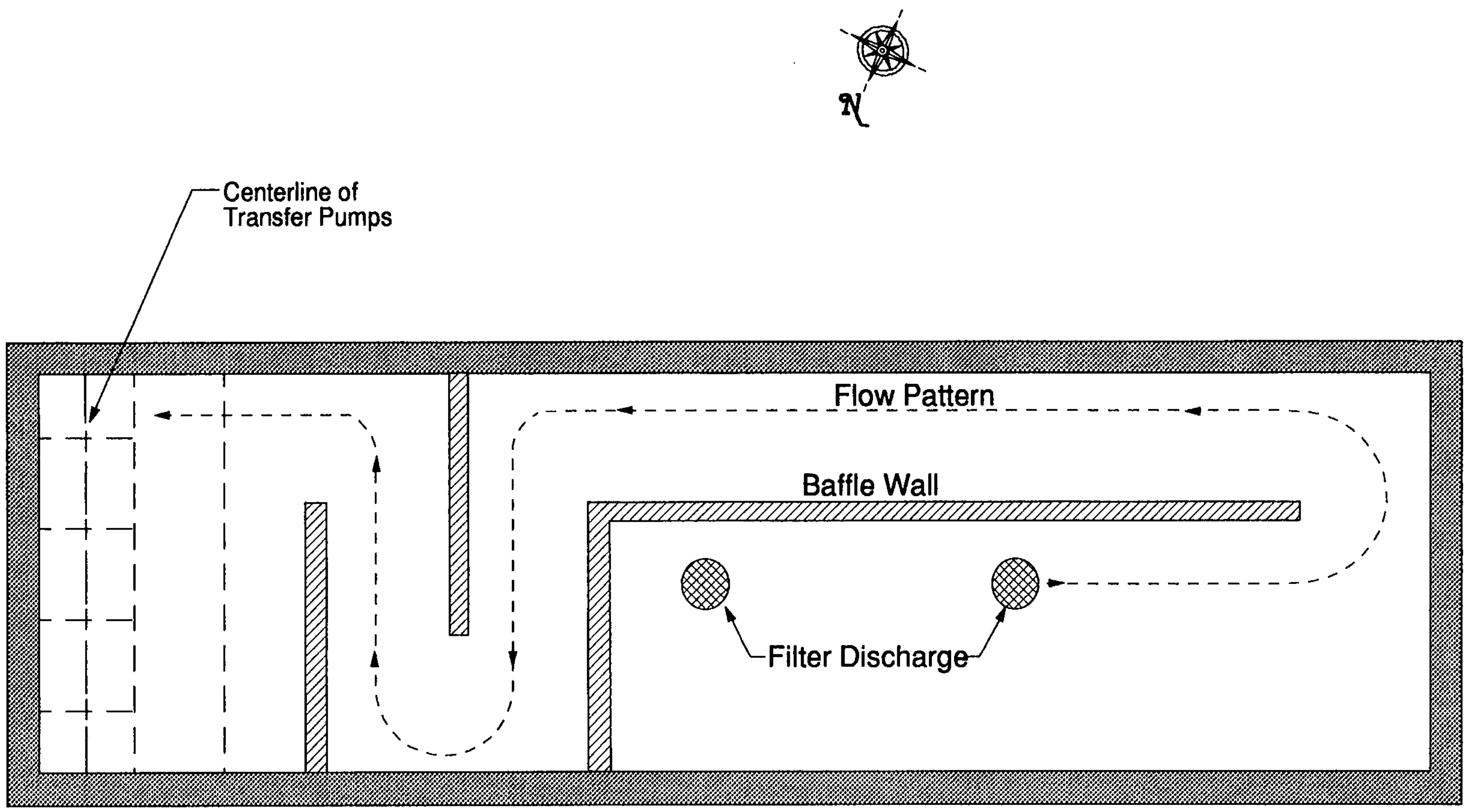
4. *Fresh Pond Water Treatment Plant*

Chlorine is currently added at the settling basin discharge. Settled water flows to the filters through approximately 85 feet of 16-inch diameter pipeline. Filtered water discharges to a 40,000 gallon below-grade clearwell, and is pumped to the 0.5 million gallon ground storage tank or to the regional distribution main. Two alternatives for achieving compliance with disinfection CT criteria under the Surface Water Treatment Rule when adding ammonia for chloramine formation prior to the ground storage tank were evaluated: (1) ammonia addition at the two filter discharge pipelines at the entrance to the clearwell, and (2) ammonia addition at the filtered water pump suction.

Evaluation of available T_{10} disinfection times for the combined settled water pipeline and the filters indicates that compliance with CT criteria could not be achieved under minimum temperature and average pH conditions. (CT calculations for the Fresh Pond plant are summarized in Appendix I, and are therefore not presented here). Required chlorine residual levels for compliance with CT criteria at a minimum temperature of 10 C would be approximately 4.9 mg/L and 5.9 mg/L at pH 6.5 and 7.0, respectively. Maintaining these high free chlorine residuals across the filters would result in chloramine concentrations following ammonia addition which exceed probable future maximum allowable levels. The additional chlorine contact time provided within the clearwell would therefore be required to achieve compliance with CT criteria.

Baffles must be installed within the clearwell to increase effective (T_{10}) detention times to levels required to comply with SWTR disinfection criteria. A suggested baffle configuration is shown on Figure VII-1. As the plant typically operates only 5 to 6 months per year, installation of baffles can be easily accomplished during the winter months when the plant is out of service and the clearwell is empty. Considering the limited access to the clearwell interior, installation of either concrete block/masonry walls or woven stainless steel baffle walls would be recommended (concrete block wall installation would be more labor-intensive, but effective life would be significantly greater than for the woven steel baffle walls).

Ammonia can be added at either the filtered water pump suction or the clearwell discharge pipeline. Advantages/disadvantages of anhydrous and aqua ammonia systems were discussed above for the RO and Skyco plants. Both anhydrous and aqua ammonia feed systems were considered for the Fresh Pond plant, and probable costs for each system are summarized in Section VIII. Ammonia storage



CLEARWELL PLAN VIEW

Approximate Scale: 1" = 6'

FRESH POND WATER TREATMENT PLANT
CLEARWELL BAFFLE CONFIGURATION

Figure VII-1

BLACK & VEATCH
PROGRESS BY DESIGN

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requirements are based on 30 days' storage at an average ammonia dosage of 1 mg/L at the maximum plant operating rate of 1.4 mgd. The anhydrous ammonia feed system would consist of space for four 150 lb ammonia cylinders, one twin-cylinder scale, one ammonia supply manifold with auto switchover capability, two cabinet-type ammonia solution feeders, and a separate enclosure for the ammonia feed equipment and cylinder storage. As treated water hardness at the Fresh Pond plant typically exceeds 50 mg/L as $CaCO_3$ (average 95-100 mg/L as $CaCO_3$), provisions for softening of the ammonia dilution water should be provided. The aqua ammonia feed system would consist of storage for approximately eight 55-gallon drums of 15 percent aqua ammonia (1.12 lb ammonia per gallon), two drum scales, two metering pumps, and a separate enclosure for the feed equipment and storage of the drums.

B. Alternative Disinfectant

As discussed in Section V, using a primary disinfectant which does not form undesirable DBPs, with chloramines as a secondary disinfectant within the distribution system, is another method to achieve compliance with impending DBP regulations. For this study, ozone was evaluated as an alternative to chlorine for primary disinfectant at the RO and Skyco plants. Ozone is being used with increasing frequency in water treatment facilities, and its use is expected to expand considerably following promulgation of new DBP regulations. In addition to disinfection, potential benefits associated with use of ozone for treatment of groundwater supplies include oxidation of iron, manganese, color, and, to a limited extent, TTHM and THAA precursor compounds. Ozonation must precede conventional granular media filtration in most cases to ensure effective removal of (1) the flocculated particles resulting from the partial oxidation of dissolved organic materials present in the raw water supply, and (2) precipitates formed during oxidation of iron and/or manganese. Failure to remove these precipitates can result in passage of the precipitates into the distribution system, with resulting water quality problems at consumer taps. Research conducted by Black & Veatch and others indicates that while ozonation prior to chlorine addition may not reduce ultimate TTHM formation levels, it can often reduce the rate of TTHM formation, thereby yielding lower TTHM levels in the distribution system. Most important, ozone eliminates the need for free chlorine as the primary disinfectant.

Ozone is applied in gaseous form, and because of its instability, is generated onsite. A contact chamber with multiple ozone feed/reaction cells is required to achieve optimum ozone utilization and effectiveness, and to satisfy disinfection contact time requirements. As ozone treatment does not yield a sustainable residual, a secondary disinfectant (typically chlorine or chloramines) must be added to prevent microbial regrowth within the distribution system. Because of its highly reactive nature, ozone should be applied before filtration at a point where water quality is highest. This results in maximum disinfection efficiency, reduced ozone demands, and minimum formation of disinfection byproducts.

Disadvantages of ozonation include high construction costs for the ozone generation and contact equipment, high operating costs due to high energy consumption rates, and general unfamiliarity of operators with the process. Ozonation of waters containing bromide also results in the formation of bromate, a potential human carcinogen which will likely be regulated at low levels under the impending D/DBP regulation.

Use of ozone as the primary disinfectant at the RO and Skyco plants is discussed below.

1. Reverse Osmosis Plant

Ozonation of the combined raw water bypass and RO permeate streams, with subsequent addition of chlorine and ammonia to form chloramines, would reduce TTHM and THAA concentrations in the distribution system to well below probable future allowable levels. However, the presence of bromide in the blended water may result in unacceptable levels of bromate in the ozonated water. The potential range of bromate resulting from ozonation of waters containing bromide has not been well documented. However, pilot-scale investigations conducted by others indicate that bromate levels as high as 60 ug/L could be observed when bromide concentrations are approximately 1 mg/L. (Limited monitoring data indicates that bromide levels in the blended RO permeate/raw water stream may exceed 1 mg/L at relatively low blending rates.) Limited testing conducted by other utilities indicates that formation of bromate during ozonation can, in some cases, be controlled by adding ammonia prior to ozonation. The ammonia combines with bromide to form bromamine, a relatively unstable compound which decomposes rapidly. Formation of bromamine prior to ozonation has been shown to reduce the formation of bromate during ozonation. However, effectiveness of this treatment technique is apparently site-specific and highly pH-dependent (effectiveness at pH less than approximately 8.0 is apparently limited). Conversations with officials involved in the development of the impending D/DBP regulation indicate that an MCL for bromate of 10 ug/L will likely be recommended. The ability to meet this stringent bromate MCL through addition of ammonia prior to ozonation cannot be readily predicted; pilot studies using the blended RO permeate and raw water would need to be conducted to assess process effectiveness. Based on these uncertainties, ozonation of the RO treated water is not considered a viable alternative to free chlorine for reducing DBP formation at this time.

2. *Skyco Water Treatment Plant*

Review of historical TTHM monitoring data for portions of the system served by the Skyco plant indicated that chloroform is the predominant THM species present, and thus raw water bromide levels may be low enough to permit use of ozonation as the primary disinfectant. Ozone demand and TTHM formation potential following ozonation for Skyco treated water were therefore evaluated.

As discussed in Section VI, ozonation did not reduce TTHM formation at extended free chlorine contact times (i.e., greater than 24 hours) to levels which would permit continued use of free chlorine as the secondary disinfectant within the distribution system. TTHM formation for the ozonated sample exceeded the impending MCL of 80 ug/L and the potential future MCL of 40 ug/L at free chlorine contact times of approximately 40 hours and 6 hours, respectively. Use of chloramines as the secondary disinfectant following chlorine could, however, limit TTHM formation to levels which would comply with both the impending MCL of 80 ug/L and the potential future MCL of 40 ug/L.

Addition of ozonation capability would require construction of an ozone contact chamber and granular media filters between the existing ion exchange softeners and the treated water storage reservoir. The ozone contact chamber would be divided into four cells, with ozone fed to the first two cells through fine-bubble diffusers. The third and fourth cells would provide detention time for dissipation of ozone residual before the water is discharged from the contactor. A contact cell depth of 18 to 20 feet would be provided to ensure efficient transfer of ozone to the process stream, and the multi-cell design would facilitate maintenance of ozone residuals required for disinfection. Total contact chamber detention time would be 12 to 14 minutes at plant design flow rates. Hydraulic head loss through the chamber would be approximately 3 feet because of the need to provide a weir discharge and water drop at the contactor discharge for dissipation of dissolved oxygen and any residual ozone prior to filtration. Repumping of the ozone contactor discharge flow would therefore be required to maintain the required hydraulic gradient between the softeners and the treated water storage tank. Chlorine and ammonia would be added at the filter influent to form monochloramine.

Use of an air-feed ozonation system has been assumed for development of probable construction and annual operations and maintenance costs. A design applied ozone dosage of 5 mg/L, and an average applied dosage of 3 mg/L was assumed. Ozone transfer efficiency of 90 percent or greater should be achieved for the proposed contactor design.

Use of dual media (anthracite over sand) pressure filters is assumed for development of probable construction costs. Filtration would be required to remove the precipitates formed during ozone oxidation of iron/manganese and color. Design hydraulic loading rate would be 4 gpm/sq ft, and the filters would be equipped with hydraulic surface wash capability. The filters would be backwashed using treated water from the storage reservoir, and backwash flows would be discharged to the existing onsite softener brine disposal pond.

As compliance with impending DBP regulations could not be achieved using free chlorine for residual maintenance within the distribution system, provisions for adding ammonia at each of the three treatment facilities to form chloramines would be required.

C. Removal of DBP Precursor Compounds

A third approach to controlling DBP formation is to remove the organic precursor compounds which form DBPs prior to addition of chlorine. Treatment techniques for precursor removal include adsorption using granular activated carbon, membrane separation using reverse osmosis or nanofiltration, and ion exchange using anionic exchange resins. These precursor removal techniques are discussed in detail below.

1. Carbon Adsorption

Feasibility of using granular activated carbon (GAC) to remove organic DBP precursor compounds has been evaluated through both pilot-scale and full-scale testing at numerous locations throughout the United States since the late 1970s, when the existing MCL for TTHMs was proposed. While GAC has demonstrated the ability to remove DBP precursor compounds, effectiveness is somewhat site-specific, and cost-effectiveness is dependent upon the level of precursor removal required and the "adsorbability" of the precursor compounds. Data on control of non-TTHM DBPs through GAC adsorption of precursors is limited; however, the available information shows indications of removal rates proportional to that for TTHMs.

a. Process Performance. GAC contactors typically exhibit three specific breakthrough characteristics when used to remove DBP precursor compounds. The first is an immediate breakthrough of the "non-adsorbable" fraction of the influent precursor concentration. This "non-adsorbable" fraction is typically equivalent to 5 to 20 percent of the influent precursor concentration for most U.S. waters. The second phase is characterized by a gradual breakthrough to a "steady-state" effluent precursor concentration. The third phase consists of long-term "steady-state" precursor removal. This third phase is characterized by long-term removal of (typically) 20 to 40 percent of the influent precursor, with no apparent total breakthrough of precursors to the contactor effluent. The two phases of primary importance when evaluating use of GAC for precursor removal are the first and second phases. If the non-adsorbable precursor fraction is relatively high, treatment of waters with high DBP formation potentials may not be feasible because of excessive passage of precursors through the carbon contactors during initial operation. Likewise, if the increase in effluent precursor levels occurs very rapidly during the second phase of contactor operation, run times between carbon removal/replacement may be very short, thereby increasing GAC purchase and replacement labor costs. Contactor run times to breakthrough are greatly accelerated for waters exhibiting high DBP formation potentials.

Pilot- and full-scale operating experience with DBP precursor removal has shown that GAC contactor breakthrough to unacceptable levels (as measured through determination of TTHM formation potential of the contactor effluent) typically occurs within several weeks of initial contactor operation. Contactor run times can be extended somewhat through use of multiple contactors operating in parallel and in a "staggered exhaustion" mode. Operation in this manner results in more efficient carbon utilization, as individual contactors can be operated past the point that breakthrough to the desired treated water DBP formation level occurs; blending of the discharge from all contactors results in a treated water that meets the desired treated water DBP formation potential. However, for waters with high DBP formation potential (i.e., THMFP greater than about 200 ug/L), the need for frequent replacement of GAC may make this alternative cost-prohibitive.

Applicability of the GAC adsorption process, and implementation requirements for the RO and Skyco water treatment facilities are discussed below.

b. RO Water Treatment Plant. Effectiveness of GAC for reducing treated water DBP formation potential would be limited, due to the presence of bromide in the blended RO permeate/raw water stream. While GAC would reduce the organic content of the treated water (as measured by total organic carbon content) it would not effectively reduce treated water bromide levels. The resulting increase in the ratio of bromide to TOC concentrations would likely result in little or no decrease in treated water TTHM concentrations, as formation of brominated THM species would be enhanced at the higher bromide/TOC ratios. Further evaluation of GAC adsorption of DBP precursors at the RO plant was therefore not conducted.

c. Skyco Water Treatment Plant. GAC could be used to reduce treated water DBP formation potential at the Skyco plant. An additional benefit would be reductions in treated water total organic carbon concentrations to levels less than the potential future maximum allowable level of 2 mg/L. However, the high TTHM formation potential of the raw water (300 ug/L) would result in short contactor run times prior to DBP precursor breakthrough. Assumptions used in the development of probable construction and annual operating costs are discussed below.

GAC contactors would be pressure downflow units. Softened water from the ion exchange softeners would be pumped to the contactors, and contactor effluent would flow by gravity to the treated water storage reservoir (pumping would be required to maintain the required hydraulic gradient between the softeners and the reservoir). A multiple contactor configuration would be used in order to maximize carbon utilization prior to replacement. An empty bed contact time of 15 minutes was assumed, based on results of pilot- and full-scale evaluation of DBP precursor adsorption. In order to reduce onsite fresh and spent GAC storage requirements, and to simplify GAC transfer equipment requirements, use of contactors sized to hold a standard 20,000 pound bulk shipment of GAC was also assumed. Under this operating scenario, a single spare contactor would be required. (Virgin carbon would be transferred from the delivery vehicle to the spare contactor, and exhausted carbon from another contactor would then be transferred to the delivery vehicle and transported to the disposal site.) Use of a commercial replacement/disposal service is assumed for periodic removal/replacement of exhausted GAC. Advantages associated with use of a contract carbon service include the following:

- Capital expenditure is minimized through reduction of onsite carbon storage and associated transfer piping and equipment. All carbon transfer operations are carried out utilizing transfer piping directly connected to the GAC contactors and an onsite truck loading facility.
- Ultimate disposal of the spent carbon becomes the responsibility of the contractor, thereby limiting the exposure of the utility to potential future liability.
- Labor requirements for plant maintenance are reduced.

Contactors designed to hold a 20,000 pound bulk carbon shipment are typically 10 feet in diameter, with a GAC depth of approximately 10 feet. A total of 10 GAC contactors (9 online, one spare) would be required to provide an empty bed carbon contact time of 15 minutes at the plant design flow capacity of 5 mgd.

A primary factor in the overall operating cost of a carbon adsorption facility is the relative efficiency of carbon utilization, or carbon usage rate. Carbon usage rate is dependent upon feedwater organics concentrations, treatment objectives, and contactor design and configuration. Carbon usage rates can be predicted through (1) use of conventional pilot-scale testing techniques and/or accelerated "microcolumn" performance testing, or (2) evaluation of pilot-scale or full-scale GAC performance data for waters similar to the water supply under consideration. While pilot-scale testing is typically recommended to generate site-specific performance data required for full-scale facilities design, interpretation of data developed for other utilities can be used to develop preliminary opinions of probable construction and annual operations and maintenance costs. Estimates of GAC usage rates developed during research conducted for the American Water Works Association Research Foundation indicate that for water with a TTHM formation potential of 300 ug/L, a carbon usage rate of about 2.2 pounds per 1,000 gallons treated can be expected, based on a treated water TTHM formation potential of 50 ug/L. This usage rate is based on operation of a single carbon contactor; blending of effluent from multiple contactors would result in longer contactor run times between regenerations, and therefore lower carbon usage rates. A 35 percent reduction in GAC usage rates over that for a single contactor (i.e., 1.5 pounds per 1000 gallons treated) has been assumed in the development of probable construction and annual operation and maintenance costs presented in this report. This usage rate corresponds to an average GAC contactor run time of approximately 9 weeks at the projected average plant flow rate of 1.9 mgd and 3.4 weeks at the design plant capacity of 5 mgd.

2. Membrane Processes

Both reverse osmosis and nanofiltration ("membrane softening") have demonstrated the ability to remove DBP precursors from highly-organic groundwater supplies to levels which yield low treated water TTHM formation potentials. Rejection of TTHM precursors typically ranges from 90 to 97 percent for nanofiltration membranes, and 95 to 98 percent for conventional RO membranes. DBP control alternatives utilizing membrane treatment are discussed below.

a. Reduce/Eliminate Bypass at RO Plant. As discussed in Section VI, treated water DBP formation following blending of the RO treated water with treated water from the Skyco/Fresh Pond plants could be reduced by reducing or eliminating the amount of raw well water blended with RO permeate prior to addition of chlorine. As the RO membranes remove the majority of the bromide present in the raw water, maximum reduction in treated water bromoform levels would be realized through elimination of the raw water bypass flow. However, membrane permeate has both low alkalinity and hardness (5-6 mg/L alkalinity, hardness less than 5 mg/L as $CaCO_3$), and would therefore exhibit highly corrosive tendencies within the distribution system. A phosphate-based corrosion inhibitor (zinc orthophosphate) is currently added to the blended permeate/raw water flow to prevent corrosion of distribution system piping and appurtenances. However, zinc orthophosphate corrosion inhibitors typically exhibit maximum effectiveness over a fairly narrow pH range (7.4 - 7.8); effectiveness decreases rapidly at higher pH due to precipitation of zinc within treated water storage facilities prior to distribution. For waters with poor buffering capabilities (i.e., low alkalinity levels), pH fluctuations within the distribution system can be significant. These fluctuations would adversely impact the performance of the corrosion inhibitor. Reduction or elimination of permeate/raw water blending would therefore require that provisions for adding alkalinity to the treated water be added in order to maximize effectiveness of the corrosion inhibitor. Provisions for ensuring that treated water pH does not exceed the optimum range for corrosion inhibition must also be included.

Alkalinity supplementation is typically accomplished by adding alkaline compounds such as sodium hydroxide, lime, soda ash, or sodium bicarbonate. However, addition of any of these compounds to a low alkalinity water at dosages required to yield desirable alkalinity concentrations will also increase its pH to levels well above the optimum range for effective performance of phosphate-based corrosion inhibitors. Treated water pH can be maintained at desired levels through addition of carbon dioxide (CO_2) simultaneously with the alkalinity adjustment compound. CO_2 reduces the pH of the process stream, but does not consume alkalinity, as do most acidic compounds.

Based on current availability of sodium hydroxide (caustic) feed capability at the RO plant, and on the desire to minimize use of chemicals in dry form, use of sodium hydroxide and carbon dioxide is recommended for adding alkalinity to the membrane permeate prior to distribution. Installation of a liquid CO_2 storage and feed system, with provisions for adding the CO_2 near the current point of caustic addition, would be required. Projected caustic/CO_2 dosages to provide treated water alkalinities ranging from 20 to 40 mg/L as $CaCO_3$ at a treated water pH of approximately 7.5 and for various permeate/raw water blending rates are summarized in Table VII-1. Based on an average CO_2 dosage of approximately 30 mg/L (40 mg/L alkalinity addition with no bypassing of raw water), a CO_2 storage tank with minimum capacity of approximately 11 tons would be required for 30 days' storage at the design plant capacity of 3 mgd. Use of a pre-engineered storage unit, including the tank, refrigeration unit, vaporizer, insulation, safety equipment, and instrumentation was assumed for development of probable costs presented in Section VIII. A vacumm-operated, solution-type feed system would deliver CO_2 from the storage facility to the point of application.

b. RO Treatment of Skyco Water. As discussed in Section III, 144 of the Dare Regional Water Supply System's original UOP/Fluid Systems RO membranes were replaced during 1989 and are currently stored at the RO plant. Water Production Department staff have expressed interest in evaluating use of these membranes for treating the Skyco water supply in a "sidestream" mode to reduce treated water DBP levels. As membrane elements are typically the most expensive portion of a membrane treatment facility, this idea merits investigation.

Table VII-1
Chemical Requirements for Alkalinity/pH
Adjustment at RO Plant*

Treated Water Conductivity	Bypass Rate %	Chemical Requirements at Indicated Alkalinity mg/L		
		20 mg/L	30 mg/L	40 mg/L
200	0	11.7 NaOH 9.8 CO_2	19.8 NaOH 19.2 CO_2	28.0 NaOH 28.6 CO_2
300	1.6	8.1 NaOH 5.9 CO_2	16.3 NaOH 15.3 CO_2	24.4 NaOH 24.6 CO_2
500	4.8	1.0 NaOH 0 CO_2	9.1 NaOH 7.4 CO_2	17.2 NaOH 16.8 CO_2

* Treated water pH 7.5; raw water alkalinity 281 mg/L $CaCO_3$ (average).

The membrane manufacturer provided computer projections of probable membrane performance for treatment of the raw Skyco well supply. A total of 138 available elements was assumed, based on a standard 6 elements/pressure tube configuration. (Evaluation of the condition and performance capabilities of several of the 144 existing membranes by the manufacturer should be conducted to assess membrane condition and to ensure that performance characteristics have not deteriorated during storage; these procedures essentially destroy the membrane being evaluated.) The computer projections indicate that a raw-to-product conversion rate of 75 percent could be achieved, using a two-stage design configuration, with maximum system conversion rate limited by raw water silica levels. The optimum membrane element configuration would consist of 90 first-stage elements and 48 second-stage elements, (15 first-stage / 8 second-stage pressure tubes). Maximum treated water production capacity would be 500 gpm (0.72 mgd) at a membrane feed pressure of 210-220 psi. Total hardness of the membrane permeate would be approximately 4-5 mg/L as $CaCO_3$, and permeate total alkalinity would be 3-4 mg/L as $CaCO_3$.

While treatment of the Skyco supply using the existing membranes is feasible, maximum membrane permeate production capacity is inadequate to affect any significant reductions in treated water DBP formation levels (using THMFP as the basis for evaluation). For example, at an annual average plant production rate of 1.9 mgd and an average raw water THMFP of 300 ug/L, operation of the membrane facility at 500 gpm would reduce THMFP of the blended IX/RO product to only 190 ug/L (at 97 percent membrane THMFP rejection). Total plant production capacities as a function of raw water THMFP for a treated (IX/RO blended) water THMFP of 50 ug/L are tabulated in Table VII-2. The data presented in Table VII-2 assume operation of the membrane treatment facility at a constant 500 gpm production capacity and 97 percent rejection of THMFP.

Table VII-2
Combined RO/IX Plant Capacities for Treated Water THMFP = 50 μg/L

Raw Water THMFP μg/L	IX Plant mgd	RO Plant mgd	Total Plant mgd
150	0.33	0.72	1.05
200	0.21	0.72	0.93
250	0.15	0.72	0.87
300	0.12	0.72	0.84
350	0.09	0.72	0.81

Based on the information presented above, treatment of Skyco raw water using the existing RO membranes would not reduce treated water THMFP to levels which would result in compliance with impending DBP regulations under most operating conditions. Additional membrane treatment capacity would therefore be required to yield a blended IX/RO treated water THMFP of 50 ug/L. While additional RO elements could be purchased to provide the required total plant capacity, use of nanofiltration membranes would provide more economical operation. As nanofiltration membranes provide THMFP reductions essentially equivalent to that for conventional RO membranes at significantly lower feedwater pressures, cost savings would be realized through reductions in feedwater pumping costs. Nanofiltration treatment of the Skyco water supply is discussed below.

c. Nanofiltration Treatment of Skyco Water. For this alternative, a nanofiltration ("membrane softening") plant would be constructed at the Skyco plant site. As the membrane treatment process provides simultaneous removal of hardness, color, and DBP precursor compounds, the existing ion exchange softening process would be removed from service. The existing high service pumps and 2 million gallon treated water storage reservoir would remain in service with no modifications.

Water Production Department staff have operated a 3 mgd conventional reverse osmosis treatment facility since 1989, and are therefore familiar with both the operating and maintenance requirements associated with membrane treatment technology. Nanofiltration plant facilities and operating requirements are essentially identical to conventional reverse osmosis facilities; the most significant differences are in membrane construction and feedwater pressure requirements, and characteristics of the permeate produced. Nanofiltration process development and operating characteristics are discussed below.

The term "nanofiltration" (NF) was first used by the FilmTec Corporation to describe a new membrane product introduced during 1984. The term is now generally used throughout the industry to identify membranes that exhibit performance characteristics which fall between that of conventional RO membranes and ultrafiltration membranes. While the first NF membranes were developed primarily to achieve high rejection of divalent ions which cause hardness, early testing indicated that the membranes also exhibited excellent rejection of DBP precursor compounds and color. These characteristics have led to widespread use of the NF process in Florida, where treatment of the hard, organics-laden groundwater supplies using conventional treatment and disinfection processes frequently leads to unacceptable levels of TTHMs and other DBPs in the treated water.

NF membranes typically operate at feedwater pressures significantly lower than for conventional RO membranes (80-120 psi, vs. 200-300 psi for current RO membranes). These lower operating pressures allow use of non-metallic piping, in some cases, which reduces plant construction costs. While nominal flux ratings for NF membranes are higher than for RO membranes, most operating facilities utilize design flux rates similar to RO plants (15-18 gallons per day per square foot of membrane area for spiral-wound membranes). Raw-to-product conversion rates for NF systems are also generally higher than for typical RO facilities, as many compounds which will foul RO membranes at relatively low plant conversion rates are not as highly rejected by the NF membranes, and are therefore not as highly concentrated within the membrane elements. Conversion rates for NF plants typically range from 80 to 90 percent.

Based on review of operating performance of existing NF plants, pilot-scale testing data for numerous locations throughout the southeastern United States, and NF membrane manufacturer recommendations, a conservative THMFP rejection rate of 92-93 percent was used for development of a preliminary plant design to provide a total finished water production capacity of 5 mgd. (TTHM rejection rates for operating plants and for various membrane pilot studies are summarized in Appendix J.) For an average raw water THMFP of 300 ug/L, NF treatment capacity required to produce a treated water with a THMFP of 50 ug/L would be approximately 4.5 mgd. A maximum of 0.5 mgd of raw water would bypass the membrane system and be blended with NF permeate to yield a total plant production capacity of 5 mgd (i.e., 10 percent average raw/total finished water blend ratio).

The three primary manufacturers of NF membranes (Dow Chemical (FilmTec), Hydranautics, UOP/Fluid Systems) provided computer-based projections of system configuration and performance characteristics for a 4.5 mgd NF system, based on Skyco raw water quality. Projected system conversion rates ranged from 70 to 85 percent, and feedwater pressure requirements ranged from 100 to 130 psig. All manufacturers indicated that raw water silica concentrations would limit achievable raw-to-product conversion rates. Membrane selection impacted achievable conversion rates significantly (two manufacturers proposed use of membranes with higher rejection rates than the third manufacturer; the higher rejection rates resulted in lower achievable recovery rates due to increased silica removal, with corresponding increases in silica levels in the membrane concentrate stream). Projected permeate hardness (prior to blending with the bypass stream) ranged from 31 to 70 mg/L as $CaCO_3$, and projected treated water total hardness after blending ranged from 45 to 80 mg/L as $CaCO_3$.

Based on evaluation of the membrane manufacturers' projections, a preliminary process design for a new NF treatment facility was developed. Assumptions used in the development of opinions of probable construction and annual operations and maintenance costs for the NF plant are summarized in Table VII-3.

Manufacturers' performance projections indicate that acidification of membrane feedwater may not be required to inhibit scale formation within the membranes (use of a proprietary antiscalent compound would, however, be recommended). Elimination of acid addition would also eliminate the need for degassification equipment to remove carbon dioxide from the membrane permeate. The manufacturers recommend that a pilot study be conducted during preliminary plant

Table VII-3
Design and O&M Parameters for
Skyco Nanofiltration Plant

Membrane Capacity, mgd	4.5
Blend Rate, % of total finished	10
Blend Rate (Max), mgd	0.5
Membrane Conversion Rate, %	85
Number of Membrane Trains	3
Raw Water Required (Max), mgd	5.8
Membrane Feedwater Pressure, psi	105
Membrane Elements Per Train	312
Pressure Tubes Per Train	
1st Stage	30
2nd Stage	14
3rd Stage	8
Membrane Elements Per Pressure Tube	6
Average Permeate Flux, gal/ft·day	15.3
Average Chemical Dosages	
Antiscalent	4
Sodium Hydroxide	5
Membrane Replacement, % per year	12
Treated Hardness, mg/L as $CaCO_3$	
Permeate	70
Finished (10% bypass)	80

project design phases to assess both the need for acidification of membrane feedwater and the potential for problems due to silica scaling of membranes.

Provisions for adjusting treated water pH to approximately 7.5 using sodium hydroxide are assumed. Membrane process concentrate flows would be discharged to the existing ion exchange regeneration waste disposal lagoon. Provisions for emergency power generation, and for computer-based monitoring and control of all critical plant operating functions are also included in the opinion of probable plant construction cost. The plant would produce a finished water with a projected average hardness of 80 mg/L as $CaCO_3$ and an average THMFP of 50 ug/L or less.

As all of the water directed to the nanofiltration treatment process is not recovered as treated water, raw water supply required to provide a total finished water production capacity of 5 mgd would be approximately 5.8 mgd (4,030 gpm) at a nanofiltration process conversion rate of 85 percent. Total capacity of the existing wells is 5,200 gpm; construction of additional wells would therefore not be required to meet annual max-day treated water demands.

d. Increased RO Plant Production. As discussed in Section III, RO plant production will be reduced over the next several years due to production cost considerations and power usage restrictions. Current projections indicate that the RO plant will supply approximately 30 percent of the total system demand in the near future. However, this reduction may have significant negative impact on system-wide DBP concentrations, as less of the higher-quality RO product water will be present in the distribution system. Table VII-4 presents a summary of TTHM concentrations for the regional water distribution system as a function of RO plant production. The RO production data presented in Table VII-4 represent the relative proportion of RO plant production to total production for all three treatment plants for the 7-day period preceding collection of the TTHM samples. The data presented in Table VII-4 show a clear trend toward higher TTHM concentrations as the amount of RO-treated water delivered to the distribution system decreases. This information suggests that compliance with current and impending MCLs for TTHMs could potentially be achieved by increasing RO plant production rates to approximately 70 percent of the total system production. The primary advantage associated with this DBP reduction alternative is that the need for construction of new treatment facilities is eliminated. Another advantage is the ability to continue to use free chlorine for disinfection and distribution system residual maintenance. Disadvantages include increased water production costs and the potential for continued high TTHM concentrations for Manteo and for Nags Head when the Fresh Pond plant supplies the majority of the treated water demand. In addition, it is unlikely that expanded RO plant production would result in compliance with an impending future TTHM MCL of 40 ug/L. However, increased RO production is considered a viable "short-

Table VII-4
Trihalomethane Levels for Regional Distribution System vs. RO Plant Production

Month/Year	% RO*	Total Trihalomethanes, ug/L		
		RO System	Skyco System	Total System
07/92	18.0	121.2	67.7	94.5
01/93	29.0	116.1	65.8	91.0
04/93	36.4	94.9	91.7	93.3
11/92	40.2	101.3	79.8	90.6
09/91	50.9	96.1	83.8	90.0
05/91	51.7	83.0	104.0	93.5
04/92	70.7	44.6	55.5	50.1
11/91	77.2	54.3	69.9	62.1
02/91	79.7	50.8	108.2	79.5
02/92	83.7	33.6	66.7	50.2

*Percent of total system production for 7 days preceding TTHM sampling.

term" alternative for achieving compliance with the current TTHM MCL of 0.10 mg/L, and potentially with the impending TTHM MCL of 80 ug/L.

3. Anion Exchange Resin

Development of anion exchange resins with macroporous structures has generated interest in the use of these resins to remove organic DBP precursor compounds (primarily humic acids). While pilot-scale studies have demonstrated that these resins can effectively remove organic compounds, including THM precursors, full-scale plant experience in this country is extremely limited (only one operating U.S. plant was identified during this study). The potential for using the anion exchange process for DBP control at Dare County is discussed below.

a. Operation. Conventional ion exchange involves removal of charged particles from solution through replacement of ions on the surface of a solid resin medium. The solution passes through the resin bed in a manner similar to that for a conventional granular media filter. The resin bed is typically operated in a downflow mode. In the exchange process, the ions retained by the charged functional groups on the surface of the resin are released into solution, and the charged particles are retained on the resin. When the exchange sites on the resin surface have been expended, the resin is regenerated in place using a solution of high ionic strength. Most applications of ion exchange in the municipal water treatment field have involved removal of hardness ions (as for the Skyco plant) or demineralization using a combination of resins designed to remove both cationic and anionic compounds.

The use of ion exchange to remove organic compounds has been made possible through the development of resins with macroporous structures. The macroporous resin structure exposes the functional groups on the interior of the resin, thereby making them more accessible to larger molecules, such as organics. Most of the investigations conducted to date have focused on the use of strong-base anion exchange resins in the chloride form (the resin is regenerated using a concentrated sodium chloride (salt) solution). A number of "decolorizing" resins are available which have demonstrated the ability to remove color and dissolved organic carbon; data on removal of specific DBP precursor compounds, however, is extremely limited.

b. Pilot-Scale Operating Experience. Literature on the use of strong-base macroporous anion exchange resins to remove DBP precursor compounds is limited: available literature was reviewed and is summarized below.

Pilot-scale studies were conducted during 1990 at the University of Houston using an acrylic resin (IRA 958, manufactured by Rohm and Haas) to treat filtered water (prior to disinfection) from the City of Houston's water treatment plant. (Raw water source is Lake Houston.) Empty-bed resin contact time was approximately 10 minutes. TTHM formation potential (6-day) at the resin column inlet averaged 250 to 280 ug/L during the testing period. An immediate breakthrough to approximately 50-60 ug/L treated water THMFP was observed, and THMFP increased steadily to the influent concentration of 250 ug/L at a treated flow volume equivalent to approximately 500 bed volumes treated (83 hours column operation). The rapid THMFP breakthrough exhibited during the testing would preclude application of this treatment technique at Dare County, as the treated water goal of 50 ug/L could not be achieved on a continuous basis. It should be noted that the resin used during this testing was an acrylic-based material; several resin manufacturers/suppliers indicated that styrene-based resins are more selective for organic materials than acrylic resins, and do not typically exhibit rapid organics breakthrough.

Pilot studies are currently being conducted at Cape Hatteras, North Carolina to evaluate use of anion exchange resins for TTHM control. While information on removal of THMFP across the resin bed is not currently available, the resin reduces the influent TOC of 10.5-13.5 mg/L to approximately 2 mg/L during initial exchange vessel operation (i.e., less than 250 bed volumes throughput). TOC removal efficiency decreases at higher throughput rates. Sufficient testing has not been completed at this time to predict overall applicability of the process to TTHM control at Cape Hatteras.

c. Full-Scale Operating Experience. A 15.3 mgd capacity plant located in Hannover, West Germany uses a polystyrene-based macroporous anion resin to treat a highly-colored groundwater supply. While the resin effectively removes dissolved organic carbon (approximately 50 percent reduction at flow throughputs of up to 5,000 bed volumes), data on THMFP reduction are not readily available for this facility.

The West Carteret Water Corporation in Western Carteret County, North Carolina, owns and operates a groundwater treatment plant which includes a 1.56 mgd ion exchange system utilizing a macroporous anion resin for removal of color. The plant was placed in service during September 1991. Three 10-foot diameter exchange vessels (two currently equipped with resin, one unequipped), each with a capacity of 360 gpm, are used to treat approximately 50 percent of the total plant flow. (Raw well water is aerated, and a portion of the aerated water is softened using the sodium-cycle ion exchange process. The anion exchange process treats a portion of the softened water.) Empty-bed resin contact time is approximately 4.9 minutes at design flow rates. The anion resin ("Tulsion A-72MP", manufactured by Thermax Ltd.) was originally developed for decolorization of sugar processing wastestreams. The resin supplier stated that this is the only municipal water treatment plant in the United States which uses macroporous anion exchange resin to remove color and organics. The resin is currently regenerated "every six months" using a conventional sodium chlorine brine solution. The regeneration waste is said to resemble "used crankcase oil" during initial stages of the regeneration process. Regeneration waste discharges to a "sand pit" equipped with an underdrain system; flow from the underdrain discharges directly to a stream. The resin effectively removes color from the raw water supply (average raw color is 20-25 units). Long-term data on THMFP reduction capabilities are not available.

However, a single set of samples taken during November 1991 (approximately two months after plant startup) showed that the anion exchange vessel influent THMFP of 258 ug/L was reduced to 45 ug/L following the exchange process.

d. Conclusions. Although macroporous anion exchange resins have been available for several decades, use of these resins by municipal systems to treat colored water supplies and/or to remove organics/DBP precursors has not been investigated to any significant extent. While initial experience with these resins appears promising, full-scale operating experience is extremely limited, as is information on specific resin performance capabilities (particularly for the polystyrene-based resins). EPA has not expressed any intention to include the anion exchange process on its list of "best-available" technologies to comply with the impending D/DBP rule. This treatment process is therefore regarded as experimental at this time. Concerns related to use of this technology which will need to be addressed prior to widespread implementation include: (1) long-term resin reliability and structural stability, (2) efficiency of regeneration under long-term usage (are organic materials retained on the resin, thereby eventually reducing its effectiveness?), and (3) ability to reliably remove TTHM and other DBP precursor compounds to levels which will permit continued use of free chlorine as the disinfectant.

Based on the above considerations, a recommendation to proceed with use of the anion exchange process to reduce treated water DBP levels in the Dare County system cannot be made at this time. However, a preliminary opinion of probable costs was prepared for a 5 mgd anion exchange treatment system at the Skyco plant in order to evaluate potential costs relative to other DBP control alternatives under consideration. Should this treatment technique compare favorably with other, well-established DBP reduction methods, pilot-scale studies could be conducted to evaluate site-specific performance characteristics.

VIII. Evaluation of DBP Control Alternatives

Probable costs for the DBP control alternatives discussed in Section VII are presented below. A matrix evaluation which considers other factors (ease of implementation, compatibility with future requirements, water quality, risk/reliability, flexibility), and recommendations for achieving compliance with both current and future regulations are also presented.

A. Construction Costs

Opinions of probable cost for the DBP reduction alternatives discussed in Section VII are summarized below. All costs reflect May 1993 price levels. Probable construction costs are presented for each unit process and for major structures and equipment. The cost for each component includes component-specific excavation and sitework, piping, equipment and instrumentation, and construction labor. Also included in each component is an allowance for general contractor overhead and profit. Construction costs were developed based on past construction costs for similar projects, from information provided by equipment suppliers, and from U.S. EPA cost curves for water treatment facilities. To account for items not included in the major cost component tabulations, and for engineering and administrative/legal fees a 30 percent service factor has been added to the individual component tabulations to arrive at the total probable project cost. Probable project costs are summarized in Tables VIII-1 through VIII-6.

Table VIII-1
Probable Project Cost for
Reduced RO Plant Bypass

Component	Probable Cost $
Liquid CO_2 Equipment	150,000
Electrical/Instrumentation	25,000
Sitework/Piping	15,000
Subtotal	190,000
Contingencies/Engineering/Administrative	55,000
Total Project Cost	245,000

Table VIII-2
Probable Project Cost for Chloramination

Component	Probable Cost	
	Aqua Ammonia $	Anhydrous Ammonia $
Feed Equipment, Building		
RO WTP	45,000	42,000
Skyco WTP	55,000	45,000
Fresh Pond WTP	40,000	37,000
Skyco Chlorine Contact Basin	70,000	70,000
Fresh Pond Clearwell Baffles	3,000	3,000
Electrical/Instrumentation	20,000	20,000
Sitework	10,000	10,000
Subtotal	243,000	227,000
Contingencies/Engineering/ Administrative	72,000	68,000
Public Notification Program	75,000	75,000
Total Project Cost	390,000	370,000

Probable costs for chloramination presented in Table VIII-2 include an allowance for development and implementation of a public notification program.

B. Operation and Maintenance Costs

Annual operation and maintenance (O&M) costs were developed for the DBP control alternatives based on the following parameters:

- Annual treated water production:
  - RO WTP = 361.77 MG/year
  - Skyco WTP = 677.71 MG/year
  - Fresh Pond WTP = 133.68 MG/year
- Electrical power cost = $0.06/kWh
- Labor cost (average including benefits) = $15/hour

Table VIII-3
Probable Project Cost for 5 mgd
Anion Exchange Plant

Component	Probable Cost $
Exchange Vessels, Regeneration Equipment	1,250,000
Anion Resin	460,000
Building	270,000
Booster Pumping	100,000
Electrical/Instrumentation	310,000
Sitework	120,000
Subtotal	2,510,000
Contingencies/Engineering/Administrative	750,000
Total Project Cost	3,260,000

Table VIII-4
Probable Project Cost for 5 mgd
Carbon Adsorption Plant

Component	Probable Cost $
Contactors, Piping	1,780,000
Initial GAC Charge	200,000
Backwash System	80,000
Building	570,000
Booster Pumping	100,000
Electrical/Instrumentation	410,000
Sitework	160,000
Subtotal	3,300,000
Contingencies/Engineering/Administrative	990,000
Total Project Cost	4,290,000

Table VIII-5
Probable Project Cost for 5 mgd
Ozonation/Filtration Plant

Component	Probable Cost $
Ozone Generation/Contactor	1,280,000
Ozone Building	125,000
Pressure Filters	1,070,000
Booster Pumping	100,000
Electrical/Instrumentation	350,000
Sitework	150,000
Subtotal	3,075,000
Contingencies/Engineering/Administrative	920,000
Subtotal	3,995,000
Aqua Ammonia Feed Systems	315,000
Total Project Cost	4,310,000

- Chemical unit costs:
  - Aqua Ammonia = $1,020/ton of NH_3
  - Anhydrous Ammonia = $1,040/ton of NH_3
  - Carbon Dioxide (liquid form) = $98/ton
  - Sodium Hydroxide = $338/ton
  - Sodium Chloride (salt) = $49/ton
  - Antiscalent (membrane treatment) = $1,800/ton

Other cost parameters which are specific to individual alternatives are discussed below.

1. Reduced Bypass at RO Plant

Annual O&M costs presented in Table VIII-7 were developed using average CO_2/caustic dosages of 30 mg/l each, which should yield a treated water alkalinity of

Table VIII-6
Probable Project Cost for 4.5 mgd Nanofiltration Plant

Component	Probable Cost $
Membranes, Racks	1,980,000
Cartridge Filters	80,000
High Pressure Pumps	280,000
Cleaning System	70,000
Chemical Feed Systems	110,000
Building	910,000
Emergency Power Generation	570,000
Electrical/Instrumentation/Controls	590,000
Sitework	390,000
Subtotal	4,980,000
Contingencies/Engineering/Administrative	1,490,000
Total Project Cost	6,470,000

Table VIII-7
Probable Annual Operations and Maintenance Costs for Reduced RO Plant Bypass

Component	Annual Cost $/Year
Materials/Supplies	2,500
Power	4,900
Labor	1,400
Chemicals	
Carbon Dioxide	4,500
Sodium Hydroxide	15,700
Total O&M	28,700

approximately 40 mg/L at a pH of approximately 7.5. Projected chemical dosages assume no blending of raw water with RO membrane permeate; treated water alkalinity prior to caustic/CO_2 addition would therefore be less than 10 mg/L, and average membrane permeate pH is assumed to be approximately 6.5.

2. Chloramination

Annual O&M costs presented in Table VIII-8 are based on feeding ammonia at an average dosage of 1 mg/L at each of the Regional Water Supply System's three treatment plants. Costs are presented for both aqua and anhydrous ammonia systems. Included in the annual costs is an allowance for increased laboratory testing (i.e., standard plate count test for each routine coliform monitoring sample) required by North Carolina DEH when using chloramines as the secondary disinfectant.

Table VIII-8
Probable Annual Operation and Maintenance Costs
for Chloramination

Component	Annual Cost	
	Aqua Ammonia $/Year	Anhydrous Ammonia $/Year
Materials/Supplies	3,000	3,000
Power	1,400	700
Labor	8,200	8,200
Ammonia	5,000	5,100
Laboratory Testing	10,000	10,000
Total O&M	27,600	27,000

3. Anion Exchange Plant

Annual O&M costs presented in Table VIII-9 assume regeneration of the anion exchange resin every 3 months, and complete replacement of the resin every 8 years at a unit cost of $200 per cubic foot (per manufacturer's price quotations). Power

Table VIII-9
Probable Annual Operation and Maintenance Costs for 5 mgd Anion Exchange Plant

Component	Annual Cost $/Year
Materials/Supplies	10,000
Power	9,700
Labor	11,000
Salt	2,600
Resin Replacement	57,500
Total O&M	90,800

costs include energy required for booster pumping at an average pressure of approximately 13 psi (i.e., 30 ft total hydraulic head increase).

4. Carbon Adsorption Plant

Annual O&M costs presented in Table VIII-10 are based on an average GAC consumption rate of 1.5 pounds per 1,000 gallons treated, and a GAC replacement cost of $1.10 per pound. Power costs include energy required for booster pumping at an average pressure of approximately 13 psi (i.e., 30 ft total hydraulic head increase).

5. Skyco Ozonation/Filtration Plant

Annual O&M costs presented in Table VIII-11 assume ozone addition at an average applied dosage of 3 mg/L, and a unit energy requirement for ozone generation of 11 kWh per pound of ozone. Power costs also include energy required for booster pumping at an average pressure of approximately 13 psi (i.e., 30 ft total hydraulic head increase).

6. Skyco Nanofiltration Plant

Parameters used in developing the annual O&M costs presented in Table VIII-12 were summarized in Section VII. Membrane replacement is assumed at 12 percent per year at a unit cost of $1,200 per membrane element. Addition of sodium

Table VIII-10
Probable Annual Operation and Maintenance Costs for 5 mgd Carbon Adsorption Plant

Component	Annual Cost $/Year
Materials/Supplies	10,000
Power	12,200
Labor	15,600
Carbon Replacement	1,144,300
Total O&M	1,182,100

Table VIII-11
Probable Annual Operation and Maintenance Costs for 5 mgd Ozonation/Filtration Plant

Component	Annual Cost $/Year
Materials/Supplies	
Ozone	3,600
Filtration	2,800
Power	
Ozone	13,000
Filtration/Pumping	7,900
Labor	
Ozone	8,300
Filtration	18,500
Subtotal Ozone/Filtration	54,100
Aqua Ammonia Feed Systems	27,600
Total O&M	81,700

Table VIII-12
Probable Annual Operation and Maintenance
Costs for 4.5 mgd Nanofiltration Plant

Component	Annual Cost $/Year
Materials/Supplies	31,000
Power	74,000
Labor	60,000
Chemicals	27,000
Membrane Replacement	135,000
Total O&M	327,000

hydroxide at the membrane plant discharge at an average dosage of 5 mg/L is assumed for adjustment of treated water pH to approximately 7.5. The projected labor cost assumes plant staffing requirements as follows:

- 1 plant superintendent
- 5 plant operators
- 1 mechanic (25%)
- 1 electrician (25%)

As the nanofiltration plant would replace the ion exchange softening portion of the existing Skyco plant, it is assumed that the current plant staff would operate the new plant. Labor costs presented in Table VIII-12 therefore reflect only those costs in excess of the current Skyco plant total annual labor cost of approximately $143,000.

7. *Increased RO Plant Production*

Annual O&M costs associated with this alternative assume increased RO plant production to 70 percent (821.25 MG/year) of the projected annual treated water demand, with the Skyco and Fresh Pond plants providing the remaining 25 percent (293.84 MG/year) and 5 percent (58.07 MG/year), respectively. Unit treated water production costs assumed for each plant, as discussed in the Dare Regional Water Supply System "3rd Annual Report", are as follows:

- RO Plant = $1.335/1000 gallons
- Skyco Plant = $0.842/1000 gallons
- Fresh Pond Plant = $0.920/1000 gallons

Based on the information presented above, total annual O&M for this alterative is approximately $1,397,200/year.

C. Present Worth Costs

The total costs associated with building and operating each of the alternative DBP control alternatives discussed above can be compared by adding the probable project costs for the treatment facilities to the present worth of the annual operation and maintenance costs incurred over an extended period of time for each alternative. For the comparison presented below, a planning period of 20 years and an interest rate of 7.5 percent was assumed.

As discussed in Section V, DBP control practices must consider treated water quality for both the RO and Skyco plants (development of DBP control alternatives for the Fresh Pond plant was not included in the Scope of Work for this study; costs for DBP control at the Fresh Pond plant were therefore not developed). DBP control alternatives incorporating both the RO and Skyco plants were therefore used in developing the present worth costs presented below. All alternatives (with the exception of the chloramination alternative, which encompasses all of the Regional Water Supply System's three treatment plants, and the expanded RO production alternative) assume that provisions for reduced blending of membrane permeate and raw water at the RO plant will be added. Present worth costs are summarized in Table VIII-13.

D. Unit Water Costs

Unit water production costs ($ per 1000 gallons treated) for the DBP control alternatives discussed above are summarized in Table VIII-14. The current unit water production cost ($1.00/1000 gallons) is also shown in Table VIII-14; this value is based on current treated water production rates for each of the three treatment facilities at the unit production costs discussed above.

Table VIII-13
Present Worth Costs for
DBP Control Alternatives

Alternative	Total Project Cost $	Present Worth of Annual O&M $	Total Present Worth $
Chloramination	390,000	281,000	671,000
Increased RO Plant Production	0	2,249,200	2,249,200
Skyco Anion Exchange Plant; Reduced RO Bypass	3,505,000	1,218,000	4,723,000
Skyco Ozonation/ Filtration; Reduced RO Bypass	4,555,000	1,125,000	5,680,000
Skyco Nanofiltration Plant; Reduced RO Bypass	6,715,000	3,626,000	10,341,000
Skyco GAC Plant; Reduced RO Bypass	4,535,000	12,343,000	16,878,000

E. Matrix Evaluation

A weighted matrix evaluation was conducted in order to evaluate the DBP reduction alternatives based on both total cost and "non-cost" related criteria. The alternatives were compared and rated on a scale of 1 (worst) to 6 (best) based on eight factors. The factors were weighted from 3 (most important) to 1 (least important). The eight weighted factors were as follows:

- Construction Cost
- Annual Operation and Maintenance Cost
- Risk/Reliability
- Quality of Water Produced
- Control/Flexibility
- Ability to Meet Current/Future Regulatory Requirements

Table VIII-14
Unit Water Costs for
DBP Control Alternatives

Alternative	Total Project Cost $	Annual O&M $/year	Unit Water Cost* $/1000 gals
Current WTP Operation	0	1,176,600	1.00
Chloramination	390,000	1,204,200	1.06
Increased RO Plant Production	0	1,397,200	1.19
Skyco Anion Exchange Plant; Reduced RO Bypass	3,505,000	1,296,100	1.39
Skyco Ozonation/ Filtration; Reduced RO Bypass	4,555,000	1,287,000	1.48
Skyco Nanofiltration Plant; Reduced RO Bypass	6,715,000	1,532,300	1.87
Skyco GAC Plant; Reduced RO Bypass	4,535,000	2,387,400	2.42

*Includes total project cost amortized over 20 years at 7.5% interest rate.

- Waste Disposal Requirements
- Ease of Implementation / Compatibility with Existing Facilities

Construction/annual O&M cost ratings are based on the information summarized in Table VIII-13. "Risk/Reliability" considers: (1) use of proven treatment technology, (2) potential for undesirable changes in water quality within the distribution system, (3) potential for consumer complaints, and (4) potential for regulatory agency acceptance. For example, chloramination received a low rating for this parameter due to the potential for nitrification within the distribution system and/or problems with fish kills and dialysis system users. Nanofiltration and carbon treatment at the Skyco plant received relatively high ratings due to the ability to continue to use free chlorine as the secondary disinfectant within the distribution system, and their demonstrated ability to remove DBP precursor compounds.

"Quality of Water Produced" considers the ability to reduce formation of DBPs and other treatment-related benefits (removal of total organic carbon, hardness, and chlorine demand). While both nanofiltration and carbon treatment were rated highly for this parameter, chloramination would not provide any appreciable change in water quality other than reductions in system DBP levels. "Control/Flexibility" considers: (1) ease of treatment process operation, (2) demands on operator time, and (3) the degree of control that can be exerted over the quality of the water produced. "Ability to Meet Current/Future Regulatory Requirements" considers both DBP reduction capabilities with respect to current and impending regulations, and the ability to meet other quality-related requirements, such as reduction of total organic carbon levels under the impending Disinfectant/Disinfection Byproducts rule.

"Waste Disposal" considers the quantities and characteristics of the wastestreams produced by the various treatment alternatives, and associated disposal requirements. "Ease of Implementation/Compatibility with Existing Facilities" considers the requirements associated with interfacing of the various treatment alternatives with the existing facilities (i.e., potential for disruption of service during construction/tie-in of the new facilities; required modifications to current treatment practices). Chloramination was rated highly for this parameter, as construction of new facilities is minimized, while ozonation/filtration at the Skyco plant received a low rating due to extensive construction of new facilities and the need for intermediate pumping of the process stream.

Results of the matrix evaluation are presented in Table VIII-15. As shown in Table VIII-15, increased RO plant production would be the most desirable alternative, when all factors are considered. Systemwide implementation of chloramination, and construction of a nanofiltration plant at the existing Skyco plant site in conjunction with reductions in the amount of raw water bypassing the existing RO plant ranked slightly lower than increased RO plant production; given the somewhat subjective nature of the matrix-type evaluation, these three alternatives are considered approximately equivalent.

Table VIII-15
Matrix Evaluation

Alternative Rating (1 to 6)						Criteria (Weighting Factor)
Increase RO Production	Chloramines	Skyco Anion Exchange	Skyco GAC	Skyco Ozone/ Filtration	Skyco Nanofiltration	
6	5	3	2	2	1	Construction Cost (3)
3	6	4	1	5	2	O&M Cost (3)
4	2	1	5	3	6	Risk/Reliability (3)
4	1	3	5	2	6	Water Quality (2)
6	5	3	3	2	3	Control/Flexibility (1)
4	5	3	6	3	6	Regulatory Compliance (3)
4	6	3	5	1	4	Waste Disposal (1)
6	5	2	3	1	4	Implementation/Compatib. (2)
81	77	49	66	48	72	TOTAL RATING

IX. Conclusions

Over the last several years, Water Production Department staff have implemented procedures to reduce the levels of DBPs within the distribution systems served by the Dare Regional Water Supply System. Continuing problems in meeting the current MCL for trihalomethanes have reinforced the need for additional corrective measures to ensure compliance with both the existing regulation and the more stringent requirements under the impending Disinfectant/Disinfection Byproducts Rule. Proposed increases in the amounts of Fresh Pond and Skyco treated water to be delivered to the regional distribution system are also likely to increase the severity of current TTHM compliance problems, as water from these plants has significantly higher TTHM formation potential than the treated water produced at the RO plant.

Treatment alternatives which would provide reductions in the levels of treated water DBPs were identified and evaluated. A weighted matrix evaluation which considers both total costs and "non-cost" related criteria was also conducted. Based on these evaluations, systemwide implementation of chloramination is considered the most cost-effective treatment alternative. Chloramination minimizes the need for construction of new facilities. All other alternatives considered have higher construction and/or annual operations and maintenance costs. Implementation of chloramination would also eliminate the need to modify current treatment practices at the RO plant (reductions in the amount of raw water bypassing the membrane treatment process would not be required).

As discussed in Section VII, increasing current RO plant production levels is considered a viable "short-term" alternative for achieving compliance with the current TTHM MCL of 0.10 mg/L, and potentially with the impending TTHM MCL of 80 ug/L. However, this alternative provides no real "guarantee" of regulatory compliance, and problems could potentially be experienced with high TTHM concentrations at Manteo and within the Nags Head system when the Fresh Pond plant supplies the majority of the Nags Head treated water demand. Feasibility of this alternative could be readily evaluated through adjustment of plant production rates (i.e., increase RO production to supply approximately 70 percent of the total system demand) approximately one to two weeks prior to collection of the next group of TTHM monitoring samples (currently scheduled for September 1993). Operation in this manner would provide valuable information on the impact of increased RO plant production on overall system TTHM levels, and should therefore be considered.

Water Production Department staff have expressed reservations regarding use of chloramines. While some risk is associated with the chloramination process (i.e., potential for nitrification within the distribution system and adverse impacts on kidney dialysis patients and fish-rearing operations), these risks are not considered excessive, and can be minimized/eliminated by maintaining proper chlorine/ammonia ratios at the treatment plants and by conducting a comprehensive public notification program prior to implementing chloramination. Additional measures required by the North Carolina Department of Environment, Health, and Natural Resources when using chloramines (i.e., monitoring of heterotrophic plate count for each routine system coliform sample, annual reversion to free chlorine for a short period) will also help to ensure the continued delivery of a high-quality treated water to the Regional Water Supply System's consumers.

Water Production Department staff are encouraged to contact other North Carolina utilities which are currently using chloramines (these utilities, and the individual to contact, are summarized in Appendix B). In all cases except one, experience with chloramines has been very positive (in the one case, no specific problems have been experienced, but the plant superintendent does not like using chloramines and considers them a "temporary" solution to the utility's TTHM problems; the utility is currently investigating other treatment alternatives).

The importance of conducting a comprehensive public notification program prior to implementing the chloramination process cannot be overstated. Based on the seasonal shifts in Dare County's population, this program should ideally be initiated approximately one year prior to implementation of chloramination. This would ensure that all consumers are notified of the impending changes, and would provide a reasonable period of time for installation of equipment to remove chloramines prior to kidney dialysis units and to properly condition the water used in fish-rearing operations to avoid fish kills. (Pet stores and other commercial agencies involved in tropical fish- rearing should also be notified in order to allow them to notify customers of the potential impacts of chloramines and to provide remedial measures.) An aggressive program utilizing electronic media (radio/television), newspaper advertisements, and monthly notices in consumer bills could reduce the duration of the public notification period to three to six months. Other large utilities which have converted to chloramines (Metropolitan Water District of Southern California is one example) have developed informative publications which could be used to assist the County in preparing and implementing the public notification process.

Should Dare County management feel that the risks associated with use of chloramines are unacceptable, the most desirable alternative, when all factors are considered (and assuming that increased RO plant production does not yield compliance with current and impending TTHM MCLs), would be to (1) reduce the amount of raw water bypassing the RO process and install provisions for stabilization of treated water (i.e., carbon dioxide feed facilities), and (2) construct a nanofiltration membrane treatment plant to replace the existing Skyco treatment facility. While these modifications would reduce DBP formation levels for treated water from the RO and Skyco plants, they do not address reductions in DBP levels for treated water from the Fresh Pond plant. Treated water DBP levels for the Nags Head system could therefore continue to approach (or exceed) current and impending future MCLs for DBPs (the extent to which this occurs would depend upon the relative proportions of Fresh Pond and RO/Skyco treated waters delivered to the Nags Head system).

While use of anion macroporous resins cannot be recommended at this time due to limited full-scale operating experience, preliminary opinions of probable cost for this treatment alternative indicate that it could provide a cost-effective means of reducing current treated water DBP levels. If implementation of chloramination is determined to be unacceptable by Dare County management, a more detailed investigation of treatment using macroporous anion resins could be considered. Water Production Department staff should monitor results of pilot testing currently being conducted at Cape Hatteras using anion resins. If the pilot study indicates that macroporous resins can provide effective DBP control, a similar pilot study at Dare County, using softened water from the Skyco plant, could be conducted to assess feasibility and site-specific operating requirements. Full-scale implementation would require installation of treatment facilities using anion macroporous resins at the Skyco plant, and possibly at the Fresh Pond plant, to ensure systemwide compliance with current/impending DBP regulations. (Reductions in raw water bypass rates at the RO plant would also be recommended in conjunction with installation of anion resin treatment.)

Appendix A

Distribution System THM Data

Dare County THM Monitoring Data Summary

Location	11/90	02/91	05/91	09/91	11/91
A. System Served Primarily by RO Plant					
1. Sanderling					
Chloroform	1.7	7.3	11.0	10.9	5.7
Bromoform	40.2	45.8	62.1	71.1	68.7
Bromodichloromethane	1.4	5.2	9.2	11.9	7.4
Chlorodibromomethane	4.5	10.4	13.8	26.2	19.6
Total THMs	47.8	68.7	96.1	120.1	101.4
2. Kitty Hawk El. Sch.2.					
Chloroform	1.1	4.5	10.4	18.0	1.7
Bromoform	30.9	45.4	60.9	41.9	29.8
Bromodichloromethane	1.0	3.1	8.8	18.0	2.4
Chlorodibromomethane	4.0	8.9	13.8	27.0	8.0
Total THMs	37.0	61.9	93.9	104.9	41.9
3. Murray's Auto Supply					
Chloroform	1.2	3.0	12.9	15.3	2.0
Bromoform	33.4	29.6	34.2	34.2	30.3
Bromodichloromethane	1.1	2.5	10.0	16.1	2.4
Chlorodibromomethane	4.3	7.7	12.0	24.7	8.1
Total THMs	40.0	42.8	69.1	90.3	42.8
4. KH Fire Station					
Chloroform	<1.0	<1.0	9.4	14.3	1.4
Bromoform	22.3	23.8	44.3	23.2	22.2
Bromodichloromethane	0.7	0.9	7.6	13.6	1.9
Chlorodibromomethane	3.4	5.2	11.7	17.8	5.6
Total THMs	26.4	29.9	73.0	68.9	31.1
B. System Served Primarily by Skyco Plant					
5. 8th Street					
Chloroform	1.0	<1.0	1.0	10.0	<1.0
Bromoform	20.1	18.7	17.2	2.8	13.2
Bromodichloromethane	1.1	0.8	1.2	11.5	<0.5
Chlorodibromomethane	3.6	4.4	3.9	11.3	2.2
Total THMs	25.8	23.9	23.3	35.6	15.4
6. Gull Street					
Chloroform	47.7	71.6	60.0	43.5	18.4
Bromoform	1.9	1.6	2.4	1.3	20.7
Bromodichloromethane	38.5	47.6	47.2	33.9	20.3
Chlorodibromomethane	23.6	25.6	29.4	20.0	22.6
Total THMs	111.7	146.4	139.0	98.7	82.0

Dare County THM Monitoring Data Summary (continued)

Location	11/90	02/91	05/91	09/91	11/91
7. Manteo PW Building					
Chloroform	49.1	64.2	62.0	40.9	33.4
Bromoform	1.7	1.8	2.6	1.3	4.3
Bromodichloromethane	37.9	45.8	46.7	32.1	32.5
Chlorodibromomethane	22.9	25.5	29.8	19.2	25.5
Total THMs	111.6	137.3	141.1	93.5	95.7
8. Manteo WTP					
Chloroform	55.2	58.2	50.0	46.2	29.5
Bromoform	1.9	1.5	1.7	1.9	3.7
Bromodichloromethane	42.1	42.1	37.9	37.0	29.5
Chlorodibromomethane	24.7	23.4	22.8	22.5	23.6
Total THMs	123.9	125.2	112.4	107.6	86.3
C. Average for 8 Sample Locations					
Chloroform	19.6	26.1	27.1	24.9	11.6
Bromoform	19.0	21.0	28.2	22.2	24.1
Bromodichloromethane	15.5	18.5	21.1	21.8	12.0
Chlorodibromomethane	11.4	13.9	17.2	21.1	14.4
Total THMs*	65.5	79.5	93.5	90.0	62.1
D. 4-Quarter Running THM Average					
Chloroform				24.4	22.4
Bromoform				22.6	23.9
Bromodichloromethane				19.2	18.4
Chlorodibromomethane				15.9	16.7
Total THMs*				82.1	81.3

*Values based on average of total THM data for 8 sample point; "Total THM" value may not be equal to sum of individual components.

Dare County THM Monitoring Data Summary (continued)

Location	02/92	04/92	07/92	11/92	01/93
A. System Served Primarily by RO Plant					
1. Sanderling					
Chloroform	1.0	2.2	22.7	12.2	15.8
Bromoform	41.4	52.0	53.0	73.2	64.1
Bromodichloromethane	1.0	2.8	32.6	35.8	18.4
Chlorodibromomethane	4.7	7.2	54.4	18.9	31.0
Total THMs	48.1	64.2	162.7	140.1	129.3
2. Kitty Hawk El. Sch.2.					
Chloroform	<1.0	1.1	23.3	12.3	21.6
Bromoform	23.4	40.3	30.2	32.4	33.9
Bromodichloromethane	0.5	1.5	28.4	35.4	28.0
Chlorodibromomethane	2.4	4.7	33.7	18.1	35.3
Total THMs	26.3	47.6	115.6	98.2	118.8
3. Murray's Auto Supply					
Chloroform	<1.0	1.1	22.5	7.5	21.3
Bromoform	20.4	30.8	27.8	30.0	33.4
Bromodichloromethane	<0.5	1.6	27.0	22.6	27.8
Chlorodibromomethane	2.0	4.6	31.1	10.6	35.1
Total THMs	22.4	38.1	108.4	70.7	117.6
4. KH Fire Station					
Chloroform	1.0	1.0	17.6	12.3	20.1
Bromoform	32.5	22.5	33.9	34.6	21.8
Bromodichloromethane	0.6	1.4	20.6	30.6	25.5
Chlorodibromomethane	3.4	3.7	26.1	18.6	31.1
Total THMs	37.5	28.6	98.2	96.1	98.5
B. System Served Primarily by Skyco Plant					
5. 8th Street					
Chloroform	<1.0	<1.0	24.8	21.0	<1.0
Bromoform	17.4	15.0	2.6	2.6	18.5
Bromodichloromethane	<0.5	<0.5	22.1	18.8	<0.5
Chlorodibromomethane	1.7	1.7	16.9	13.4	1.7
Total THMs	19.1	16.7	66.4	55.8	20.2
6. Gull Street					
Chloroform	28.5	31.2	20.7	36.3	27.0
Bromoform	10.6	4.2	2.0	2.7	3.3
Bromodichloromethane	23.2	30.5	15.9	30.3	27.3
Chlorodibromomethane	16.9	23.4	12.3	19.8	21.9
Total THMs	79.2	89.3	50.9	89.1	79.5

Dare County THM Monitoring Data Summary (continued)

Location	02/92	04/92	07/92	11/92	01/93
7. Manteo PW Building					
Chloroform	36.9	24.5	31.3	31.7	29.5
Bromoform	3.5	2.7	2.6	3.0	3.4
Bromodichloromethane	34.9	20.4	28.0	29.6	28.2
Chlorodibromomethane	25.2	15.8	20.4	20.7	22.0
Total THMs	100.5	63.4	82.3	85.0	83.1
8. Manteo WTP					
Chloroform	25.4	20.0	27.2	37.2	28.3
Bromoform	2.9	2.5	2.1	2.5	3.0
Bromodichloromethane	22.3	17.0	23.9	30.2	27.7
Chlorodibromomethane	17.4	13.1	18.0	19.4	21.6
Total THMs	68.0	52.6	71.2	89.3	80.3
C. Average for 8 Sample Locations					
Chloroform	11.6	10.1	23.8	21.3	20.5
Bromoform	19.0	21.3	19.3	22.6	22.7
Bromodichloromethane	10.3	9.4	24.8	29.2	22.9
Chlorodibromomethane	9.1	9.3	26.6	17.4	25.0
Total THMs*	50.1	50.1	94.5	90.5	90.9
D. 4-Quarter Running THM Average					
Chloroform	18.8	14.6	14.3	16.7	18.9
Bromoform	23.4	21.7	20.9	20.6	21.5
Bromodichloromethane	16.3	13.4	14.1	18.4	21.6
Chlorodibromomethane	15.5	13.5	14.9	15.6	19.6
Total THMs*	74.0	63.1	64.2	71.3	81.5

*Values based on average of total THM data for 8 sample point; "Total THM" value may not be equal to sum of individual components.

Dare County THM Monitoring Data Summary (continued)

Location	04/93
A. System Served Primarily by RO Plant	
1. Sanderling	
Chloroform	17.2
Bromoform	60.6
Bromodichloromethane	18.7
Chlorodibromomethane	22.7
Total THMs	119.2
2. Kitty Hawk El. Sch.2.	
Chloroform	17.8
Bromoform	35.4
Bromodichloromethane	20.1
Chlorodibromomethane	24.7
Total THMs	98.0
3. Murray's Auto Supply	
Chloroform	22.2
Bromoform	23.6
Bromodichloromethane	22.7
Chlorodibromomethane	23.4
Total THMs	91.9
4. KH Fire Station	
Chloroform	12.9
Bromoform	27.5
Bromodichloromethane	13.3
Chlorodibromomethane	16.7
Total THMs	70.4
B. System Served Primarily by Skyco Plant	
5. 8th Street	
Chloroform	35.0
Bromoform	2.5
Bromodichloromethane	32.7
Chlorodibromomethane	20.4
Total THMs	90.6
6. Gull Street	
Chloroform	34.1
Bromoform	2.4
Bromodichloromethane	30.9
Chlorodibromomethane	19.3
Total THMs	86.7

Dare County THM Monitoring Data Summary (continued)

Location	04/93
7. Manteo PW Building	
Chloroform	38.3
Bromoform	2.5
Bromodichloromethane	35.7
Chlorodibromomethane	22.2
Total THMs	98.7
8. Manteo WTP	
Chloroform	34.8
Bromoform	2.3
Bromodichloromethane	32.9
Chlorodibromomethane	20.8
Total THMs	90.8

C. Average for 8 Sample Locations

Chloroform	26.5
Bromoform	19.6
Bromodichloromethane	25.9
Chlorodibromomethane	21.3
Total THMs*	93.3

D. 4-Quarter Running THM Average

Chloroform	23.0
Bromoform	21.0
Bromodichloromethane	25.7
Chlorodibromomethane	22.6
Total THMs*	92.3

*Values based on average of total THM data for 8 sample point; "Total THM" value may not be equal to sum of individual components.

Kill Devil Hills THM Monitoring Data Summary

Location	02/92	04/92	09/92	12/92	02/93	04/93
1. Ground Storage Tank						
Chloroform	1.0					
Bromoform	21.8					
Bromodichloromethane	<0.5					
Chlorodibromomethane	1.8					
Total THMs	24.6					
2. Clipper Court						
Chloroform	1.0	4.8	25.2	9.0	16.7	24.3
Bromoform	34.8	72.3	38.5	54.0	52.8	44.3
Bromodichloromethane	0.9	6.7	32.6	15.9	17.3	30.8
Chlorodibromomethane	4.0	17.2	39.6	32.4	27.1	42.7
Total THMs	40.7	101.0	135.9	111.3	113.9	142.1
3. East Arch Street						
Chloroform		1.9	20.5	9.7	13.5	23.6
Bromoform		36.4	70.7	44.0	41.4	22.7
Bromodichloromethane		2.6	27.6	9.8	13.4	24.9
Chlorodibromomethane		7.0	44.7	14.5	16.9	24.4
Total THMs		47.9	163.5	78.0	85.2	95.6
4. 1524 Village Lane						
Chloroform		<1.0	18.1	8.8	17.9	23.9
Bromoform		21.6	42.0	38.7	30.2	21.4
Bromodichloromethane		0.8	19.8	8.8	17.9	24.6
Chlorodibromomethane		2.6	24.5	11.9	18.5	23.1
Total THMs		25.0	104.4	68.2	84.5	93.0
5. 7-11 Deli						
Chloroform		4.9	15.5	13.1	20.5	23.6
Bromoform		37.3	52.1	40.4	31.6	22.7
Bromodichloromethane		5.5	20.4	14.6	20.8	24.9
Chlorodibromomethane		8.8	30.6	22.4	20.5	24.4
Total THMs		56.5	118.6	90.5	93.4	95.6
6. Quarterly Average						
Chloroform		2.9	19.8	10.2	17.2	23.8
Bromoform		41.9	50.8	44.3	39.0	27.8
Bromodichloromethane		3.9	25.1	12.2	17.4	26.3
Chlorodibromomethane		8.9	34.9	20.3	20.7	28.7
Total THMs		57.6	130.6	87.0	94.3	106.6
7. 4-Quarter Average						
Chloroform				11.0	12.5	17.8
Bromoform				45.7	44.0	40.5
Bromodichloromethane				13.7	14.7	20.2
Chlorodibromomethane				21.4	21.2	26.1
Total THMs				91.8	92.4	104.6

Kill Devil Hills THM Monitoring Data Summary (continued)

Location	Avg.	Range
8. Housing Development*		
Chloroform	11.8	9.7 - 12.2
Bromoform	71.4	45.9 - 93.0
Bromodichloromethane	17.1	14.3 - 19.2
Chlorodibromomethane	34.0	21.0 - 40.3
Total THMs	134.3	93.4 - 154.4

*Data from June 1992; average of 5 sites located in development at extremities of KDH system.

Nags Head THM Monitoring Data Summary

Location	03/92	04/92	08/92	11/92	04/93
1. Oregon Inlet Marina					
Chloroform	21.0	37.2	45.9	39.3	39.1
Bromoform	48.9	22.8	3.3	4.9	36.5
Bromodichloromethane	27.3	43.5	38.0	20.4	38.5
Chlorodibromomethane	44.0	48.8	24.3	17.5	35.9
Total THMs	141.2	152.3	111.5	82.1	150.0
2. Gull St. Pump Station					
Chloroform	22.6		30.9	26.7	46.9
Bromoform	27.1		1.8	3.5	5.2
Bromodichloromethane	22.8		25.6	23.0	39.8
Chlorodibromomethane	27.1		17.0	18.9	25.3
Total THMs	99.6		75.3	72.1	117.2
3. ABC Store (US 158)					
Chloroform	<1.0	8.8			
Bromoform	20.1	23.8			
Bromodichloromethane	<0.5	8.8			
Chlorodibromomethane	1.9	9.9			
Total THMs	22.0	51.3			
4. Ace Hardware (US 158)					
Chloroform	<1.0	13.9			
Bromoform	20.9	28.4			
Bromodichloromethane	0.5	15.7			
Chlorodibromomethane	2.0	21.5			
Total THMs	23.4	79.5			
5. Town Hall					
Chloroform	1.6	13.9	31.4	26.4	30.4
Bromoform	26.0	34.0	16.6	17.3	22.1
Bromodichloromethane	2.1	20.4	30.9	34.8	34.5
Chlorodibromomethane	5.8	37.5	16.2	34.9	40.1
Total THMs	35.5	105.8	95.1	113.4	127.1
6. Water Plant					
Chloroform			30.3	7.6	34.4
Bromoform			5.7	27.8	8.3
Bromodichloromethane			29.7	11.6	33.6
Chlorodibromomethane			19.8	17.8	28.8
Total THMs			85.5	64.8	105.1
7. Plant Lab Tap*					
Chloroform			24.9	4.9	
Bromoform			4.4	2.0	
Bromodichloromethane			23.5	3.9	
Chlorodibromomethane			21.9	5.0	
Total THMs			74.7	15.8	

Nags Head THM Monitoring Data Summary (continued)

Location	03/92	04/92	08/92	11/92	04/93
8. Quarterly Average					
Chloroform	9.0	18.4	34.6	25.0	37.7
Bromoform	28.6	27.3	6.9	13.4	18.0
Bromodichloromethane	10.5	22.1	31.1	22.4	36.6
Chlorodibromomethane	16.2	29.4	19.3	22.3	32.6
Total THMs	64.3	97.2	91.9	83.1	124.9
9. 4-Quarter Average					
Chloroform				21.8	28.9
Bromoform				19.0	16.4
Bromodichloromethane				21.5	28.1
Chlorodibromomethane				21.8	25.9
Total THMs				84.1	99.3

*Plant tap not included in samples reported for compliance monitoring.

Appendix B

Experience with Chloramines at North Carolina Utilities

BLACK & VEATCH

TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
Washington Chloramine Experience

B&V Project 23464.150
B&V File B
March 12, 1993
4:00 p.m.

From: Jerry Cuttler
Company: City of Washington, NC
Phone No.: (919) 975-9310

Recorded by: DBE

Washington has been using chloramines in the distribution system to limit THM formation since 1988. Jerry indicated that he initially had reservations about converting to chloramine, based on concerns regarding addition of both ammonia and phosphate (for corrosion control) in conjunction with use of a disinfectant which is much "weaker" than free chlorine.

Chlorine is added at the plant at the filter influent, and ammonia is added at the filter effluent (Jerry indicated that this provides a contact time of "21 minutes" to meet SWTR CT requirements). A treated water chloramine level of about 4 mg/L is typically maintained at the plant discharge. Settled water pH is about 5.5, and pH is increased to 7.8 - 8.0 following addition of ammonia at the filter discharge. (Washington treats a "highly organic" surface water with high THM formation potential.)

Jerry indicated that the state regulatory agency "requires" that the utility revert to free chlorine within the distribution system for two weeks every year. However, Washington has not done this; no problems with nitrification have apparently been experienced.

Problems with maintaining free chlorine residuals in low-flow areas of the distribution system have been eliminated since conversion to chloramines. Jerry stated that maintaining required disinfectant residual levels throughout the system is "much easier" since converting to chloramines.

Jerry was unaware of "problems" with chloramines experienced at Elizabeth City; he stated that he visited the Elizabeth City plant and discussed use of chloramines with the plant staff prior to implementing chloramination at Washington's plant.

Jerry feels that Washington's experience with chloramine has been very positive; customer complaints regarding the high free chlorine levels previously required have been largely eliminated.

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TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
Elizabeth City Chloramine Experience

B&V Project 23464.150
B&V File B
March 15, 1993
8:00 a.m.

To:	Deb Clow
Company:	City of Elizabeth City
Phone No.:	(919) 338-3981
Recorded by:	DBE

Elizabeth City has used chloramines for THM reduction since 1988. The treatment plant is rated at 5 mgd, but typical throughput is 2.5 mgd. Both chlorine and ammonia are added at the plant headworks in order to maintain a low chloramine residual through the entire treatment process. Chlorine and ammonia are added at the filter effluent to yield a combined residual of about 2 - 2.5 mg/L leaving the plant (this is increased slightly during the summer to maintain adequate residuals throughout the entire system). Ammonia is received in aqueous form in drums.

Deb indicated that the system converts back to free chlorine once per year (per regulatory agency requirement), and that customer complaints have not been received during this period. System flushing is carried out during this period. HPC is monitored for each coliform sample, again per state requirements. The additional HPC testing has apparently not placed any significant burden on the staff.

Overall, the experience with chloramine at Elizabeth City has apparently been very positive. Deb indicated that water quality complaints have decreased significantly, and that the chloramination process is easy to control.

BLACK & VEATCH

TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
Currituck County Chloramine Experience

B&V Project 23464.150
B&V File B
March 15, 1993
9:00 a.m.

To: Leland Gibbs
Company: Currituck County Water Dept.
Phone No.: (919) 453-2155

Recorded by: DBE

Currituck County has used chloramines to limit THM formation since November 1991. The County treats a groundwater supply with high THM formation potential. Treatment plant capacity is currently 1 mgd. Treatment consists of aeration, addition of chlorine, permanganate, and polymer at the aerator discharge, pressure filtration using greensand media, ion exchange softening, and addition of chlorine/ammonia prior to a 500,000 gallon treated water storage reservoir. The typical treated water chloramine residual leaving the plant is about 4 mg/L. Ammonia is received in drums as a 29 percent aqueous solution, and is diluted by about 50 percent prior to application. The ratio of chlorine-to-ammonia is maintained at about 3.5 to 1.

The County system is apparently fairly extensive (the system extends outward from the plant by approximately 48 miles), with many long mains serving areas with very low consumption. Prior to conversion to chloramines, maintaining residuals throughout the system was very difficult (a booster chlorination station located at about the mid-point of the system was operated prior to conversion to chloramines). Problems with residual maintenance have been essentially eliminated since conversion to chloramines.

The County has not experienced problems with reversion of chloramine to free chlorine/ammonia, even in areas where the system detention time is in excess of two to three weeks. HPC is monitored for each coliform sample; Leland indicated that all plate counts have been "less than 100". Conversion back to free chlorine for a short period (per state regulatory agency requirement) has been accomplished recently with no significant problems or complaints (several "high chlorine" calls were received, but Leland indicated that better customer notification prior to the conversion would likely have eliminated these).

Leland indicated that the entire ammonia feed system was installed for "about $20,000". Use of chloramines has reduced customer water quality complaints by "more than 90 percent". Experience with chloramine overall is considered very positive.

BLACK & VEATCH

TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
High Point Chloramine Experience

B&V Project 23464.150
B&V File B
June 2, 1993
3:00 p.m.

To: Tom Gore
Company: City of High Point
Phone No.: (919) 883-3410

Recorded by: DBE

High Point uses chloramines during the summer months to reduce TTHM levels within the distribution system. Conversion to chloramination initially occurred during summer 1992. The initial point of chlorine addition is the filter inlet, and ammonia is added at the filter discharge. Average chloramine residual leaving the plant is approximately 3.5 mg/L. A 3.5 to 1 chlorine to ammonia ratio is maintained.

Ammonia is received in anhydrous form and fed as a solution. Storage capacity is approximately 1000 gallons; the tank is located outside.

No problems have been experienced with tastes or odors; Tom indicated that chlorine-based complaints during the summer months have actually decreased since use of chloramines was implemented. No significant change in plate count results for system monitoring locations has been noticed. Tom indicated that the only problem experienced during conversion to chloramines last year was "a lot of dead fish". (Note that an effective public notification program mignt have reduced the severity of the problem.)

BLACK & VEATCH

TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Control Study
Cape Hatteras Chloramine Experience

B&V Project 23464.150
B&V File B
January 26, 1993
11 a.m.

To: Jim Coleman
Company: Cape Hatteras, NC Water Dept
Phone No.: 919-995-5061

Recorded by: DBE

Cape Hatteras converted to chloramine disinfection within the distribution system during March 1991. Cape Hatteras treats a "highly organic" groundwater using conventional coagulation/flocculation/sedimentation/filtration, followed by ion exchange softening and clearwell storage. THM levels in the distribution system exceeded 250 ug/L prior to conversion to chloramination. Following the conversion, THM levels are less than the current MCL (last quarter sample average was 65 ug/L).

Prior to conversion to chloramines, chlorine was added at the plant headworks "as an oxidant"; potassium permanganate is now added (Jim indicated that average permanganate demand is 22 mg/L!). Chlorine is added at the clearwell inlet at levels sufficient to maintain a minimum residual of 0.2 mg/L at the clearwell discharge. Chlorine and ammonia (aqua form) are added at the clearwell discharge to provide an average chloramine residual concentration of 4 mg/L.

Jim is not at all happy with use of chloramines; he indicated that chloramination is "difficult to work with", and regards this as a "temporary solution" to the utility's THM problems. He sited difficulties in keeping free ammonia levels within the system down and chloramine residuals at desired levels. He also feels that the chloramine contributes to lead/copper problems (the utility was OK on lead during the first round of testing; 90th percentile copper concentration was 1.304 mg/L). Odor problems within the system have not been experienced.

The utility is preparing to do pilot work on use of an anionic resin for removing THM precursors; preliminary bench-scale work indicates that this may have some potential.

Jim suggested that we contact Currituck County and Elizabeth City regarding their experience with chloramines (he indicated that the experience at Elizabeth City has also not been positive). He also indicated that Raleigh discontinued chloramination during the late 1970s, but plans to return to chloramines in the near future.

BLACK & VEATCH

TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
North Carolina Chloramine Experience

B&V Project 23464.150
B&V File B
January 26, 1993
9:15 a.m.

From: Fred Hill
Company: North Carolina Division Environmental Health
Phone No.: (919) 946-6481

Recorded by: DBE

We discussed experience with use of chloramines in North Carolina. Fred was apparently surprised to hear that Cape Hatteras was not happy with chloramine, as he was not aware of any specific problems experienced. (He "suggested" that the utility's dissatisfaction with chloramine might simply be due to the need to add another chemical and the additional monitoring required.) Fred indicated that the configuration of the Cape Hatteras treatment facility resulted in the need to add ammonia "in the middle of the clearwell", which probably makes control of the chloramination process more difficult than would be the case if ammonia was added at the clearwell inlet or outlet.

Other utilities using chloramines are Elizabeth City (contact Deb Clow (919) 338-3981), Washington (contact Jerry Cuttler), Currituck County (contact Leland Gibbs; (919) 453-2155), Fort Bragg, and a number of other small utilities. Fred expects use of chloramines to expand over the next several years in response to more restrictive THM/disinfection byproduct regulations.

North Carolina has adopted several policies with respect to use of chloramine;

- The utility must carry a minimum 2.0 mg/L total chlorine residual throughout the distribution system.
- All routine coliform monitoring samples must also be analyzed for heterotrophic plate count (HPC).
- The system must revert back to free chlorine once per year for a short period of time to ensure that biofilm problems within the distribution system are not experienced.

DEH does not have any particular aversion to the use of chloramine, as long as adequate disinfection prior to addition of ammonia or ammonia/chlorine is accomplished.

cc: Bill Bizzell

Appendix C

Comparative TTHM / THAA Data

MONTGOMERY LABORATORIES
555 East Walnut Street, P.O. Box 7009
Pasadena, California 91109-7009
(818) 796-9141

Laboratory Report

for

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City, MO 64114

Attention: Doug Elder

MONTGOMERY LABORATORIES
Submitted on
APR 30 1993
HDS
Hillary

Report#: 6627

MONTGOMERY LABORATORIES
555 East Walnut Street, P.O. Box 7009
Pasadena, California 91109-7009
(818) 796-9141

Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423010 Sample ID 340 SANDERLING Project ____________

Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	6.3			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	13			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	8.0			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	2.2			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	9.4			2	28-apr-1993	dym	28-apr-1993	dym

Report #: 6627

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423009 Sample ID 184 K.H. SCHOOL Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	7.1			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	11			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	7.9			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	10			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423008 Sample ID 164 MURRAY AUTO Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	7.8			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	9.3			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	9.3			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	12			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423005 Sample ID 132 K.H. FIRE STATION Project

Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	4.9			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	7.8			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	5.9			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	7.1			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423003 Sample ID 005 8TH ST. Project

Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	9.8			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	4.6			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	14			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	15			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423004 Sample ID 006 GULL ST. Project ____________
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	11			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	5.0			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	15			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	18			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423007 Sample ID 155 DETENTION CENTER Project ____
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	2.0			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	18			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423006 Sample ID 153 MANTEO WATER PLANT Project ____
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	11			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	5.2			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	15			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	16			2	28-apr-1993	dym	28-apr-1993	dym

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Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423002 Sample ID 003 RO PLANT PUMP #1 Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	2.5			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym

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Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423001 Sample ID 002 SKYCO PLANT PUMP #2 Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Haloacetic Acids (ML/EPA 552)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromochloracetic acid	ug/l	7.6			2	28-apr-1993	dym	28-apr-1993	dym
Dibromoacetic acid	ug/l	4.3			2	28-apr-1993	dym	28-apr-1993	dym
Dichloroacetic acid	ug/l	10			2	28-apr-1993	dym	28-apr-1993	dym
Monobromoacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Monochloroacetic acid	ug/l	ND			2	28-apr-1993	dym	28-apr-1993	dym
Trichloroacetic acid	ug/l	10			2	28-apr-1993	dym	28-apr-1993	dym

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423010 Sample ID 340 SANDERLING Project

Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	61		5	2.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	15			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	29			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	23			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	128			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423009 Sample ID 184 K.H. SCHOOL Project __________
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	41			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	18			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	30			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	25			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	114			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423008 Sample ID 164 MURRAY AUTO Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	41			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	19			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	35			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	29			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	124			0.5	27-apr-1993	chd	27-apr-1993	chd

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Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423005 Sample ID 132 K.H. FIRE STATION Project ____
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	47			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	14			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	24			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	18			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	103			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423003 Sample ID 005 8TH ST. Project ________
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	2.4			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	34			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	22			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	34			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	92			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423004 Sample ID 006 GULL ST. Project

Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	2.4			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	37			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	24			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	37			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	100			0.5	27-apr-1993	chd	27-apr-1993	chd

Report #: 6627

MONTGOMERY LABORATORIES
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(818) 796-9141

Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423007 Sample ID 155 DETENTION CENTER Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	2.5			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	41			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	25			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	36			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	105			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423006 Sample ID 153 MANTEO WATER PLANT Project ______
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	2.6			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	36			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	23			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	34			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	96			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
8400 Ward Parkway

Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423002 Sample ID 003 RO PLANT PUMP #1 Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	20			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	ND			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	2.0			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	0.7			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	23			0.5	27-apr-1993	chd	27-apr-1993	chd

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Laboratory Report

Black and Veatch. Missouri
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Kansas City , MO 64114
ATTN: Doug Elder

Sample # 930423001 Sample ID 002 SKYCO PLANT PUMP #2 Project
Sample Type Water Sampled 22-apr-1993 Received 23-apr-1993 Reported 30-apr-1993

Trihalomethane (ML/EPA 501.2)

Parameter	Units	Result	%Rec Conc.	Dilution	Det.Limit	Prepared	By	Analyzed	By
Bromoform	ug/l	3.0			0.5	27-apr-1993	chd	27-apr-1993	chd
Chloroform (Trichloromethane)	ug/l	37			0.5	27-apr-1993	chd	27-apr-1993	chd
Dibromochloromethane	ug/l	26			0.5	27-apr-1993	chd	27-apr-1993	chd
Bromodichloromethane	ug/l	36			0.5	27-apr-1993	chd	27-apr-1993	chd
Total Trihalomethanes (THM's/T	ug/l	102			0.5	27-apr-1993	chd	27-apr-1993	chd

Report #: 6627

Appendix D

Testing Results for RO Plant

Oxford Laboratories, Inc.
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KANSAS CITY, MO 64114

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

1. BLENDED WATER TEST 1 300 COND. 15 MIN.
2. BLENDED WATER TEST 1 300 COND. 30 MIN.
3. BLENDED WATER TEST 1 300 COND. 1 DAY
4. BLENDED WATER TEST 1 300 COND. 4 DAYS
5. BLENDED WATER TEST 1 300 COND. 7 DAYS
6. BLENDED WATER TEST 2 300 COND. 15 MIN.

RESULTS

	1	2	3	4	5	6
Residual Chlorine, PPM	7.8	7.2	7.8	8.1	7.8	16.5
Chloroform, PPB	<1.0	<1.0	1.0	1.1	<1.0	<1.0
Bromoform, PPB	2.7	2.6	3.1	3.4	3.8	2.7
Bromodichloromethane, PPB	<0.5	<0.5	0.5	0.7	0.9	<0.5
Chlorodibromomethane, PPB	<0.5	<0.5	1.1	1.5	1.9	<0.5
Total THM, PPB	2.7	2.6	5.7	6.7	6.6	2.7
DATE EXTRACTED	5/5	5/5	5/10	5/10	5/12	5/5
DATE ANALYZED	5/5	5/5	5/10	5/10	5/12	5/5

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

7. BLENDED WATER TEST 2 300 COND. 30 MIN.
8. BLENDED WATER TEST 2 300 COND. 1 DAY
9. BLENDED WATER TEST 2 300 COND. 4 DAYS
10. BLENDED WATER TEST 2 300 COND. 7 DAYS
11. BLENDED WATER TEST 1 400 COND. 15 MIN.
12. BLENDED WATER TEST 1 400 COND. 30 MIN.

RESULTS

	7	8	9	10	11	12
Residual Chlorine, PPM	17.3	18.9	19.3	15.4	6.3	6.4
Chloroform, PPB	<1.0	1.2	1.3	<1.0	<1.0	<1.0
Bromoform, PPB	2.6	3.0	3.4	3.3	2.6	2.7
Bromodichloromethane, PPB	<0.5	0.6	0.9	1.2	<0.5	<0.5
Chlorodibromomethane, PPB	<0.5	1.1	1.6	1.9	<0.5	<0.5
Total THM, PPB	2.6	5.9	7.2	6.4	2.6	2.7
DATE EXTRACTED	5/5	5/10	5/10	5/12	5/5	5/5
DATE ANALYZED	5/5	5/10	5/10	5/12	5/5	5/5

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

13. BLENDED WATER TEST 1 400 COND. 1 DAY
14. BLENDED WATER TEST 1 400 COND. 4 DAYS
15. BLENDED WATER TEST 1 400 COND. 7 DAYS
16. BLENDED WATER TEST 2 400 COND. 15 MIN.
17. BLENDED WATER TEST 2 400 COND. 30 MIN.
18. BLENDED WATER TEST 2 400 COND. 1 DAY

RESULTS

	13	14	15	16	17	18
Residual Chlorine, PPM	7.7	7.3	6.7	16.1	16.1	18.6
Chloroform, PPB	1.0	1.2	<1.0	<1.0	<1.0	1.5
Bromoform, PPB	3.2	3.9	3.8	2.8	2.6	3.0
Bromodichloromethane, PPB	0.6	1.0	1.5	<0.5	<0.5	0.9
Chlorodibromomethane, PPB	1.4	2.2	2.6	<0.5	0.5	1.6
Total THM, PPB	6.2	8.3	7.9	2.8	3.1	7.0
DATE EXTRACTED	5/10	5/10	5/12	5/5	5/5	5/10
DATE ANALYZED	5/10	5/10	5/12	5/5	5/5	5/10

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

19. BLENDED WATER TEST 2 400 COND. 4 DAYS
20. BLENDED WATER TEST 2 400 COND. 7 DAYS
21. BLENDED WATER TEST 1 500 COND. 15 MIN.
22. BLENDED WATER TEST 1 500 COND. 30 MIN.
23. BLENDED WATER TEST 1 500 COND. 1 DAY
24. BLENDED WATER TEST 1 500 COND. 4 DAYS

RESULTS

	19	20	21	22	23	24
Residual Chlorine, PPM	18.9	16.7	6.0	6.2	7.0	6.7
Chloroform, PPB	1.6	1.0	<1.0	<1.0	1.1	1.1
Bromoform, PPB	3.2	3.4	2.4	2.5	4.0	5.6
Bromodichloromethane, PPB	1.3	1.7	<0.5	<0.5	0.9	1.0
Chlorodibromomethane, PPB	2.1	2.2	0.5	0.6	2.4	2.9
Total THM, PPB	8.2	8.3	2.9	3.1	8.4	10.6
DATE EXTRACTED	5/10	5/12	5/5	5/5	5/10	5/10
DATE ANALYZED	5/10	5/12	5/5	5/5	5/10	5/10

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

25. BLENDED WATER TEST 1 500 COND. 7 DAYS
26. BLENDED WATER TEST 2 500 COND. 15 MIN.
27. BLENDED WATER TEST 2 500 COND. 30 MIN.
28. BLENDED WATER TEST 2 500 COND. 1 DAY
29. BLENDED WATER TEST 2 500 COND. 4 DAYS
30. BLENDED WATER TEST 2 500 COND. 7 DAYS

RESULTS

	25	26	27	28	29	30
Residual Chlorine, PPM	6.3	16.9	15.9	17.4	17.7	17.7
Chloroform, PPB	<1.0	<1.0	<1.0	1.4	2.0	1.0
Bromoform, PPB	7.5	2.4	2.6	3.8	4.8	4.9
Bromodichloromethane, PPB	1.3	<0.5	<0.5	1.1	2.4	2.2
Chlorodibromomethane, PPB	4.2	0.5	0.7	2.6	4.5	4.5
Total THM, PPB	13.0	2.9	3.3	8.9	13.7	12.6
DATE EXTRACTED	5/12	5/5	5/5	5/10	5/10	5/12
DATE ANALYZED	5/12	5/5	5/5	5/10	5/10	5/12

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

31. BLENDED WATER TEST 1 600 COND. 15 MIN.
32. BLENDED WATER TEST 1 600 COND. 30 MIN.
33. BLENDED WATER TEST 1 600 COND. 1 DAY
34. BLENDED WATER TEST 1 600 COND. 4 DAYS
35. BLENDED WATER TEST 1 600 COND. 7 DAYS
36. BLENDED WATER TEST 2 600 COND. 15 MIN.

RESULTS

	31	32	33	34	35	36
Residual Chlorine, PPM	5.9	3.3	6.6	5.7	6.2	16.1
Chloroform, PPB	<1.0	<1.0	1.1	1.1	<1.0	<1.0
Bromoform, PPB	4.7	2.7	5.0	8.2	9.0	4.5
Bromodichloromethane, PPB	<0.5	<0.5	1.1	1.1	2.0	<0.5
Chlorodibromomethane, PPB	0.8	0.8	3.1	4.0	6.0	0.8
Total THM, PPB	5.5	3.5	10.3	14.4	17.0	5.3
DATE EXTRACTED	5/5	5/5	5/10	5/10	5/12	5/5
DATE ANALYZED	5/5	5/5	5/10	5/10	5/12	5/5

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

37. BLENDED WATER TEST 2 600 COND. 30 MIN.
38. BLENDED WATER TEST 2 600 COND. 1 DAY
39. BLENDED WATER TEST 2 600 COND. 4 DAYS
40. BLENDED WATER TEST 2 600 COND. 7 DAYS
41. BLENDED WATER TEST 1 700 COND. 15 MIN.
42. BLENDED WATER TEST 1 700 COND. 30 MIN.

RESULTS

	37	38	39	40	41	42
Residual Chlorine, PPM	12.9	17.6	16.9	16.2	4.8	2.7
Chloroform, PPB	1.0	1.7	1.9	1.3	<1.0	<1.0
Bromoform, PPB	2.9	4.5	6.0	7.5	2.9	2.9
Bromodichloromethane, PPB	<0.5	1.8	2.3	3.0	<0.5	<0.5
Chlorodibromomethane, PPB	0.9	3.7	5.3	6.0	0.7	0.8
Total THM, PPB	4.8	11.7	15.5	17.8	3.6	3.7
DATE EXTRACTED	5/5	5/10	5/10	5/12	5/5	5/5
DATE ANALYZED	5/5	5/10	5/10	5/12	5/5	5/5

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SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

43. BLENDED WATER TEST 1 700 COND. 1 DAY
44. BLENDED WATER TEST 1 700 COND. 4 DAYS
45. BLENDED WATER TEST 1 700 COND. 7 DAYS
46. BLENDED WATER TEST 2 700 COND. 15 MIN.
47. BLENDED WATER TEST 2 700 COND. 30 MIN.
48. BLENDED WATER TEST 2 700 COND. 1 DAY

RESULTS

	43	44	45	46	47	48
Residual Chlorine, PPM	5.4	5.2	5.1	13.8	11.3	16.2
Chloroform, PPB	1.3	1.4	<1.0	<1.0	1.0	1.9
Bromoform, PPB	5.7	7.1	8.9	2.7	2.7	4.5
Bromodichloromethane, PPB	1.3	1.6	1.9	<0.5	<0.5	2.0
Chlorodibromomethane, PPB	3.9	5.3	6.0	0.8	1.1	4.2
Total THM, PPB	12.2	15.4	16.8	3.5	4.8	12.6
DATE EXTRACTED	5/10	5/10	5/12	5/5	5/5	5/10
DATE ANALYZED	5/10	5/10	5/12	5/5	5/5	5/10

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: BLENDED WATER (THM-SDS)

49. BLENDED WATER TEST 2 700 COND. 4 DAYS
50. BLENDED WATER TEST 2 700 COND. 7 DAYS

RESULTS

	49	50
Residual Chlorine, PPM	15.0	15.4
Chloroform, PPB	2.1	1.5
Bromoform, PPB	4.9	6.7
Bromodichloromethane, PPB	2.6	3.3
Chlorodibromomethane, PPB	5.4	7.2
Total THM, PPB	15.0	18.7
DATE EXTRACTED	5/10	5/12
DATE ANALYZED	5/10	5/12

NOTE: INITIAL CHLORINATION WAS 10 PPM FOR TEST 1 AND 20 PPM FOR TEST 2. ALL INCUBATIONS WERE AT 55 DEGREES F.

Bruce A. Babson
BRUCE A. BABSON, CHEMIST

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: RAW WATER #1

LABORATORY IDENTIFICATION: 93W7105 #1

	TRIAL 1	TRIAL 2	TRIAL 3
TYPE OF ANALYSIS	THM FP	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41	28.11
RESIDUAL FREE CHLORINE, PPM	*	*	*
INCUBATION TIME	7 DAYS	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F	77 F
	TRIAL 1	TRIAL 2	TRIAL 2
TRIHALOMETHANES:			
CHLOROFORM, PPB	2.4	3.6	4.1
BROMODICHLOROMETHANE, PPB	0.7	2.9	5.1
CHLORODIBROMOMETHANE, PPB	0.6	3.9	7.7
BROMOFORM, PPB	1.1	7.4	14.3
TOTAL TRIHALOMETHANES, PPB	4.8	17.8	31.2

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED
* ATYPICAL BEHAVIOR IN THE RESIDUL FREE CHLORINE ANALYSIS. SAMPLES HAD A DELAYED REACTION POSSIBLY INDICATIVE OF CHLOROAMINES.

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: MEMBRANE PERMEATE #2

LABORATORY IDENTIFICATION: 93W7105 #2

	TRIAL 1	TRIAL 2	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41	28.11
RESIDUAL FREE CHLORINE, PPM	11.84	21.61	28.86
INCUBATION TIME	7 DAYS	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F	77 F
	TRIAL 1	TRIAL 2	TRIAL 2
TRIHALOMETHANES:			
CHLOROFORM, PPB	2.1	2.6	4.1
BROMODICHLOROMETHANE, PPB	1.5	1.6	3.9
CHLORODIBROMOMETHANE, PPB	2.5	1.6	3.5
BROMOFORM, PPB	1.3	<0.1	1.2
TOTAL TRIHALOMETHANES, PPB	7.4	5.8	12.7

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: BLENDED WATER (300)

LABORATORY IDENTIFICATION: 93W7105 #3

	TRIAL 1	TRIAL 2	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41	28.11
RESIDUAL FREE CHLORINE, PPM	11.43	19.44	24.91
INCUBATION TIME	7 DAYS	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F	77 F
	TRIAL 1	TRIAL 2	TRIAL 2
TRIHALOMETHANES:			
CHLOROFORM, PPB	2.2	3.5	3.3
BROMODICHLOROMETHANE, PPB	2.1	4.5	3.1
CHLORODIBROMOMETHANE, PPB	5.8	7.1	4.9
BROMOFORM, PPB	7.1	5.9	4.9
TOTAL TRIHALOMETHANES, PPB	17.2	21.0	16.2

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: BLENDED WATER (400)

LABORATORY IDENTIFICATION: 93W7105.4

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41
RESIDUAL FREE CHLORINE, PPM	11.06	22.03
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	2.3	3.1
BROMODICHLOROMETHANE, PPB	2.8	3.8
CHLORODIBROMOMETHANE, PPB	9.3	7.8
BROMOFORM, PPB	11.5	7.5
TOTAL TRIHALOMETHANES, PPB	25.9	22.2

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: BLENDED WATER (500)

LABORATORY IDENTIFICATION: 93W7105 #5

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41
RESIDUAL FREE CHLORINE, PPM	9.22	18.67
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	2.2	3.0
BROMODICHLOROMETHANE, PPB	3.0	5.2
CHLORODIBROMOMETHANE, PPB	11.1	11.6
BROMOFORM, PPB	14.3	10.1
TOTAL TRIHALOMETHANES, PPB	30.6	29.9

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

Oxford Laboratories, Inc.

Analytical and Consulting Chemists
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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: BLENDED WATER (600)

LABORATORY IDENTIFICATION: 93W7105 #6

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41
RESIDUAL FREE CHLORINE, PPM	9.68	18.78
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	2.2	3.0
BROMODICHLOROMETHANE, PPB	3.0	5.5
CHLORODIBROMOMETHANE, PPB	13.0	15.6
BROMOFORM, PPB	19.0	16.0
TOTAL TRIHALOMETHANES, PPB	37.2	40.1

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: BLENDED WATER (700)

LABORATORY IDENTIFICATION: 93W7105 #7

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41
RESIDUAL FREE CHLORINE, PPM	8.89	17.03
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	2.3	2.9
BROMODICHLOROMETHANE, PPB	2.9	6.4
CHLORODIBROMOMETHANE, PPB	15.8	18.0
BROMOFORM, PPB	27.3	20.7
TOTAL TRIHALOMETHANES, PPB	48.3	48.0

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: R/O WATER

1. RAW WATER R/O PLANT
2. MEMBRANE PERMEATE R/O PLANT
3. BLENDED WATER @ 300

RESULTS

	1	2	3
Total Alkalinity, as CaCO3, PPM	280	8	31
Bromide, as Br, PPM	6.15	.175	X
pH (Lab)	7.75	6.25	X
Total Organic Carbon, as C, PPM	6.70	10.0	X

Roger Oxford
ROGER C. OXFORD, CHEMIST

Oxford Laboratories, Inc.

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P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: 2 TOC (DARE CO.)

1. R.O. UNIT #2 PERMEATE 5-21-93
2. RAW WATER SAMPLE TAP 5-21-93

RESULTS

	1	2
Total Organic Carbon, as C, PPM	4.14	3.38

Roger Oxford

ROGER C. OXFORD, CHEMIST

Appendix E

THMFP Data for Skyco WTP Wells

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #1

LABORATORY IDENTIFICATION: 93W7101 #1

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	5.56	11.6
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	167.3	191.1
BROMODICHLOROMETHANE, PPB	46.0	49.6
CHLORODIBROMOMETHANE, PPB	15.2	15.0
BROMOFORM, PPB	<1.0	<1.0
TOTAL TRIHALOMETHANES, PPB	228.5	255.7

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #4

LABORATORY IDENTIFICATION: 93W7101 #2

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	0.19	5.7
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	124.9	141.7
BROMODICHLOROMETHANE, PPB	82.9	90.8
CHLORODIBROMOMETHANE, PPB	61.9	62.7
BROMOFORM, PPB	14.5	12.1
TOTAL TRIHALOMETHANES, PPB	284.2	307.3

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #5

LABORATORY IDENTIFICATION: 93W7101 #3

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	1.03	6.24
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	101.1	125.8
BROMODICHLOROMETHANE, PPB	70.8	90.4
CHLORODIBROMOMETHANE, PPB	62.7	54.9
BROMOFORM, PPB	14.9	11.8
TOTAL TRIHALOMETHANES, PPB	249.5	282.9

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #7

LABORATORY IDENTIFICATION: 93W7101 #4

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	21.8	30.0
RESIDUAL FREE CHLORINE, PPM	0.62	5.94
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	210.6	252.7
BROMODICHLOROMETHANE, PPB	87.0	93.7
CHLORODIBROMOMETHANE, PPB	40.5	40.9
BROMOFORM, PPB	6.0	5.1
TOTAL TRIHALOMETHANES, PPB	344.1	392.4

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #8

LABORATORY IDENTIFICATION: 93W7101 #5

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	21.8	30.0
RESIDUAL FREE CHLORINE, PPM	0.62	6.20
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	205.3	255.3
BROMODICHLOROMETHANE, PPB	83.9	93.4
CHLORODIBROMOMETHANE, PPB	38.4	39.1
BROMOFORM, PPB	5.7	4.9
TOTAL TRIHALOMETHANES, PPB	333.3	392.7

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #13

LABORATORY IDENTIFICATION: 93W7101 #6

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	0.49	6.39
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	115.1	152.2
BROMODICHLOROMETHANE, PPB	72.9	84.6
CHLORODIBROMOMETHANE, PPB	47.2	48.1
BROMOFORM, PPB	10.9	8.5
TOTAL TRIHALOMETHANES, PPB	246.1	293.4

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #9

LABORATORY IDENTIFICATION: 93W7101 #7

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	21.8	30.0
RESIDUAL FREE CHLORINE, PPM	4.52	10.6
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	167.8	187.5
BROMODICHLOROMETHANE, PPB	75.3	78.9
CHLORODIBROMOMETHANE, PPB	34.7	37.2
BROMOFORM, PPB	5.3	4.5
TOTAL TRIHALOMETHANES, PPB	283.1	308.1

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #10

LABORATORY IDENTIFICATION: 93W7101 #8

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	0.97	5.77
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	102.9	133.9
BROMODICHLOROMETHANE, PPB	70.9	82.6
CHLORODIBROMOMETHANE, PPB	39.5	51.7
BROMOFORM, PPB	13.3	10.4
TOTAL TRIHALOMETHANES, PPB	226.6	278.6

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #11

LABORATORY IDENTIFICATION: 93W7101 #9

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	1.68	7.03
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	149.0	178.6
BROMODICHLOROMETHANE, PPB	60.4	67.0
CHLORODIBROMOMETHANE, PPB	29.9	30.2
BROMOFORM, PPB	3.6	3.0
TOTAL TRIHALOMETHANES, PPB	242.9	278.8

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SKYCO WELL #12

LABORATORY IDENTIFICATION: 93W7101 #10

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	2.12	7.69
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	162.6	193.8
BROMODICHLOROMETHANE, PPB	73.2	80.8
CHLORODIBROMOMETHANE, PPB	34.2	34.9
BROMOFORM, PPB	4.3	3.6
TOTAL TRIHALOMETHANES, PPB	274.3	313.1

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: COMPOSITE WELL SAMPLE #11

LABORATORY IDENTIFICATION: 93W7101 #11

	TRIAL 1	TRIAL 2	TRIAL 3
TYPE OF ANALYSIS	THM FP	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8	30.0
RESIDUAL FREE CHLORINE, PPM	0.367	5.71	10.7
INCUBATION TIME	7 DAYS	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F	77 F

	TRIAL 1	TRIAL 2	TRIAL 3
TRIHALOMETHANES:			
CHLOROFORM, PPB	126.4	165.3	189.9
BROMODICHLOROMETHANE, PPB	67.9	78.3	84.8
CHLORODIBROMOMETHANE, PPB	34.9	38.3	39.1
BROMOFORM, PPB	7.5	5.9	5.1
TOTAL TRIHALOMETHANES, PPB	236.7	287.8	318.9

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

IEA
An Aquarion Company

1133 Sawgrass Corporate Parkway
Sunrise, Florida 33323-2805

Phone 305·846·1730
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CLIENT: BLACK AND VEATCH
8400 WARD PARKWAY
KANSAS CITY, MO 64114
ATTN: DOUG ELDER

DATE: MAY 11, 1993

DATE SAMPLED: 04/27/93

SAMPLE RECEIVED: 04/28/93

SAMPLED BY: CLIENT

SAMPLE DESIGNATION: SKYCO WATER PLANT
THMFP ANALYSIS

LABORATORY NO: 93-0992

REPORT OF ANALYSIS

SAMPLE I.D.#	CHLOROFORM	BROMOFORM	BROMODI-CHLOROMETHANE	DIBROMO-CHLOROMETHANE	TOTAL TRIHALOMETHANE
# 1	200	< 1.0	50	15	265
# 2	113	20	82	59	274
# 3	130	6.6	78	53	268
# 4	62	2.4	32	17	113
# 5	59	< 1.0	24	11	94
# 6	214	2.8	92	32	341
# 7	160	10	80	49	299
# 8	160	5.1	68	35	268
# 9	130	12	74	50	266
# 10	195	2.2	66	26	289
# 11	168	6.0	73	39	286

* All are expressed in ug/l.

SAMPLE I.D.	LOCATION
# 1	WELL #1
# 2	WELL #4
# 3	WELL #5
# 4	WELL #7
# 5	WELL #8
# 6	WELL #13
# 7	WELL #9
# 8	WELL #10
# 9	WELL #11
# 10	WELL #12
# 11	SKYCO RAW COMPOSITE

The above analysis was performed in accordance with E.P.A., A.S.T.M., Standard Methods or other approved methods. Date of analysis 05/06/93. Analyzed by SS. Laboratory I.D.-DHRS No. 86111, E-86106.

KP/db

Appendix F

Ozone Demand Testing Data
for Skyco WTP

Dare County, North Carolina
THM Reduction Study
Summary: Ozonation of Skyco Softened Water

Raw Water TOC = 2.70 mg/L
Raw Water Turbidity = 0.60 NTU
Raw Water Color = 20 units
Raw Water Iron = 0.40 mg/L
Ozone generator pressure = 14 psi
Testing date: March 9, 1993

Time (min)	Gas Flow (SPLM)	Ozone Weight %	Ozone Residual (mg/L)	Applied O3 Dosage (mg/L)
0	0.6	0.267	-	0.00
1	0.6	0.26	-	0.21
2	0.6	0.248	0	0.41
3	0.6	0.258	0	0.61
4	0.6	0.258	-	0.82
5	0.65	0.251	0	1.04
6	0.6	0.257	-	1.25
7	0.6	0.258	0	1.45
8	0.65	0.253	-	1.67
9	0.7	0.242	0	1.90
10	0.65	0.252	-	2.12
11	0.65	0.251	0	2.34
12	0.65	0.242	0.01	2.55
13	0.65	0.248	-	2.76
14	0.65	0.25	0.03	2.98
15	0.7	0.247	-	3.21
16	0.7	0.247	-	3.44
17	0.65	0.258	-	3.67
18	0.7	0.246	0.12	3.90
19	0.7	0.248	-	4.13
20	0.65	0.256	-	4.35
21	0.65	0.253	-	4.57
22	0.65	0.25	0.17	4.79
23	0.7	0.248	-	5.02
24	0.65	0.253	-	5.24
25	0.7	0.248	-	5.47
26	0.7	0.243	0.23	5.70
27	0.65	0.255	-	5.92

Dare County, North Carolina
THM Reduction Study
Summary: Ozonation of Skyco Softened Water

Time (min)	Gas Flow (SPLM)	Ozone Weight %	Ozone Residual (mg/L)	Applied O3 Dosage (mg/L)
28	0.6	0.252	-	6.12
29	0.7	0.247	-	6.36
30	0.65	0.251	0.24	6.57
	(Ozone shut off at 30 minutes)			
31			-	
32			0.22	
33			-	
34			-	
35			0.17	
36			-	
37			-	
38			-	
39			0.03	
40			-	
41			0.02	
42			-	
43			-	
44			0	

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93W5931

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KANSAS CITY, MO 64111

ATTENTION: DOUG ELDER

RE: 1 SAMPLE FOR TRIHALOMETHANE ANALYSIS

DISCUSSION:

THE DATA REPORTED HEREIN FOR MAXIMUM THM FORMATION POTENTIAL (THMFP) WAS OBTAINED USING EPA METHOD 510.1. THIS PROCEDURE DEVELOPS TOTAL TRIHALOMETHANES IN A SODIUM BORATE BUFFER (PH 9.0-9.5) USING SODIUM HYPOCHLORITE AS THE CHLORINE SOURCE. THE INCUBATION CONDITIONS ARE 7 DAYS AT 25 DEGREES C.

ALSO, IF REQUESTED, SOME SAMPLES MAY HAVE BEEN ANALYZED UNDER A SIMULATED DISTRIBUTION SYSTEM (SDS) PROTOCOL AS DESCRIBED IN STANDARD METHODS 5710E.

FOR BOTH PROTOCOLS, THE INITIAL CHLORINATION LEVELS, ACTUAL INCUBATION TEMPERATURES, AND THE RESIDUAL FREE CHLORINE AFTER INCUBATION CAN BE FOUND ON THE RESULTS FORM ATTACHED.

Bruce A. Babson
BRUCE A. BABSON, CHEMIST

Oxford Laboratories, Inc.

Analytical and Consulting Chemists
1316 South Fifth Street
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(919) 763-9793

DATE RECEIVED 03-15-93
DATE REPORTED 03-29-93
93W5931

BLACK & VEATCH
8400 WARD PARKWAY
KANSAS CITY, MO 64111

ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: RAW

LABORATORY IDENTIFICATION: 93W5931

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.1	26.2
RESIDUAL FREE CHLORINE, PPM	<0.1	6.4
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	56.7	219.3
BROMODICHLOROMETHANE, PPB	36.6	78.9
CHLORODIBROMOMETHANE, PPB	26.1	42.0
BROMOFORM, PPB	4.9	4.3
TOTAL TRIHALOMETHANES, PPB	124.3	344.5

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

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BLACK & VEATCH INC.
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KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: 16 THM

1. RAW TRIAL 1 30 MIN. INCUBATION
2. RAW TRIAL 2 30 MIN. INCUBATION
3. RAW TRIAL 1 6 HRS INCUBATION
4. RAW TRIAL 2 6 HRS INCUBATION
5. RAW TRIAL 1 24 HRS INCUBATION
6. RAW TRIAL 2 24 HRS INCUBATION

RESULTS

	1	2	3	4	5	6
Initial Chlorination, PPM	7.92	15.84	7.92	15.84	7.92	15.84
Residual Free Chlorine, PPM	1.32	9.22	0.55	7.55	<0.1	6.88
Total Trihalomethanes, PPB	23.2	32.7	48.8	66.1	66.9	96.0
Chloroform, PPB	14.9	20.7	22.8	33.9	28.0	48.8
Dichlorobromomethane, PPB	5.0	7.6	14.1	20.1	22.1	30.7
Dibromochloromethane, PPB	3.3	4.4	10.6	12.1	15.2	15.5
Bromoform, PPB	<1.0	<1.0	1.3	<1.0	1.6	1.0

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ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: 16 THM

7. RAW TRIAL 1 4 DAYS INCUBATION
8. RAW TRIAL 2 4 DAYS INCUBATION
9. OZONATED TRIAL 1 30 MIN. INCUBATION
10. OZONATED TRIAL 2 30 MIN. INCUBATION
11. OZONATED TRIAL 1 6 HRS INCUBATION
12. OZONATED TRIAL 2 6 HRS INCUBATION

RESULTS

	7	8	9	10	11	12
Initial Chlorination, PPM	7.92	15.84	7.92	15.84	7.92	15.84
Residual Free Chlorine, PPM	<0.1	4.07	2.30	9.41	0.92	8.50
Total Trihalomethanes, PPB	72.4	135.6	15.2	17.7	39.4	44.6
Chloroform, PPB	30.3	72.0	5.2	6.9	7.6	14.2
Dichlorobromomethane, PPB	25.0	42.7	3.1	4.3	9.9	13.0
Dibromochloromethane, PPB	15.2	19.7	5.0	5.5	16.5	15.1
Bromoform, PPB	1.9	1.2	1.9	1.0	5.4	2.3

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P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: 16 THM

13. OZONATED TRIAL 1 24 HRS INCUBATION
14. OZONATED TRIAL 2 24 HRS INCUBATION
15. OZONATED TRIAL 1 4 DAYS INCUBATION
16. OZONATED TRIAL 2 4 DAYS INCUBATION

RESULTS

	13	14	15	16
Initial Chlorination, PPM	7.92	15.84	7.92	15.84
Residual Free Chlorine, PPM	0.53	7.64	<0.1	5.04
Total Trihalomethanes, PPB	62.1	71.3	82.3	112.2
Chloroform, PPB	12.0	23.8	16.4	41.0
Dichlorobromomethane, PPB	19.0	24.1	26.4	38.6
Dibromochloromethane, PPB	23.4	20.2	30.1	28.7
Bromoform, PPB	7.7	3.2	9.4	3.9

NOTE: FOR ALL SAMPLES THE INCUBATION TEMPERATURE WAS 55 DEGREES FAHRENHEIT.

Bruce A Babson
BRUCE A. BABSON, CHEMIST

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93W6071

PAGE 1 OF 1

BLACK & VEATCH INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: 1 TOC

1. RAW WATER

RESULTS

	1
Total Organic Carbon, as C, PPM	2.70

Roger Oxford
ROGER C. OXFORD, CHEMIST

Appendix G

Testing Results for Skyco WTP

SKYCO

PPB

		SKYCO	RO	FR PND
TEST 1				
	1 DAY	94.1	12.2	75.5
TEST 2				
	1 DAY	112.5	12.6	95.5
TOC		3.30		4.62

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93W7103

BLACK & VEATCH INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: SKYCO PLANT (THM-SDS)

1. TEST 1 15 MIN.
2. TEST 1 30 MIN.
3. TEST 1 1 DAY
4. TEST 1 4 DAYS
5. TEST 1 7 DAYS
6. TEST 2 15 MIN.

RESULTS

	1	2	3	4	5	6
Residual Chlorine, PPM	3.0	3.1	2.1	1.6	1.4	10.6
Chloroform, PPB	12.8	15.1	41.5	47.8	61.6	16.8
Bromoform, PPB	<1.0	<1.0	1.7	1.9	2.1	<1.0
Bromodichloromethane, PPB	3.7	5.5	31.8	38.5	42.5	5.4
Chlorodibromomethane, PPB	2.2	3.7	19.1	20.1	23.6	3.1
Total THM, PPB	18.7	24.3	94.1	106.4	129.8	25.3
DATE EXTRACTED	5/5	5/5	5/10	5/10	5/12	5/5
DATE ANALYZED	5/5	5/5	5/10	5/10	5/12	5/5

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93W7103

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P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: SKYCO PLANT (THM-SDS)

7. TEST 2 30 MIN.
8. TEST 2 1 DAY
9. TEST 2 4 DAYS
10. TEST 2 7 DAYS

RESULTS

	7	8	9	10
Residual Chlorine, PPM	12.2	12.7	10.6	7.9
Chloroform, PPB	20.6	55.9	73.6	91.6
Bromoform, PPB	<1.0	1.2	1.4	1.5
Bromodichloromethane, PPB	7.7	36.6	43.7	52.3
Chlorodibromomethane, PPB	4.4	18.8	21.4	25.1
Total THM, PPB	32.7	112.5	140.1	170.5
DATE EXTRACTED	5/5	5/10	5/10	5/12
DATE ANALYZED	5/5	5/10	5/10	5/12

NOTE: INITIAL CHLORINATION WAS 10 PPM FOR TEST 1 AND 20 PPM FOR TEST 2. ALL INCUBATIONS WERE AT 55 DEGREES F.

Bruce A Babson
BRUCE A. BABSON, CHEMIST

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93W7102

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8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: SKYCO WATER

1. SKYCO WELL #1
2. SKYCO WELL #4
3. SKYCO WELL #5
4. SKYCO WELL #7
5. SKYCO WELL #8
6. SKYCO WELL #13

RESULTS

	1	2	3	4	5	6
Total Organic Carbon, as C, PPM	2.41	2.87	4.10	9.54	4.49	3.00

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P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: SKYCO WATER

7. SKYCO WELL #9
8. SKYCO WELL #10
9. SKYCO WELL #11
10. SKYCO WELL #12
11. COMPOSITE WELL

RESULTS

	7	8	9	10	11
Total Organic Carbon, as C, PPM	13.3	2.74	3.32	5.65	3.13
Bromide, as Br, PPM	X	X	X	X	.180
Silica, as Si02, PPM	X	X	X	X	27.4

Roger Oxford
ROGER C. OXFORD, CHEMIST

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93W7289

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BLACK & VEATCH INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: SKYCO PLANT (TOC)

1. SKYCO PLANT SOFTENER DISCHARGE

RESULTS

	1
Total Organic Carbon, as C, PPM	3.30

Roger Oxford
ROGER C. OXFORD, CHEMIST

DATE RECEIVED 04-28-93
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93W7101

BLACK & VEATCH, INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: SOFTENER DISCHARGE #12

LABORATORY IDENTIFICATION: 93W7101 #12

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	14.0	21.8
RESIDUAL FREE CHLORINE, PPM	3.30	9.18
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F
	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	157.0	180.5
BROMODICHLOROMETHANE, PPB	76.6	83.1
CHLORODIBROMOMETHANE, PPB	38.5	39.1
BROMOFORM, PPB	5.9	5.1
TOTAL TRIHALOMETHANES, PPB	278.0	307.8

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

Appendix H

Testing Results for Fresh Pond WTP

Oxford Laboratories, Inc.

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93W7110

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BLACK & VEATCH INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: FRESH POND FROM KS (THM-SDS)

1. SETTLED WATER TEST 1 15 MIN.
2. SETTLED WATER TEST 1 30 MIN.
3. SETTLED WATER TEST 2 15 MIN.
4. SETTLED WATER TEST 2 30 MIN.
5. FILTERED WATER TEST 1 30 MIN.
6. FILTERED WATER TEST 1 1 HR.

RESULTS

	1	2	3	4	5	6
Residual Chlorine, PPM	9.7	9.7	20.4	19.3	9.1	9.4
Chloroform, PPB	3.1	4.0	4.4	5.5	9.6	11.1
Bromoform, PPB	<1.0	<1.0	<1.0	<1.0	1.0	1.1
Bromodichloromethane, PPB	2.1	2.9	2.6	4.0	7.1	7.7
Chlorodibromomethane, PPB	2	2.5	2.2	3.0	5.7	5.9
Total THM, PPB	7.2	9.4	9.2	12.5	23.4	25.8
DATE EXTRACTED	5/5	5/5	5/5	5/5	5/5	5/10
DATE ANALYZED	5/5	5/5	5/5	5/5	5/5	5/10

DATE RECEIVED 04-28-93
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93W7110

BLACK & VEATCH INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: FRESH POND FROM KS (THM-SDS)

7. FILTERED WATER TEST 1 8 HRS.
8. FILTERED WATER TEST 1 1 DAY
9. FILTERED WATER TEST 1 4 DAYS
10. FILTERED WATER TEST 1 7 DAYS
11. FILTERED WATER TEST 2 30 MIN.
12. FILTERED WATER TEST 2 1 HR.

RESULTS

	7	8	9	10	11	12
Residual Chlorine, PPM	8.3	8.3	7.2	6.0	18.6	19.1
Chloroform, PPB	18.0	31.9	43.1	57.1	11.0	12.5
Bromoform, PPB	1.7	2.1	2.3	2.4	<1.0	1.0
Bromodichloromethane, PPB	15.8	25.4	32.2	37.1	8.4	9.2
Chlorodibromomethane, PPB	11.4	16.1	17.8	17.6	6.2	6.7
Total THM, PPB	46.9	75.5	95.4	114.2	25.6	29.4
DATE EXTRACTED	5/10	5/10	5/10	5/12	5/5	5/10
DATE ANALYZED	5/10	5/10	5/10	5/12	5/5	5/10

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KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: FRESH POND FROM KS (THM-SDS)

13. FILTERED WATER TEST 2 8 HRS.
14. FILTERED WATER TEST 2 1 DAY
15. FILTERED WATER TEST 2 4 DAYS
16. FILTERED WATER TEST 2 7 DAYS

RESULTS

	13	14	15	16
Residual Chlorine, PPM	18.8	19.6	17.7	16.2
Chloroform, PPB	22.4	46.2	62.7	85.2
Bromoform, PPB	1.5	2.0	2.2	2.1
Bromodichloromethane, PPB	18.1	29.8	35.2	42.2
Chlorodibromomethane, PPB	11.9	17.5	18.0	18.8
Total THM, PPB	53.9	95.5	118.1	148.3
DATE EXTRACTED	5/10	5/10	5/10	5/12
DATE ANALYZED	5/10	5/10	5/10	5/12

NOTE: INITIAL CHLORINATION WAS 10 PPM FOR TEST 1 AND 20 PPM FOR TEST 2. ALL INCUBATIONS WERE AT 55 DEGREES F.

Bruce A. Babson
BRUCE A. BABSON, CHEMIST

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KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: FRESH POND FROM KS

1. SETTLED WATER FRESH POND FROM KANSAS
2. FILTERED WATER FRESH POND FROM KANSAS

RESULTS

	1	2
pH (Lab)	6.70	7.1
Total Organic Carbon, as C, PPM	X	4.62

Roger Oxford
ROGER C. OXFORD, CHEMIST

Oxford Laboratories, Inc.

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DATE RECEIVED 04-22-93
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93W6967

BLACK & VEATCH, INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

PAGE 2 OF 2

ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: FRESH POND WTP - RAW WATER

LABORATORY IDENTIFICATION: 93W6967

	TRIAL 1	TRIAL 2
TYPE OF ANALYSIS	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	11.7	23.4
RESIDUAL FREE CHLORINE, PPM	9.63	24.2
INCUBATION TIME	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F

	TRIAL 1	TRIAL 2
TRIHALOMETHANES:		
CHLOROFORM, PPB	326.0	401.7
BROMODICHLOROMETHANE, PPB	65.8	68.3
CHLORODIBROMOMETHANE, PPB	22.2	21.1
BROMOFORM, PPB	2.0	1.5
TOTAL TRIHALOMETHANES, PPB	416.0	492.6

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7 RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

Oxford Laboratories, Inc.

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8400 WARD PARKWAY
KANSAS CITY, MO 64114

PAGE 2 OF 2

ATTENTION: DOUG ELDER

YOUR SAMPLE IDENTIFICATION: FILTERED WATER FRESH POND FROM KANSAS

LABORATORY IDENTIFICATION: 93W7109

	TRIAL 1	TRIAL 2	TRIAL 3
TYPE OF ANALYSIS	THM FP	THM FP	THM FP
INITIAL CHLORINATION LEVEL, PPM	13.44	23.41	28.11
RESIDUAL FREE CHLORINE, PPM	7.22	16.43	20.79
INCUBATION TIME	7 DAYS	7 DAYS	7 DAYS
INCUBATION TEMPERATURE	77 F	77 F	77 F
	TRIAL 1	TRIAL 2	TRIAL 2
TRIHALOMETHANES:			
CHLOROFORM, PPB	185.2	208.1	215.9
BROMODICHLOROMETHANE, PPB	58.6	62.7	62.8
CHLORODIBROMOMETHANE, PPB	23.8	26.2	26.1
BROMOFORM, PPB	3.9	3.3	3.0
TOTAL TRIHALOMETHANES, PPB	271.5	300.3	307.8

NOTE: THE TEST IS INVALID PER METHOD 510.1 IF THE DAY 7
RESIDUAL FREE CHLORINE DOES NOT EXCEED 0.2 PPM
ND = NOT DETECTED
NA = NOT ANALYZED

Oxford Laboratories, Inc.

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93W6965

PAGE 1 OF 1

BLACK & VEATCH INC.
8400 WARD PARKWAY
KANSAS CITY, MO 64114

P.O. #

ATTENTION: DOUG ELDER

SAMPLE DESCRIPTION: FRESH POND WTP

1. FRESH POND WTP RAW WATER

	RESULTS 1
Bromide, as Br, PPM	.115
Total Organic Carbon, as C, PPM	4.98

Roger Oxford
ROGER C. OXFORD, CHEMIST

Appendix I

Disinfection CT Calculations for Fresh Pond WTP

Fresh Pond WTP Disinfection CT Calculations

1. Assumptions / Operating Conditions

Max. settled/filtered pH 6.5 - 7.0; max. clearwell discharge pH 7.5 - 8.0

Min temperature: Evaluate at 10C, 15C

Min. chloramine residual at plant discharge = 2 mg/L

Max. plant flow = 1000 gpm

Removal credits (from NCDEH): Giardia cysts = 2.07-log
Viruses = 1.66-log

2. Facilities

Filter influent pipeline (from point of chlorination) = 85 ft; 16-inch diameter

Neglect filter inlet, outlet piping

Filters: 2 at 144 sq ft each
Water depth above media = 4.25 ft (assume 1 ft freeboard in box)

Clearwell: Plan area = 606.76 sq ft (4540 gallons per ft. depth)
Total depth (no freeboard) = 9 ft
Min depth for CT analyses = 4 ft (from previous tracer testing)
Sump volume = 900 gallons
At 4 ft depth, volume = 18,160 gallons + 900 gallons sump
= 19,000 gallons

3. Available T10 Times

Filter influent pipe: Volume = $((16/12)^2\pi/4)(85)(7.48)$ = 888 gallons

Detention (plug flow) = 888 gals/1000 gpm = 0.89 minutes

Filters: Volume above media = (144 sq ft)(2)(4.25 ft)(7.48) = 9156 gallons

T at 1000 gpm = 9156 gals/1000 gpm = 9.16 minutes

T_{10} (T_{10}/T ratio of 70%) = 6.4 minutes

T_{10} for filter influent pipe + filters = 0.89 + 6.4 = 7.29 minutes

4. Check CTs Using Only "Pre-Clearwell" T_{10} Times

a: Temperature 15C; pH 6.5

CT req'd (0.93-log cyst inact.) at 3 mg/L chlorine = 24

CT provided = (7.29 minutes)(3 mg/L) = 21.9

CT ratio = 21.9/24 = 0.91 (ratio < 1.0, too low)

At 3.3 mg/L residual, CT provided = (7.29 minutes)(3.3 mg/L) = 24.1

CT ratio = 24.1/24 = 1.00 (OK)

b: Temperature 15C; pH 7.0

CT req'd (0.93-log cyst inact.) at 3 mg/L chlorine = 28

C req'd = 28/7.29 = 3.84 mg/L

c: Temperature 10C; pH 6.5

CT req'd (0.93-log cyst inact.) at 3 mg/L chlorine = 36

C req'd = 36/7.29 = 4.94 mg/L

d: Temperature 10C; pH 7.0

CT req'd (0.93-log cyst inact.) at 3 mg/L chlorine = 43

C req'd = 43/7.29 = 5.90 mg/L

e: Summary

Chlorine residuals required for compliance with CT criteria range from 3.3 to 5.90 mg/L. This may lead to unacceptably high chloramine concentrations following addition of ammonia at the filter discharge pipelines. Additional contact time (using clearwell) would allow use of lower free chlorine residuals, with corresponding reductions in treated water chloramine levels.

Fresh Pond WTP Disinfection CT Calculations (continued)

5. Evaluate CTs Using Clearwell Storage

Assume: Min. free chlorine residual across filters/clearwell of 2.5 mg/L during "worst-case" temperature and pH conditions.

Filter discharge max pH 7.0

Clearwell discharge max pH 8.0 (caustic added at filter discharge)

CT provided prior to clearwell = (2.5 mg/L)(7.29 minutes) = 18.23

Theoretical clearwell detention time, T, at 1000 gpm = 19,000 gals/1000 gpm
= 19 minutes

a: Temperature 15C

CT req'd (0.93-log cyst inact.) at 2.5 mg/L chlorine, pH 7.0 = 23

CT ratio provided prior to clearwell = 18.23/23 = 0.79

CT ratio req'd for clearwell = 1.0 - 0.79 = 0.21

CT req'd (0.93-log cyst inact.) at 2.5 mg/L chlorine, pH 8.0 = 40

Clearwell T_{10} req'd = (0.21)(40)/2.5 mg/L = 3.36 minutes

Clearwell T_{10}/T ratio req'd = 3.36/19 = 0.18

b: Temperature 10C

CT req'd (0.93-log cyst inact.) at 2.5 mg/L chlorine, pH 7.0 = 41

CT ratio provided prior to clearwell = 18.23/41 = 0.44

CT ratio req'd for clearwell = 1.0 - 0.44 = 0.56

CT req'd (0.93-log cyst inact.) at 2.5 mg/L chlorine, pH 8.0 = 60

Clearwell T_{10} req'd = (0.56)(60)/2.5 mg/L = 13.44 minutes

Clearwell T_{10}/T ratio req'd = 13.44/19 = 0.71

Fresh Pond WTP Disinfection CT Calculations (continued)

c. Summary

Detention time provided by the clearwell will be required to comply with disinfection CT criteria. Clearwell will need to be baffled to reduce short circuiting and yield required T_{10}/T ratios. Add ammonia at pump suction or in clearwell discharge pipe.

Appendix J

THMFP Reduction Experience for Nanofiltration

Dare County, North Carolina
Nanofiltration THMFP Removal Summary

B&V Project 23464.150

Location	Test	THMFP, ug/L Raw	 Perm	Rej.	Membrane
Daytona Beach, FL	Pilot	224	10	95.5	NF70
Indian River County, FL	Plant	232	12	94.8	PVD1 CPA2
Flagler Beach, FL	Pilot	400	20	95.0	NF70
West Jupitor, FL	Plant	429	5	98.8	NF70
Palm Beach County, FL	Plant	630	56	91.1	NF70
Punta Gorda, FL	Pilot	880	37	95.8	NF70
Edisto River, SC	Pilot	985	50	94.9	ROGA LP
		985	8	99.2	PVD1
ACME Impr. District, FL	Pilot	1066	32	97.0	N50
Dismal Swamp, VA	Pilot	2440	20	99.2	NF70
		2440	22	99.1	ROGA LP
		2440	59	97.6	PVD1
Brevard County, FL	Pilot	2500+		96.0	FT-50

NF70, N50, FT-50 membranes manufactured by Dow/Filmtec
PVD1, CPA2 membranes manufactured by Hydranautics
ROGA LP membranes manufactured by Fluid Systems Div., UOP

Appendix K

Macroporous Anion Exchange Resin Information

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TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
Thermax Anionic Resin

B&V Project 23464.150
B&V File B
May 7, 1993
12:45 p.m.

From:	Brian Larson
Company:	Thermax Ltd.
Phone No.:	(313) 474-3050
Recorded by:	DBE

Brian returned my call regarding experience with Thermax's Tulsion A-72MP decolorizing resin at Western Carteret County, North Carolina. The county operates a groundwater treatment plant which includes a 1.55 mgd macroporous anion exchange resin system for removal of color and THMFP. The Thermax resin was initially developed for decolorizing of wastes from sugar cane processing operations. Brian indicated that the Thermax resin differs from decolorizing resins manufactured by Dow and R&H, as it is a styrene-based material (apparently the Dow and R&H resins are acrylic-based). He also indicated that the plant was regenerating the resin (using a conventional salt brine) only every six months, and that throughput rates were averaging 170,000 gallons per cubic foot of resin volume. Regeneration produces a wastestream that has the appearance of "used crankcase oil" during initial stages of the regeneration process. Raw water color is 20 to 25 units.

Brian did not have any specific data on raw/treated water THMFP; he suggested that I call Dan Fortin, the Systems Manager (pager number is (919) 274-8929; office number is (919) 393-8720) to check on availability of THMFP information. (also no info on TOC removal) Brian stated that, to his knowledge, the Western Carteret County plant is the only U.S. municipal plant using a macroporous strong base anionic resin for color/THMFP removal.

He also suggested that we contact Spencer Bush at Refinite Water Conditioning in Rock Hill, NC; Refinite supplied the treatment system hardware.

I referred to the work completed by Jim Symons at the Univ.of Houston, and the early breakthrough of THMFP that was observed. Brian was familiar with the work; he stated that early breakthrough is not a problem with the Thermax resin, as it differs from the resin used during Symon's study (the resin used by Symons was acrylic-based). Brian stated that the polystyrene-based Thermax resin is more selective for organic materials, and that effective resin pore sizes are higher than for similar Dow/R&H resins. "Approximate" unit cost for the Thermax resin is $200/cubic foot.

I asked if costs for conventional ion exchange softening equipment could be used to develop order-of-magnitude cost estimates for a treatment system using the Thermax resin. Brian indicated that equipment would be essentially identical to that for conventional cation exchange softening plants.

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TELEPHONE MEMORANDUM

Dare County, North Carolina	B&V Project 23464.150
THM Reduction Study	B&V File B
West Carteret County WTP Information	May 10, 1993
	10:00 a.m.

From: Dan Fortin
Company: Western Carteret Water Corporation
Phone No.: (919) 393-8720

Recorded by: DBE

Dan called back with information on the Thermax anion exchange resin portion of Western Carteret County's water treatment plant.

The plant was placed in service during September 1991, and the anion resin system has performed very well. The system consists of three exchange vessels, each rated at 360 gpm (one of the three units is not equipped with resin at this time). Exchange vessels are 10 ft. diameter, with a resin depth of approximately 36 inches. Approximately 50 percent of the total plant flow is directed through the anion exchange vessels. Each vessel is currently treating approximately 15 MG of flow between regeneration cycles. This is equivalent to a throughput rate between regenerations of approximately 4250 bed volumes. (Current average plant production is about 250,000 gpd; anion resin throughput average is therefore about 125,000 gpd.)

The primary purpose of the anion resin is to remove color. Raw water color averages 20 to 25 units.

THMFP was determined for the anion resin vessel inlet and discharge during November 1991 (2 months after plant startup). At that time, 7-day THMFP for the aerated, IX softened water was 258 ug/L; the anion resin reduced THMFP to 45 ug/L.

Regeneration is accomplished using a conventional salt brine. No caustic has been used for regeneration to date. Regeneration waste is discharged to a "sand pit" equipped with an underdrain collection system. Flow from the underdrain is discharged to a stream.

Dan indicated that he is "very pleased" with the performance of the plant thus far.

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TELEPHONE MEMORANDUM

Dare County, North Carolina
THM Reduction Study
Cape Hatteras Anion Resin Testing

B&V Project 23464.150
B&V File B
May 10, 1993
11:45 a.m.

From: Jim Coleman
Company: Cape Hatteras, NC Water Dept.
Phone No.: (919) 995-5061

Recorded by: DBE

Cape Hatteras is currently conducting pilot tests using an anion exchange resin supplied by Matson & Co. out of Chicago (contact is Clyde Faust). Jim thinks that the resin supplied has been "tailored" to some extent to meet the utility's THM reduction requirements. Following conventional coagulation, sedimentation, and filtration, the groundwater is softened using a cation exchange system. TOC following IX softening ranges from 10.5 to approximately 13.5 mg/L. The anion resin reduces TOC to "2.2 mg/L or less", for the first 50,000 gallons treated. (Resin volume used is 40 cubic feet; this flow corresponds with a throughput rate of only about 250 bed volumes.) Anion exchange resin discharge TOC increases to "2.5 to 5.2 mg/L" at flow throughput volumes between 50,000 gallons and 120,000 gallons.

No information on untreated/treated THMFP is currently available. Samples were recently sent to Oxford Laboratories for analysis of THMFP; results should be available in "4 to 6 weeks".