Report from the

Delta Municipal and Industrial Water Quality Workgroup

to

the California State Water Resources Control Board

for

the Proceedings on the

San Francisco Bay/Sacramento-San Joaquin Delta Estuary

APPENDIX A

October 17, 1989

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Supplementary Material and References

Other References:

14. Science Advisory Board Drinking Water Committee Meeting of October 11, 1989 Discussion of Strawman Rule for Disinfectants and Disinfection By-Products by Stephen W. Clark, USEPA, dated September 22, 1989.

15. Krasner, S.W., M.J. McGuire, J.G. Jacangelo, N.L. Patania, K.M. Reagan and E.M. Aieta, "The Occurrence of Disinfection By-products in US Drinking Water", Journal of the AWWA vol. 81, no. 8, August 1989.

16. McGuire, M.J., M.K Davis, C.H. Tate, E.M. Aieta, I.E Wallace, J.C. Crittenden, "Evaluation of Granular Activated Carbon for Trihalomethane Control" Presented at the AWWA Research Foundation/U.S. EPA Conference, May 9-10, 1989, Cincinnati, Ohio.

17. Brown and Caldwell, Delta Drinking Water Quality Study, May, 1989 prepared for the California Urban Water Agencies

1. Summary of Presentation by Steve Clark

Steve Clark, USEPA, spoke about DBP Regulations. Maximum Contaminant Levels (MCLs) for chlorine, chloramine, and other oxidants are likely to be proposed in fall, 1991 and finalized in fall, 1992 if no "major" comments are received. Major comments would be new information that would require reevaluation and additional time for public comment. Under this timetable, compliance would be required in 1994.

DBP standards are likely for both chlorinated DBP's as well as other oxidant DBP's. He indicated that they will present to the Science Advisory Board a Strawman rule for discussion and that there will be workshops later in the fall or early winter. By September 1990, treatment, health effects and other documents will be put together. In 1991, they will start to put together the details of the regulations in an open fashion, with considerable feedback from the public.

He emphasized that the regulations will take into account the need for high levels of disinfection to protect against microbial agents of disease.

Table 1 shows disinfectants under consideration for regulations.

Table 1. MCLs For Disinfectants

Chlorine
Chloramines
Chlorine Dioxide
- Chlorite
- Chlorate

Table 2 shows DBPs under consideration.

Table 2. Chlorination By-Products

- Trihalomethanes
- Haloacetic Acids
- Haloacetonitriles
- Haloketones
- Chloral Hydrate
- Chlorophenols
- Chloropicrin
- Cyanogen Chloride
- MX
- N-Organochloramines

DBP standards could be promulgated as:

- Treatment Technique
- MCLs for Total Organic Halide (TOX)
- MCLs for Selected Groups
- MCLs for Individual Compounds

Specification of a treatment technique to control DBPs is not likely, although EPA may provide guidance on how to minimize MX formation and to control assimilable organic carbon.

The revised total THM standard is currently being studied but is likely to be between 25 and 50 ppb.

He indicated there is a list of oxidant by-products, formed in part to take ozone into account. Bromine substituted compounds and aldehydes are compounds under serious consideration for regulation. Data are still being collected on bromate and iodate.

Table 3. Oxidation By-Products Under Consideration

- Aldehydes
- Acids
- Bromine Substituted
- Hydrogen Peroxide
- Bromate
- Iodate
- Ketones
- Peroxides
- Epoxides
- Nitrosamines
- N-Oxy Compounds

Clark covered major issues, treatment techniques and the

regulatory approach. Some of the major issues include:

- o Awaiting data on chlorination by-products.
- o Lack of data on oxidant by-products.
- o Disinfectant residual levels; especially toxicity of chloramine.
- o Health effects.
- o Selection of groups.
- o National impacts.
- o Estimating risk reduction.

DBP treatment techniques can be grouped into one of three categories:

Precursor removal:	conventional, GAC, membrane filtration
Alternative oxidants:	chlorine dioxide, ozone, chloramines, ultra violet light, all of which have advantages & disadvantages
Removal of by-products:	aeration (not promising) GAC (not feasible for chlorination by-products)

A likely rule structure will be MCLs for:

THMs	chlorine
chloroacetic acids	chlorine dioxide
chloropicrin	chlorite
cyanogen chloride	chlorate
TOX	contaminants
aldehydes	

There is likely to be guidance for:

AOC
MX
Disinfection practices

He noted that classes will probably be regulated, rather than individual compounds. Standards likely will continue to be based on a mass per volume basis. The likely regulatory approach is to have MCLs for groups follow the THM model and meet the risk reduction goals. Table 4 lists DBP's that will probably have

monitoring requirements.

Table 4. Monitoring Requirements

Chlorination	TTHMs Haloacetic Acids Total Organic Halides (?) Total Oxidizing Substances (?) Chloropicrin (?) Cyanogen Chloride (?) Total Chlorine Residual
Chloramination	TTHMs Chloropicrin (?) Cyanogen Chloride (?) Total Chloramine Residual (?)
Chlorine Dioxide	Total Oxidizing Substances (?) Chlorine Dioxide Chlorite Chlorate
Ozonation	Formaldehyde (?) Total Oxidizing Substances (?) Bromate (?) Iodate (?) Hydrogen Peroxide (?)

2. Summary of Presentation by Jennifer Orme

Jennifer Orme, USEPA, spoke about health aspects of DBPs. She outlined the methodology used to set MCLs (maximum contaminant levels) and MCLGs (goals). The methodology includes a risk assessment and assessment of the monitoring capabilities for particular contaminants. If a contaminant is a known or probable human carcinogen, the MCLG is set at zero. Other levels are set in accordance with EPA Reference dose procedures for noncancer health effects.

Regulators must balance the health risks of DBPs against the health risks of microbial disease. EPA recognizes that many disinfectants may themselves pose health risks and EPA will soon be promulgating standards for chlorine, chloramine, chlorine dioxide, chlorite and chlorate. In conjunction with MCLs for disinfectants, DBP's are also scheduled for new regulations in 1991.

Chlorine has been used as a disinfectant for approximately 80 years without undergoing a rigorous toxicological investigation to ascertain its human health effects from ingestion. Short term studies in animals indicate that chlorine can affect kidneys and thyroid hormone levels in animals. A weak correlation has been developed between consumption of chlorinated surface water and occurrence of bladder cancer in humans.

Short-term studies have shown that chloramines affect organ weights of mice and rats. Additional studies are underway that

may affect the risk assessment for chloramine.

Chlorine dioxide toxicity differs from the toxicity of its two inorganic by-products, chlorite and chlorate. Chlorine dioxide and chlorite affect red blood cells. Chlorine dioxide also appears to have developmental and neurotoxic affects that chlorite and chlorate do not appear to have. There are, at present, not a great deal of data on chlorate health effects.

EPA is studying and re-studying a wide-range of DBPs (see Table 1). Prior chloroform standards were based on a test in which chloroform was introduced into mice and rats via corn oil. Recent tests with a drinking water vehicle suggest that the chloroform cancer risk assessment was too conservative. EPA is evaluating the cancer risk for brominated THMs which were tested with a corn oil vehicle and thus may have a similar vehicle-of-administration issue as chloroform. Each brominated THM has been classified as a probable or possible human carcinogen by EPA.

Table 1. Disinfectants and Disinfection By-Products Considered for Development of MCLGs and MCLs

Disinfectants

- Chlorine[1]
- Chlorine Dioxide
- Chloramine
- Ozone[2]
- Iodine
- Bromine
- Potassium Permanganate
- High pH
- Ionizing Radiation
- Silver
- UV light
- Ferrate

Disinfection By-Products

- Trihalomethanes:
  - Chloroform
  - Bromoform
  - Bromodichloromethane
  - Dibromochloromethane
- Chlorinated Acetic Acids/Brominated Acetic Acids
- Chlorinated Alcohols
- Chlorinated Aldehydes
- Chlorinated Ketones
- Chlorite and Chlorate
- Haloacetonitriles
- Chlorophenols
- Chloropicrin
- Cyanogen Chloride
- Iodide, Iodate
- Bromide, Bromate
- MX

Chlorinated acetic acids have been found to occur in concentrations comparable to THM concentrations. (Brominated acetic acids may also be a problem. EPA is investigating potential health effects.) Some information from animal studies suggests that dichloroacetic acid is a potent neurotoxin. The di- and trichloroacetic acids may also be carcinogenic.

Haloacetonitriles are currently believed to have possible

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[1] Chlorine, Chlorine Dioxide and Chloramine are the only ones likely to be regulated.

[2] No residual to base an MCL.

carcinogenic effects based on results for mouse skin painting studies. They have also been shown to be fetotoxic. Information on chloropicrin that is administered by ingestion is currently under study with results expected in the next several months. Cyanogen chloride (once used as a nerve gas agent in World War I) is a by-product of chloramination. Information on its health effects is limited.

MX is a highly unstable potential mutagen. The health effects of MX and its by-products are currently under study.

General topics that are currently generating much debate and that are under investigation include:

1. Vehicle of administration issues
2. Relative source contribution
3. Use of 10 fold uncertainty factor to estimate lifetime exposure from less than lifetime study exposures
4. Reactivity of disinfectants--risks at high doses may be independent of risks at low doses
5. Interpretation of epidemiological data issues
6. Validity of the threshold mechanism for certain DBPs

3. Summary of Presentation by John Gaston

John Gaston of CH2M-Hill, representing the State Water Contractors, spoke about pollutant impacts on domestic water supplies taken from the Sacramento-San Joaquin Delta. He examined Delta water supplies and historical data with emphasis on three potential health problems: sodium, asbestos and organic contaminants, including pesticides and THM precursors. Referring to State Water Contractors exhibit 204 from the Bay-Delta Hearings, Gaston stated that asbestos and sodium levels do not generally cause problems for drinking water obtained from the Delta. A revised THM standard will be difficult to meet however. Currently there are several utilities which have had difficulty meeting the existing standard, including Long Beach, Inglewood, Palos Verdes, Vallejo and Castaic Lake.

Gaston pointed out that the July 1980 EPA Region 9 review of the Sacramento/San Joaquin Delta, Suisun Marsh Plan of the SWRCB states that the plan "should, as part of the triennial review, evaluate the following to determine new or additive standards to protect beneficial uses...", and included in the list are trihalomethane precursors.

Analyses presented by the SWC show that 172 µg/l of THMFP is generated within the Delta. This is based on a mass balance, assuming that most of the water exported at Clifton Court is from the Sacramento River (70% at 250 µg/l THMFP) and 30% from the San Joaquin (450 µg/l THMFP). Of this 172 µg/l, his analysis found that 125 µg/l is attributable to agricultural drainage. The

remainder (47 µg/l) is attributed to natural delta channel processes. The 125 µg/l contributed by the drains is roughly equivalent to 25 µg/l of THM in the distribution system. This analysis is based on mean THMFP data from the IDHAMP program.

Gaston showed examples of the 260 drains, some of which are of significant size, with up to six 36" diameter discharge pipes (found near Terminous).

Preliminary cost data for 60 large and small water treatment plants that treat water obtained from the Delta suggest that a switch to ozonation will cost an average of $25 per AF. (See attached tables.) An independent cost estimate by the City of Tracy for their system estimates a additional cost of $55-60 per AF. A switch to GAC for THM precursor removal is predicted to cost an average of $140 per AF.

In response to a question, Gaston indicated the contribution of THMFP from the ocean is small, but is responsible for a shift in species (that is, when seawater intrusion is important, more brominated forms are produced, but the total THMFP is not greatly affected).

TABLE 3

COST FOR EXISTING SURFACE WATER
TREATMENT PLANTS TO ADD GAC

AGENCY	PLANT NAME	DESIGN FLOW MGD	CAPITAL COST $Million	AMORITIZED CAPITAL $Mil/yr.	O & M COST $Mil/yr.	TOTAL COST $Mil/yr.
Alameda CFCWOD, Zone 7	Patterson Pass	14	$16	$1.6	$1.5	$3.1
Alameda CFCWOD, Zone 7	Del Valle	18	$19	$1.9	$1.9	$3.8
Alameda CWD		10	$13	$1.3	$1.1	$2.4
American Canyon WD		2	$6	$0.6	$0.3	$0.9
Antelope Val/East Kern	Eastside	3	$7	$0.7	$0.4	$1.1
Antelope Val/East Kern	Rosamond	14	$16	$1.6	$1.5	$3.1
Antelope Val/East Kern	Quartz Hill	28	$25	$2.5	$2.9	$5.4
Antioch		16	$17	$1.7	$1.7	$3.4
Avenal		2	$6	$0.6	$0.3	$0.9
Benicia, City of		10	$13	$1.3	$1.1	$2.4
Castaic Lake Water Agen.	Earl E. Schmidt	12	$14	$1.4	$1.3	$2.7
Coalinga		12	$14	$1.4	$1.3	$2.7
Contra Costa WD	Bollman	90	$61	$6.2	$9.1	$15.3
Crestline-Lake Arrow.	Crestline-Lk.Arrow	5	$9	$0.9	$0.6	$1.5
Fairfield	Waterman	22	$21	$2.1	$2.3	$4.4
Fairfield	Fairfield	30	$26	$2.6	$3.1	$5.7
Huron		2	$6	$0.6	$0.3	$0.9
Kern Co WA, ID #4		28	$25	$2.5	$2.9	$5.4
Martinez, City of		12	$14	$1.4	$1.3	$2.7
Metropolitan WD SoCal	Mills	236	$139	$14.1	$23.9	$38.0
Metropolitan WD SoCal	Skinner	554	$282	$28.7	$51.9	$80.6
Metropolitan WD SoCal	Jensen	870	$394	$40.1	$83.5	$123.6
Metropolitan WD SoCal	Weymouth	500	$264	$26.9	$47.4	$74.3
Metropolitan WD SoCal	Diemer	710	$346	$35.2	$69.7	$104.9
Napa	Hennessey	20	$20	$2.0	$2.1	$4.1
Naval AS-Lemoore		8	$11	$1.1	$0.9	$2.0
Oakley		6	$10	$1.0	$0.7	$1.7
Palmdale		12	$14	$1.4	$1.3	$2.7
Pittsburg		12	$14	$1.4	$1.3	$2.7
Santa Clara VWD	Penitencia	40	$32	$3.3	$4.1	$7.4
Santa Clara VWD	Rinconada	75	$52	$5.3	$7.6	$12.9
Santa Clara VWD	Santa Teresa	100	$66	$6.7	$10.0	$16.7
Tracy		12	$14	$1.4	$1.3	$2.7
Vallejo		5	$9	$0.9	$0.6	$1.5
Vallejo		30	$26	$2.6	$3.1	$5.7
T O T A L S :		3520	$2,021	$205.0	$344.3	$549.3

AMORTIZATION AT 8% AND 20 YEARS

TABLE 4

COST FOR EXISTING SURFACE WATER
TREATMENT PLANTS TO ADD OZONE TREATMENT

AGENCY	PLANT NAME	DESIGN FLOW MGD	CAPITAL COST $Million	AMORITIZED CAPITAL $Mil/yr.	O & M COST $Mil/yr.	TOTAL COST $Mil/yr.
Alameda CFCWOD, Zone 7	Patterson Pass	14	$4.2	$0.42	$0.41	$0.84
Alameda CFCWOD, Zone 7	Del Valle	18	$4.9	$0.50	$0.47	$0.97
Alameda CWD		10	$3.3	$0.34	$0.30	$0.64
American Canyon WD		2	$1.1	$0.12	$0.17	$0.28
Antelope Val/East Kern	Eastside	3	$1.5	$0.15	$0.19	$0.35
Antelope Val/East Kern	Rosamond	14	$4.2	$0.42	$0.41	$0.84
Antelope Val/East Kern	Quartz Hill	28	$6.6	$0.67	$0.61	$1.28
Antioch		16	$4.5	$0.46	$0.44	$0.91
Avenal		2	$1.1	$0.12	$0.17	$0.28
Benicia, City of		10	$3.3	$0.34	$0.30	$0.64
Castaic Lake Water Agen.	Earl E. Schmidt	12	$3.8	$0.38	$0.39	$0.77
Coalinga		12	$3.8	$0.38	$0.39	$0.77
Contra Costa WD	Bollman	90	$14.4	$1.47	$1.66	$3.13
Crestline-Lake Arrow.	Crestline-Lk.Arrow	5	$2.1	$0.21	$0.22	$0.43
Fairfield	Waterman	22	$5.6	$0.57	$0.53	$1.10
Fairfield	Fairfield	30	$6.9	$0.70	$0.64	$1.34
Huron		2	$1.1	$0.12	$0.17	$0.28
Kern Co WA, ID #4		28	$6.6	$0.67	$0.61	$1.28
Martinez, City of		12	$3.8	$0.38	$0.39	$0.77
Metropolitan WD SoCal	Mills	236	$27.5	$2.80	$3.60	$6.39
Metropolitan WD SoCal	Skinner	554	$48.5	$4.94	$8.02	$12.96
Metropolitan WD SoCal	Jensen	870	$65.6	$6.68	$13.55	$20.24
Metropolitan WD SoCal	Weymouth	500	$45.3	$4.62	$7.74	$12.36
Metropolitan WD SoCal	Diemer	710	$57.3	$5.84	$9.68	$15.52
Napa	Hennessey	20	$5.3	$0.54	$0.50	$1.04
Naval AS-Lemoore		8	$2.9	$0.29	$0.28	$0.57
Oakley		6	$2.4	$0.24	$2.49	$2.73
Palmdale		12	$3.8	$0.38	$0.39	$0.77
Pittsburg		12	$3.8	$0.38	$0.39	$0.77
Santa Clara VWD	Penitencia	40	$8.4	$0.85	$0.83	$1.68
Santa Clara VWD	Rinconada	75	$12.8	$1.30	$1.24	$2.54
Santa Clara VWD	Santa Teresa	100	$15.5	$1.58	$1.94	$3.51
Tracy		12	$3.8	$0.38	$0.39	$0.77
Vallejo		5	$2.1	$0.21	$0.22	$0.43
Vallejo		30	$6.9	$0.70	$0.64	$1.34
	T O T A L S :	3520	$394	$40.18	$60.35	$100.53

AMORTIZED COST AT 8% AND 20 YEARS

4. Summary of Presentation by Mike McGuire and Stuart Krasner

Mike McGuire and Stuart Krasner, of the Metropolitan Water District of Southern California, spoke about the EPA/California DHS DBP survey. The scope of the project was to gather data on the levels of DBP's in water at 25 utilities nationwide and 10 utilities in California (total of 35). Twenty DBPs were identified.

They stated that every method of water disinfection has drawbacks and tradeoffs. They noted that bromide, oxidant concentration, contact time, the character of organics present, temperature and pH all affect DBP formation.

Ozonation is a frequently mentioned alternative disinfection process. Ozone by itself should not produce chloroform or other chlorinated disinfection by-products. (Since ozone does not provide residual disinfection, addition of chlorine/chloramines will produce some DBPs.) However, if bromide is present in the source water, ozonation will cause the formation of hypobromous acid, which will react with organic precursor material to form bromoform and other brominated DBPs.

Tradeoffs among various DBPs were cited. For example, if halogenated ketones are present in a treated water supply, raising the pH to minimize lead leaching in the distribution system will increase the rate at which halogenated ketones are converted to chloroform. Similarly, chloramination tends to increase the formation of cyanogen chloride at the same time it decreases the formation of THMs. Health effects of cyanogen

chloride at low concentrations are not presently known.

Krasner discussed various DBP's concerned in the study. (These are listed in Table 1, along with measured values.)

There exists a correlated relationship between total THMs and total DBPs. In general, the presence of bromide implies a higher concentration of brominated DBPs.

The THM results from the DBP survey were found to be representative of the THM levels for the country as a whole. (See Figure 1.) THM's were found in the highest concentrations of all the DBPs measured. Haloacetic acids were found in the next highest amounts followed by aldehydes. (See Figure 2.) Data also showed that Br^- levels significantly increase DBP formation, not only in THM's but also haloacetic acids. There appears to be a shift to brominated forms when Br^- is present. (See Tables 2 and 3.)

Krasner also showed data that indicated cyanogen chloride is much higher when chloramination is used as opposed to chlorine. (See Figure 3.)

Aldehyde data were also shown, which again indicated an aldehyde/THM tradeoff, even with ozone/chloramine disinfection. (See Tables 4 and 5.) The study showed a correlation between the sum of THM's and all DBP's, and also a correlation between haloacetic acids and all DBP's.

In summary, the survey of 35 cities was representative of the US distribution of THM results and is believed to be representative of US levels of DBPs. Bromide is an important

factor and exacerbates DBP formation, and there is a complex set of kinetics that are responsible for DBP formation.

McGuire stated that GAC is not a cure-all technology. Leakage through GAC filters was demonstrated regardless of empty bed contact time. (See Figures 4 and 5.) Some DBP precursors get through GAC due to size and/or hydrophobicity of the precursor compounds.

GAC is a very expensive technology (see Tables 6 and 7). Using GAC for taste and odor control is very different than using GAC for THM removal. McGuire stated he believes GAC cannot be considered a Best Available Technology (BAT) for THM control because it is not affordable.

A PEROXONE study is under way; McGuire indicated that a hydrogen peroxide plus ozone combination is a better oxidant than either one separately. In general ozone + chloramination and PEROXONE + chloramination combinations produce lower concentrations of DBPs than does chlorine + any other oxidant combination. (See Figure 6.) He indicated PEROXONE technology could save MWD about $100 million as compared to the use of ozone.

He indicated, however, that there are families of ozone by-products about which little is known. Similarly, production of assimilable organic carbon by ozonation and its affect on bacteria regrowth in the distribution system is poorly understood. Without more research, jumping into ozone may present a large risk in terms of capital investments.

TABLE I

Disinfection By-Products in Drinking Water:
Summary of Quarterly Median Values

Disinfection By-Products µg/L	1st Quarter (Spring 1988)	2nd Quarter (Summer 1988)	3rd Quarter (Fall 1988)	4th Quarter (Winter 1989)
Trihalomethanes				
Chloroform	15	15	13	9.6
Bromodichloromethane	6.9	10	5.5	4.1
Dibromochloromethane	2.6	4.5	3.8	2.7
Bromoform	0.33	0.57	0.88	0.51
Total Trihalomethanes*	34	44	40	30
Haloacetonitriles				
Trichloroacetonitrile	<0.012	<0.012	<0.029	<0.029
Dichloroacetonitrile	1.2	1.1	1.1	1.2
Bromochloroacetonitrile	0.50	0.58	0.70	0.59
Dibromoacetonitrile	0.54	0.48	0.51	0.46
Total Haloacetonitriles	2.8	2.5	3.5	4.0
Haloketones				
1,1-Dichloropropanone	0.52	0.46	0.52	0.55
1,1,1-Trichloropropanone	0.80	0.35	0.60	0.66
Total Haloketones	1.4	0.94	1.0	1.8
Haloacids				
Monochloroacetic Acid	<1.0	1.2	<1.0	1.2
Dichloroacetic Acid	7.3	6.8	6.4	5.0
Trichloroacetic Acid	5.8	5.8	6.0	4.0
Monobromoacetic Acid	<0.5	<0.5	<0.5	<0.5
Dibromoacetic Acid	0.9	1.5	1.4	1.0
Total Haloacids	18	20	21	13
Aldehydes				
Formaldehyde	NA**	5.1	3.5	2.0
Acetaldehyde	NA	2.7	2.6	1.8
Total Aldehydes	NA	6.9	5.5	4.2
Miscellaneous				
Chloropicrin	0.16	0.12	0.10	0.10
Chloral Hydrate	1.8	3.0	2.2	1.7
Cyanogen Chloride	0.45	0.60	0.65	0.80
2,4,6-Trichlorophenol	<0.3	<0.4	<0.4	<0.4
Halogenated DBP_{sum}#	64	82	72	58
Total Organic Halide	150	180	170	175

TABLE I (continued)

Plant Influent Characteristics

Total Organic Carbon, mg/L	NA	2.9	2.9	3.2
Ultraviolet Absorbance, cm^{-1}	NA	0.11	0.11	0.13
Chloride, mg/L	NA	28	32	23
Bromide, mg/L	NA	0.07	0.10	0.07

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*Total class median values are not the sums of the medians of the individual compounds, but rather the medians of the sums of the compounds within that class.

**NA = not analyzed

#The halogenated DBP_{sum} median values are not the sum of the class medians for all utilities, but rather the medians of the halogenated DBP_{sum} values for all utilities. This value is only the sum of XDBPs measured in this study.

TABLE 2

DBP Concentrations at Utility with Highest Bromide Level

Component	Utility #10* Summer 1988	Fall 1988	Winter 1989
PLANT INFLUENT VALUES, mg/L			
Total Organic Carbon	4.6	4.9	5.3
Chloride	640	561	680
Bromide	3.0	2.9	2.8
CLEARWELL EFFLUENT VALUES, µg/L			
Chloroform	0.95	0.59	0.72
Bromodichloromethane	3.8	2.9	4.1
Dibromochloromethane	8.6	9.2	11
Bromoform	30	40	31
Total Trihalomethanes	43	53	47
Trichloroacetonitrile	<0.012	<0.029	<0.029
Dichloroacetonitrile	0.34	0.24	0.27
Bromochloroacetonitrile	1.2	1.1	1.1
Dibromoacetonitrile	5.9	6.7	6.0
Total Haloacetonitriles	7.4	8.0	7.4
Monochloroacetic Acid	<1.0	<1.0	1.0
Dichloroacetic Acid	0.9	0.8	0.9
Trichloroacetic Acid	<0.6	<0.6	<0.6
Monobromoacetic Acid	1.2	1.2	1.4
Dibromoacetic Acid	19	13	7.8
Total Haloacetic Acids	21	15	11

*Data for spring 1988 not included because bromide was not measured that quarter.

TABLE 3

DBP Concentrations at Utility
with Seasonal Change in Bromide Levels

Component	Utility #12* Summer 1988	Fall 1988	Winter 1989
PLANT INFLUENT VALUES, mg/L			
Total Organic Carbon	2.6	2.2	2.8
Chloride	111	215	202
Bromide	0.41	0.78	0.79
CLEARWELL EFFLUENT VALUES, μg/L			
Chloroform	4.7	1.4	0.86
Bromodichloromethane	13	7.5	6.5
Dibromochloromethane	28	25	24
Bromoform	26	72	53
Total Trihalomethanes	72	106	84
Trichloroacetonitrile	<0.012	<0.029	<0.029
Dichloroacetonitrile	0.74	0.24	0.19
Bromochloroacetonitrile	1.6	0.96	1.4
Dibromoacetonitrile	4.6	7.0	11
Total Haloacetonitriles	6.9	8.2	13
Monochloroacetic Acid	<1.0	<1.0	<1.0
Dichloroacetic Acid	2.9	1.7	0.9
Trichloroacetic Acid	1.6	1.2	0.8
Monobromoacetic Acid	1.0	1.6	1.3
Dibromoacetic Acid	14	17	13
Total Haloacetic Acids	20	22	16

*Data for spring 1988 not included because bromide was not measured that quarter.

TABLE 4

Aldehyde Levels in Plant Influents and Effluents*

Utility	Formaldehyde, µg/L		Acetaldehyde, µg/L	
	Influent	Effluent	Influent	Effluent
Utility #9	3.9	8.7	4.4	6.1
Utility #14	6.4	4.1	2.4	4.5
Utility #22	1.2	4.3	<1.0	2.2
Utility #29	2.0	8.0	<1.0	4.6
Utility #30	<1.0	4.3	1.3	2.2
Ozone Plants:				
Utility #19	<1.0	7.5	<1.0	3.9
Utility #25	3.2	19	16	5.5
Utility #32	1.4	21	<1.0	2.1

---

* Selected utility data shown for illustrative purposes.

TABLE 5

Levels of Aldehydes and THMs in Selected Clearwell Effluents

Utility	Formaldehyde, ug/L			Acetaldehyde, ug/L			TTHMs, ug/L		
	Summer 1988	Fall 1988	Winter 1989	Summer 1988	Fall 1988	Winter 1989	Summer 1988	Fall 1988	Winter 1989
Utility #2	10	8.2	NR*	4.2	4.4	NR	90	82	60
Utility #9	12	6.2	8.7	4.1	2.8	6.1	95	54	40
Utility #26	17	8.6	2.1	6.0	7.1	2.1	164	100	98
Utility #29	NR	13	8.0	4.3	5.2	4.6	109	180	259
Ozone Plants:									
Utility #19	5.8	10	7.5	4.8	5.3	3.9	15	20	5.9
Utility #25	31	22	19	15	9.9	5.5	34	16	9.0
Utility #32	30	24	21	3.5	2.8	2.1	3.1	1.4	0.72

---

*NR = not reported; analytical problem with sample.

TABLE 6

TOTAL METROPOLITAN SYSTEM COST ESTIMATES FOR GAC
(Total Capacity - 2970 mgd)

Cost Category	SDSTHM (μg/l)/TOC (mg/l)			
	5/0.16	10/0.25	20/0.44	50/1.0 *
Capital ($million)	3,900	1,980	1,300	730
O & M ($million/yr)	430	200	140	76
Unit Annual # ($/1000 gallons)	1.46	0.68	0.47	0.29
Unit Annual # ($/acre-foot)	480	220	150	95

* SDSTHM/TOC relationship is extrapolated from experimental data for TOC concentrations > 0.75 mg/l.

Includes total annual amortized Capital and total annual O & M costs.

TABLE 7

OTHER UTILITIES COST SUMMARY TABLE FOR GAC

CAPITAL COSTS
($million)

UTILITY	SDSTHM (ug/l) 5	10	20	50
Cincinnati (235 mgd)	689	149	74	---*
Jefferson Parish (70 mgd)	482	184	33	---*
Palm Beach Co. (16 mgd)	148	42	31	26
Philadelphia (320 mgd)	634	152	---*	---*

UNIT ANNUAL COSTS
(includes annual amortized Capital and O&M costs)
($/1000 gallons)

UTILITY	SDSTHM (ug/l) 5	10	20	50
Cincinnati	5.34	0.93	0.30	---*
Jefferson Parish	13.40	4.82	0.52	---*
Palm Beach County	19.06	4.42	3.06	2.21
Philadelphia	3.38	0.58	---*	---*

* No value reported because breakthrough was not reached during the RSSCT test for this SDSTHM

FIGURE 1

FREQUENCY DISTRIBUTIONS OF THM SURVEY DATA

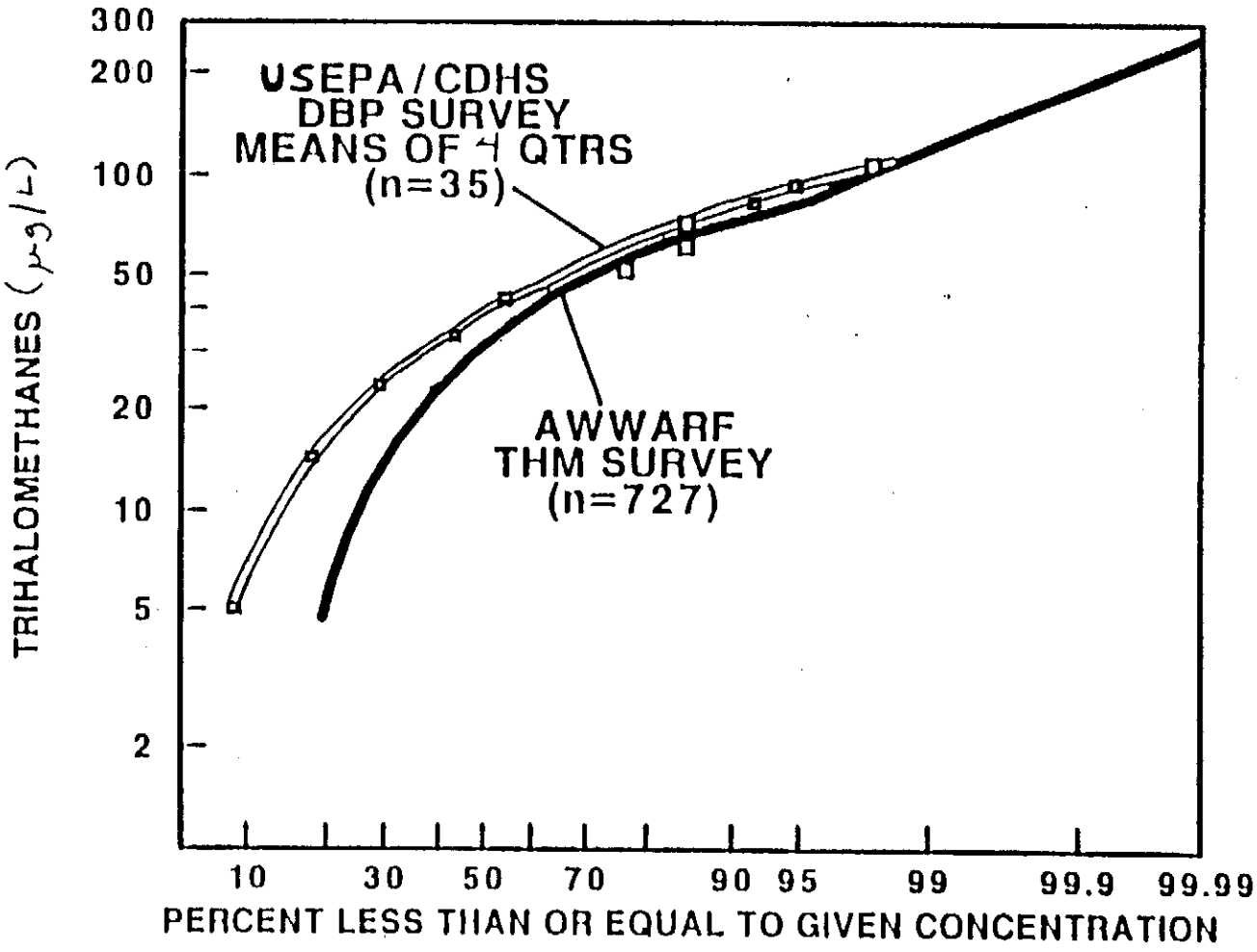


FIGURE 2

DBP Concentration by Class : Third Quarter

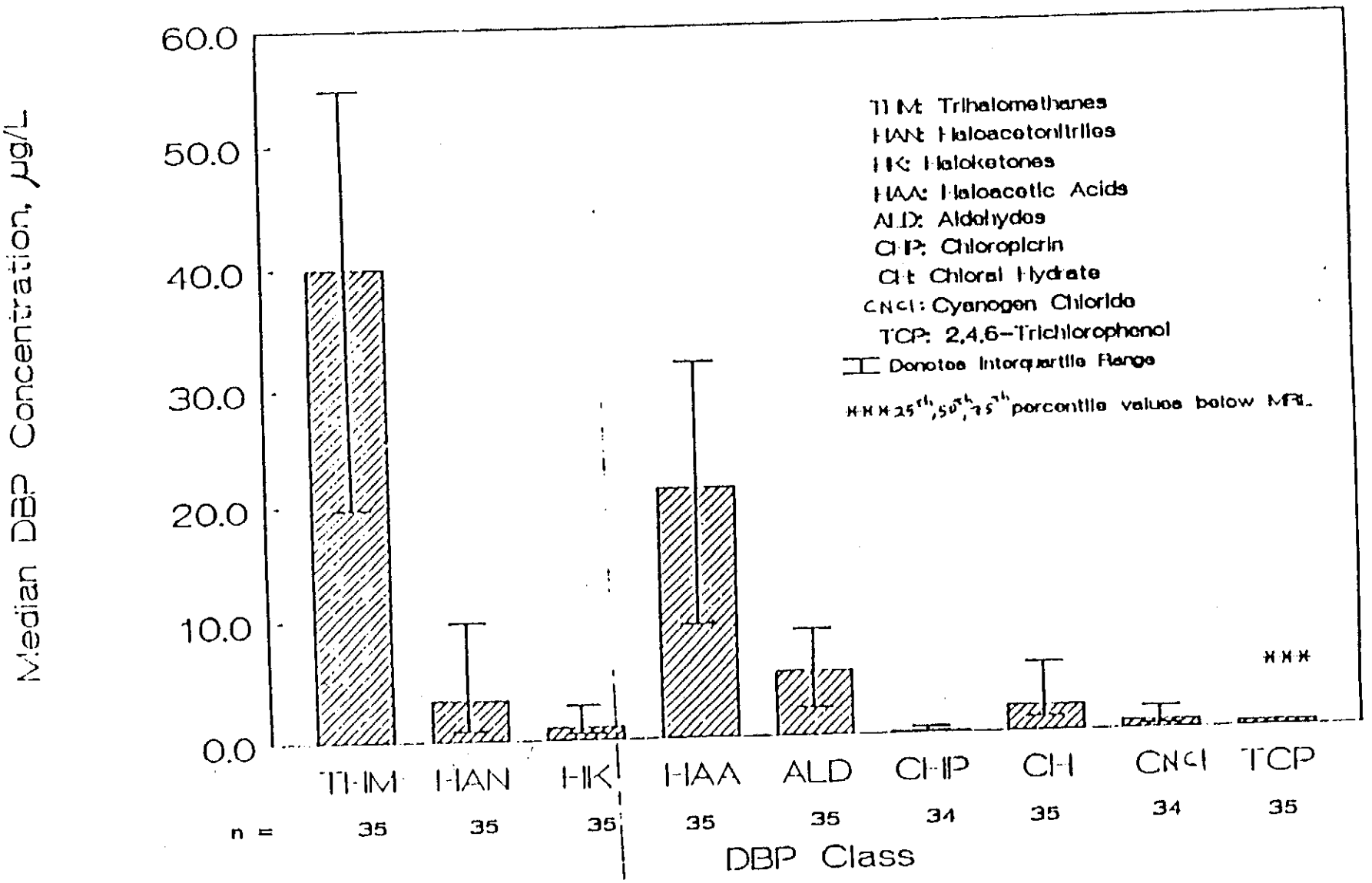
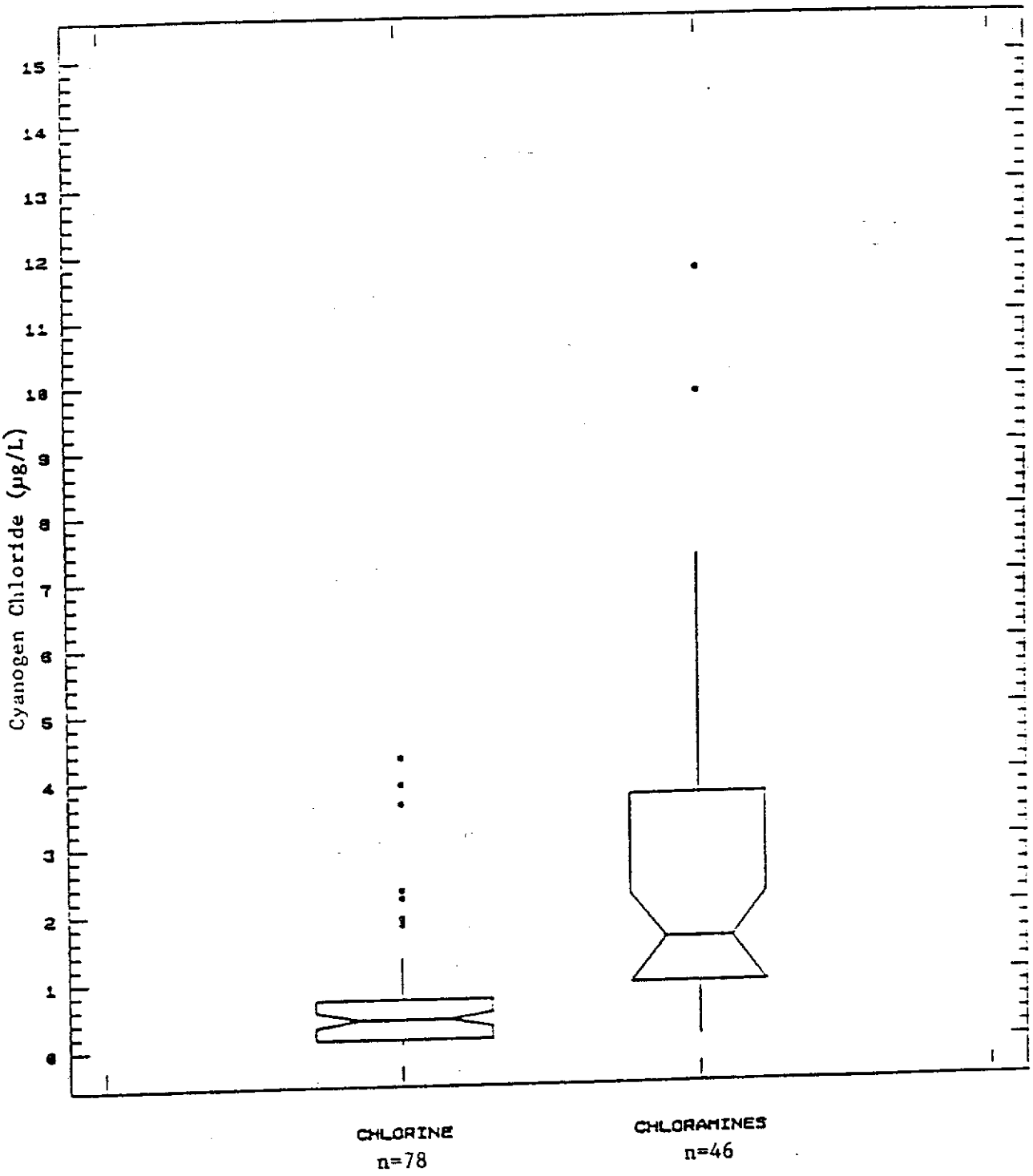


FIGURE 3

Notched Box-and-Whisker Plot of

Cyanogen Chloride by Final Disinfectant



n = number of observations

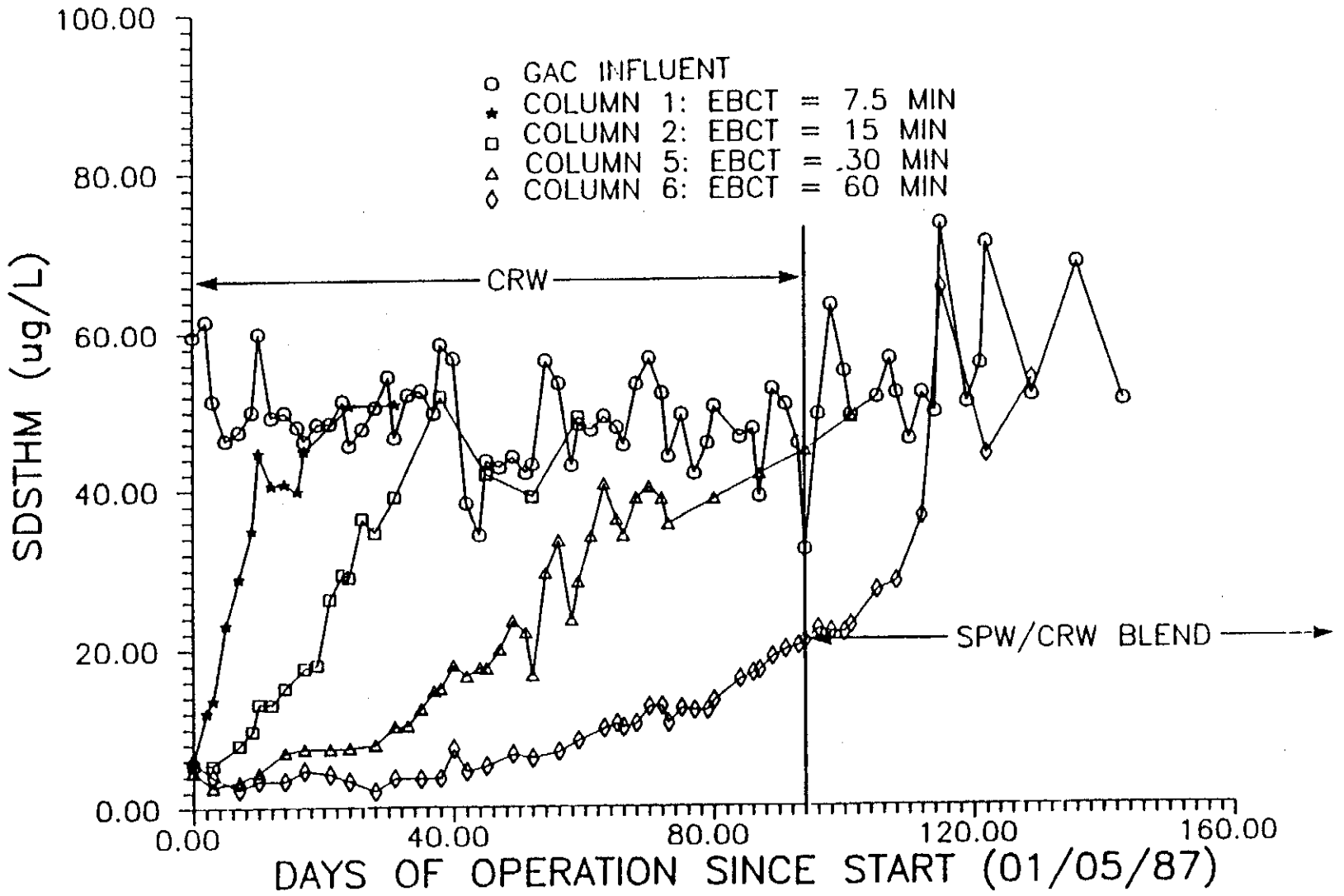


Figure 4 GAC Column Influent SDSTHM$_{Cl}$ Concentrations and SDSTHM$_{Cl}$ Breakthrough Profiles for GAC Columns 1,2,5 and 6

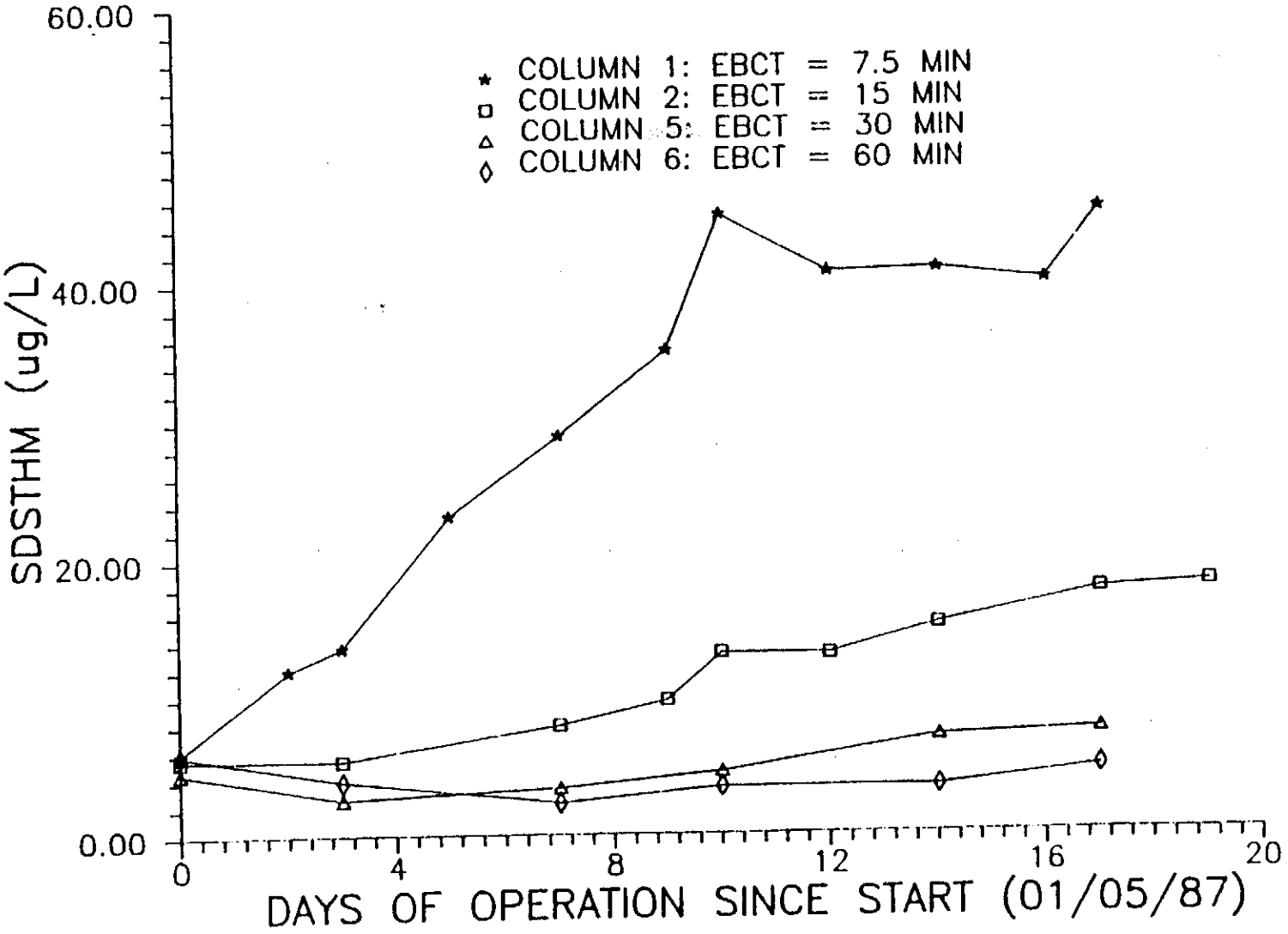
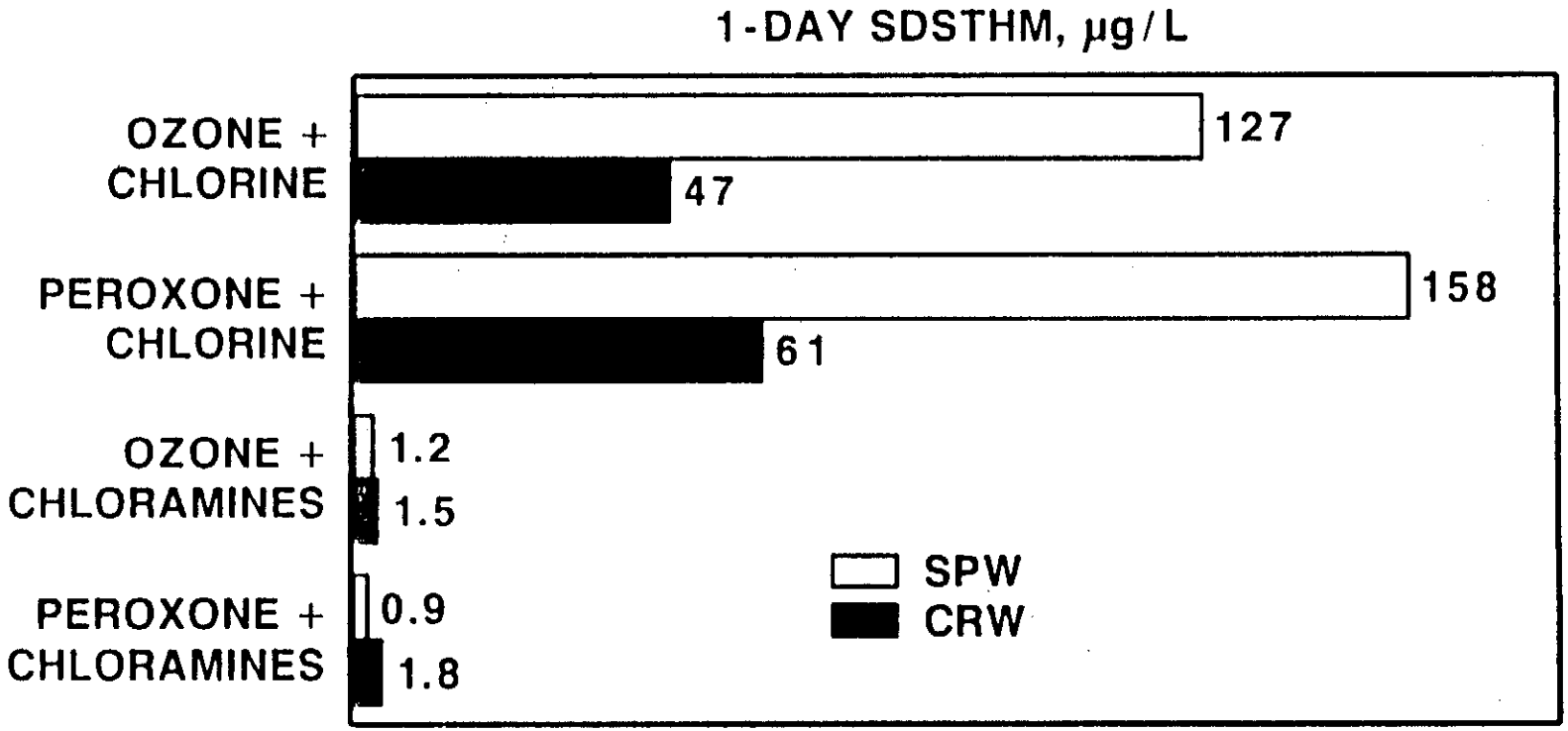


Figure 5 GAC Column Influent $SDSTHM_{Cl}$ Concentrations and $SDSTHM_{Cl}$ Breakthrough Profiles for GAC Columns 1,2,5 and 6. (First 20 days of Column Operation.)

Figure 6

SDSTHM RESULTS FOR SPW AND CRW PHASE III / EXPERIMENT 2



OZONE DOSE = 2.0 mg/L
PEROXIDE/OZONE RATIO = 0.2
CONTACT TIME = 12 MINUTES

SDS CONDITIONS: CHLORINE DOSE = 2.5 mg/L
CHLORAMINES DOSE = 1.5 mg/L
ONE DAY, 25°C

5. Summary of the presentation by Carol James, Montgomery Engineers

PRE-OZONATION/DEEP BED FILTRATION PILOT AND PROTOTYPE INVESTIGATION

Carol Ruth James of James M. Montgomery, Consulting Engineers, Inc. presented the results of a water treatment case study that was conducted for Contra Costa Water District from 1984 through 1988. The case study consisted of two phases, Phase 1 a 10 gpm pilot study and Phase 2 a 200 gpm prototype study. The process train recommended in the pilot study and demonstrated in the prototype study included pre-ozonation, deep bed filtration with granular activated carbon (GAC) and sand, post-ozonation and chloramination. Figure 1 is a schematic diagram of this process train.

BACKGROUND

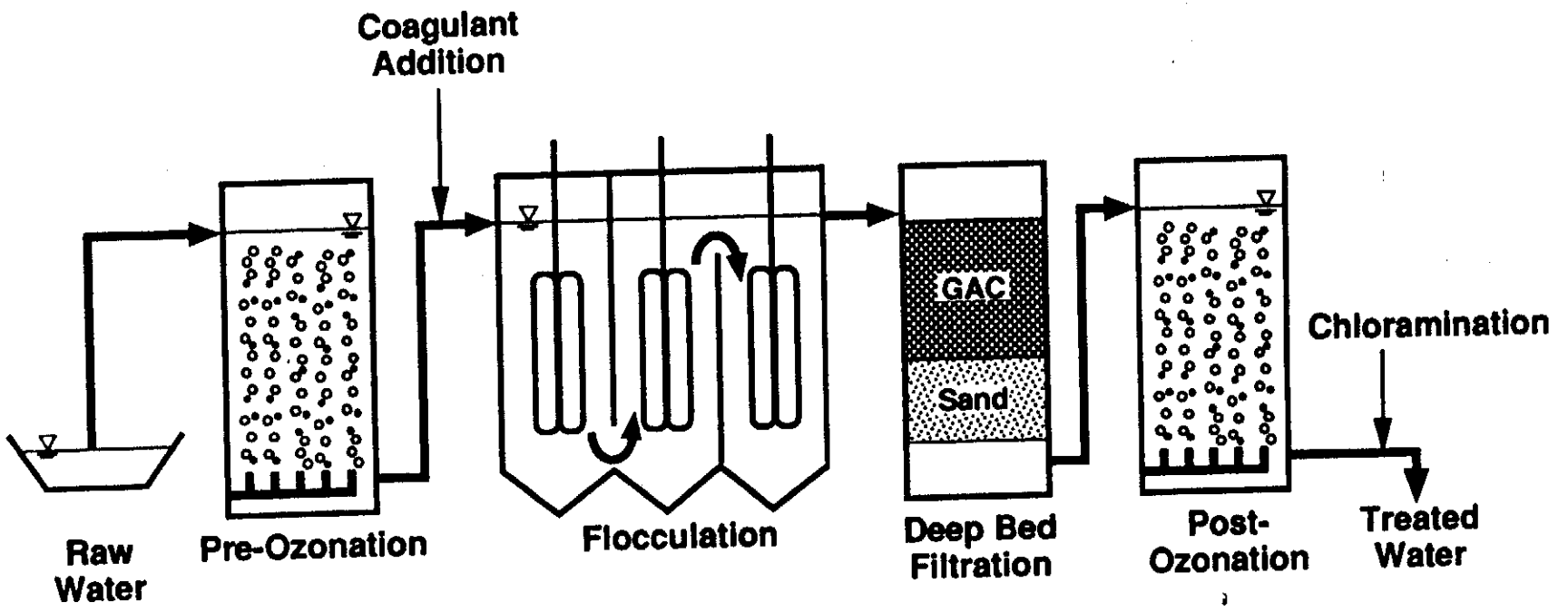
The water treated during the study was drawn from the Contra Costa Canal which is fed by the Sacramento-San Joaquin Delta at Rock Slough. Table 1 is a summary of the range of water quality values experienced during Phase 2 of the study. Particulate removal, THM control, microbiological parameter reduction, taste and odor removal and protection against potential synthetic organic chemical spikes were the identified treatment issues.

Pre-ozonation was selected for 1) organics oxidation, 2) microbiological parameter reduction, 3) THM control, 4) taste and odor control and 5) coagulant chemical dose reduction. GAC was selected to provide 1) particulate removal, 2) taste and odor control and 3) an organics barrier. Post-ozonation was selected for final disinfection. Chloramination was selected to provide a distribution disinfection residual.

The finished water quality goals established for the prototype demonstration study were as follows:

- Turbidity $\leq$ 0.1 NTU
- THM $<$ 20 ug/L
- Total Coliform $<$ 1 organism/100ml[1]
- Heterotrophic Plate Count (HPC) $<$ 100 CFU/ml
- Odor $\leq$ 3 TON

(1 - Less than 1 organism/100 ml reflects the Non Detectable level achievable with the Membrane Filtration technique. This is equivalent to less than 2.2 which is associated with the Most Probable Number (MPN) technique used by the JMM laboratory and approved by DOHS.)



JOINT WATER TREATMENT PLANT
PROCESS TRAIN

PRE-OZONATION/DEEP BED FILTRATION WITH GAC

FIGURE 1

TABLE 1

WATER QUALITY MONITORING PARAMETERS, RATIONALE FOR SELECTION

	EPA & DOHS Regulations	Public Concern	Process Control	Surrogate Parameter	General Water Quality
Physical/ Aesthetic					
Temperature			•		•
pH			•		•
Dissolved Oxygen			•		•
Turbidity	•		•		•
Particle Size Distribution			•	•	
Odor		•	•		•
Flavor Profile		•	•		•
Electrical Conductivity					•
Corrosivity	•				•
Inorganic					
Alkalinity	•		•		•
Aluminum			•		
Asbestos	•		•		
Bromide			•		•
Calcium					•
Chloride					•
Hardness					•
Organic					
TOC			•	•	•
TOX	•		•	•	
THM	•	•	•	•	
THMFP				•	•
Microbiological					
Total Coliform	•		•		•
Heterotrophic Plate Count	•		•		•
Algae			•		•
Other					
Headloss			•		
Disinfection Residual	•		•		

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These goals reflect the current and potential changes to the primary and secondary drinking water quality regulations. In addition to these parameters, the water quality parameters listed in Table 2 were also monitored during the study. The rationale for monitoring each of the identified parameters is also summarized in this table. For example, turbidity was monitored 1) to determine if the EPA and DOHS regulations were met, 2) as a process control parameter and 3) to develop a general water quality database. Seasonal variations of the parameters in Table 2 are depicted in the Phase 2 report, "Pre-Ozonation/Deep Bed Filtration Prototype Demonstration Study".

RESULTS

In general the pre-ozonation/deep bed filtration process train with post-ozonation and chloramination was found to be very effective at meeting all the finished water quality goals established for the project. A detailed discussion of the results and recommendations are documented in the Phase 2 report. Below is a brief summary of the results from this study.

Process Train Performance Through Filtration

Figure 2 is a detailed schematic of the process train from pre-ozonation through filtration. Pre-ozonation doses of 1 to 1.5 mg/L were found to be effective throughout the year including periods of high algae counts. Average alum and Cat Floc C doses of 2.7 and 1.4 mg/L were found to be most effective for the flocculation process. A dual filter media design of 1.7 mm effective size GAC and 0.65 mm effective size sand was determined to produce the best water quality. Table 3 is a summary of the water quality removals achieved with the pre-ozonation/deep bed filtration process train.

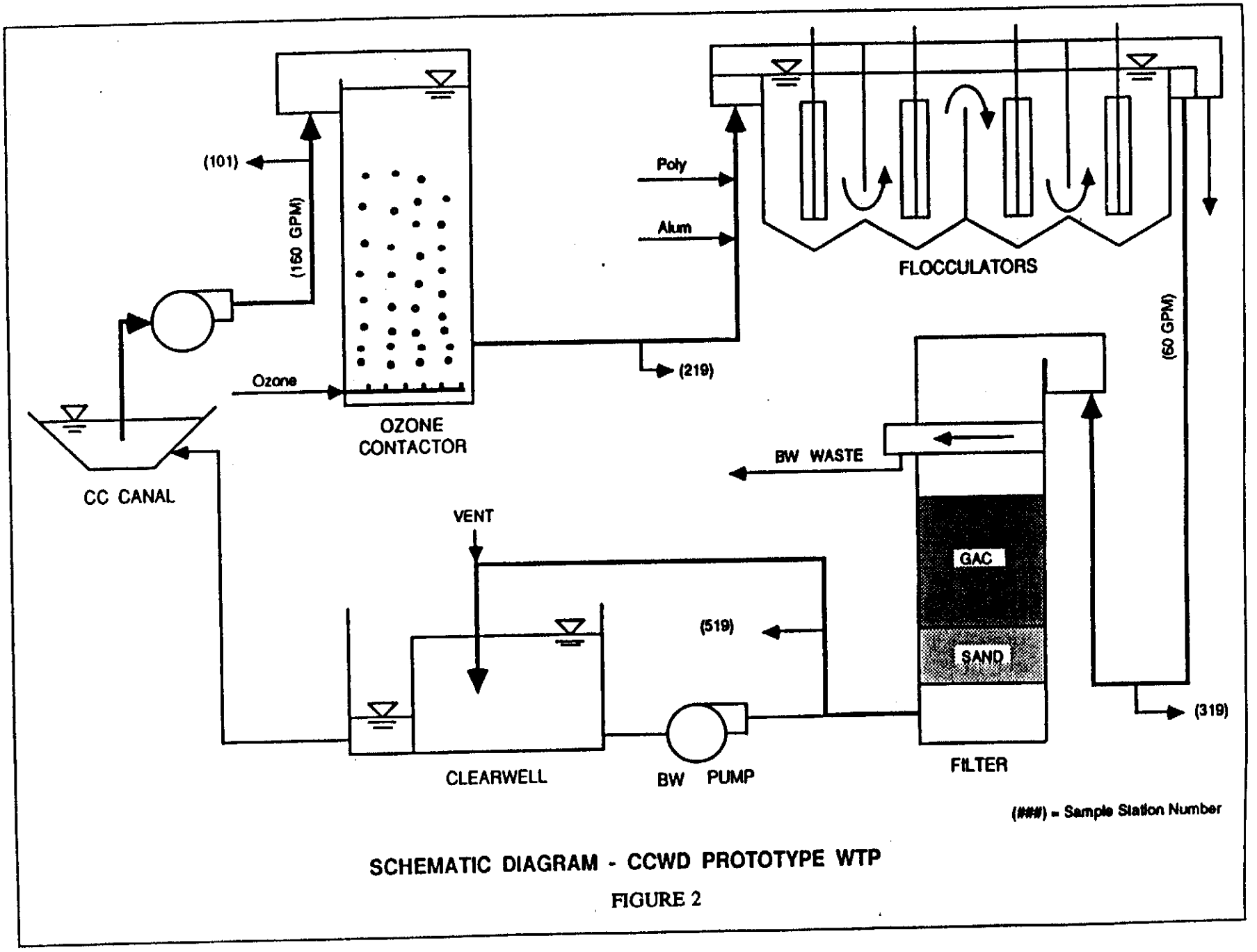
- **Turbidity** - Turbidity removal through filtration is depicted in Figure 3. The turbidity goal of less than or equal to 0.1 NTU, which is the proposed DOHS maximum contaminant limit goal (MCLG), was achieved 95 percent of the time. The highest filter operating turbidity was 0.14 NTU.

- **Taste and Odor** - Taste and odor was reduced primarily by the GAC with some minimal reduction in pre-ozonation, as indicated in Table 3. Earthy, grassy and musty are the primary smell descriptors for the raw water. These descriptors are common for surface waters. Figure 4 is a frequency plot of these smell descriptors and others assoicated with the raw, pre-ozonated and filtered waters. As this figure indicates the GAC filter media was able to provide the greatest removal of these

TABLE 2

RAW WATER QUALITY

PARAMETERS	UNITS	RANGE
Physical/Aesthetic		
Turbidity	NTU	5 - 20
pH		7.5 - 8.5
Temperature	°C	8 - 26
Flavor Profile		Earthy
Odor	TON	1 - 8
Inorganics		
Alkalinity	mg / L as CaCO3	43 - 103
Bromide	mg / L	0.36 - 1.2
Chloride	mg / L	17 - 236
Organics		
TOC	mg / L as C	2 - 9
THM	µg / L	<1
THMFP	µg / L	300 - 580
Tox	µg / L as Cl	10 - 40
Microbiological		
Total Coliform	MPN / 100 ml	30 - 1,300
HPC	CFU / ml	310 - 12,000
Algae	# / ml	45 - 81,870



SCHEMATIC DIAGRAM - CCWD PROTOTYPE WTP

FIGURE 2

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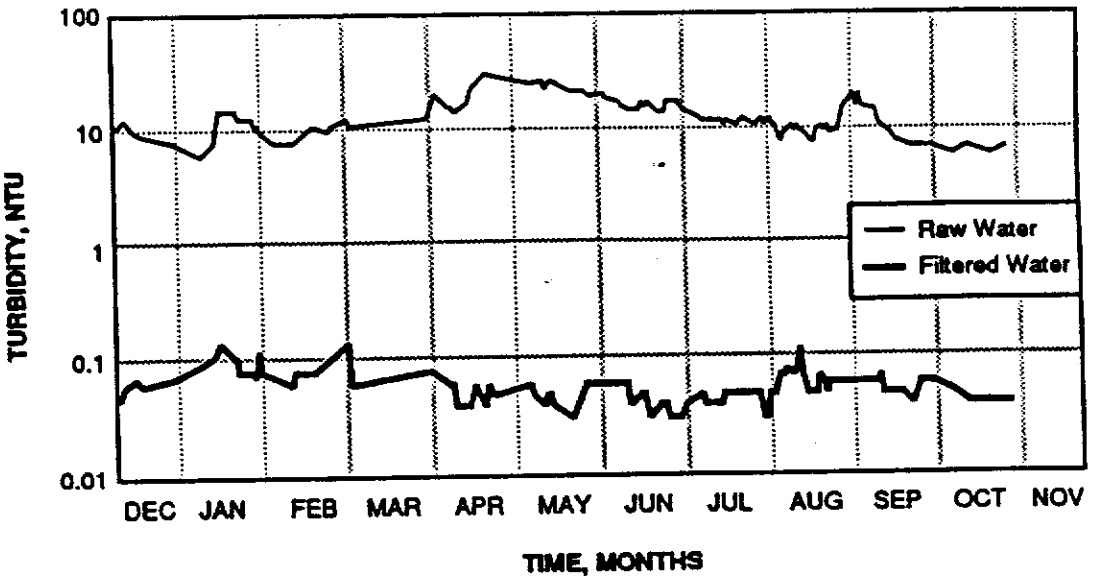
TABLE 3

PROTOTYPE PROCESS TRAIN PERFORMANCE [1]

PARAMETERS	UNITS	RAW	PRE-OZONATED	FILTERED
Turbidity	NTU	11	11	0.08
THM	µg / L	< 1	< 1	< 1
THMFP	µg / L	425	NA [2]	215
TOC	mg / L	3.5	3	2.1
TOX	µg / L	21.5	15.8	12.5
Total Coliform	MPN / 100 ml	230	17	6
HPC	CFU / ml	3,200	9,200	6,200
Asbestos	MFL	120	NA	ND [3]
Odor	TON	4	3	1
	Smell	Earthy Grassy Musty	Earthy Grassy Musty	None

1 Mean opr median values
2 NA = Not Analyzed
3 ND = Not Detectable



TURBIDITY IN RAW AND FILTERED WATERS

FIGURE 3

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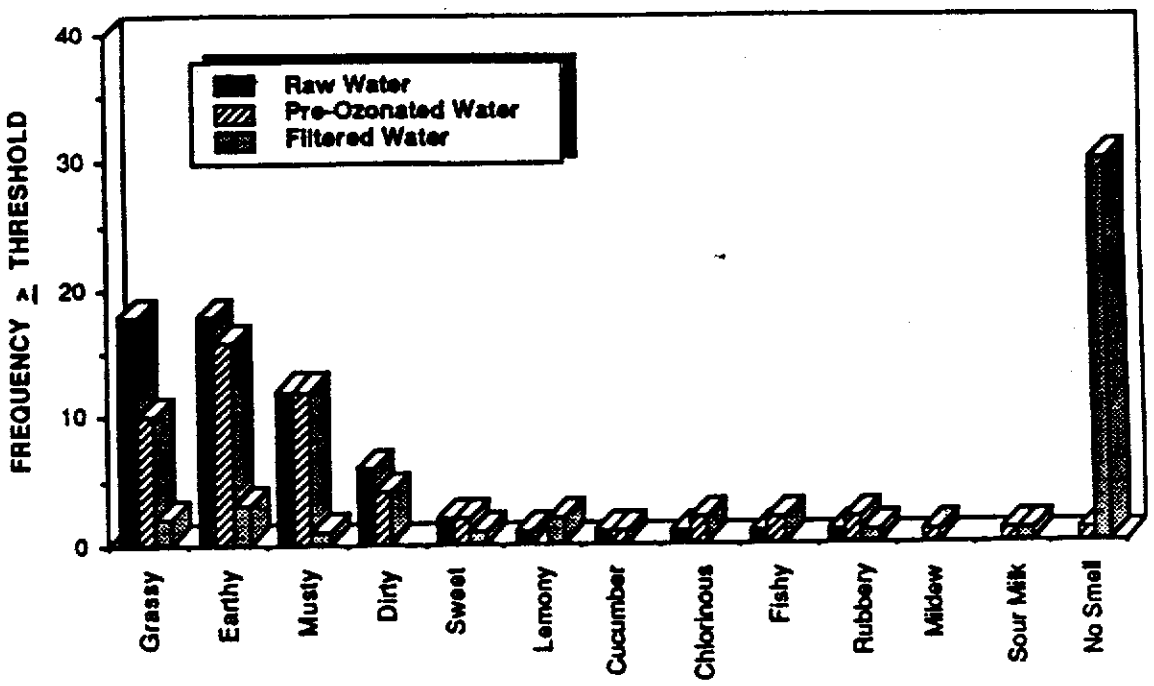

DISTRIBUTION OF SMELL DESCRIPTORS

FROM FLAVOR PROFILE ANALYSIS

FIGURE 4

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descriptors, with the primary filtered water smell descriptor being "No Smell".

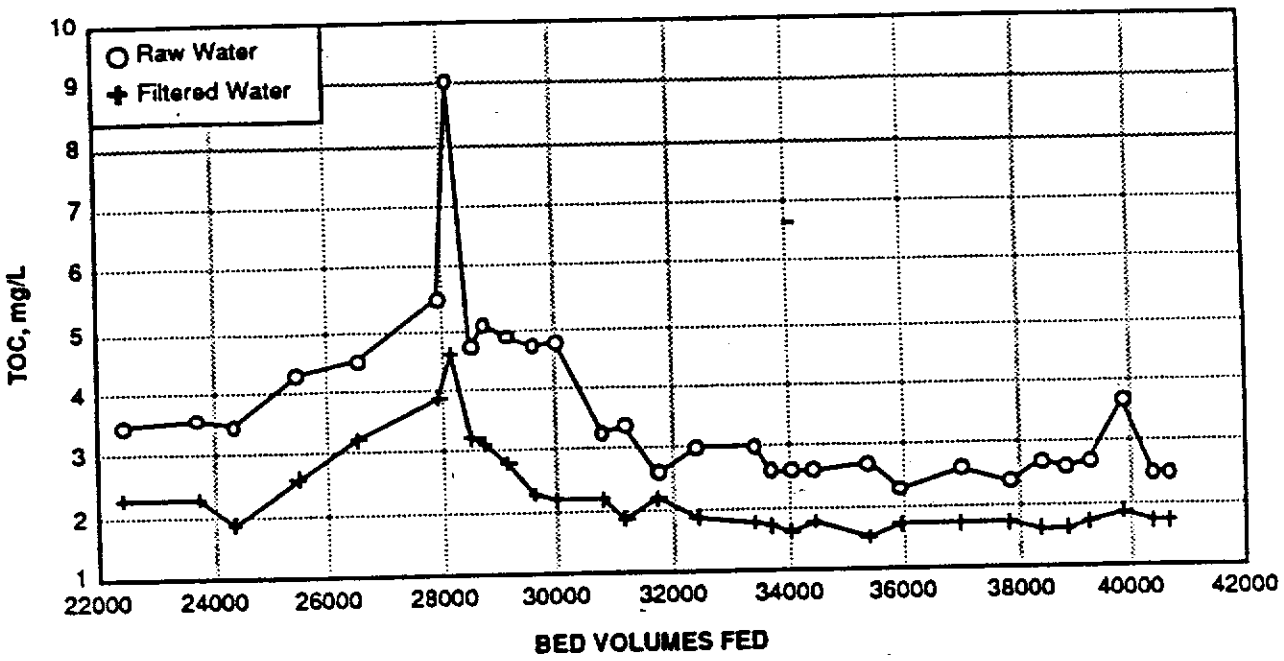
- **THM** - THM production was below the detection limit of 1 ug/L. This low level of THM was achievable because chlorine was not used in the treatment process train. In addition, although the bromide level did reach 1.2 mg/L, bromoform was not produced because the demand for ozone exerted by bromide is secondary to the demand exerted by organics and other inorganics. Therefore, the pre-ozone doses used in this process train, 1 and 1.5 mg/L, would oxidize organics and other inorganics before oxidizing bromide.

- **THMFP** - A 50 percent reduction in trihalomethane formation potential (THMFP) was achieved with the pre-ozonation/deep bed filtration process. This reduction was probably achieved due to the oxidation of organic and inorganic matter by the pre-ozonation process as well as the adsorption of these parameters on the GAC.

  THMFP is a parameter which is used to evaluate the maximum level of THM which can be produced if a raw water is chlorinated. There is considerable discussion regarding the utility of this parameter because of the high chlorine doses and holding times used in this analysis. Most importantly is the fact that this parameter has little significance if free chlorine is not used in the treatment process as is the case in this process train. Free chlorine means that the chlorine is not tied up with another chemical, such as ammonia, in the water.

- **TOC** - On average a 50 percent removal of total organic carbon (TOC) was achiveable through filtration. As shown in Figure 5 even greater removals were achieved when spikes of TOC occurred in the raw water. TOC was used as a surrogate parameter to evaluate this process train's capability of controlling a synthetic organic chemical (SOC) spike should it occur in the raw water. This figure indicates that the spike would be controlled by the GAC. Tests were conducted in Phase 1 - "Pre-Ozonation/Deep Bed Filtration Pilot Plant Study" with actual SOC spikes that support these results as well.

- **Total Coliforms** - A 93 percent removal of total coliforms was achievable through pre-ozonation with an additional 5 percent removal through filtration. While the numbers of total coliforms were above the testing goal of less than 1 organism/100ml, good reductions did occur at the front end of the process train. Final disinfection was identified as the location for primary control of this parameter.



TOTAL ORGANIC CARBON IN RAW AND FILTERED WATERS

FIGURE 5

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- **HPC** - Heterotrophic plate count (HPC) appears to increase as the water is pre-ozonated. What actually is occurring is that the colonies of bacteria identified as HPC in the raw water exist in large clumps which are broken down into smaller clumps through pre-ozonation but not reduced. These smaller clumps are then counted as colonies resulting in a larger HPC count. When doses of ozone greater than 1.5 mg/L were used in pre-ozonation there was enough ozone available not only to break up the large HPC colonies but reduce them as well. This type of control was recommended for achievement in final disinfection as opposed to pre-oxidation.

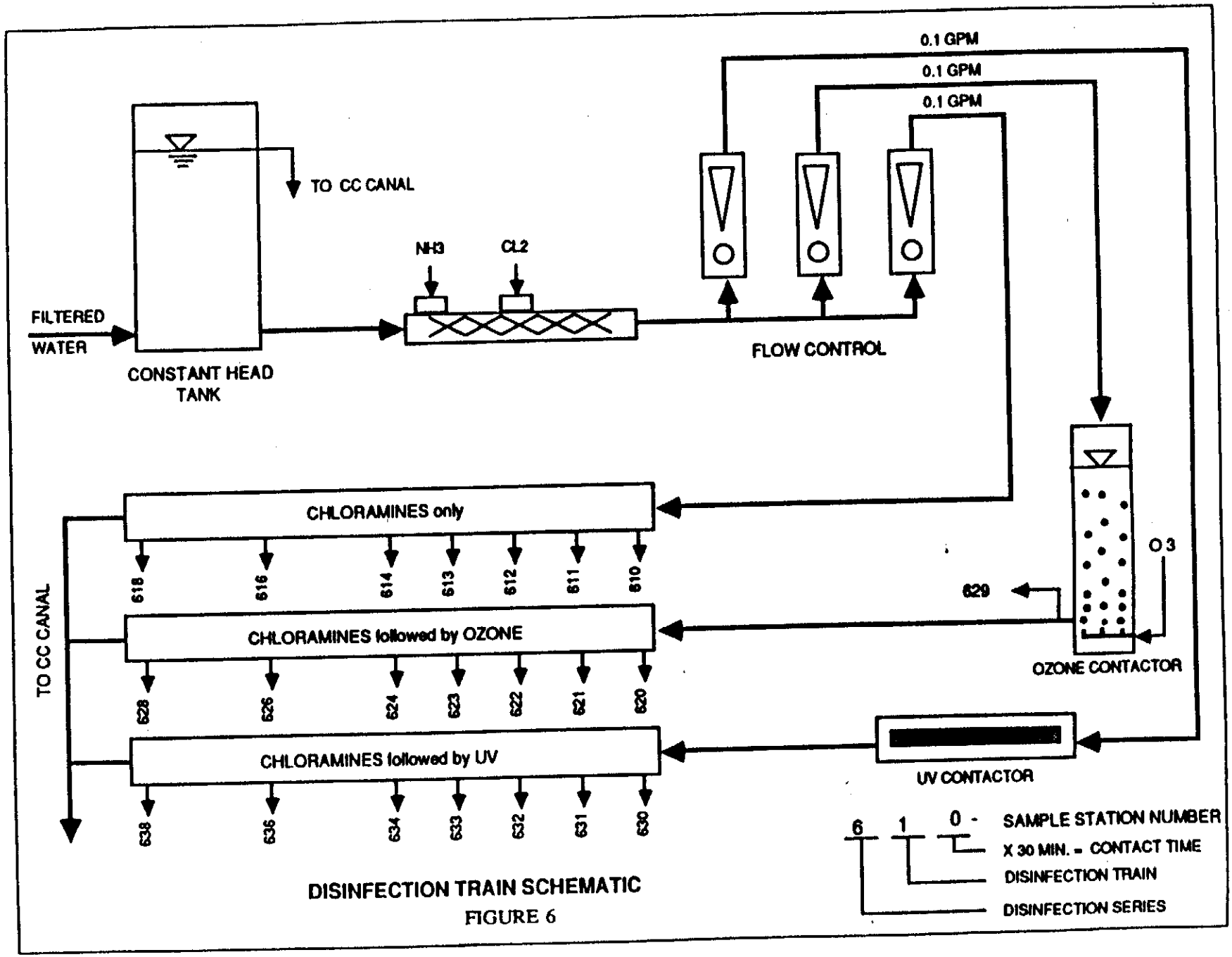
Final Disinfection

A sidestream of 0.3 gpm was taken from the filtered water line and used for the evaluation of three final disinfection alternatives. These alternatives included chloramination, post-ozonation plus chloramination, and ultra violet adsorption plus chloramination. Figure 6 is a schematic of these disinfection alternatives.

A chloramine dose of 1.5 mg/L, pre-ozone dose of 1 mg/L and UV dose of 60,000 uW-sec/cm^2 were used for final disinfection. Chlorination was not evaluated long term because of the corresponding production of THMs. In general, post-ozonation plus chloramination performed the best of the three options. Table 4 is a summary of the results of these tests.

- **THM** - Very low THMs were produced by all three final disinfection options, median levels were below the detection limit of 1 ug/L. The reason for these low THMs is because free chlorine was not used in the process train. While the chloramine process does use chlorine, the ammonia was added first followed by chlorine. This addition sequence along with very good mixing avoided the occurrence of free chlorine in this water.

  The data points in Table 4 reflect median values and do not reflect the ranges which occurred. When the bromide levels in the raw water were 1.2 mg/L a THM level of 8 ug/L was produced by the post-ozone plus chloramine option. Bromoform was the predominant component of THM produced. Both of the other final disinfection options produced THMs below the detection limit of 1 ug/L during the high bromide period. The reason bromoform was formed in post-ozonation and not pre-ozonation was because the demands for ozone exerted by the organics and other inorganics were primarily met during pre-ozonation. This



DISINFECTION TRAIN SCHEMATIC

FIGURE 6

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TABLE 4

PROTOTYPE FINAL DISINFECTION PERFORMANCE [1, 2]

PARAMETERS	UNITS	FILTERED	CHLORAMINES	CHLORAMINES PLUS OZONE	CHLORAMINES PLUS UV
Total Coliform	org. / 100 ml[3]	2	< 1	< 1	< 1
HPC	CFU / ml	6,400	420	2	10
THM	µg / L	< 1	< 1	< 1	< 1
THMFP	µg / L	215	210	170	200
TOX	µg / L	11	90	37	66

1 Disinfection results at 30 min after chemical addition
2 Values shown are either mean or median values
3 org - organisms

allowed for the reaction between ozone and bromide to occur in post-ozonation.

- **Total Coliforms** - All three final disinfection options provided effective process control for this parameter. The finished water goal of less than 1 organism/100ml was achieved by all three.

- **HPC** - The post-ozone plus chloramine final disinfection option produced the best results for HPC control with chloramine alone performing the worst. HPC is not currently regulated but will be an important parameter in the future disinfection regulations.

- **TOX** - Total organic halogens (TOX) was used as a surrogate measure of the other disinfection by-products which might be formed during final disinfection. As expected, this parameter increased through final disinfection. The post-ozone plus chloramine option produced the smallest increase of the three final disinfection options with chloramine alone producing the highest increase.

SUMMARY

In summary, the pre-ozonation/deep bed filtration process train with post-ozonation and chloramination met all the finished water quality goals. Also, the process train met several process operation goals which were not addressed in this presentation. DOHS found the results of the study to be very promising and the design of the 40 mgd Joint Water Treatment Plant -- currently underway -- is based on this process train. A cost comparison of this process train with conventional treatment was conducted during preliminary design. The capital costs were found to be comparable for the two facilities but the operation and maintenance costs for the Pre-Ozonation/Deep Bed Filtration facility were found to be lower.

6. Summary of Presentation by Phillippe Daniel

Phillippe Daniel, Camp Dresser & McKee,Inc., discussed a pilot study using a South Bay Aqueduct supply. The objectives of the disinfection by-products (DBP) portion of this work were to:

- Examine the frequency and levels existing in the distribution system.
- Examine the effectiveness of various disinfection methods controlling DBP formation while considering taste and odor and disinfection concerns.
- Identify any problems associated with the candidate disinfection methods (e.g., impact of seasonally high bromide ion concentrations).

Disinfectant dose and type and pH are two key variables in DBP formation. THM production decreases as pH decreases; however, total organic halogen (TOX) production increases with decreasing pH. When considered with corrosion concerns and other DBP groups, it is clear that there are trade-offs involved in the selection of a final pH.

Five DBP groups were examined: trihalomethanes, haloacetonitriles, haloketones, haloacetic acids, and chloropicrin (all low molecular weight DBP). Chemical equilibria exists amongst many DBP which are a function of pH. For example, haloacetonitriles can decompose to form haloacetic acids depending on pH conditions. Three types of control strategies are generally considered: removal of precursors, removal of by-products after formation, or alteration of disinfection procedures to minimize DBP formation. The first two alternatives

are generally found to be prohibitively expensive. This study focused on alternative disinfection techniques.

The bromide ion concentration of source water is one of the key parameters that can influence DBP formation. The following disinfection schemes were tested:

- Prechlorination and post-chloramination.
- Prechloramination and post-chloramination.
- Preozonation and post-chlorination.
- Preozonation and post-chloramination.

It is generally found that DBP concentrations were greatly reduced when preozonation was followed by post-chloramination as opposed to post-chlorination. These reductions were greater than 90 percent for the THMs (down to levels under 10 µg/l) and in the range of 70 to 90 percent for the haloacids (also less than 10 µg/l). Pre- and post-chloramination resulted in similarly low DBP levels.

There is some concern about the regrowth potential of Delta water, particularly when ozonating. When encouraging biodegradation processes to occur in the filter (in order to reduce nutrients), heterotrophic bacteria can proliferate. These levels are effectively reduced by a minute of free chlorine contact time after filtration. THM formation kinetics, however, are accelerated when bromide ion is present. This is of concern since bromide ion levels can range from below detection to greater than 1 mg/l on the South Bay Aqueduct.

The potential for DBP formation by ozone itself,

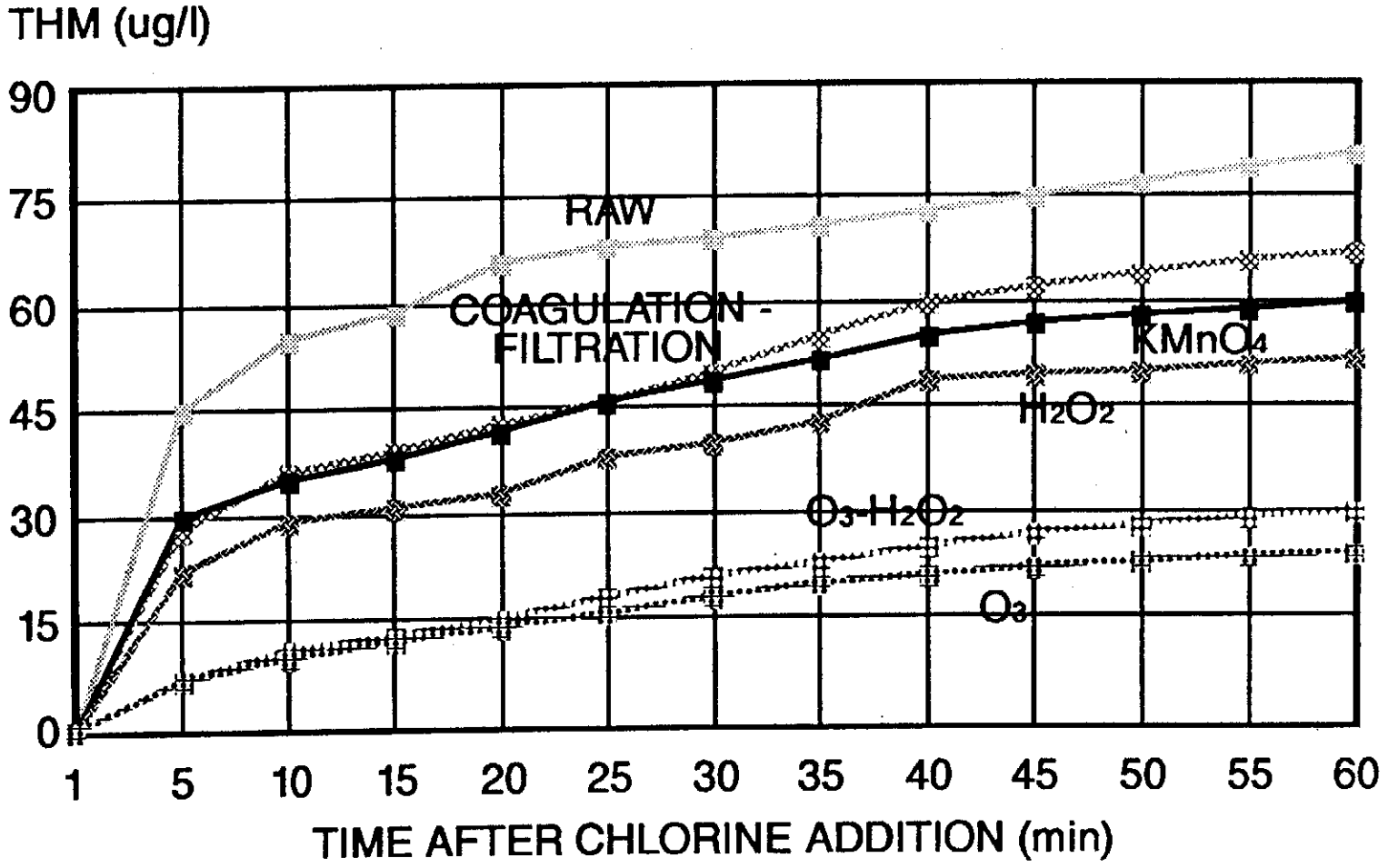
particularly bromoform, is possible. It depends upon the ozone dose and the bromide ion concentration (i.e., at high ozone doses (4 mg/l) and high bromide ion concentrations (1 mg/l), the potential formation of brominated organics in the contactor is possible). It is significant to note, however, that addition of a small amount of ammonia before ozonation effectively controls the formation of brominated DBP in the ozone contactor.

Conclusions from this study are as follows:

- DBP formation potential of Delta water is high.
- Ozonation followed by chloramination controls DBP and meets disinfection requirements under normal water quality conditions.
- A short free chlorine contact time is desirable from a microbiological standpoint.
- When bromide ion is present at higher concentrations:
  - Brominated DBPs can predominate.
  - DBP concentrations can increase.
  - Brominated DBP can be formed during ozonation.
  - Taste and odor treatment efficiency is diminished.
- Problems of DBP formation with bromide ion and ozone can be effectively circumvented by ammonia addition before ozonation.

RAW WATER QUALITY

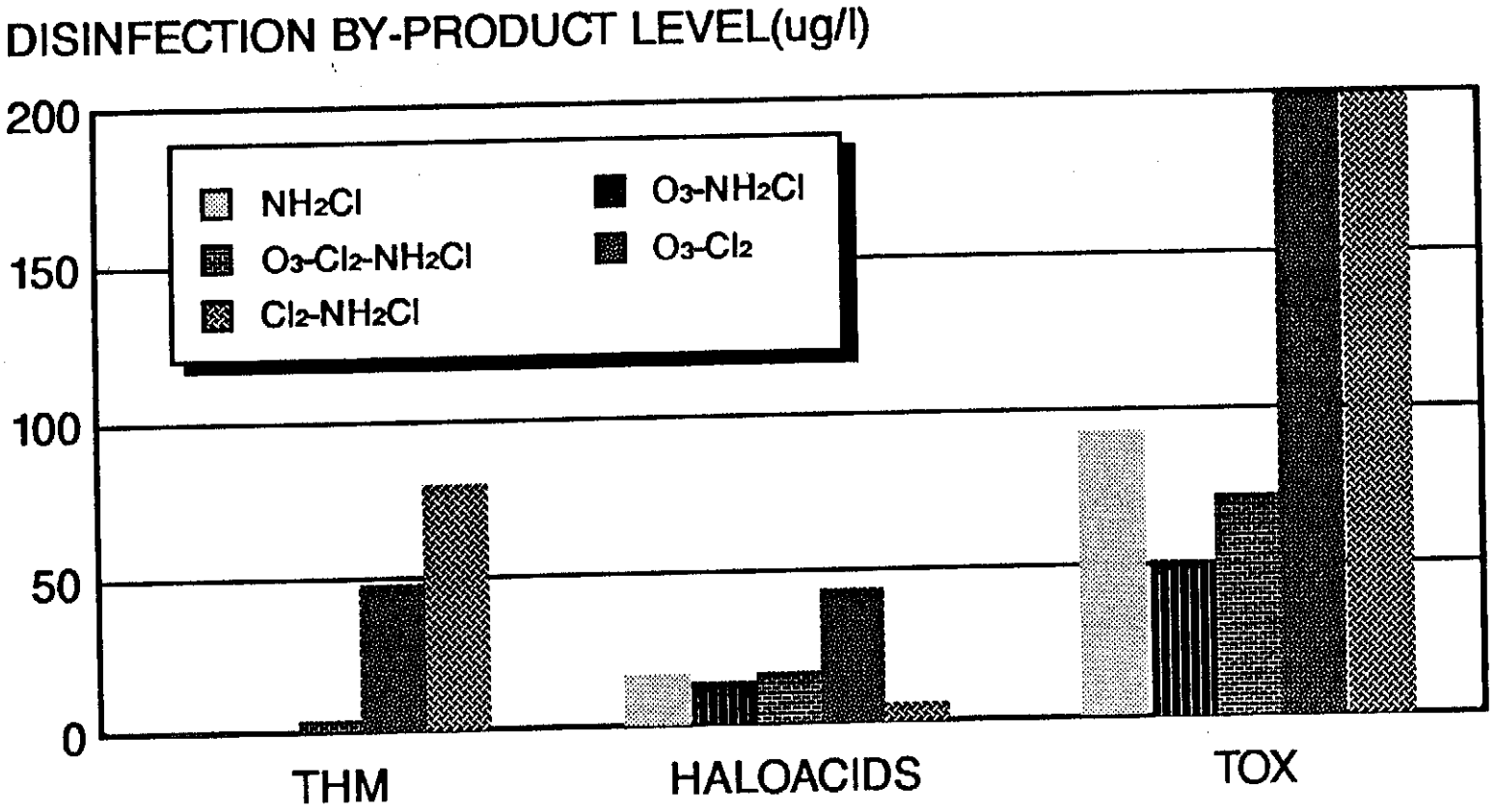
Alkalinity	68 mg/l of CaO_3
Hardness	136 mg/l of $CaCO_3$
Bromide	0.1 mg/l
Chloride	171 mg/l
Turbidity	10 NTU
Temperature	51°F
pH	7.8
Total Organic Carbon	3.8 mg/l



NOTES:

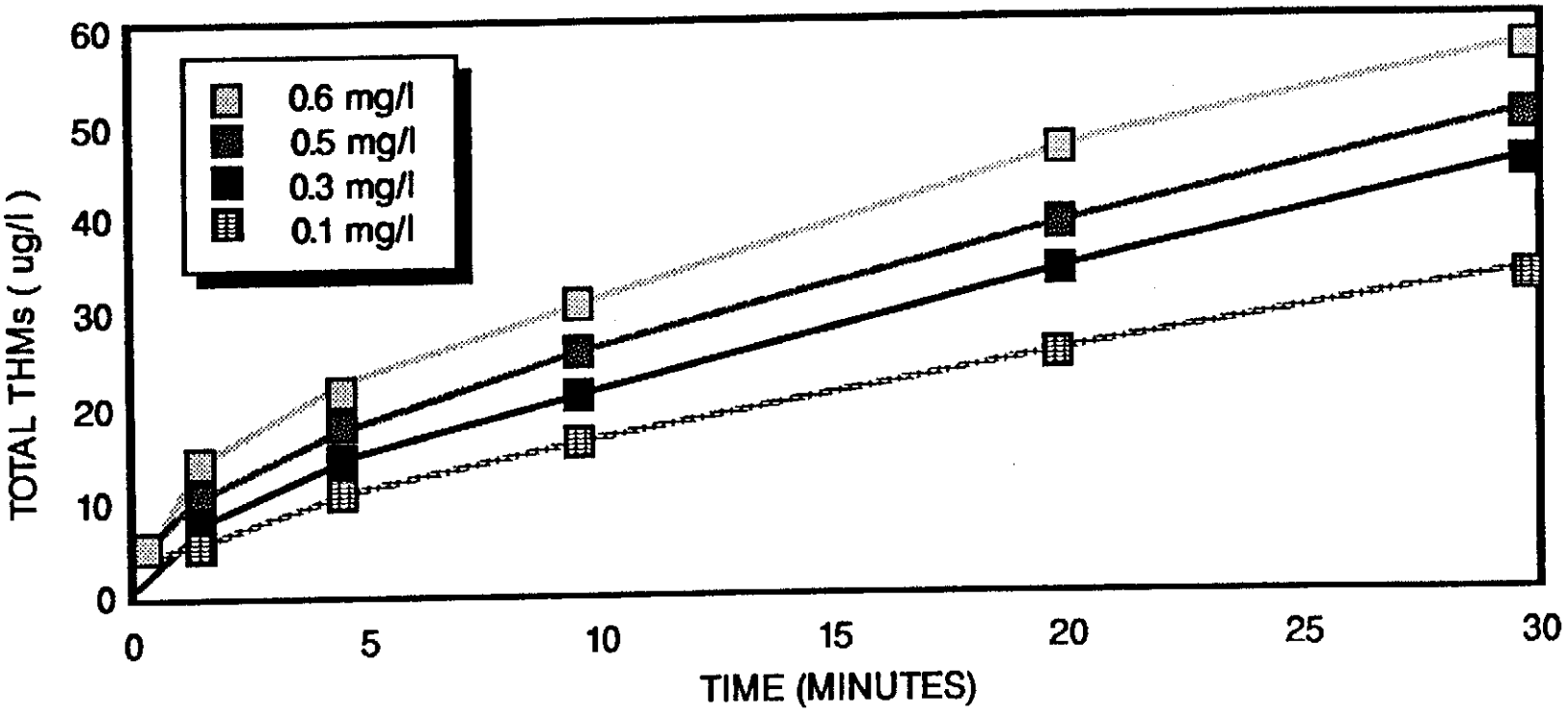
1. ALL SAMPLES EXCEPT RAW WERE COAGULATED & FILTERED THEN CHLORINATED
2. Cl_2 RESIDUAL ≈ 2 mg/l
3. TOC = 3.4 mg/l
4. SAMPLES WERE QUENCHED WITH THIOSULFATE

EFFECT OF DISINFECTANT MODE ON DBP LEVELS



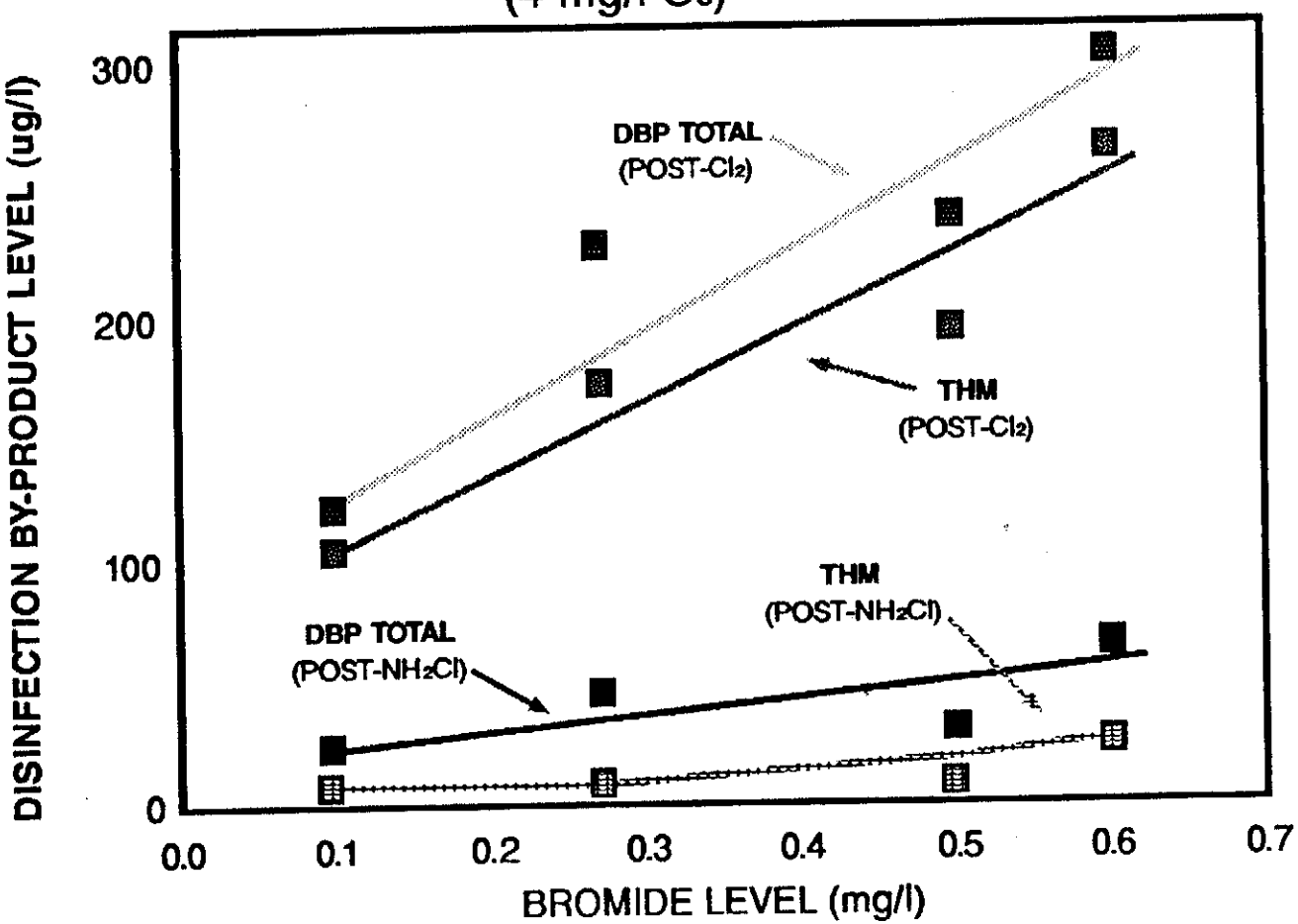
IMPACT OF BROMIDE LEVELS ON THM FORMATION KINETICS

1 mg/l pre-ozone
2 mg/l post-chlorine

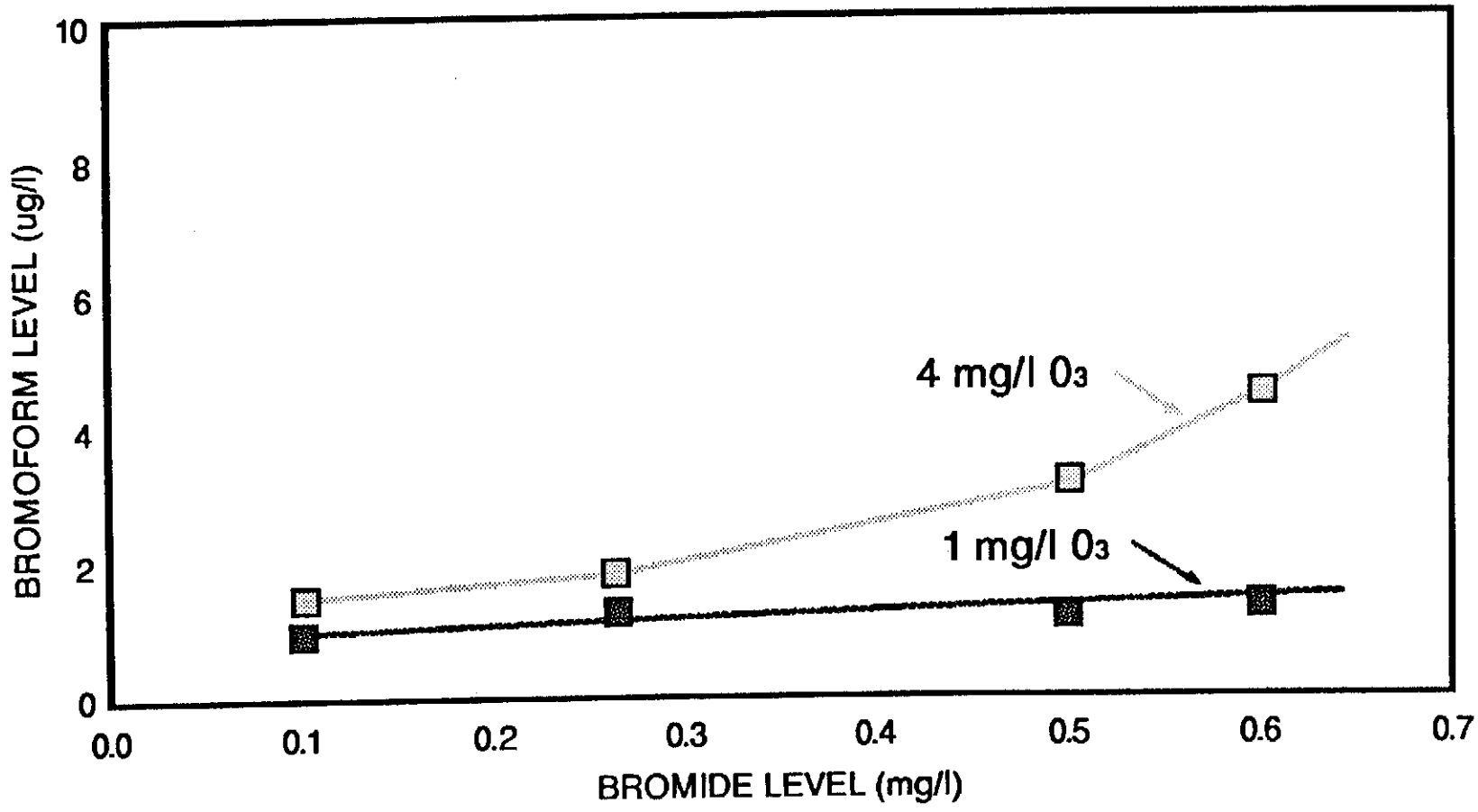


DISINFECTION BY-PRODUCT CONCENTRATION vs BROMIDE LEVEL

(4 mg/l O_3)



IMPACT OF OZONE DOSE ON IN-CONTACTOR BROMOFORM FORMATION



7. Summary of Presentation by Robert Harris

Dr. Robert Harris, Environ Corp., spoke on public health aspects of water supplies. His work attempts to evaluate relative differences in health risks associated with alternative water supplies. Quantitative evaluations of water supply risks are difficult because of a lack of comprehensive data. Data are typically collected infrequently and constituents are often found at concentrations below analytical detection limits. Mathematical models for risk assessment are sometimes used, but they suffer from the same lack of input data. His study involved relative differences between suplies. He stressed that nothing in his work indicates the suitability or unsuitability of any particular supply.

Qualitative means of evaluating supplies were discussed. He illustrated this by showing the types of discharges into three water supply watersheds. (See Figure 1.) He also indicated pesticide discharges into the same areas, as an indication of pollutants liable to show up in a water supply. (See Figure 2.)

He indicated that the ability to evaluate the significance of such qualitative measures is limited. One example is the fact that once discharged, some chemicals may quickly be diluted to below detection limits, but not necessarily below levels of concern from a health standpoint. He showed some chemicals which have significant health risks at levels below present detection limits. (See Figure 3.)

A major portion of the risk of a treated drinking water

supply derives from disinfection by-products (DBPs). Chlorination can create a series of DBPs, as shown by the figure at the end of this summary. (See Figure 4.)

THMs are the most well-known DBPs. Yet THMs are not currently believed to be a major contributor to the overall mutagenicity of a water supply. (See Figure 5.) Note, however, that there have been no carcinogenic studies of MX to date.

He indicated that risk assessment is an inexact science, that many DBP's are unknown, and that there is a lack of quantitative data on the carcinogenicity of many compounds in water supplies. In general a correlation has been found between mutagenicity and carcinogenic potential. If one assumes that similar mutagenicity implies similar carcinogenic potential, then one can estimate carcinogenic potential of different water supplies. Within an order of magnitude analysis, the risk of drinking Delta water is similar to the risk of drinking water from most other urban supplies. (See Figure 6.)

He showed a similarity between the sum of risks for different DBP's and the lifetime cancer risk results from epidemiological studies. (See Figure 7.)

The DBP issue is much broader than the THM issue. It is conceivable that a program to decrease THMs could increase other DBPs such that the overall risk of using the water supply increases. Conversely, a program to decrease THMs could also decrease another DBP: for example, MX precursors are the same as THM precursors.

DBPs produced by disinfection technologies other than chlorination are known to exist, but are less understood than chlorination-induced DBPs (See Figure 8). Even granular activated carbon treatment poses some risks related to variable treatment efficiency and the formation of bacterial endotoxins.

FIGURE 1

DISCHARGERS INTO THE AMERICAN RIVER, SACRAMENTO RIVER, AND DELTA*

AMERICAN	SACRAMENTO	DELTA
SEWERAGE SYSTEMS	PAPER MILLS	PAPER MILLS
SAW MILLS & PLANING MILLS	SAW MILLS & PLANING MILLS	SAW MILLS & PLANING MILLS
	SEWERAGE SYSTEMS	SEWERAGE SYSTEMS
	REFUSE SYSTEMS	REFUSE SYSTEMS
	INDUSTRIAL ORGANIC CHEMICALS	PAPERBOARD MILLS
	SOAP & OTHER DETERGENTS	INDUSTRIAL ORGANIC CHEMICALS
	PETROLEUM BULK STATIONS	INDUSTRIAL INORGANIC CHEMICALS
	LOGGING	PESTICIDES & AGRICULTURAL CHEMICALS
	GOLD ORES	CRUDE PETROLEUM & NATURAL GAS
	COPPER ORES	CRUDE PETROLEUM PIPELINES
	ELECTRICAL SERVICES	INORGANIC PIGMENTS
	CANNED FRUITS, VEGETABLES PRESERVES, JAMS & JELLIES	WOOD PRESERVING/WOOD PRODUCTS
	BEEF CATTLE FEEDLOTS	PHOSPHATIC FERTILIZERS
	GENERAL MEDICAL & SURGICAL HOSPITALS	ASPHALT FELTS & COATINGS
	HARDWOOD VENEER & PLYWOOD	EXPLOSIVES
		GOLD ORES
		STEEL WORKS, BLAST FURNACES, AND ROLLING MILLS
		TIRES & INNER TUBES
		LEATHER TANNING & FINISHING
		BEET SUGAR
		READY MIXED CONCRETE
		FABRICATED METAL PRODUCTS
		SECONDARY SMELTING REFINING OF NON-FERROUS METALS
		GLASS CONTAINERS
		MEAT PACKING PLANTS
		CLAY, CERAMIC & REFRACTORY MINERALS
		GENERAL MEDICAL & SURGICAL HOSPITALS
		PETROLEUM REFINING
		ELECTRICAL SERVICES
		DRY CONDENSED & EVAPORATED DAIRY PRODUCT
		CANNED FRUITS, VEGETABLES, PRESERVES, JAMS & JELLIES

* LIST INCLUDES MUNICIPAL SEWERAGE REFUSE SYSTEMS AND INDUSTRIES COVERED BY EFFLUENT GUIDELINES FOR TOXIC DISCHARGES UNDER THE CLEAN WATER ACT REGULATIONS (40 CFR PARTS 40[illegible]1))

FIGURE 2

PESTICIDES COMPRISING MORE THAN 85% OF THE 1987 PESTICIDE USE BY WEIGHT
FOR THE AMERICAN, SACRAMENTO, AND DELTA WATERSHEDS

AMERICAN TOP 85%	SACRAMENTO TOP 85%	DELTA TOP 85%
PETROLEUM OIL, UNCLASSIFIED	SULFUR	SULFUR
THIOBENCARB (BOLERO)	MOLINATE	1,3-DICHLOROPROPENE
COPPER SULFATE, PENTAHYDRATE	COPPER SULFATE, PENTAHYDRATE	SODIUM CHLORATE
MOLINATE	PETROLEUM OIL, UNCLASSIFIED	PETROLEUM OIL, UNCLASSIFIED
METHYL BROMIDE	1,3-DICHLOROPROPENE	METHYL BROMIDE
BENTAZON, SODIUM SALT	METHYL BROMIDE	PETROLEUM HYDROCARBONS
HEXAZINONE	THIOBENCARB (BOLERO)	PROPARGITE
CHLOROPICRIN	MCPA, DIMETHYLAMINE SALT	CRYOLITE
MCPA, DIMETHYLAMINE SALT	ZIRAM	S,S,S-TRIBUTYL PHOSPHOROTRITHIOATE
AZINPHOS-METHYL	BENTAZON, SODIUM SALT	COPPER HYDROXIDE
	MINERAL OIL	ZIRAM
	XYLENE	XYLENE
	CARBARYL	METHOMYL
	PARATHION	PARATHION
		PARAQUAT DICHLORIDE
		PROFENOFOS
		CHLORPYRIFOS
		MINERAL OIL
		CARBARYL
		CHLOROPICRIN
		AZINPHOS-METHYL
		TRIFLURALIN
		PETROLEUM DISTILLATES, AROMATIC
		ETHEPHON
POUNDS PER SQUARE MILE 41	403	694

0665B

FIGURE 3

COMPARISON OF THE DETECTION LIMITS AND THE ONE IN A MILLION RISK LEVEL FOR SOME CARCINOGENIC PESTICIDES WHOSE POTENCY HAS BEEN DETERMINED

PESTICIDE	CONCENTRATION AT ONE IN A MILLION RISK (PPB)	DETECTION LIMIT (PPB)
1,2-DICHLOROPROPANE	0.55	0.2
1,3-DICHLOROPROPENE	0.20	0.1-0.5
ALACHLOR	0.44	1-2[A]
BROMACIL	9.2	1[A]
CAPTAN	15	0.5[A]
CLOROTHALONIL	1.5	2-5
DICOFOL	0.080	1[A]
ETHYLENE DIBROMIDE	0.00085	0.01-0.2
LINDANE	0.026	0.05
PARATHION	19	0.01-2.5[B]
TOXAPHENE	0.032	0.5
TRIFLURALIN	4.6	1[A]

A THESE DETECTION LIMITS WERE BASED UPON DETECTION LIMITS FOR SIMILAR PESTICIDES.

B METHYL AND ETHYL PARATHION.

NOTE: THE ONE IN A MILLION RISK CONCENTRATION LEVEL FOR SEVEN OUT OF THE 12 CARCINOGENIC PESTICIDES IS AT OR BELOW THE DETECTION LIMIT.

FIGURE 4

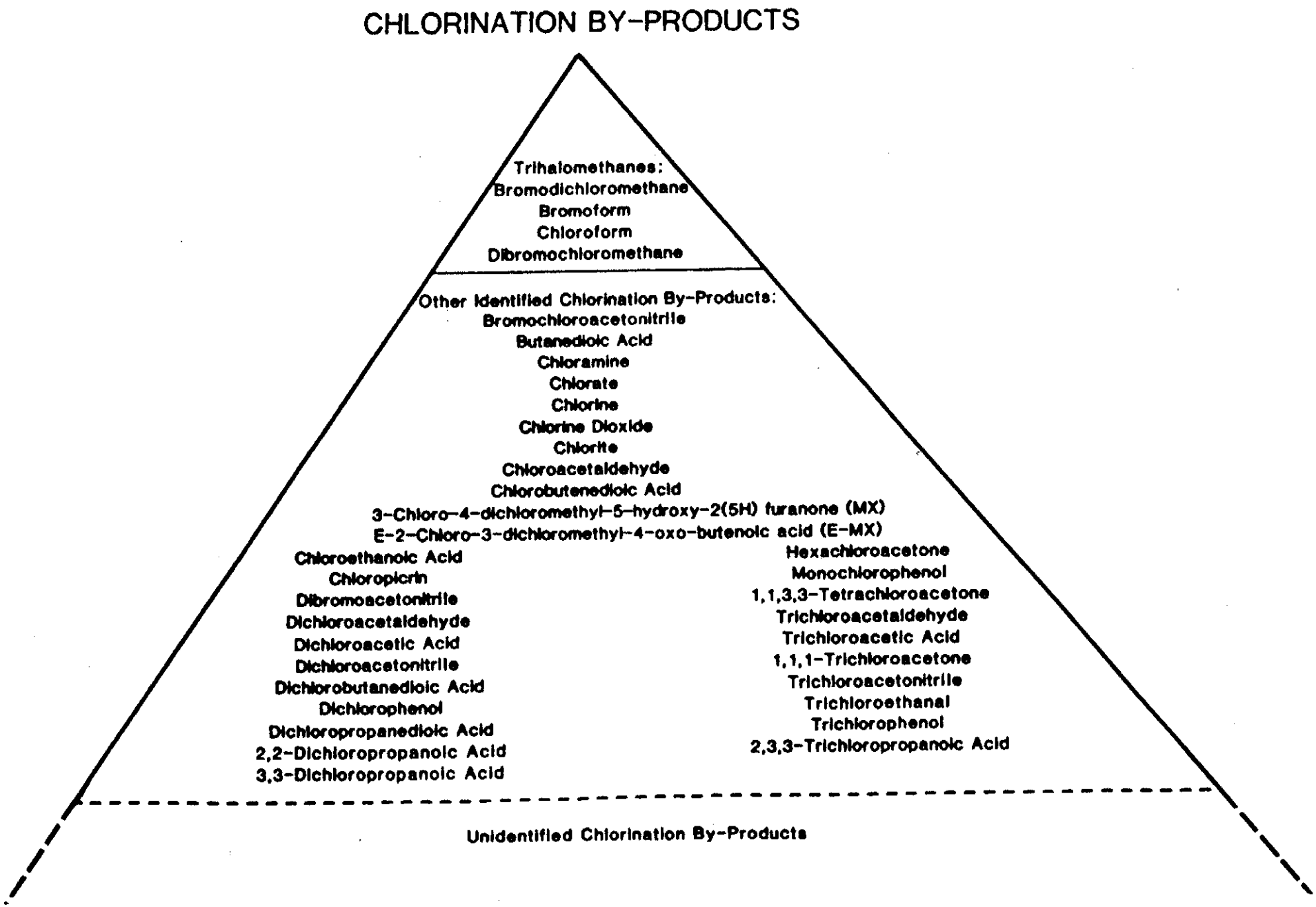

CHLORINATION BY-PRODUCTS
Trihalomethanes:
Bromodichloromethane
Bromoform
Chloroform
Dibromochloromethane
Other Identified Chlorination By-Products:
Bromochloroacetonitrile
Butanedioic Acid
Chloramine
Chlorate
Chlorine
Chlorine Dioxide
Chlorite
Chloroacetaldehyde
Chlorobutenedioic Acid
3-Chloro-4-dichloromethyl-5-hydroxy-2(5H) furanone (MX)
E-2-Chloro-3-dichloromethyl-4-oxo-butenoic acid (E-MX)
Chloroethanoic Acid
Chloropicrin
Dibromoacetonitrile
Dichloroacetaldehyde
Dichloroacetic Acid
Dichloroacetonitrile
Dichlorobutanedioic Acid
Dichlorophenol
Dichloropropanedioic Acid
2,2-Dichloropropanoic Acid
3,3-Dichloropropanoic Acid
Hexachloroacetone
Monochlorophenol
1,1,3,3-Tetrachloroacetone
Trichloroacetaldehyde
Trichloroacetic Acid
1,1,1-Trichloroacetone
Trichloroacetonitrile
Trichloroethanal
Trichlorophenol
2,3,3-Trichloropropanoic Acid
Unidentified Chlorination By-Products

FIGURE 5

MUTAGENICITY CONTRIBUTIONS OF CHLORINATED BY-PRODUCTS IN DRINKING WATER

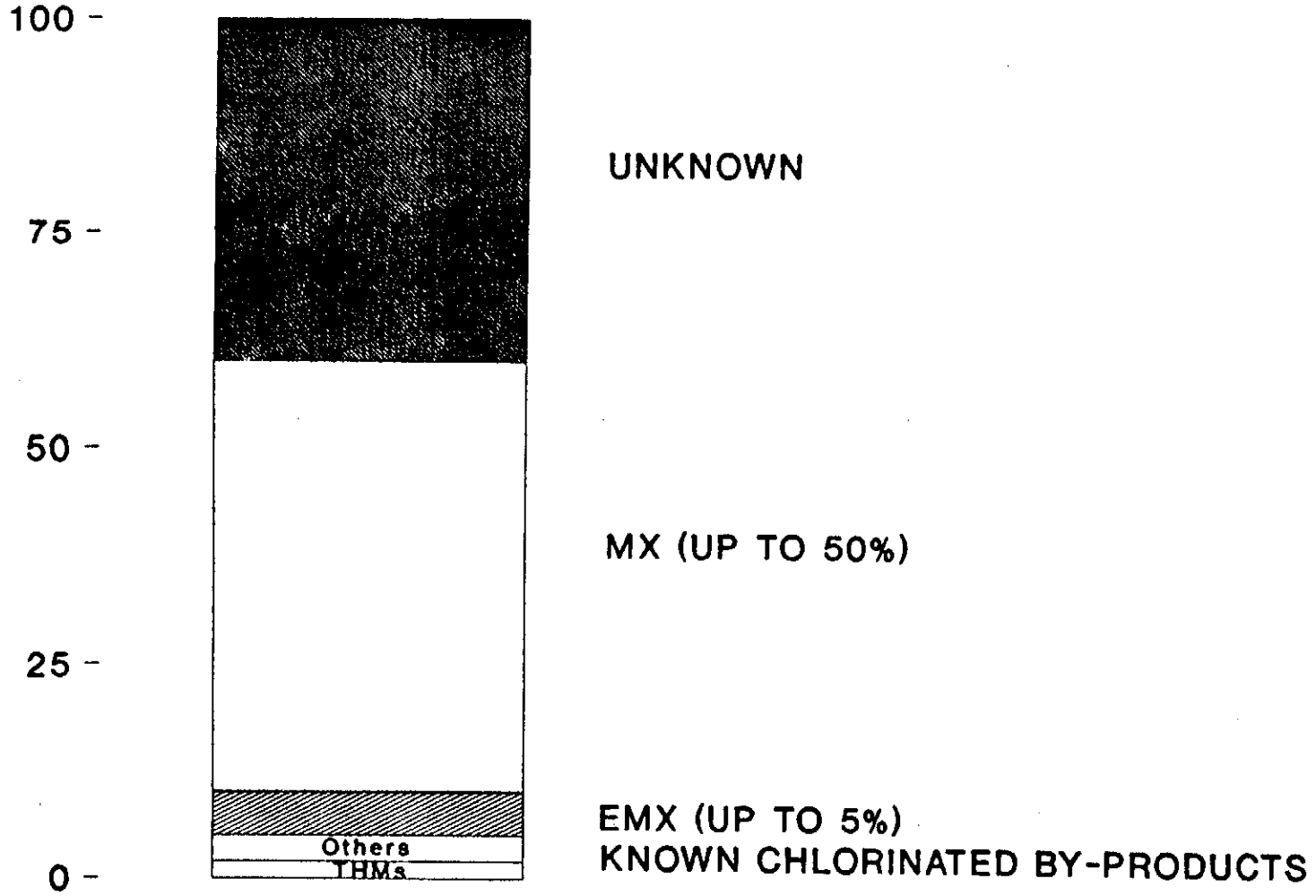
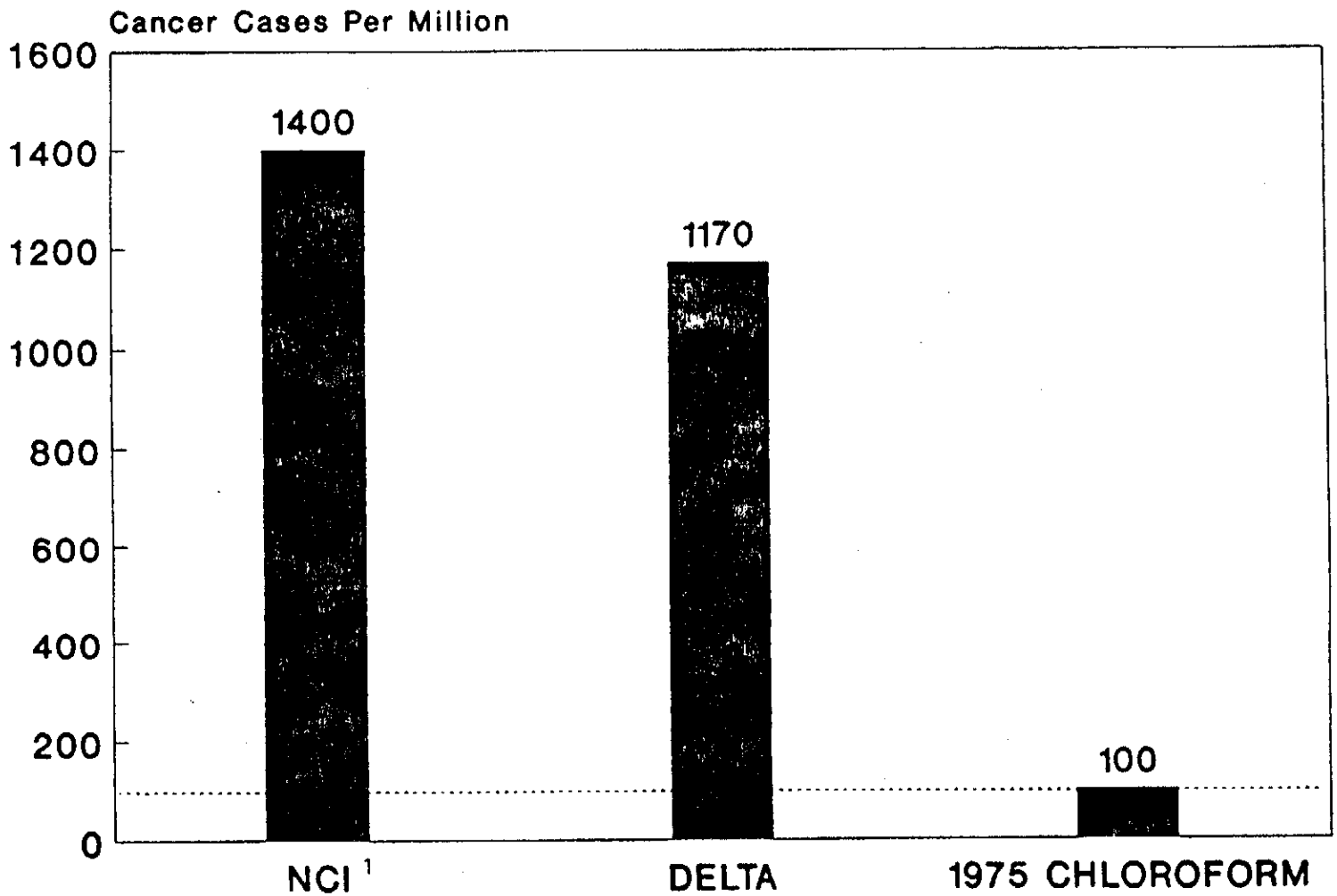


FIGURE 6

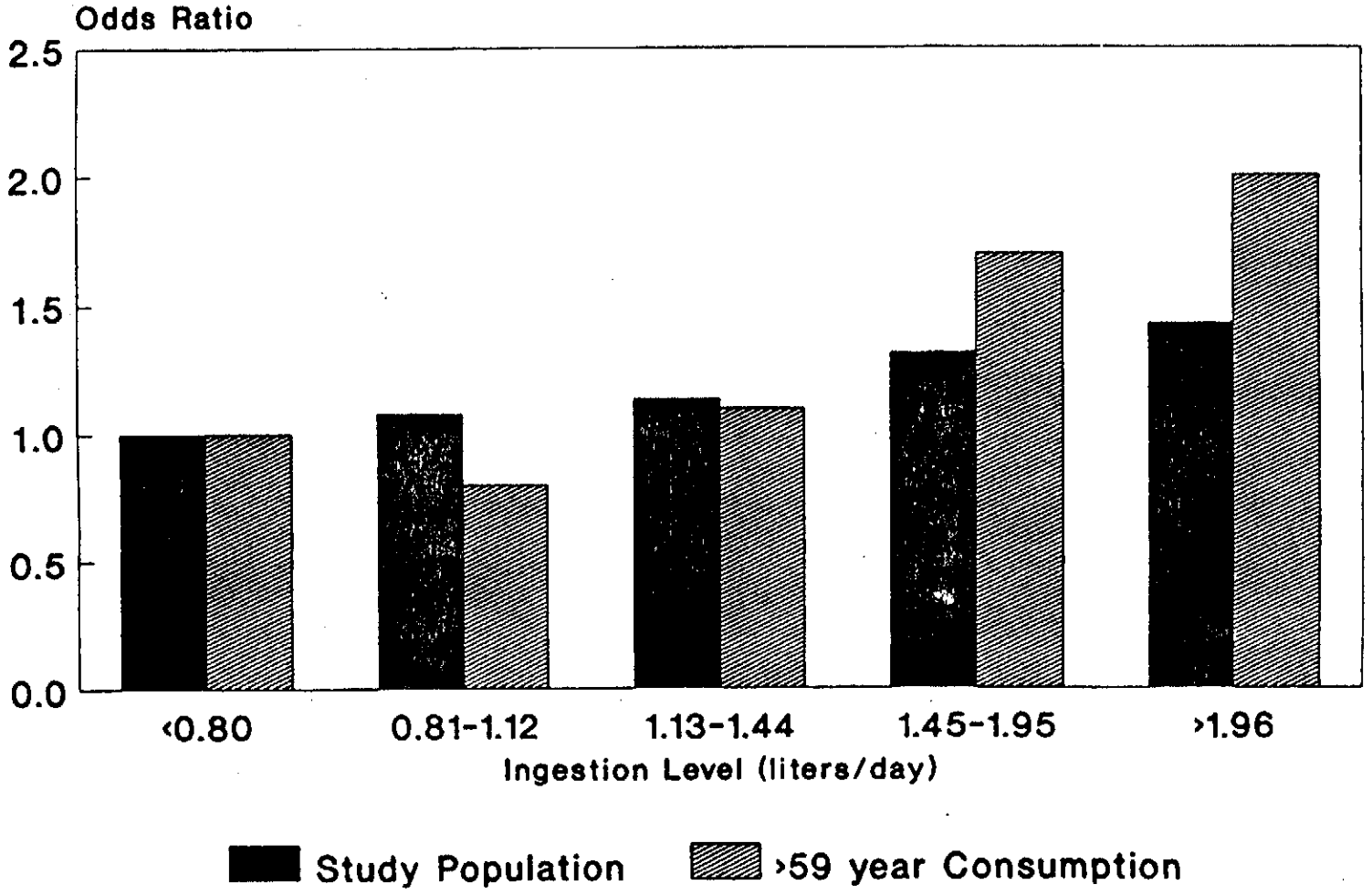
COMPARISON OF ESTIMATED LIFETIME CANCER RISKS FROM CHLORINATED DRINKING WATER



[1]Derived from NCI cancer data and Cantor et al., 1987.

FIGURE 7

HUMAN BLADDER CANCER RISKS AND INGESTION OF CHLORINATED DRINKING WATER



Source: Cantor et al., 1987.

FIGURE 8

ALTERNATIVE DISINFECTION TECHNOLOGIES

TECHNOLOGY	DISADVANTAGES
Chlorine	•Formation of THMs •May produce other carcinogenic by-products
Ozone	•High initial cost •No residual protection against recontamination •May produce toxic by-products
Chloramine	•Lower effectiveness •May produce toxic by-products •Adverse effects on dialysis patients
Chlorine Dioxide	•Greater costs •May produce toxic by-products

8. Summary of Presentation by Marvin Jung

Marvin Jung, Marvin Jung & Associates, spoke about the Interagency Delta Health Aspects Monitoring Program (IDHAMP) and the Delta Agriculture Drainage Investigation (DADI). DWR is the lead agency for both of these programs. Both programs are primarily directed at measuring trihalomethane formation potential (THMFP), as well as other water quality data that are related to human health concerns. Samples are collected monthly by the IDHAMP program at twenty locations throughout the Delta. The IDHAMP program is now in its sixth year.

Jung stated that raw water THMFPs cannot be directly correlated to trihalomethane (THM) concentrations in a distribution system. However, lower source water THMFP implies lower THM concentrations in drinking water for some ranges of conditions. IDHAMP results indicate that THMFP in the Delta is approximately twice the THMFP at the Sacramento R. at Greene's Landing. The results also indicate that the formation potential of brominated species of THMs increases as the influence of sea water increases.

Jung showed slides that indicated THMFP ranges in the Delta. These are included at the end of this section and cover 1983-1987. (See attached figures.) Some of the highest levels are found in agricultural drains, where the levels are normally many times higher than found in Delta channels.

A 1954-55 DWR ag drain study (Report No. 4, 1956) showed a winter peak, related to winter leaching and a summer drainage

peak related to high consumptive use. Delta water quality is, therefore, most likely to be affected during these two peak drainage seasons. In the channels, there is often a peak in THMFP following very high flows or floods. Brominated THMs typically decrease with higher flows in the rivers but chloroform potential increases. Therefore, the use of upstream flows to regulate THMs may not be as effective as hoped. Overall, there is a wide variation in the values found. (See attached figures.)

Jung mentioned that other water quality parameters are measured, but on a monthly basis. No attempt has been made to examine the variability of parameters over the tidal cycle.

The DADI study is still in progress and has identified 260 agricultural drains located on 55 Delta islands. The program currently has 54 monitoring sites. As previously observed in the 1954-55 study, agricultural drainage is seasonal, with peaks occurring generally in December-January due to leaching practices and in July-August due to irrigation practices. DADI findings to-date indicate that discharges from agricultural drains have consistently higher concentration of THMFP than do receiving Delta channels and that THMFP concentrations vary significantly from island to island. The relative contribution of ag drainage to THMFP in the Delta is also dependent on net Delta outflow because if net Delta outflow increases rapidly, Delta channels will have more THMFP because of increased chloroform potential. (See attached figures.)

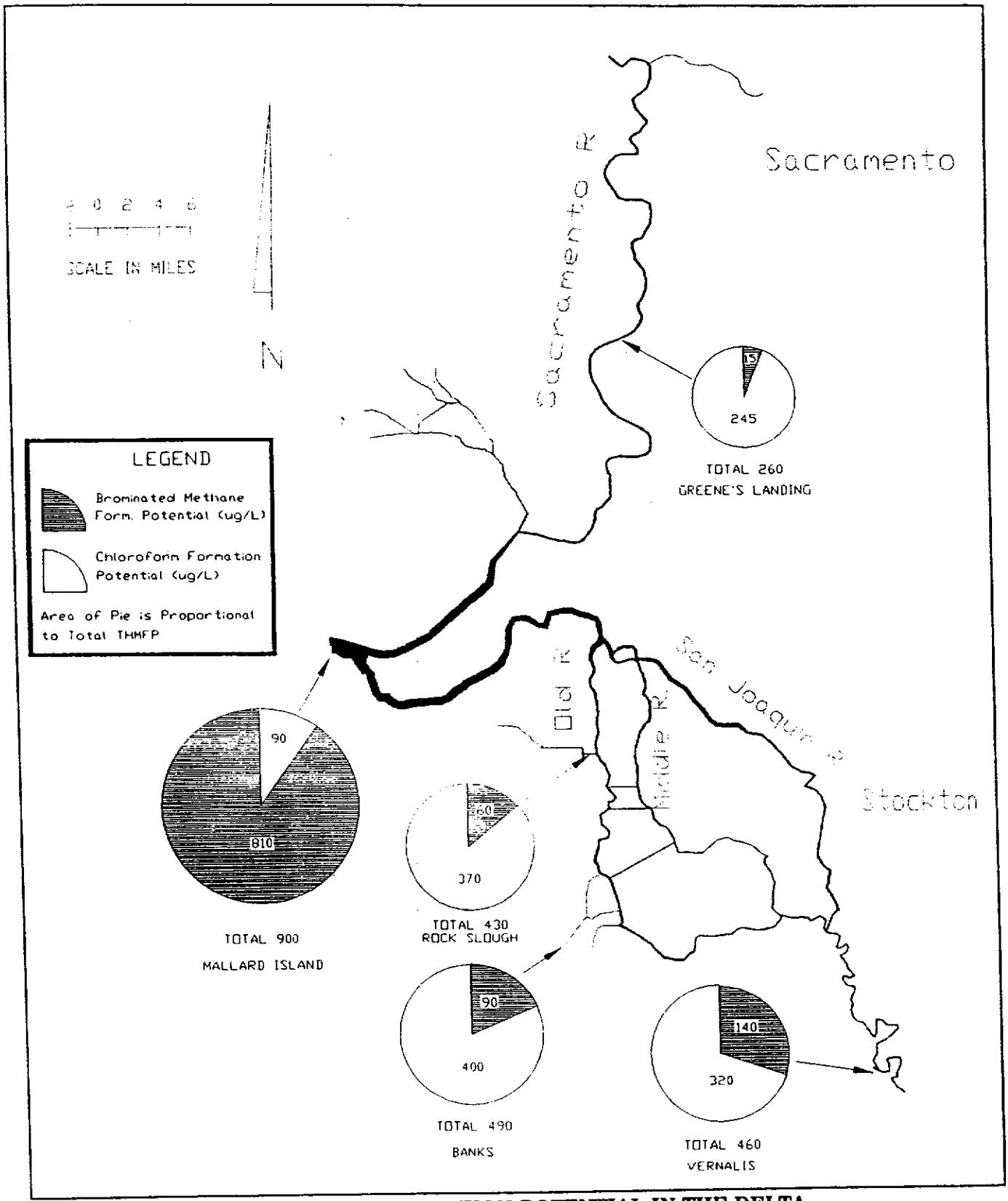


Figure 4. THM FORMATION POTENTIAL IN THE DELTA, 5-YEAR MEDIAN, 1983-1987

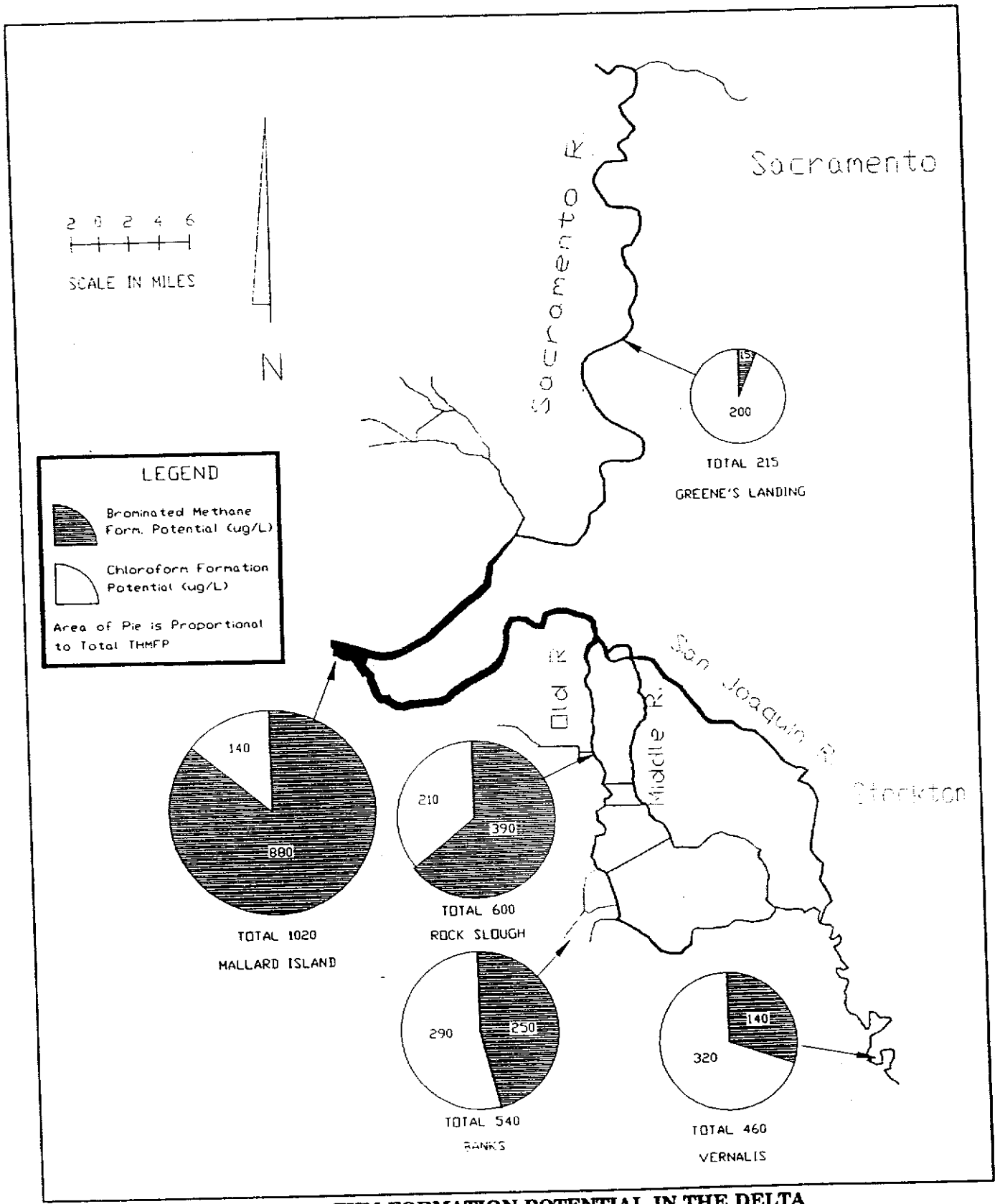


Figure 5. THM FORMATION POTENTIAL IN THE DELTA UNDER LOW FLOW CONDITIONS , OCTOBER 1985

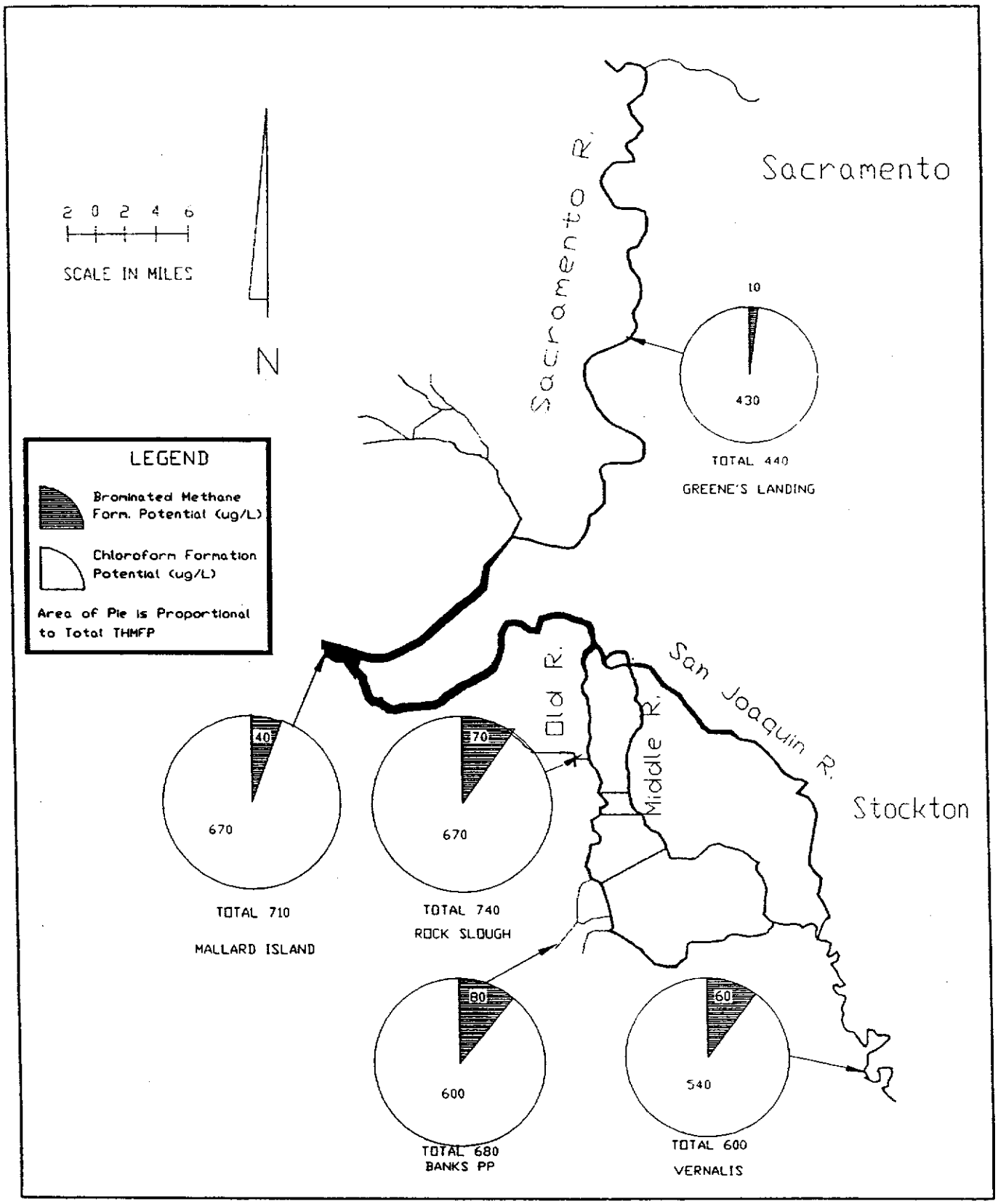


Figure 6. THM FORMATION POTENTIAL IN THE DELTA UNDER HIGH FLOW CONDITIONS, MARCH 1986

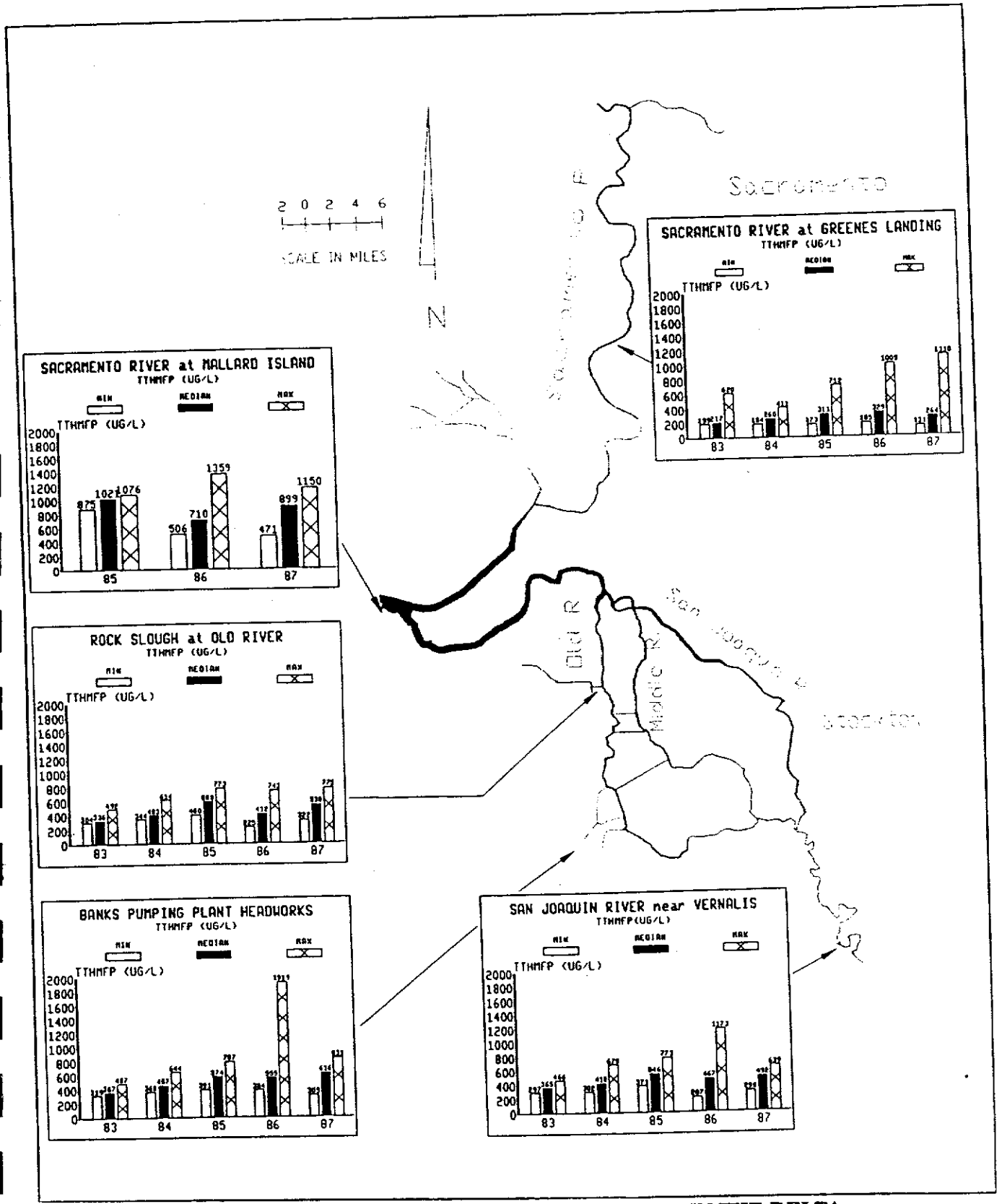


Figure 7. TOTAL THM FORMATION POTENTIAL IN THE DELTA, 1983-1987 MAXIMUM, MINIMUM, MEDIAN

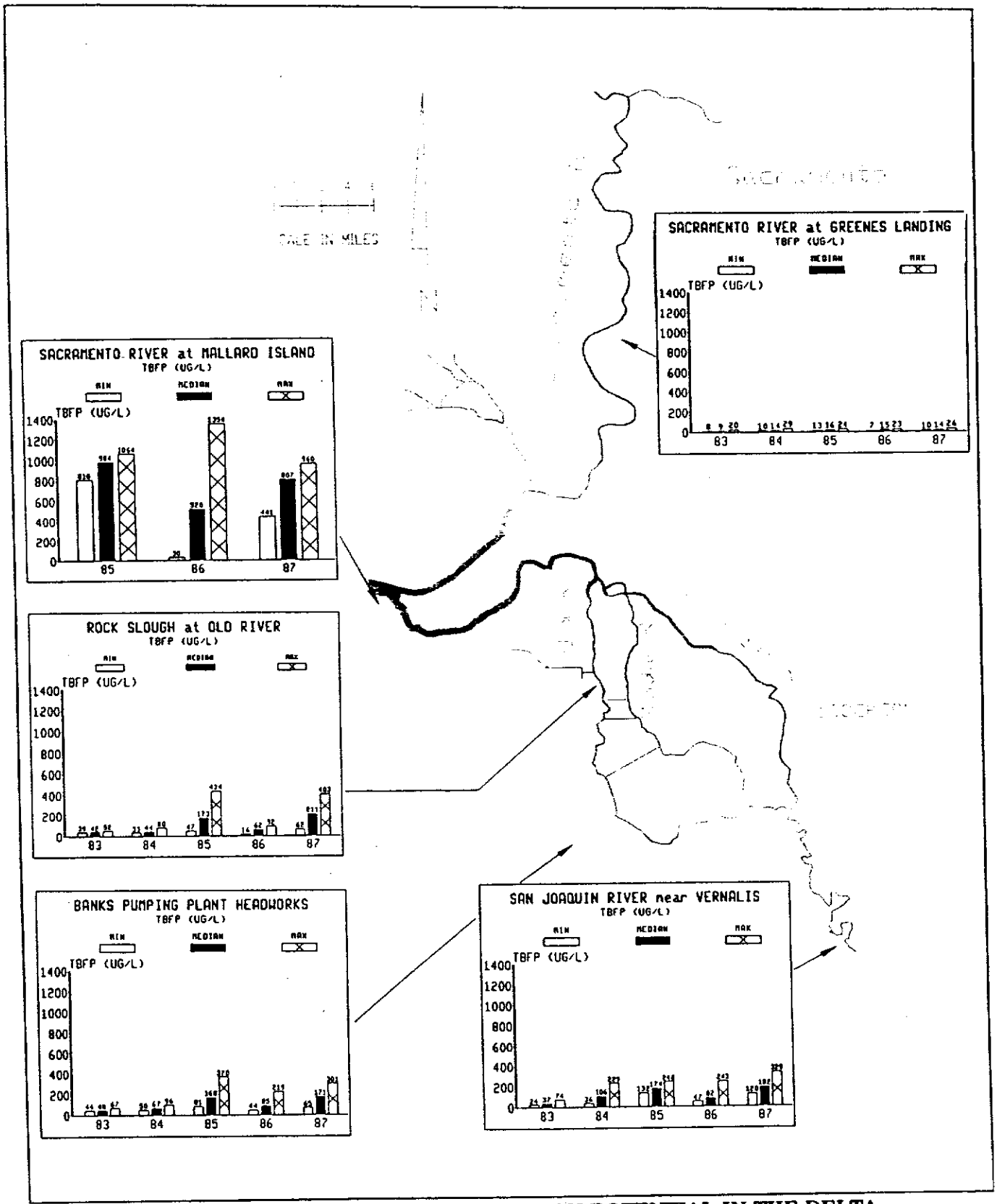
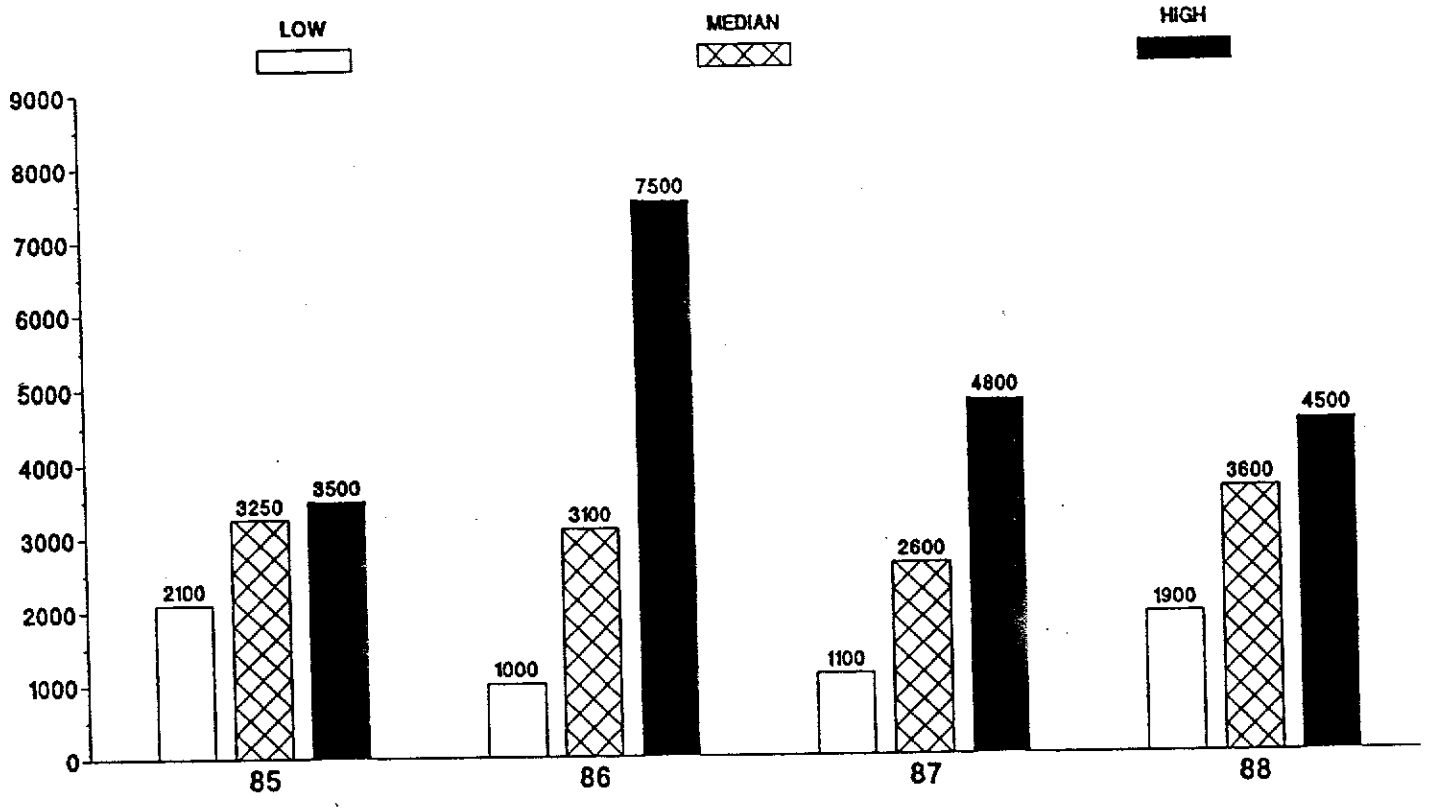


Figure 8. BROMINATED THM FORMATION POTENTIAL IN THE DELTA, 1983-1987 MAXIMUM, MINIMUM, MEDIAN

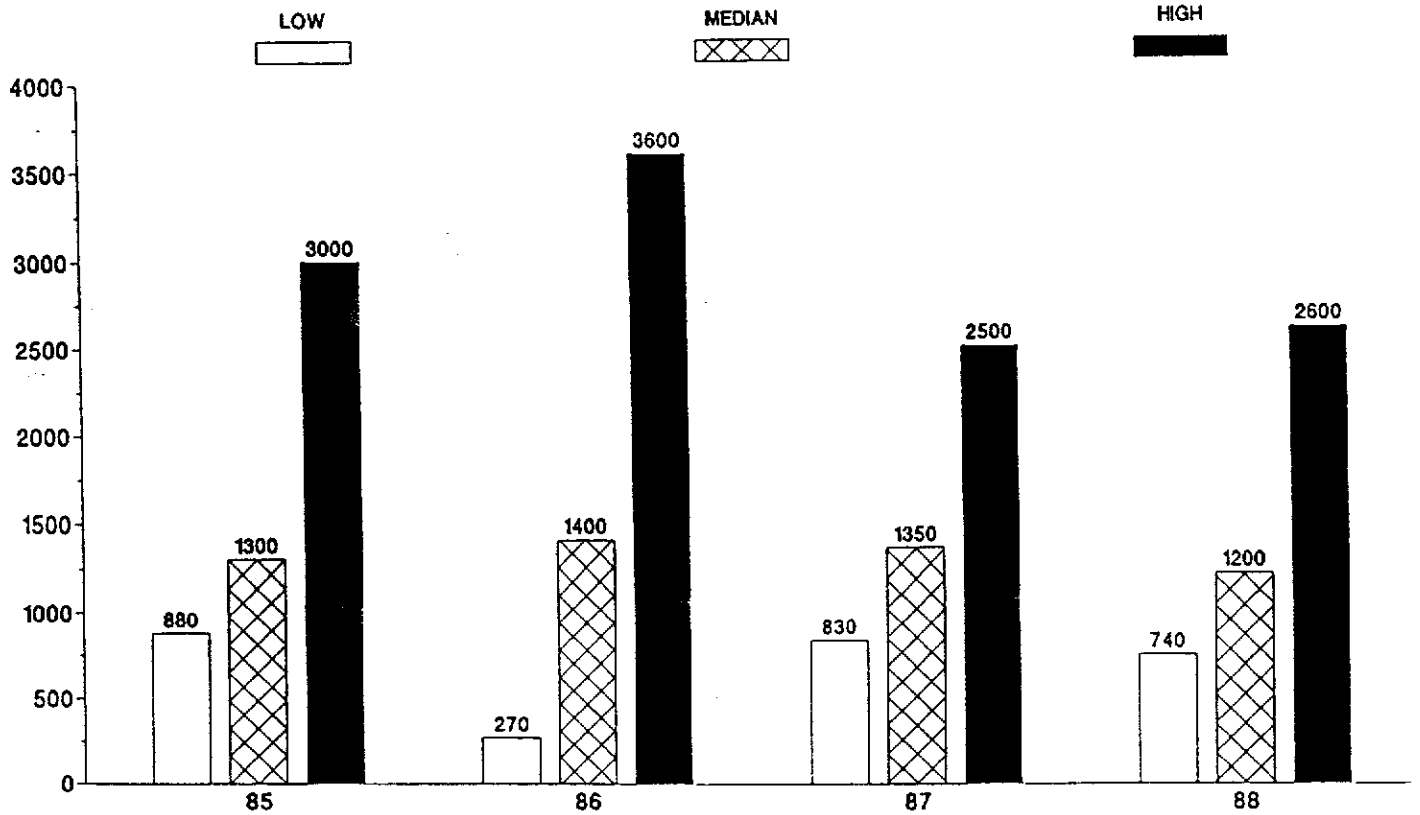
AGRICULTURAL DRAIN at EMPIRE TRACT

TTHMFP (ug/L)



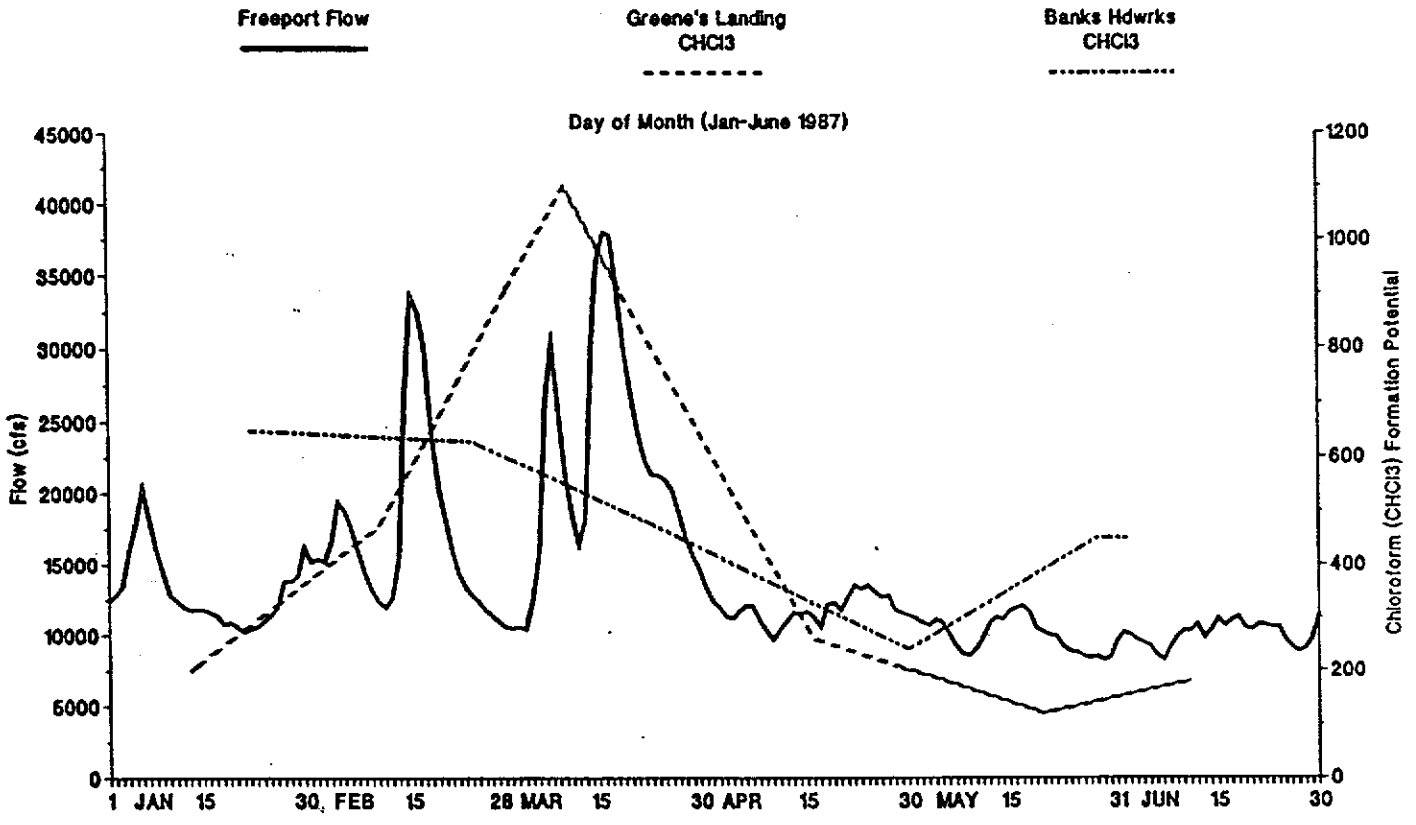
AGRICULTURAL DRAIN at GRAND ISLAND

TTHMFP (ug/L)



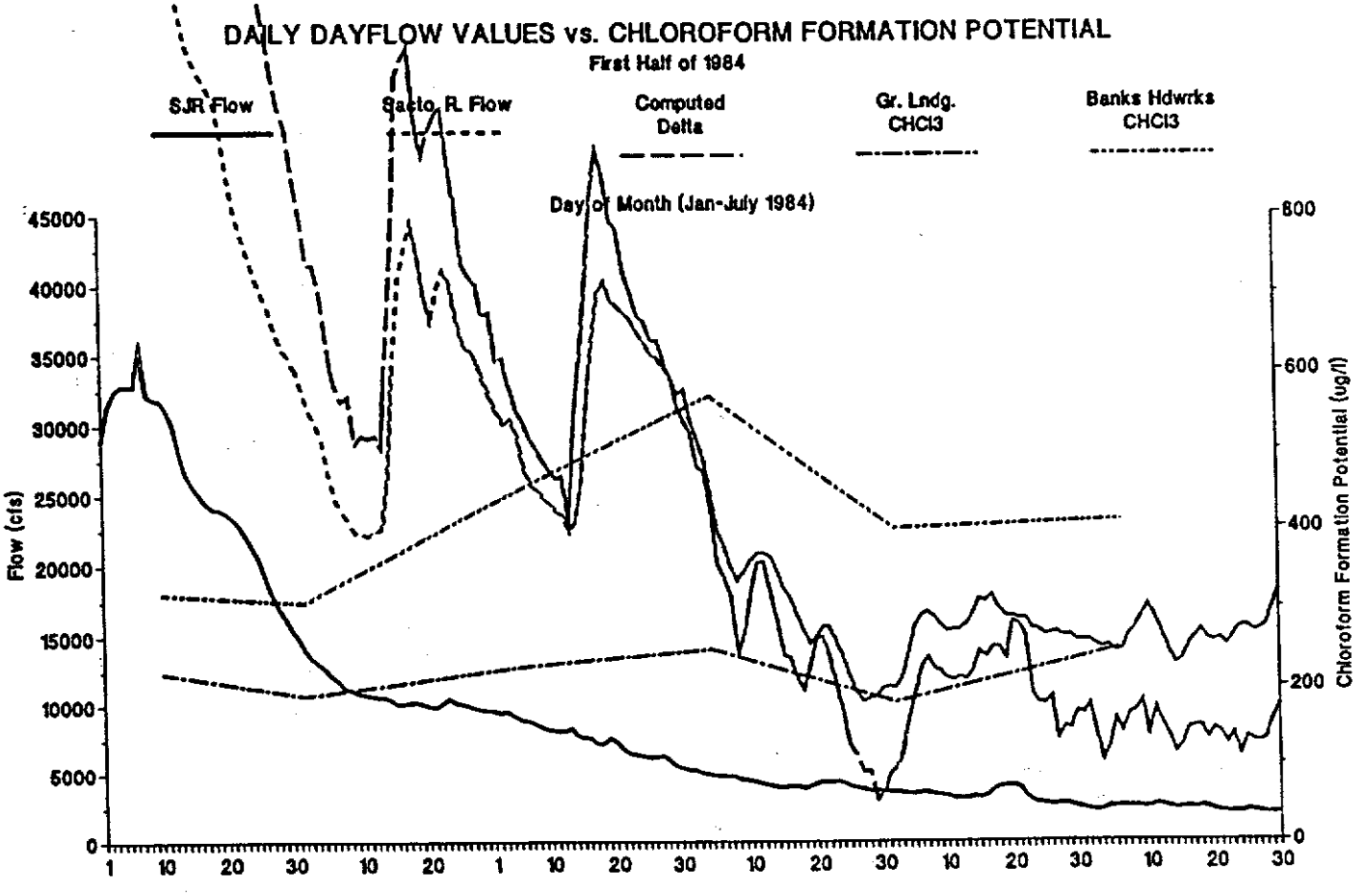
FLOW (cfs) vs. CHCL3 FORMATION POTENTIAL (ppb)

Sacramento River



DAILY DAYFLOW VALUES vs. CHLOROFORM FORMATION POTENTIAL

First Half of 1984



9. Summary of Presentation by Elaine Archibald

Elaine Archibald, Brown and Caldwell, spoke about the recently completed Delta Drinking Water Quality Study. This study was funded by a consortium of urban water agencies. Each participating agency also contributed staff time to form a technical advisory committee which guided the study. The study was done in part because of a growing concern about drinking water quality and a loss of consumer confidence in treated water, with as many as 50% of the public using bottled water or home treatment devices.

The study included water quality parameters such as TDS, chloride, bromide, sodium, biocides, total organic carbon (as a possible surrogate for THM precursors), THMFP, and organic precursors (of THM and of taste and odor problems). The study indicated a wide range of THMFP and TDS concentrations in different source waters. (See Figures 3.2 and 3.6.)

This study examined the water quality improvement that could be achieved by six alternatives. Capital costs, treatment costs, and savings to consumers were also evaluated.

1) Delta transfer system improvements proposed by DWR.
2) San Joaquin conjunctive use (includes Delta transfer improvements)
3) Delta agriculture drainage management (includes Delta transfer improvements).
4) Peripheral Canal.
5) Dual transfer system.

6) Sierra Source-To User System.

The peripheral canal was included for completeness and to aid in evaluating the other alternatives. The report showed expected water quality improvements for each option. These are shown on the enclosed "Water Quality Improvement" chart.

Based on results from this study, the isolated transfer systems offer the greatest source water quality improvements. Major findings of this report are that:

1. There is currently a wide range of water quality conditions in the Delta source waters.
2. The cost to achieve source water quality improvements is offset by the treatment and consumer cost reductions.

Environmental mitigation costs and political feasibility were not considered. This report does not recommend a specific alterntive for improving drinking water quality.

In addition, Archibald stated the study confirms the SWRCB's findings as referee for EDF v. EBMUD in which the SWRCB stated that "...prudence requires that public water suppliers should minimize treatment uncertainties by seeking water from the best available source."

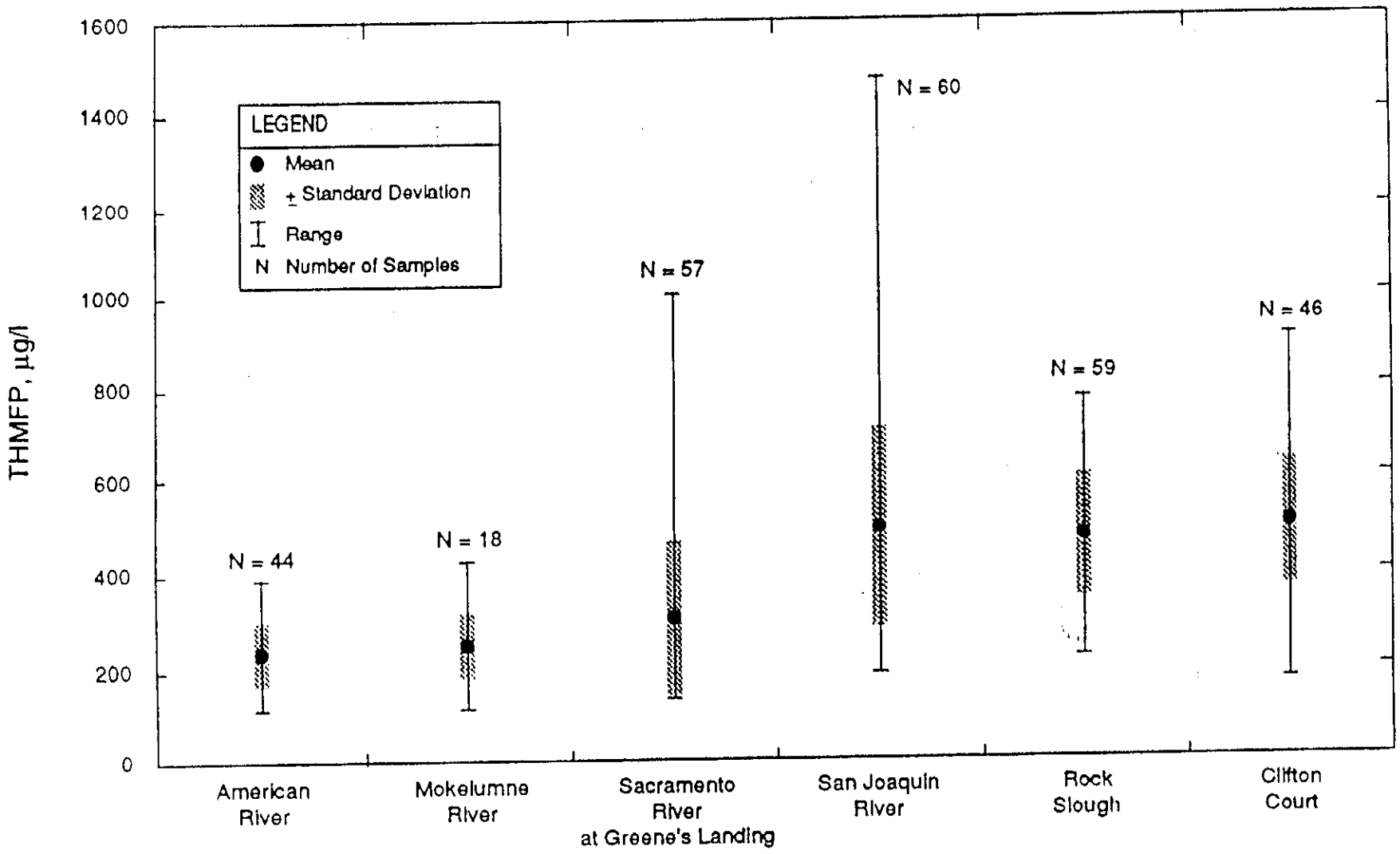


Figure 3-2. THMFP (DWR) in the Delta Source Waters

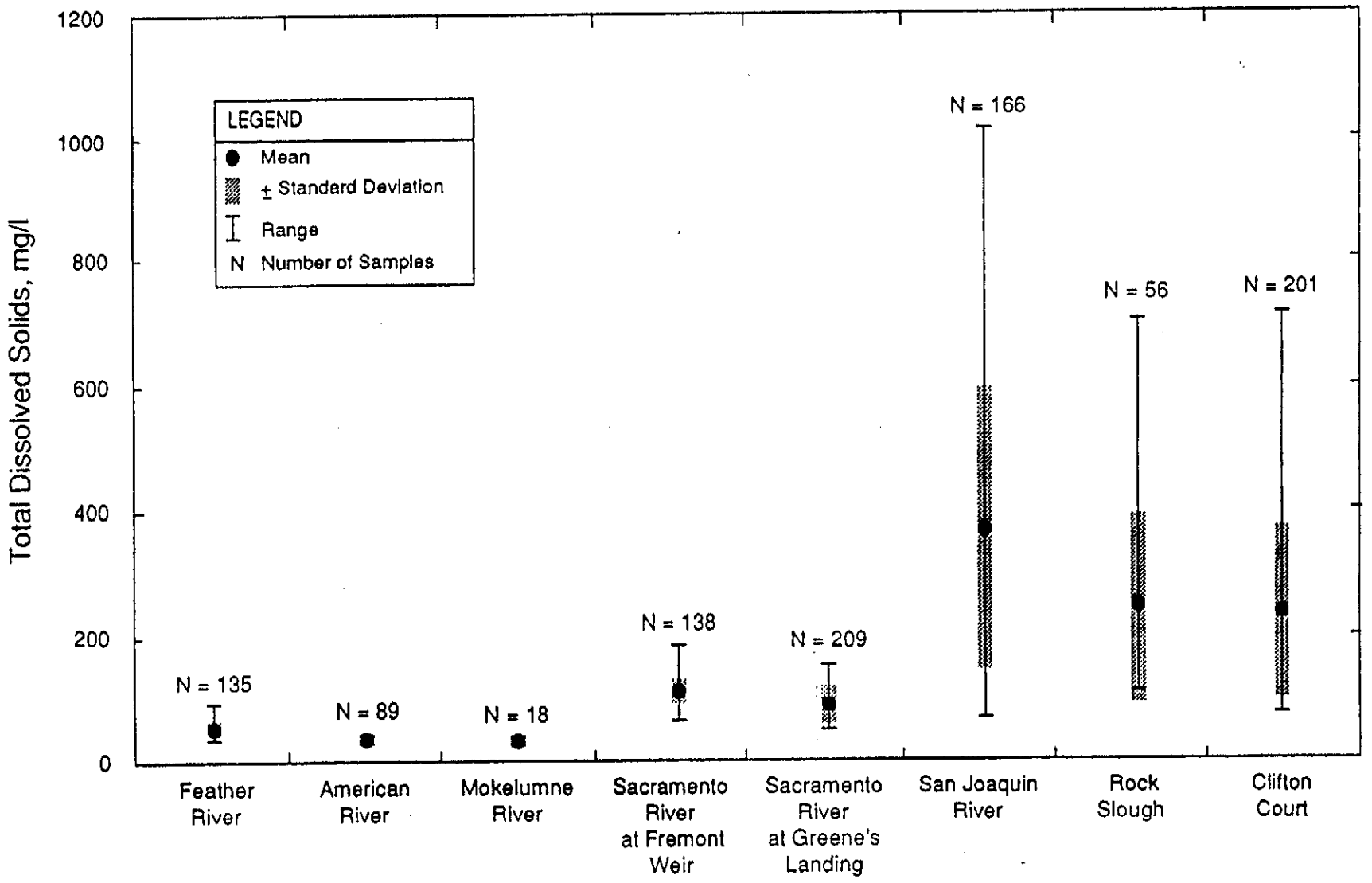
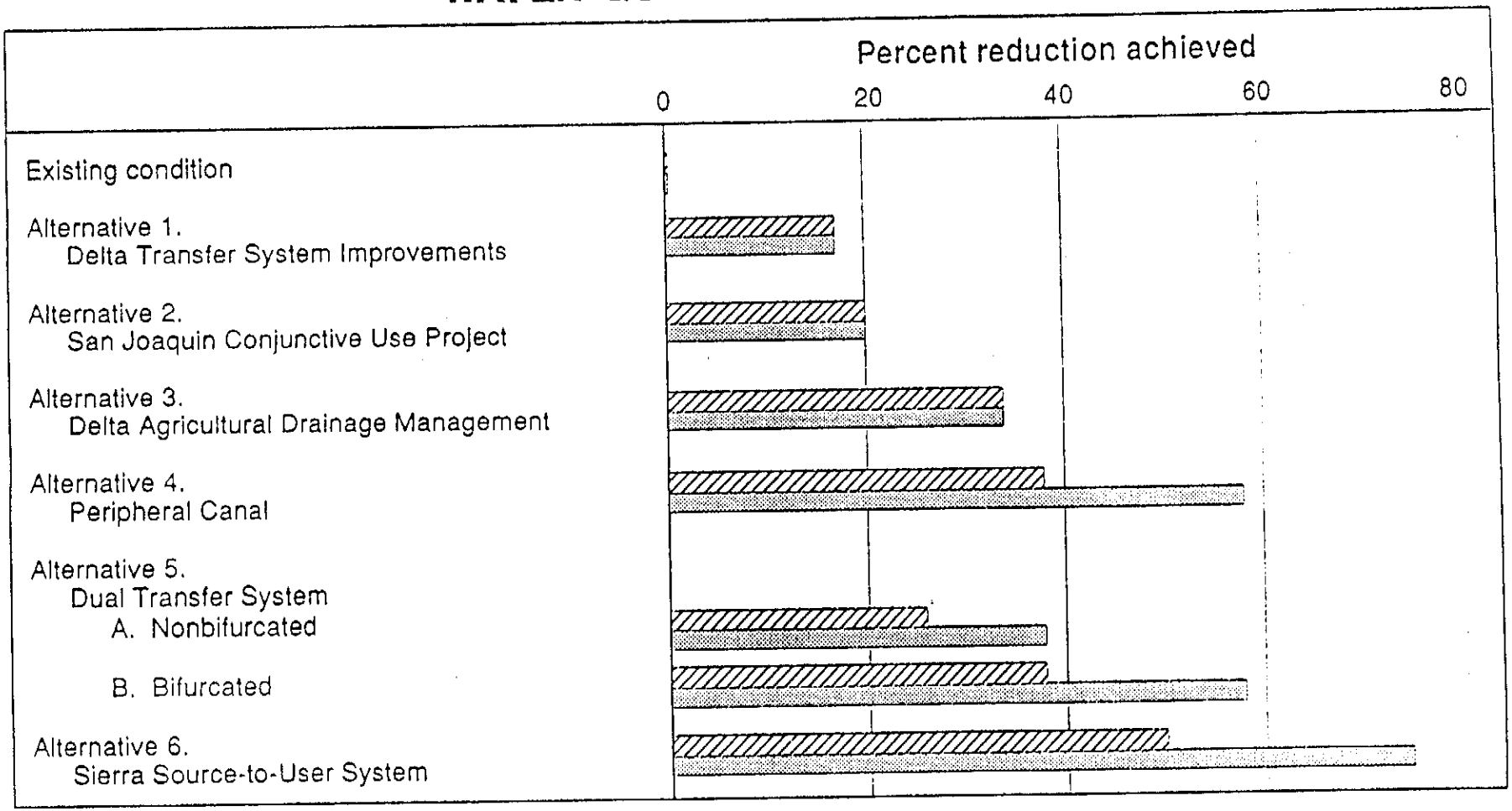


Figure 3-6. Total Dissolved Solids in the Delta Source Waters

WATER QUALITY IMPROVEMENT



10. Summary of the presentation by Stuart W. Krasner: "Comments on the Bay-Delta M&I Issues", by Stuart W. Krasner, Michael J. McGuire and Edward G. Means, Metropolitan Water District
THM Data from the Metropolitan Water District
Supplemental Material on THMs in Agency Systems, from MWD

METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

FOR THE STATE WATER CONTRACTORS, INC.

COMMENTS ON BAY-DELTA MUNICIPAL AND INDUSTRIAL ISSUES AS IDENTIFIED BY SWRCB STAFF

by

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Senior Chemist

Michael J. McGuire, Ph.D.
Director of Water Quality

Edward G. Means
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Metropolitan Water District of Southern California
1111 Sunset Boulevard
Los Angeles, California 90054

SUMMARY

As a part of the workgroup process, the Bay-Delta Municipal and Industrial (M&I) Work Group held a technical workshop on August 14, 1989, with invited speakers from the U.S. Environmental Protection Agency (USEPA), water utilities, and other interested parties. The general subject of Delta water quality and treatment were discussed and specific issues identified for inclusion in the next phase of the Bay-Delta hearings. This paper summarizes some of the material presented at that workshop.

At that meeting of the M&I workgroup, Mr. Steve Clark of the USEPA informally indicated that the current total trihalomethane (THM) maximum contaminant level (MCL) of 100 micrograms per liter (μg/L) will likely be lowered to between 25 and 50μg/L. This issue, along with the knowledge that other disinfection by-products (DBPs) will also be regulated, is the main regulatory concern which faces the water utilities using the Delta as a source.

Data were presented that indicate that chloride can be used as a surrogate measure of bromide concentration for M&I intakes influenced by seawater intrusion. Setting a chloride

objective of less than 50 milligrams per liter (mg/L) at Clifton Court will reduce bromide levels to less than 150 µg/L and will significantly reduce levels of brominated DBPs produced by chlorination, chloramination, and ozonation. Bromide from seawater intrusion into the Delta contributes to the production of significant levels of brominated disinfection by-products (DBPs) once the water is disinfected for M&I uses.

However, in order for utilities to meet a 50 µg/L THM MCL and avoid expensive alternative disinfectants like ozone, the chloride level must be reduced significantly below 50 mg/L. To comply with a 25 µg/L THM MCL, a chloride objective of less than 50 milligrams per liter will be required even with ozonation and prechloramination. The Metropolitan Water District of Southern California (Metropolitan) believes that bromide levels (and accordingly, chloride) should be reduced as much as feasible to reduce the health risk to consumers of Delta water regardless of the treatment technology used by water utilities.

In addition, agricultural drains and production of organic material in the Delta contributes to the precursor loading at M&I intakes. These issues must be addressed by requiring, at a minimum, monitoring at selected Delta sites and at all agricultural drains. Monitoring must include analyses for THM formation potential (THMFP), bromide, chloride, pertinent pesticides and herbicides, total nitrogen, nitrate-nitrogen, total phosphorus, orthophosphate, trace metals, and any other constituent that could affect the water quality of M&I users. These data must be used to devise strategies to minimize the impact of the agricultural drains on Delta water quality. Where individual drains directly impact the quality of water at a municipal intake, the drain must be treated, moved or eliminated. Similar monitoring should be instituted at Delta sites representing the range of water quality delivered to M&I users. These sites could be selected through consultation with the Department of Water Resources (DWR).

Introduction of DBP precursors (represented by bromide and organic material) into the Sacramento/San Joaquin River Delta (Delta) must be controlled in order to control THM production at water treatment plants and minimize the health risk to consumers of Delta water.

The weight of evidence regarding bromide contamination due to seawater intrusion, agricultural drain contaminant contributions, and in-Delta production of THM precursors strongly argues for construction of Delta transfer facilities to avoid the contamination occurring in the Delta. The use of additional

information dated August 14, 1989. Because the database on non-THM DBPs is insufficient to set objectives for their precursors, the following discussion only develops a rationale for setting limits on only the THM precursors that are delivered to municipal utilities. However, recent evidence indicates that controlling THM precursors will control many other halogenated DBPs ("The Occurrence of Disinfection By-Products in US Drinking Water" JAWWA, Vol. 81, No. 8, pp. 41-53, 1989, copy attached).

These comments will present the relationship between bromide and chloride in Delta waters, the relationship between bromide and brominated THMs in treated Delta waters, and the chloride level that should be achieved to minimize DBPs produced by chlorination, prechlorination and postchloramination, and preozonation and postchloramination. The board staff are encouraged to review Metropolitan's Exhibit 204 and Department of Water Resources' data regarding TOC from Delta and agricultural drain sources and its relationship to the formation of DBPs.

CHLORIDE AND BROMIDE RELATIONSHIP IN DELTA WATERS

As a result of seawater intrusion, various chloride levels are detected in SPW exported to Metropolitan. Seawater intrusion also increases bromide levels in the export water. Bromide ion "plays" a significant role in the formation of THMs. There is a direct relationship between the concentration of chloride and bromide ions in seawater, such that bromide ion levels in Delta waters can be predicted based upon measured chloride ion levels (assuming that seawater is the only source of bromide/chloride ion). This relationship has been derived as follows:

The concentrations of chloride and bromide in seawater are 18,980 mg/L and 65 mg/L, respectively (Sverdrup, Johnson, & Flemming, The Oceans, Prentice-Hall, Inc., 1942). If bromide and chloride in Bay-Delta water were only from seawater diluted with unsalty freshwater, then the equation:

$$Br^- = 0.0034 \times Cl^-$$

can be used to predict bromide levels given a measured chloride level. To test the predictive value of this relationship, actual bromide and chloride values for H.O. Banks, O-Neill Forebay, San Luis Reservoir, Tehachapi Pumping Plant, Lake Pyramid, Castaic Lake (Metropolitan's Jensen plant influent), Silverwood Lake, Devil Canyon (Mills plant influent), and Lake Perris were plotted against the predicted bromide/chloride values based on the above equation (Figure 1). The actual bromide and chloride values measured at the indicated locations are close to the predicted values (straight line depicted in

bromide in seawater are 18,980 mg/L and 65 mg/L, respectively (Sverdrup, Johnson, & Flemming, The Oceans, Prentice-Hall, Inc., 1942). If bromide and chloride in Bay-Delta water were only from seawater diluted with unsalty freshwater, then the equation:

$$Br^- = 0.0034 \times Cl^- \qquad (1)$$

can be used to predict bromide levels given a measured chloride level.

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SPW travels from the Sacramento/San Joaquin Delta through the California Aqueduct to Southern California, where it splits into the West and East Branches, a total of 444 miles (715 kilometers) (Figure 2). Metropolitan's Mills treatment plant receives East Branch SPW (EBSPW) from Silverwood Lake through the Devil Canyon Afterbay (Figure 3). The Jensen plant receives West Branch SPW (WBSPW) from Castaic Lake (Lake Pyramid is upstream of Castaic) (Figure 3). Drought conditions in recent years resulted in an increase in the chloride and bromide levels from the Delta. Because of the relatively short holding time in Silverwood Lake (0.2-year retention time), higher chloride/bromide levels were experienced in EBSPW (Figure 4) as compared to WBSPW (Figure 5). The Pyramid/Castaic lake system has a longer holding time of approximately 2.1 years; therefore, changes in SPW reach the Jensen plant later.

Furthermore, measured chloride and bromide levels in SPW were examined using a linear regression, least squares best fit (Figure 6). A good correlation exists for this data set (the correlation coefficient, r, equals 0.955). The broken lines, which describe the 95-percent confidence interval,

demonstrate that bromide levels can be predicted from chloride measurements in SPW. The best fit equation:

$$Br^- = 0.00289 \times Cl^- + 0.00671 \qquad (2)$$

closely matches the relationship found in seawater. More importantly, this equation provides a means of predicting bromide levels in SPW with a high degree of accuracy. Using the equation, measured and predicted bromide levels in SPW were found to agree within 4.6 percent, on the average (Table 1).

Using equation (2), the bromide levels associated with four benchmark Delta chloride levels are presented below:

Chloride Level mg/L	Predicted Bromide Level mg/L
250	0.73
150	0.44
100	0.30
50	0.15

Figure 7 depicts the variation in chloride levels from Metropolitan's source waters (EBSPW, WBSPW and Colorado River water [CRW]). Wide swings in chloride values appear on the East Branch of the State Water Project and less wide swings occur on the West Branch. The long detention time in the WBSPW contributes to dampening out the chloride shifts seen in the EBSPW. Also shown are chloride levels in CRW. It is important to distinguish between SPW and CRW chloride/bromide relationships. Modern seawater intrusion is not a contributor to chloride and bromide levels in CRW. However, CRW is affected, in part, by connate water--ancient seawater that was trapped in sedimentary deposits at the time of geological formation in the Colorado River watershed. Currently, CRW contains 65 mg/L chloride and 0.07 mg/L bromide. If CRW followed the same bromide/chloride relationship as SPW, the predicted bromide level would have been 0.19 mg/L (or 0.22 mg/L if using the seawater ratio). Thus, the majority of chloride in CRW is from sources other than seawater intrusion. Accordingly, THM formation in CRW will not be impacted by lowering chloride levels. The acceptability of CRW with a chloride content of 100 mg/L should not be equated with acceptability of SPW with a similar content.

The data presented above demonstrate that bromide levels can be reasonably estimated based upon chloride levels in Delta water. The major source of bromide in Delta waters is from seawater. Controlling chloride will control bromide at Clifton Court.

BROMIDE AND THM RELATIONSHIP IN DELTA WATERS

Numerous researchers are attempting to model and predict THM formation from water quality parameters. However, it is a multivariant analysis, which must consider the water's TOC level and ultraviolet absorbance, chlorine dose and contact time, pH, temperature, bromide level, and effects of other treatment plant chemicals (e.g., use of preozonation). Since temperatures in SPW at Metropolitan's treatment plants vary significantly depending on the season (from approximately 10 to 25°C), data collected when the water temperature was moderate (approximately 18°C) will be used for illustrative purposes. Data for spring quarter samplings at the Mills plant for 1985-1989 (Table 2) indicate that as chloride levels increased, both the level of bromide and the concentration of brominated THMs increased. In fact, when chloride reached a 100 mg/L level in 1988, the bromide level was sufficiently raised to produce a substantial amount of bromoform (16 μg/L). This contributed to increasing the total THMs (TTHMs) to 99 μg/L. Since the USEPA's MCL for TTHMs is 100 μg/L, the Mills plant was forced to drop the use of prechlorination and utilize chloramines only. However, chloramination alone will not comply with the new disinfection requirements of the USEPA's Surface Water Treatment Rule for Giardia and virus inactivation which will go into effect in June 1993.

Likewise at the Jensen plant (Table 3), during free chlorination, TTHMs exceeded the current MCL when chloride was present at 125 mg/L. The differences in THM levels between the two plants may be due to differences in EBSPW and WBSPW, as well as operating conditions at the respective plants. Steve Clark of the USEPA indicated at the August 14, 1989 meeting of the M&I workgroup that the new THM regulation (to be promulgated in 1991/92) will probably set the TTHM MCL between 25 and 50 μg/L. Prechlorination and postchloramination at the Jensen plant produced TTHM levels just below 50 μg/L when the chloride levels were between 35 and 45 mg/L; however, the lowest TTHM level at the Mills plant using free chlorine only was 63 μg/L.

Research by T. Aizawa, Y. Magara, and M. Musashi on the "Effect of bromide ions on THM formation in water" (Aqua, Vol. 38, pp. 165-175, 1989) found "...the concentration of total THM increases with the augmentation of bromide ions with the same amount of chlorine dosage. The increase in THMs is up to two times higher than in the absence of bromide ions." Thus, as chloride levels increase in Delta water, the accompanying increases in bromide levels result in higher TTHM formation upon disinfection.

The above data indicate that treatment plants treating Delta water would not be able to meet a 50 μg/L TTHM MCL when free chlorinating Delta water with a chloride content of 50 mg/L. Further, prechlorination and postchloramination of Delta waters containing 35-50 mg/L of chloride produces TTHMs of 46 to approximately 78 μg/L, levels that would, on average, exceed a 50 μg/L MCL. Unless chloride levels are maintained substantially below 50 mg/L, utilities taking water from Clifton Court will have to consider alternative oxidants, such as ozone. As discussed under "Advanced Water Treatment Technologies," even with ozonation, a TTHM MCL of 25 μg/L would require that chloride levels be kept well below 50 mg/L in order to minimize brominated THMs formed during ozonation and subsequent chloramination. Bromide levels (and accordingly, chloride) should be reduced as much as feasible to reduce the health risk to consumers of Delta water regardless of the treatment technology used by water utilities.

THMFP VS SDSTHM

There is no commonly used disinfectant that does not produce DBPs. Even the use of ozone alone can produce bromoform and other brominated DBPs in high bromide waters. To totally eliminate TTHMs and other DBPs, it is necessary to remove the precursors usually characterized by the TOC and bromide levels before a disinfectant is added. A number of researchers have shown a good correlation between TOC and THMFP; however, THMFP does not relate to actual observed TTHM levels. The THMFP test is a worst case estimate using an extreme chlorine dose that would never be utilized at a treatment plant. It is, however, a valuable tool to measure relative TTHM precursor levels in Delta waters.

Metropolitan has developed a simulated distribution system (SDS) test. In this test, actual treatment conditions are simulated (i.e., chlorine dose and contact time, pH and temperature), with results that have been demonstrated to mirror actual plant-scale TTHM values. Furthermore, the SDS test has been verified to simulate the concentrations of all the chlorination DBPs under consideration for regulation by the USEPA.

Figure 8 shows the effect of varying bromide levels on SDSTHMs. Water from the H.O. Banks pumping plant was dosed at a 1:1 Cl_2 to TOC ratio (i.e., 2.17 mg/L) and held at 25°C for five days. The residual chlorine level went to zero during the test, so the THM levels produced were not maximized. (In addition, the chlorine dose used is generally less than normally used for

disinfection at a treatment plant.) At the time of this study, there was 349 μg/L bromide in the Banks sample. Additional samples were augmented with bromide (up to 862 μg/L). This range of bromide levels, based on the relationship found in SPW corresponds to 118 to 296 mg/L chloride.) Over the range of bromide levels investigated, the concentration of bromoform almost tripled (from 34 to 91 μg/L) and TTHMs increased as well (from 98 to 131 μg/L). In fact, these SDSTHM data for the non-augmented Banks sample closely match the July 1989 Jensen sample results. This experiment confirms that, for plants treating SPW using a minimal free chlorine dose, when 349 μg/L bromide (corresponding to a chloride level of 118 mg/L) is present, the utility would barely meet the existing THM regulation using free chlorination. Such utilities would certainly not meet a revised THM regulation and would be required to alter typical disinfection practices.

No better support for this hypothesis can be illustrated than the enclosed citation from the California Department of Health Services which was recently issued to the Castaic Lake Water Agency (CLWA) for violation of the THM standard. CLWA uses WBSPW from Castaic Lake and uses free chlorine without any chloramines.

OTHER DBPs

There are significant new health effects data for bromoform that has linked it to the production of a very rare form of cancer in laboratory animals. It is conceivable that the USEPA could set a specific MCL for bromoform, further arguing for the importance of controlling bromide at M&I intakes in the Delta. The USEPA has indicated that, in addition to THMs, they will probably regulate haloacetic acids (HAAs), cyanogen chloride, and halopicrins. When THMFP studies were performed on Delta agricultural drain samples that were high in TOC, high levels of THMs and HAAs were formed. The USEPA has indicated that it will also regulate ozone by-products, notably formaldehyde and other aldehydes. In pilot plant tests, ozonation of SPW produced 10 to 20 μg/L formaldehyde.

The USEPA has also included bromate on the list of ozone by-products to be regulated. Bromate is produced by ozonation of bromide. As the production of chlorate and chlorite by the disinfectant chlorine dioxide has already resulted in the California Department of Health Services not allowing the use of chlorine dioxide because of the health effects of its by-product ions, the production of bromate may create a serious problem for domestic water suppliers which ozonate high bromide waters.

Since utilities using ozone will need a secondary disinfectant (i.e., chlorine or chloramines) to control microbiological quality in distribution systems, the USEPA is also concerned with secondary reactions producing by-products, such as halopicrins, of which chloropicrin is the most widely known. Research indicates that in high bromide waters, brominated halopicrins will be formed in a manner similar to the formation of chloropicrin. It is likely that once the occurrence of brominated halopicrins is confirmed in drinking water that these compounds will be regulated by the USEPA.

ADVANCED WATER TREATMENT TECHNOLOGIES

New water treatment technologies are being investigated, including ultra-filtration, ozonation/post-chloramination, PEROXONE, and granular activated carbon (GAC). Ultra-filtration has not been used in full-scale at any major United States plant and is too new a technology to be relied on to meet the needs of the next five to ten years. Bromide is not removed by ultra-filtration and would, therefore, still react with disinfectants to produce brominated DBPs.

Preozonation followed by postchloramination does not eliminate concerns over DBPs. Figure 9 shows that when a poor quality source water (high TOC level) was ozonated, numerous aldehydes were produced. In implementing ozone, a utility trades off halogenated DBPs (e.g., THMs) for aldehydes and other ozonation by-products. If a water is high in bromide, ozone alone will produce brominated DBPs. At Metropolitan's pilot plant, ozonation of SPW containing 0.4 mg/L bromide (which would correspond to approximately 140 mg/L chloride), produced up to 10 μg/L bromoform and up to 4 μg/L dibromoacetonitrile (another DBP under regulatory consideration). Furthermore, full-scale chloramination during 1988 and 1989 at the Mills plant produced 9-19 μg/L TTHMS. The combined THM contribution of preozonation and chloramination could exceed a 25 μg/L TTHM standard. This provides further justification for minimizing chloride/bromide levels at M&I intakes, regardless of the disinfection strategy practiced by the utility.

PEROXONE (the combination of ozone and hydrogen peroxide) has promise for disinfection, oxidation of taste and odor compounds, and control of DBPs; however, its effectiveness and reliability have yet to be demonstrated at full-scale. There are unresolved questions such as how large-scale hydraulic mixing systems will affect the reactions between hydrogen peroxide and ozone and whether the disinfection efficiencies determined in pilot-scale studies be confirmed at full scale.

PEROXONE does not eliminate the need for a residual disinfectant and the associated potential for forming DBPs. Metropolitan is proceeding with plans to test PEROXONE at a 5.5 mgd demonstration scale treatment plant. These data will be available in 1992.

GAC has been shown in a major research study to be ineffective in removing organic THM precursors below levels that would produce 5 to 10 μg/L SDSTHMs and is well known to be incapable of removing inorganic ions such as chloride and bromide. Metropolitan completed the GAC study funded in part by the American Water Works Association Research Foundation, and focused on the control of THMs and other DBPs to very low levels. A major conclusion of the study was that GAC is an expensive way to control THMs (see attached report). The use of GAC on a large scale basis requires the provision of regeneration facilities in the form of large scale furnaces to heat the carbon and destroy the adsorbed organic compounds. There is little likelihood of being able to site numerous regeneration facilities in air basins similar to Los Angeles or the San Francisco Bay area due to concerns over the emissions of toxic by-products during the GAC reactivation process.

COSTS OF ALTERNATIVES STRATEGIES TO MINIMIZE DBP FORMATION

Determining costs for water treatment technologies depends largely on the water quality to be treated and local design considerations. With this in mind, Metropolitan converted to prechlorination/postchloramination at a cost of approximately $5.5 million. The approximate costs of ozonation, PEROXONE, and GAC are $300 million, $200 million, and $1.3 billion, respectively. The later costs are based on meeting a revised TTHM MCL of 25 μg/L TTHMs.

DISCUSSION

Every disinfectant currently being used produces DBPs. In the "Report of the Drinking Water Subcommittee of the Science Advisory Board's Environmental Health Committee Concerning the Scientific Basis for the Regulation of the Disinfection of Potable Water" (1989), the Precursor Removal Work Group concluded:

> "Because adding any oxidant to an organic-rich water will product (sic) a host of complex chemical reactions, analytic difficulties, and health effects questions, one attractive solution would be to eliminate to the maximum possible the quantity of precursor prior to free chlorination thus eliminating the maximum possible numbers of

> disinfection by-products...the extent of the precursor removal should be targeted to the eventual regulations promulgated. Because water treatment requires a number of technologies and the optimization of one may not be suitable for another, the regulations and the BATs must be established within the context of the effective integration of these treatments."

In order to minimize health risk, bromide ion and organic DBP precursors must be minimized where possible irrespective of the treatment technology used by water utilities. Based upon the data presented, a chloride objective of 50 mg/L at Clifton Court would likely not allow existing treatment plants to meet a THM regulation of 50 μg/L using prechlorination/postchloramination. Utilities treating Delta water from Clifton Court containing 50 mg/L of chloride would have to consider ozonation and postchloramination. If the THM MCL is set at 25 μg/L, the presence of high bromide levels could jeopardize compliance even using ozonation and postchloramination. With a 25 μg/L TTHM standard, the chloride concentration at municipal intakes should be maintained significantly below 50 mg/L.

Organic sources in the Delta must be addressed by requiring at a minimum monitoring at selected Delta sites and at all agricultural drains. Monitoring must include analyses for THMFP, bromide, chloride, pertinent pesticides and herbicides, total nitrogen, nitrate-nitrogen, total phosphorus, orthophosphate, trace metals, and any other constituent that could affect the water quality of M&I users. These data must be used to devise strategies to minimize the impact of the agricultural drains on Delta water quality. Where individual drains directly impact the quality of water at a municipal intake, the drain must be treated, moved or eliminated. Similar monitoring should be instituted at Delta sites representing the range of water quality delivered to M&I users. It should be emphasized that controlling the agricultural drain discharges will not address contribution of DBP precursors from natural sources (seawater intrusion and primary productivity in the Delta).

The weight of evidence regarding bromide contamination due to seawater intrusion and agricultural drain contaminant contributions strongly argues for construction of Delta transfer facilities to avoid the contamination occurring in the Delta. The use of additional stored water to achieve dilution of the contaminants is not reasonable and not the answer to the precursor loading problem in the Delta. Delta transfer facilities that would protect water quality for M&I users are required.

ADDITIONAL STUDIES

An evaluation of the impacts of bromide addition to water collected from the Sacramento River at Hood on DBP formation using chlorination, prechlorination/postchloramination, and ozonation/postchloramination should be conducted. The results would be compared to similar experiments conducted on water collected at Clifton Court and would serve to quantify brominated THM formation at low bromide/chloride concentrations. These data would further refine the maximum chloride objective for M&I intakes.

In additional studies, analyses need to be performed on other DBPs under regulatory consideration (i.e., haloacetonitriles, haloketones, haloacetic acids, halopicrins, chloral hydrate, cyanogen chloride, aldehydes, and bromate). In DBP studies of 25 utilities nationwide for the USEPA and 10 utilities in the State of California for the Department of Health Services, analyses were performed for a total of 19 individual halogenated DBPs (XDBPs) (this included the four THMs) (Krasner et al., JAWWA, Vol. 81, No. 8, pp.41-53, Aug. 1989). There was a strong correlation between TTHMs and the sum of XDBPs measured in this project ($r = 0.96$) (see Figure 10). As THMs represent the largest DBP fraction detected in these studies, the data were reevaluated by comparing TTHMs to the sum of non-THM XDBPs. In this instance, r decreased to 0.76. However, the latter comparison does not mean that THMs cannot be used as a surrogate or predictor of the sum of all XDBPs ($XDBP_{sum}$).

The correlation between TTHMs and $XDBP_{sum}$ is significant because it suggests that control of a utility's THMs may reflect control of the other DBPs overall. While this trend holds true for the sum of XDBPs, it does not hold true for individual compounds (e.g., comparing TTHMs to haloketones yields an r of only 0.06). Additionally, some of the other individual DBPs may require separate monitoring based on their health effects and their formation and control relative to THMs. For example, THM production can be minimized with the use of chloramines, whereas cyanogen chloride formation can be increased. Thus, while current endeavors in evaluating Delta water quality still can focus on THMs, future studies must include non-THM DBPs as well.

SWK:MJM:ra/AL6

TABLE 1
Predicted versus Measured Bromide Levels
in State Project Water

Sample Location	Sample Date	Chloride mg/L	Bromide, mg/L		Percent Diff.*
			Measured	Predicted#	
Devil Canyon	1/27/87	38	0.13	0.117	10
Devil Canyon	4/28/87	50	0.17	0.151	11
Devil Canyon	10/7/87	99	0.27	0.293	8.5
Devil Canyon	11/3/87	102	0.28	0.302	7.9
Mills Inf.	7/5/88	96	0.27	0.284	5.3
Vernallis	7/11/88	142	0.41	0.418	1.8
H.O. Banks	7/11/88	110	0.34	0.325	4.4
O'Neill Inf.	7/11/88	109	0.33	0.322	2.4
O'Neill Eff.	7/11/88	112	0.32	0.331	3.4
San Luis Res.	7/11/88	112	0.34	0.331	2.7
Tehachapi	7/12/88	105	0.30	0.310	3.3
Pyramid Inf.	7/12/88	105	0.32	0.310	3.0
Pyramid Eff.	7/12/88	106	0.30	0.313	4.3
Castaic Eff.	7/12/88	95	0.27	0.282	4.4
Silverwood Inf.	7/11/88	109	0.35	0.322	8.0
Devil Canyon	7/11/88	99	0.29	0.293	1.1
Lake Perris	7/11/88	74	0.22	0.221	0.4
Jensen Inf.	8/11/88	97	0.27	0.287	6.3
Mills Inf.	8/11/88	108	0.31	0.319	3.0
Mills Inf.	10/3/88	122	0.39	0.360	7.7
Jensen Inf.	11/3/88	100	0.28	0.296	5.7
Mills Inf.	11/3/88	137	0.39	0.403	3.3
Mills Inf.	1/9/89	148	0.47	0.435	7.4
Mills Inf.	2/14/89	148	0.43	0.435	1.1
Jensen Inf.	5/9/89	131	0.39	0.386	1.1
Mills Inf.	5/9/89	75	0.23	0.224	2.7

					4.6 Average

#Predicted bromide levels from equation:

$Br^- = 0.00289 \times Cl^- + 0.00671$

*Percent difference = 100 x |measured-predicted|/measured.

TABLE 2
Mills Plant THM Results*

	Plant Influent				Plant Effluent				
Date	Temp. °C	EC µmho/cm	Cl^- mg/L	Br^- mg/L	$CHCl_3$ µg/L	$CHCl_2Br$ µg/L	$CHClBr_2$ µg/L	$CHBr_3$ µg/L	TTHMs µg/L
5/7/85			35						
5/16/85##	17	357			30	21	11	1	63
5/8/86	15	493			25	32	28	5	90
5/13/86			68						
4/28/87			50	0.17					
5/7/87	18	472			29	29	18	2	78
5/10/87			59						
4/11/88			98						
4/28/88	16			0.28	8	25	50	16	99
5/3/88			105						
5/9/89	20	454	75	0.23	19	29	26	5	79

---

*Treatment plant: pre-chlorination/post-ammoniation.

##Free chlorine only.

TABLE 3
Jensen Plant THM Results*

Date	Plant Influent Temp. °C	EC µmho/cm	Cl^- mg/L	Br^- mg/L	Plant Effluent $CHCl_3$ µg/L	$CHCl_2Br$ µg/L	$CHClBr_2$ µg/L	$CHBr_3$ µg/L	TTHMs µg/L
8/15/85	18	447			20	16	9	1	46
8/85 CMP			35						
11/14/85	18	451			15	17	14	2	48
11/85 CMP			45						
11/6/86	18	522			12	21	25	6	64
11/86 CMP			69						
11/2/87				0.13					
11/12/87	18	486			17	21	21	4	63
11/87 CMP			58						
11/3/88	20	651	100	0.28	7	18	35	18	78
5/9/89			131	0.39					
6/89 CMP			123						
7/89 CMP			125						
7/18/89##	16				4	18	43	38	103

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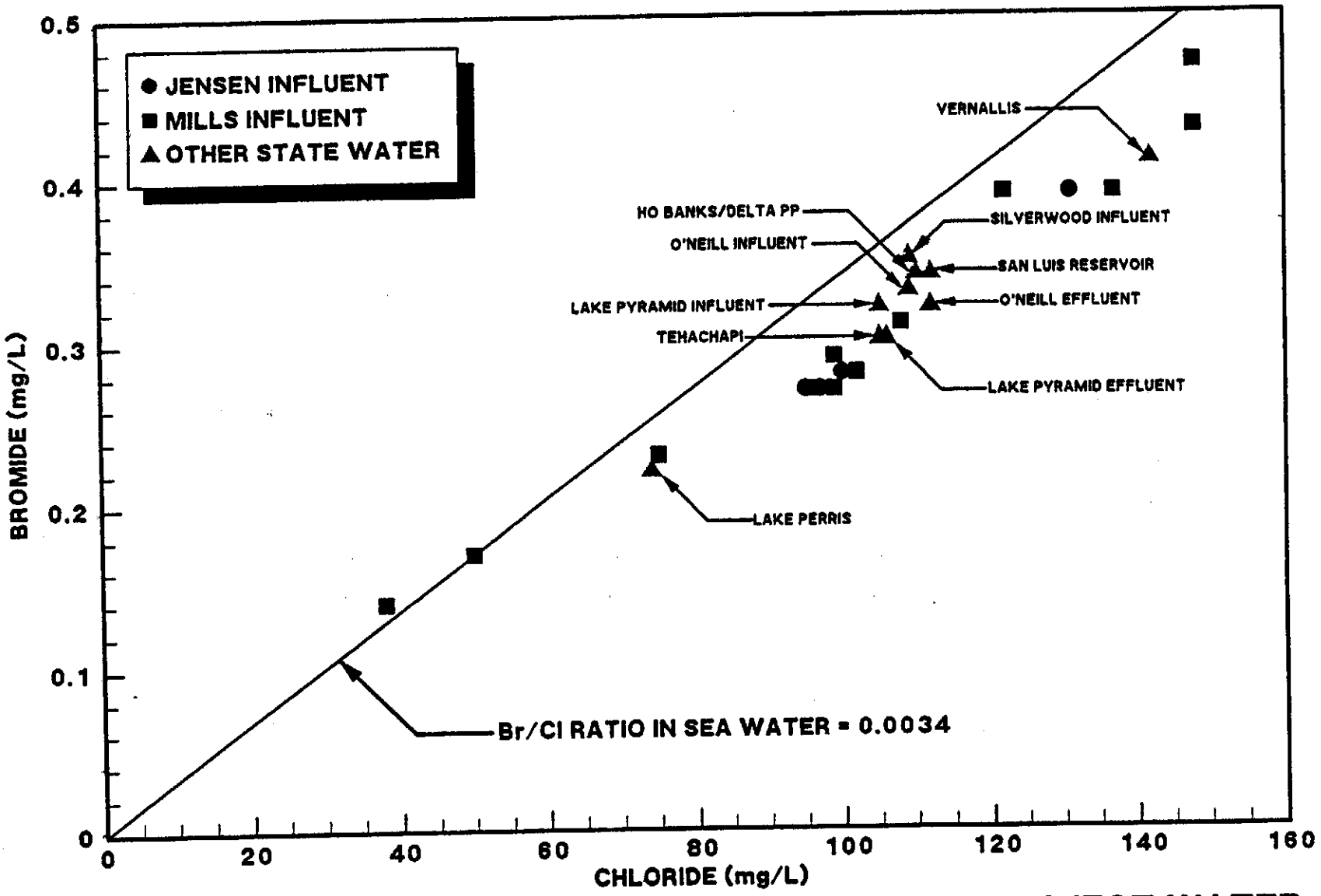
*Treatment plant: pre-chlorination/post-ammoniation.

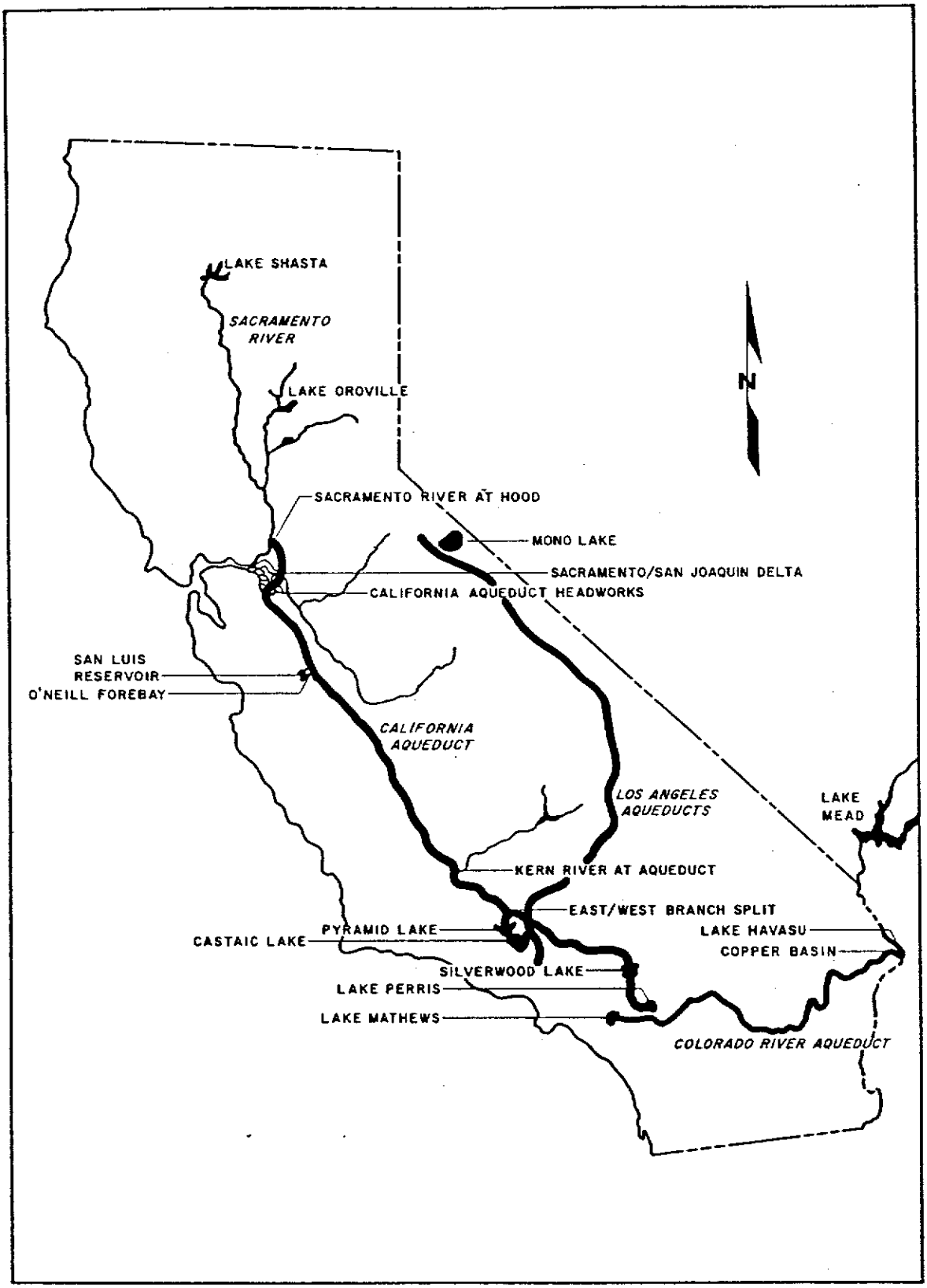
##Free chlorine only.

CMP = monthly composite sample.



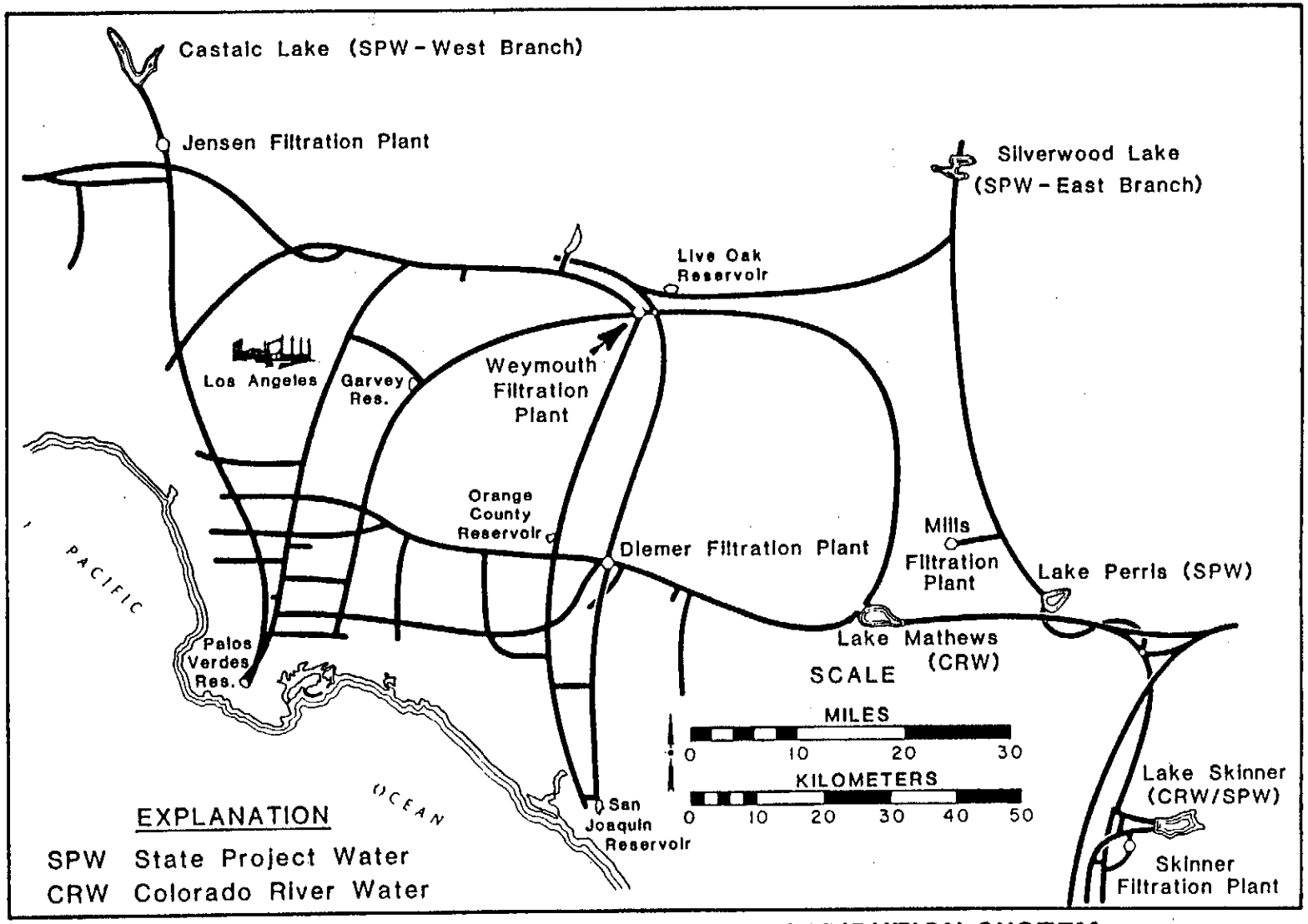
RELATIONSHIP OF CHLORIDE AND BROMIDE IN STATE PROJECT WATER

FIGURE 1



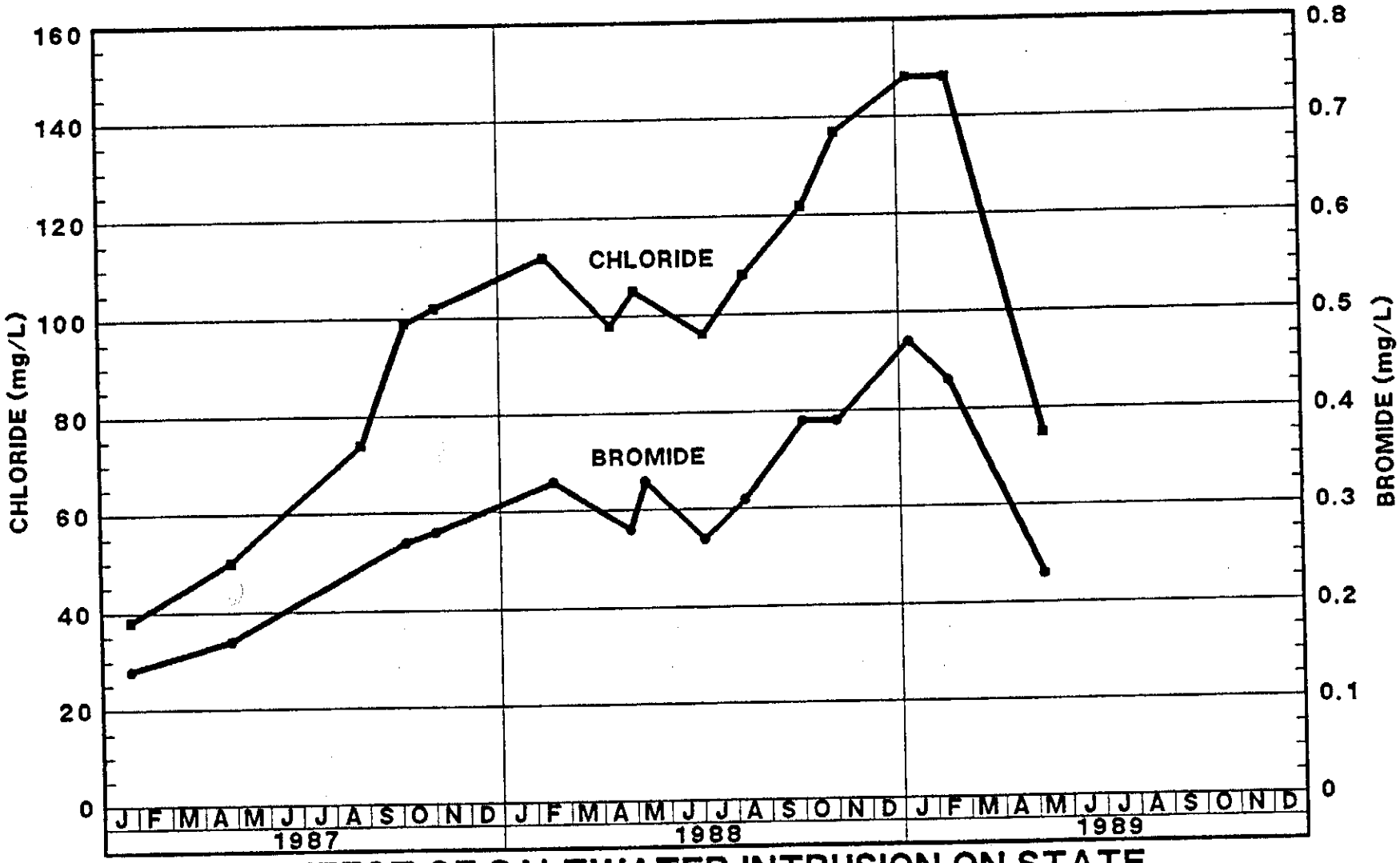
GENERAL LOCATION MAP

FIGURE 2



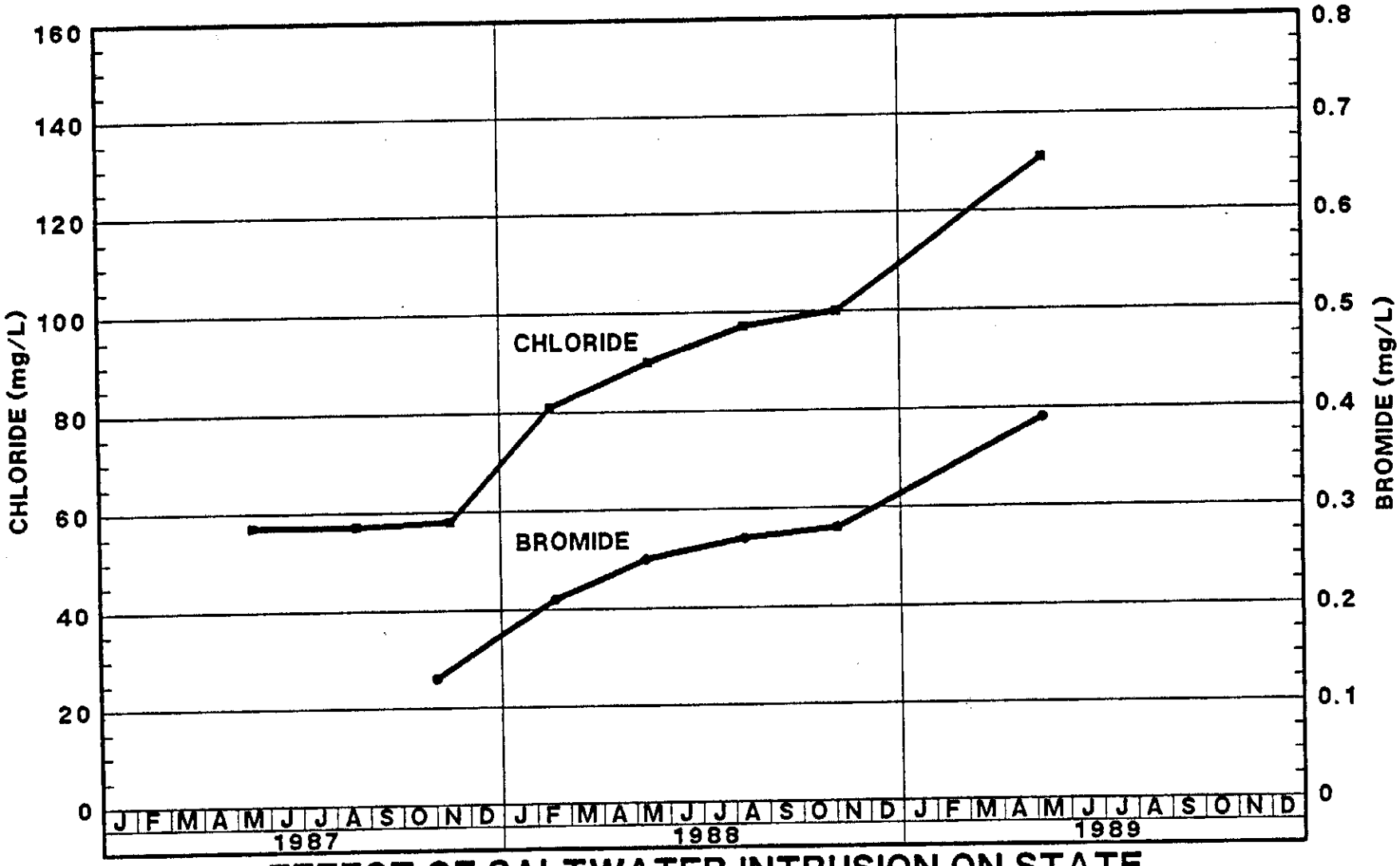
METROPOLITAN WATER DISTRICT DISTRIBUTION SYSTEM

FIGURE 3



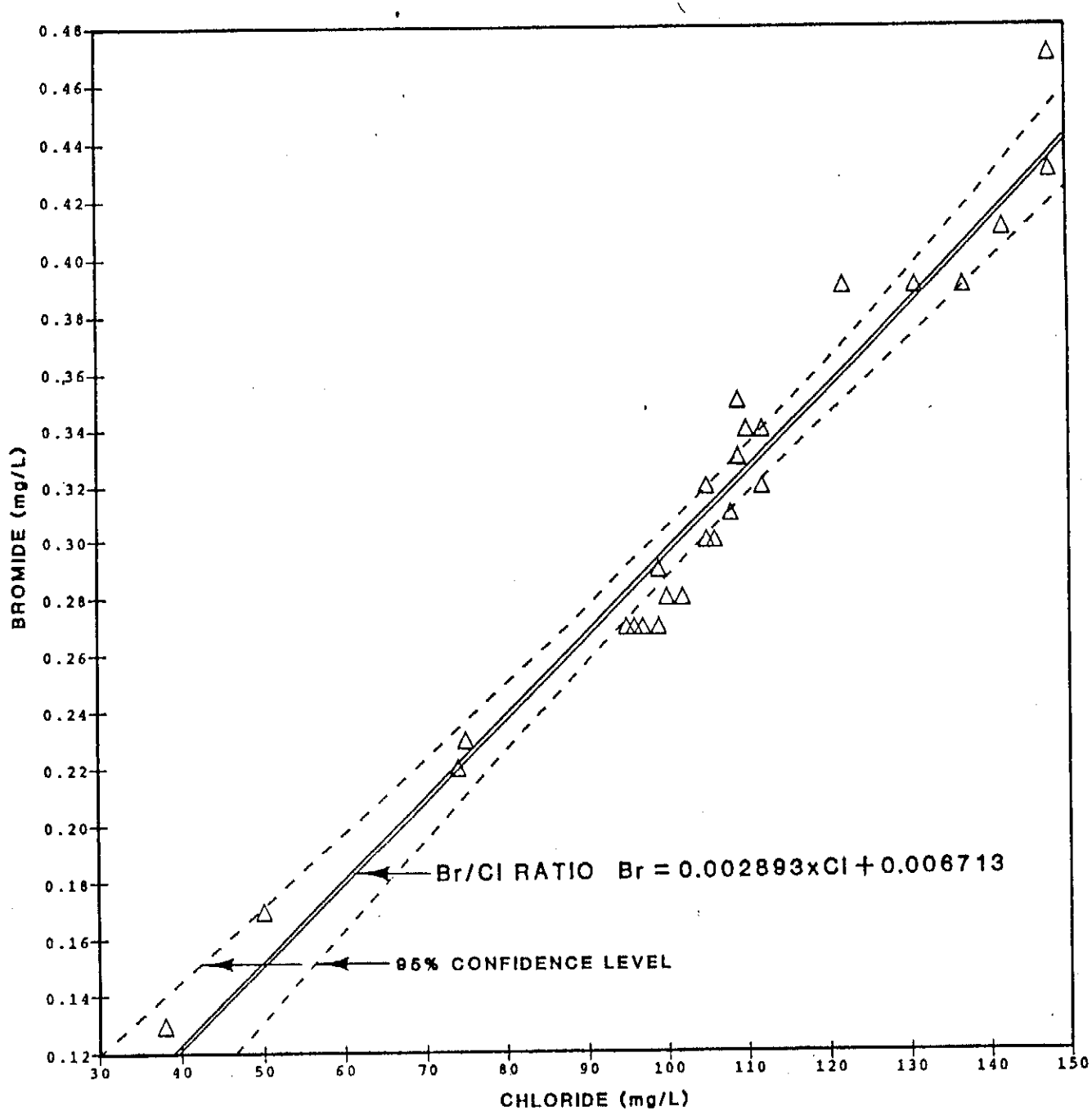
EFFECT OF SALTWATER INTRUSION ON STATE PROJECT WATER, EAST BRANCH

FIGURE 4



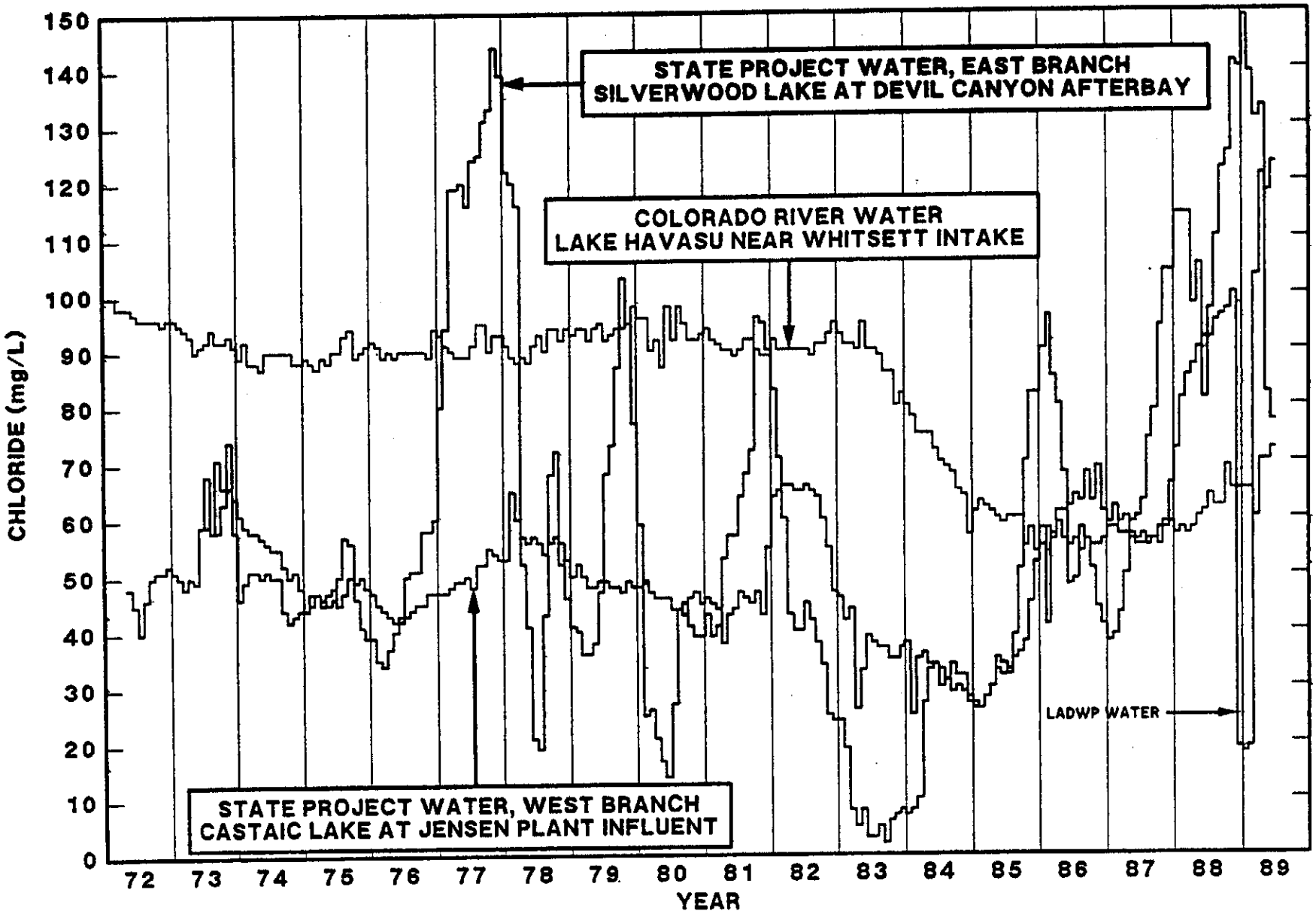
EFFECT OF SALTWATER INTRUSION ON STATE PROJECT WATER, WEST BRANCH

FIGURE 5



BROMIDE/CHLORIDE RELATIONSHIP IN STATE PROJECT WATER

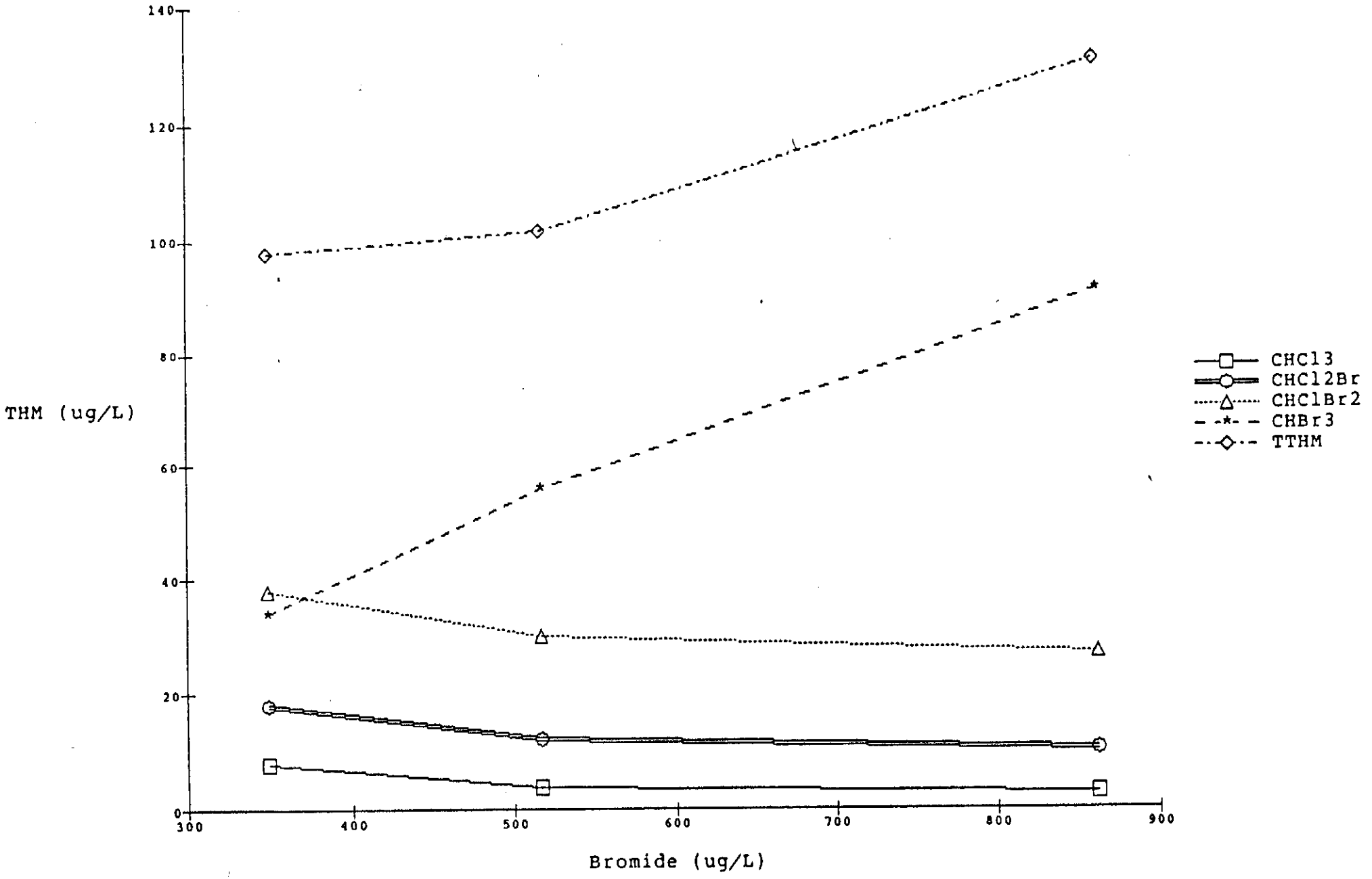
FIGURE 6



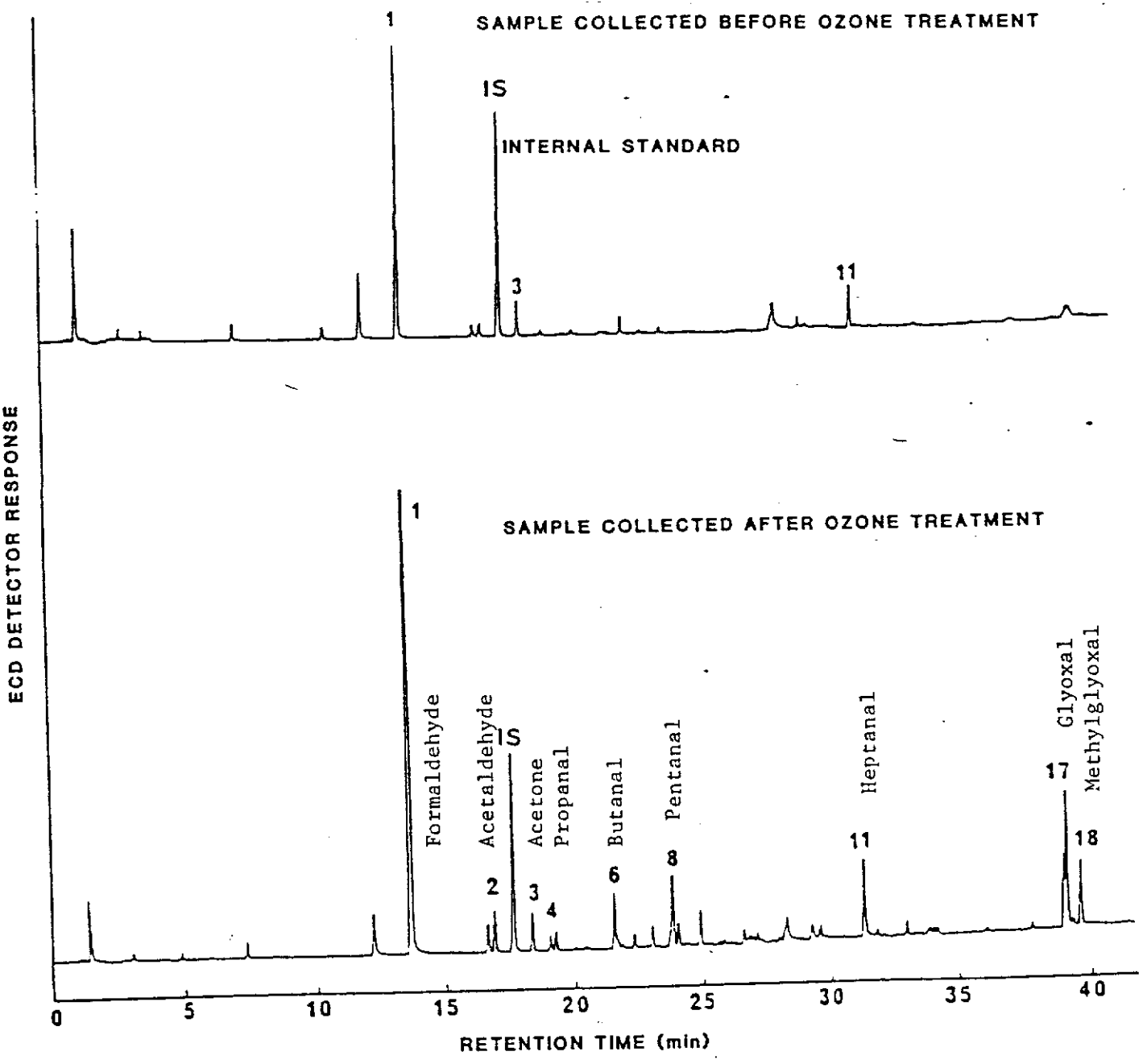
HISTORICAL CHLORIDE LEVELS IN SPW AND CRW

FIGURE 7

Figure 8
THM Speciation as a Function of Bromide Concentration in SPW

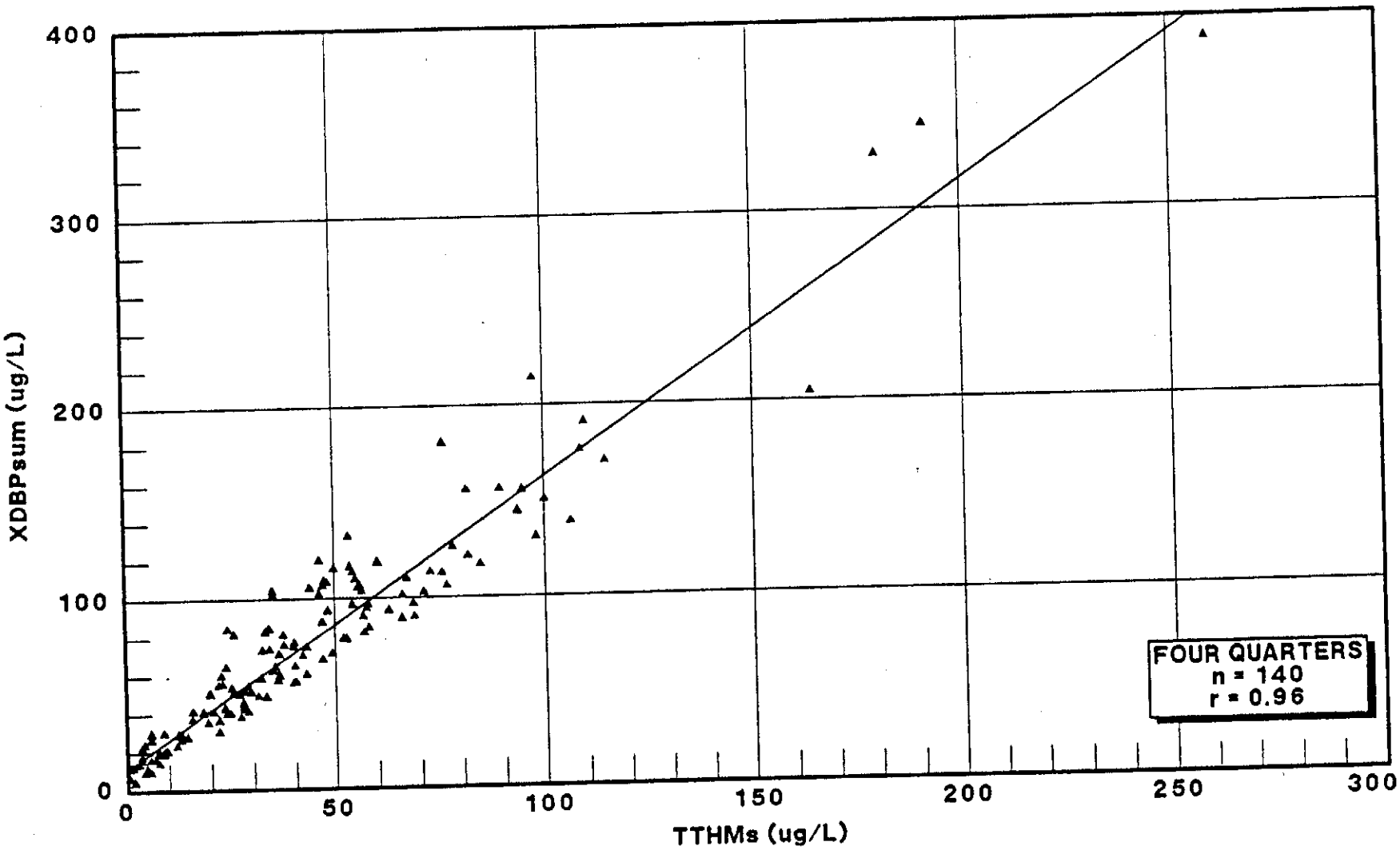


Cl dose = 2.17 mg/L. TOC = 2.17 mg/L.



EFFECT OF OZONATION ON SURFACE WATER WITH HIGH TOC LEVEL (8.4 mg/L)

FIGURE 9



CORRELATION OF HALOGENATED DBPs (XDBPs) WITH TTHMs

FIGURE 10

August 22, 1989

Mr. Donald H. Nelson
Director of Utilities
City of Thousand Oaks
2150 West Hillcrest Drive
Thousand Oaks, California 91320

Dear Mr. Nelson:

Chloride Concentration in State Project Water

This letter is in response to your July 28 letter requesting the reason for the increasing chloride concentration in the water supplied to the City of Thousand Oaks by Metropolitan's Joseph Jensen Filtration Plant (Jensen plant). As you know, the Jensen plant treats State project water (SPW). The water originates in Northern California, travels through the Sacramento-San Joaquin Delta before it enters the California Aqueduct of the State Water Project. Seawater intrusion into the Delta can cause the levels of chloride to be higher than expected in SPW. This intrusion increases as the amount of water flowing into the Delta decreases, which is affected by runoff from rain and snowmelt on the western side of the Sierra Nevada Mountains.

The last two years have been drought years in California and this year the water year has been classified as below normal. State Water Resources Control Board Decision 1485 allows the chloride concentration at Rock Slough to be a maximum of 250 mg/L. This translates to approximately 150 mg/L at the State's Banks Delta Pumping Plant. With the present inefficient method of transferring water across the Delta, such conditions occur often during dry periods. The alternative is to release more scarce water from upstream reservoirs. Unfortunately, until a Delta transfer facility is constructed, high chloride concentrations will occur, all too frequently, under such conditions.

The Jensen plant receives water from the West Branch of the State Water Project, through the Pyramid-Castaic Lake system. The 1987-88 fiscal year average chloride concentration was 73 mg/L for the Jensen plant effluent. The 1988-89 average

was 107 mg/L, excluding the four months when the Jensen plant was receiving Los Angeles Aqueduct water, which happens rarely. In June 1989, the Jensen plant effluent chloride level was 122 mg/L.

An estimate of the duration and expected high for chloride concentration at the Jensen plant can be made by looking at the values from Metropolitan's Henry J. Mills Filtration Plant (Mills plant). The Mills plant receives water from the East Branch of the State Water Project, which is more indicative of current SPW quality since the retention time in Silverwood Lake on the East Branch is significantly shorter than the retention time in the Pyramid-Castaic lake system on the West Branch. At the Mills plant, the 1987-88 fiscal year average for chloride concentration was 97 mg/L; the 1988-89 average was 119 mg/L. A high of 145 mg/L was observed in November 1988. However, in June 1989 the chloride level dropped to 80 mg/L, due to the heavy spring rains and snow melt in Northern California. From a comparison of values for the Jensen and Mills plants as shown on Tables 1 and 2, it appears that the Jensen plant chloride concentration may reach 140 mg/L within the next two months and stay at that concentration for about five months. After that, the chloride level should start to decrease. It is much more difficult to predict what will happen in the more distant future due to the unpredictable nature of weather conditions.

The Jensen plant effluent does meet all State and Federal drinking water standards and is expected to continue to meet them in the future. The State of California Health and Safety Code lists the secondary standard for chloride as 250 mg/L as a "Recommended" level. Furthermore, "Short Term" levels should not exceed 600 mg/L. Secondary standards are related to consumer acceptance and generally not related to health considerations. There is no health related standard for chloride.

However, an increase in chloride level indicates a related increase in bromide which is also a component of seawater. Higher bromide levels can result in higher trihalomethane (THM) concentrations after the use of free chlorine. We anticipate that Metropolitan and its member agencies and subagencies will continue to meet the current THM standard as a result of the use of chloramines.

I hope this information is useful. If you have any questions, please call Sylvia Barrett of my staff at (714) 392-5125.

Very truly yours,

Original signed by
Michael J. McGuire

Michael J. McGuire, Ph.D.
Director of Water Quality

SEB:ra
egm/AL5

Enclosure

cc: Mr. James Hubert, Manager
Calleguas Municipal Water
District

Mr. David Kennedy
Department of Water Resources

Mr. George R. Baumli
State Water Contractors

bcc: R. W. Balcerzak
M. B. Holburt
M. J. McGuire/E. G. Means
P. R. Singer/C. F. Voyles
R. W. Atwater
R. W. Schempp
D. J. Askenaizer
M. K. Davis
S. E. Barrett/G. A. Stalker
M. L. Sien
R. C. Clemmer

TABLE 1
HENRY J. MILLS FILTRATION PLANT EFFLUENT
CHLORIDE ANALYSES--12-MONTH AVERAGE FOR 1987-88 AND 1988-89
mg/L

July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	1-yr
1987	1987	1987	1987	1987	1987	1988	1988	1988	1988	1988	1988	AVG
68	72	91	104	106	104	107	116	107	103	103	88	97
1988	1988	1988	1988	1988	1988	1989	1989	1989	1989	1989	1989	AVG
99	112	122	120	145	141	143	140	139	115	75	80	119

TABLE 2
JOSEPH JENSEN FILTRATION PLANT EFFLUENT
CHLORIDE ANALYSES--12-MONTH AVERAGE FOR 1987-88 AND 1988-89
mg/L

July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	1-yr
1987	1987	1987	1987	1987	1987	1988	1988	1988	1988	1988	1988	AVG
57	57	57	60	60	68	72	82	86	89	92	94	73
1988	1988	1988	1988	1988	1988	1989	1989	1989	1989	1989	1989	AVG
94	98	97	99	102	22*	20*	19*	102*	122	121	122	107**

AVG = UNWEIGHTED AVERAGES
* RECEIVING WATER FROM THE LOS ANGELES AQUEDUCT
** UNWEIGHTED AVERAGE EXCLUDING THE MONTHS WHEN JENSEN WAS RECEIVING WATER FROM THE LOS ANGELES AQUEDUCT

City of Thousand Oaks

UTILITIES DEPARTMENT

DONALD H. NELSON, DIRECTOR

July 28, 1989

Dr. Michael McGuire, Water Quality Manager
Metropolitan Water District of
Southern California
P.O. Box 54153
Los Angeles, CA 90054

CHLORIDE CONCENTRATION IN THE WATER SUPPLY

I'm writing you to express the City's concern about the increasing concentration of chloride in the water delivered to the Thousand Oaks area. Our NPDES permit requirements limit the chloride concentration in the effluent discharge from the City's two wastewater treatment plants to 150 mg/l. Both of the treatment plants have experienced violations of the chloride limit since April of last year (during those times that MWD has delivered State Project water treated at the Jensen plant). Unfortunately, the Regional Water Quality Control Board has not been responsive to requests to change NPDES permit limits to reflect changes in potable water quality.

I would request that MWD supply the City with a letter indicating the reason for the increasing chloride concentration as well as any opinions regarding whether the concentration will increase or decrease in the future. Our intended use of such a letter would simply be to document the situation in relation to our NPDES permit requirements for our wastewater treatment facilities.

If you need any further information or would like to discuss this matter, please feel free to contact me at your convenience.

DONALD H. NELSON
DIRECTOR OF UTILITIES

cc: James Hubert, Manager
Calleguas MWD

DHN:jc
N1c

2150 WEST HILLCREST DRIVE · THOUSAND OAKS, CALIFORNIA 91320 · (805) 497-8611

RECEIVED
JUL 18 1989
CASTAIC LAKE WATER AGENCY

Citation No. 03-050

STATE OF CALIFORNIA
DEPARTMENT OF HEALTH SERVICES

RE : Castaic Lake Water Agency
23560 Lyons Avenue, Suite 225
Santa Clarita, CA 91321

TO : Robert C. Sagehorn
General Manager

CITATION

CITATION FOR NONCOMPLIANCE - - WATER SYSTEM NO. 19-048

Section 4032 of Chapter 7 of Part 1 of Division 5 of the California Health and Safety Code (H & S Code), authorizes the issuance of a citation for failure to comply with a requirement of Chapter 7 (California Safe Drinking Water Act), or any regulation, standard, permit, or order issued thereunder.

Violation

The Public Water Supply Branch of the Department of Health Services (hereinafter Department) hereby issues a citation to the Castaic Lake Water Agency (hereinafter Agency) (mailing address: 23560 Lyons Avenue, Suite 225, Santa Clarita, CA 91321) for the following violation:

Title 22, California Code of Regulations (CCR), Section 64439. Specifically, the Agency failed to meet the primary drinking water standard for total trihalomethanes (TTHM). The TTHM test results of April 20, 1989 put the running annual average of quarterly samples above the maximum contaminant level (MCL) of 0.10 mg/l.

In accordance with Section 4032(c) of the H & S Code, the above violation is classified as continuing.

Background

Castaic Lake Water Agency is a public agency that treats water from Castaic Lake, a State Water Project Reservoir, at their Earl Schmidt treatment Plant.

The Agency supplies water to the city of Santa Clarita and the unincorporated areas of Newhall, Saugus, Castaic, Valencia, Val Verde, and Canyon County in Los Angeles County. Four water retailers receive water from the Earl Schmidt Treatment Plant: Valencia Water Company, Newhall County Water District, Santa Clarita Water Company, and the Los Angeles County Water Works, District No. 36.

The Earl Schmidt Treatment Plant began operation in May 1980. The April 20, 1989 TTHM sample results put the running annual average above the MCL of 0.10 mg/l. The running average for the last four quarters is 0.11 mg/l. This is a violation of Section 64439 of the CCR.

The National Interim Primary Drinking Water Regulations for Control of Trihalomethanes in Drinking Water are detailed in the Code of Federal Regulations (CFR), Title 40. Section 64439 of the CCR, Title 22, incorporates these standards by reference. Section 141.12(c) of the CFR establishes the MCL for TTHM at 0.10 mg/l for community water systems serving a population of 10,000 or more and which add a disinfectant.

Directives

Castaic Lake Water Agency is hereby directed to take the following actions:

1. Within 30 days of receipt of this citation, submit to the Department for approval, a plan for achieving compliance with the MCL for TTHM. The plan shall include a time schedule for compliance.

2. Within 15 days of receipt of this citation, notify the customers of the water system of the total trihalomethanes maximum contaminant level violation in conformance with Section 64463(b) and (c), CCR, Title 22. The procedure and format used for notification must be approved by the Department. The notice shall be repeated at least once every three months as long as the system's violation continues. An example notice is attached.

3. Submit a letter to the Department within 15 days of receipt of this citation stating a commitment to comply with the requirements as set forth above. A copy of the customer notification and other responses required above, shall be submitted to:

Gary H. Yamamoto, P.E.
District Engineer
Public Water Supply Branch
1449 W. Temple Street, Room 202
Los Angeles, CA 90026

Civil Peralties

Sections 4032 (d) and (e) of the H & S Code allow for the assessment of a civil peralty for failure to comply with the requirements of Chapter 7. Failure to comply with any provision of this citation will result in the Department imposing an administrative peralty of not less than $100 (one hundred dollars) per day as of the date of violation of any provision of this citation.

7/17/89
Date

T.J. Gannon, P.E., Chief
Central California Region
Public Water Supply Branch

CASTAIC LAKE WATER AGENCY

A Public Agency Established 1962

DISTRIBUTING SUPPLEMENTAL WATER FROM
THE CALIFORNIA WATER PROJECT

August 3, 1989

State of California
Department of Health Services
Public Water Supply Branch
1449 W. Temple Street, Room 202
Los Angeles, CA 90026

ATTENTION: Gary H. Yamamoto, P.E.
District Engineer

SUBJECT: Compliance Plan for Water System No. 19-04:
Citation No. 03-050

Gentlemen:

As directed in the subject citation, the Castaic Lake Water Agency has prepared the enclosed proposed Compliance Plan for your approval. Since the receipt of this citation, measurements of total trihalomethane (TTHM) concentrations have not exceeded 100 u/l and the running annual average for the most recent period is 99.1 u/l. However, in preparation for possible future TTHM increases, the Agency has prepared a Compliance Plan to provide better TTHM monitoring and more operational flexibility. The Agency has also complied with the other directives in the citation.

Please contact us if you have any questions or need additional information.

Very truly yours,

CASTAIC LAKE WATER AGENCY

Robert C. Sagehorn
General Manager

RCS:BC
Enclosure

23560 Lyons Avenue, Suite 225 • Santa Clarita, CA 91321 • Telephone (805) 255-2866

PROPOSED COMPLIANCE PLAN

ACKGROUND

e Castaic Lake Water Agency (Agency) receives untreated State roject water from Castaic Lake. The Agency treats the water at ts Earl Schmidt Filtration Plant (ESFP) utilizing a conventional ter treatment process. Chlorination is used for disinfection.

ince the plant began operation in 1980, the total trihalomethane THM) concentrations measured in the system have generally ctuated from 50 to 110 micrograms per liter (u/l) resulting in running annual average of approximately 70 to 90 u/l. nerally, TTHM concentrations peak in autumn although spring aks have also been observed. In mid-1988 and early 1989, significantly higher TTHM concentrations (100 to 130 u/l) were corded. These measurements raised the running annual TTHM erage to 100.81 in February 1989 and 104.8 u/l in April 1989. ince that time, lower TTHM concentrations (62 to 94.3 u/l) have been measured although they still appear somewhat higher than storical measurements for these periods. These lower TTHM asurements have reduced the running annual average to below 100 u/l for the July 1989 period.

nce the observation of higher TTHM measurements in 1988, the Agency has reduced its chlorine dosages. Currently, the Agency supplies 2.0 to 2.5 mg/l of chlorine at the plant influent and 1 to 0.5 mg/l prior to filtration to maintain a residual of .5 mg/l. Previously, a residual objective was 0.8 mg/l.

e Agency is currently preparing a facilities plan for future xpansion. This plan includes an evaluation of alternative disinfectants, including advanced oxidation and chloramines to spond to anticipated changes in the requirements for isinfection byproducts. Accordingly, this compliance plan ocuses on several interim improvements at ESFP which can be readily implemented until major facilities can be constructed in esponse to the effective date of anticipated regulatory changes.

PROPOSED COMPLIANCE PLAN

ACTIVITY	ANTICIPATED COMPLETION DATE
. Procure Gas Chromatograph for operational monitoring.	November 1989
. Evaluate potential modifications to current disinfection practices including disinfectant dosages and feed points.	January 1990

ACTIVITY	ANTICIPATED COMPLETION DATE
3. Investigate the feasibility of an aqua-ammonia feed system to allow future use of chloramine disinfection or oxidant (peroxide, permanganate, etc.) addition for pre-oxidation.	March 1990
4. Prepare facilities plan for future expansion of the ESFP including alternative disinfection evaluation.	June 1990

11. THM Data from the Santa Clara Valley Water Agency.

Santa Clara Valley Water District

5750 ALMADEN EXPRESSWAY
SAN JOSE, CALIFORNIA 95118
TELEPHONE (408) 265-2600

AN AFFIRMATIVE ACTION EMPLOYER

September 15, 1989

Mr. Gregory Gartrell
Contra Costa Water District
Post Office Box H20
Concord, California 94524

FAX (415) 674-8122

Dear Mr. Gartrell:

This is in reference to the Delta M & I Workgroup and the questions generated by the State Board and the questions you raised at the September 6 meeting. Attached is a copy of the letter that we sent on August 24 to the State Board in response to their questions.

To determine the bromide/chloride levels I assumed that we would have to modify our treatment processes and probably go to ozone. The plot given to the State Board plotted bromide vs. brominated THMs. After further review I have changed the plot by calculating all of the brominated THM species as bromoform. Attached is this new plot. This would change our acceptable bromide level to 0.6 mg/l instead of 0.5 and from our data the chloride level would be 80 mg/l. I have also calculated the amount of bromide that has reacted to form THMs and for our seven years of record this averages 5.5% with a maximum of 32%. Hence the bromide levels that we are quoting are with reactions that have not been very complete and the potential is that the case could be much worse. That is, bromide levels of 0.6 mg/l could be a DBP problem if the reactions were more complete after changing processes. The data for this plot was generated from our Penitencia WTP. Penitencia uses conventional treatment with flash mixing, flocculation, sedimentation using tube settlers, and filtration. We apply a cationic polymer and alum at the head and at the end apply caustic to boost the pH to 7.3 and use zinc orthophosphate for corrosion control. For disinfection we use chlorine at the head and add throughout the process to maintain a 0.4 mg/l residual and then use chloramines at the end for our distribution system.

You asked about downstream storage as a buffer for relaxation. Our South Bay Aqueduct water provides no downstream storage and only a small quantity (1300 AF) of water from Del Valle Reservoir for blending.

If you have any questions please call me at extension 346.

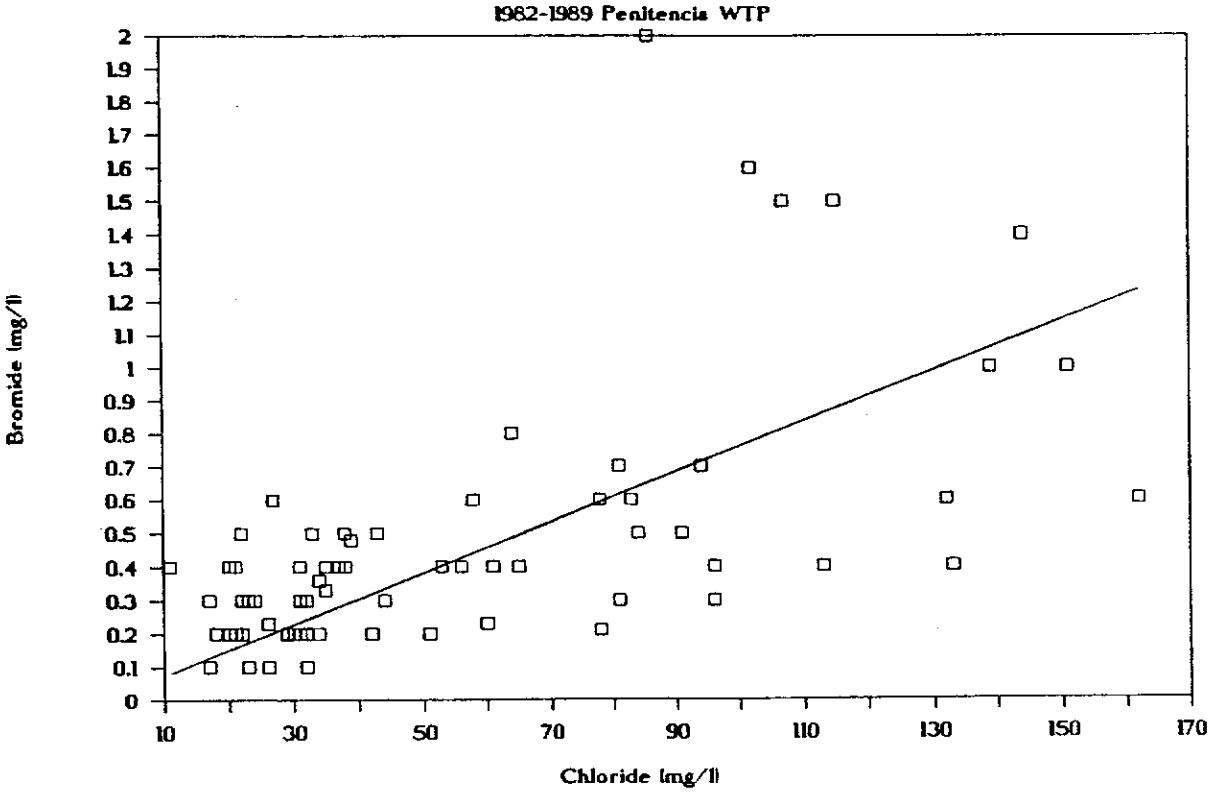
Sincerely,

William Molnar
Senior Civil Engineer
Surface Water Protection Division

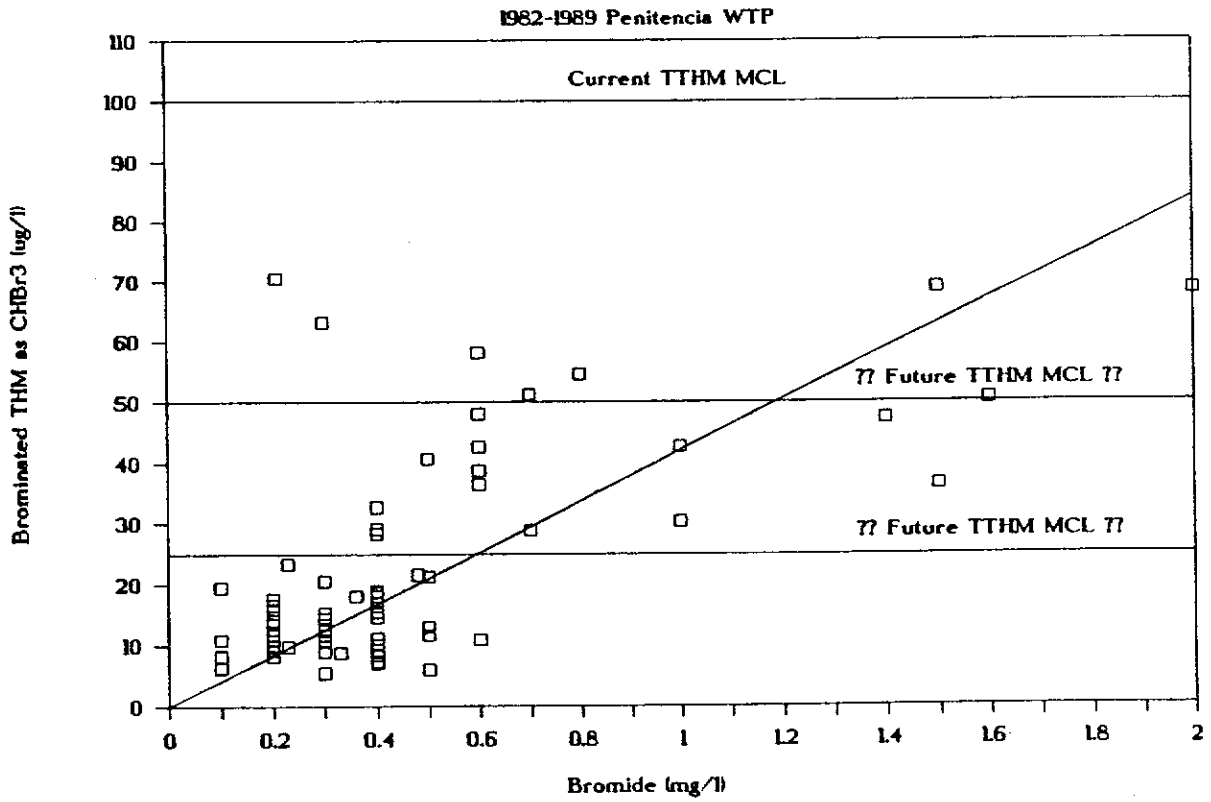
cc: Mr. Rich Satkowski
State Water Resources Control Board
901 P Street
Sacrameto, California 95814
FAX (916) 322-2765

Mr. Ed Means
MWD
1111 Sunset Boulevard
Los Angeles, California
FAX (213) 250-6951

Chloride vs. Bromide



Bromide vs. Brominated TMM species



12. THM Data from the Contra Costa Water District.

The Contra Costa Water District's (CCWD) Ralph D. Bollman Water Treatment Plant supplies treated water to over 185,000 people and has a nominal peak capacity of 90 million gallons per day (MGD). The Sacramento-San Joaquin Delta (Delta) is the sole source of raw water for the Bollman facility. Raw water can be obtained directly from Rock Slough via the Contra Costa Canal (Canal) or from Mallard Reservoir, which is filled either by the Canal or from an intake at Mallard Slough, at the western edge of the Delta opposite Chipps Island.

The Bollman plant utilizes conventional water treatment processes. Upon entering the facility, raw water is prechlorinated by a liquid stream containing chlorine. The coagulant, alum, is then added via a hydraulic flash mix. After coagulation and flocculation, the pH of the water is typically adjusted with lime and caustic soda. Chlorine and/or ammonia (to form chloramines) may also be added at this point for additional disinfection. The water then passes through dual media (sand, anthracite) filters. After filtration, chlorine and/or ammonia can once again be added to ensure adequate disinfectant residual. Finally, the water is flouridated and flows to a 10 million gallon (MG) clearwell for distribution.

The Bollman facility was designed to give CCWD the ability to alter disinfection processes in response to variable raw water quality. Chlorine is typically used as the primary disinfectant, but monochloramines can be used in place of, or in combination with, chlorine. The choice of disinfection parameters is often governed by the trihalomethane (THM) requirement. The choice also involves trade-offs; a switch to monochloramines from chlorine, for example, may lead to taste & odor problems.

Table 1 on the following page presents the THM data collected at the Bollman plant over the last four years. THM data are collected at six locations in the treated water distribution system. The THM data presented in Table 1 are the average values of the six locations. Samples are analyzed at least quarterly and sometimes more frequently. When more frequent samples are taken, an average of the samples taken in that quarter is reported to the

THM Data: Contra Costa Water District
Average of six locations in distribution system

( ) indicates that an explanatory note is provided below

DATE	CHCL3 ppb (1)	CHBRCL2 ppb (2)	CHBR2CL ppb (3)	CHBR3 ppb (4)	TTHM ppb (5)	BTP Cl ppm (6)	BTP Br ppm (7)	Addit'l Notes
3/18/85	22	13	6	nd1	41	40	0.12	(8)
8/16/85	20	23	28	16	87	112	0.33	(8)
10/02/85	6	12	21	33	71	150	0.44	
12/17/85	4	9	21	28	63	154	0.45	
3/26/86	26	21	12	nd1	58	50	0.15	
6/24/86	18	13	5	nd1	36	26	0.08	
9/29/86	21	8	4	2	34	37	0.11	
12/16/86	17	13	7	nd2	37	27	0.08	
3/25/87	15	15	8	nd2	38	44	0.13	
6/09/87	11	18	19	4	52	64	0.19	
8/13/87	9	16	39	42	107	134	0.39	
9/10/87	7	8	26	43	84	185	0.54	
10/19/87	5	5	15	17	42	214	0.63	
1/19/88	4	11	28	26	70	185	0.54	
6/01/88	6	10	15	10	42	78	0.23	
8/31/88	2	10	33	79	123	222	0.65	
12/06/88	5	9	27	54	94	228	0.67	
2/28/89	6	16	43	58	123	185	0.54	
3/09/89	6	11	30	43	90	186	0.54	
5/03/89	7	9	8	3	28	71	0.21	
7/26/89	17	21	19	5	62	55	0.17	

note 1: chloroform
note 2: dichlorobromoform
note 3: dibromochloroform
note 4: bromoform. nd1= not detected, less than 2 ppb
nd2= not detected, less than 0.1 ppb
note 5: total trihalomethanes, may not add exactly due to round-off
note 6: chlorides at Bollman Treatment Plant Clearwell
note 7: calculated bromides at Bollman Treatment Plant Clearwell
based on MWD relationship: Br = .00289 * Cl + .0067
note 8: Rock Slough chloride concentration is assumed at BTP
because BTP chloride measurement is unavailable

Table 1 Contra Costa Water District Trihalomethane Data, 3/85-7/89

Department of Health Services to satisfy the THM quarterly reporting requirement.

As indicated above, disinfection practices are flexible and results at the Bollman plant depend on the disinfection practices utilized. Table 1 does not account for differences in disinfectant choice, dosage, or contact time. Chlorine contact times ranged from 1 minute to 45 minutes. A low chlorine contact time means that monochloramines function as the primary disinfectant. Monochloramines minimize THM formation, but are a less effective disinfectant than is chlorine. Future use of monochloramines as a primary disinfectant is likely to be severely restricted by contact time regulations promulgated to ensure virus removal.

Other parameters that affect THM formation, such as the total organic carbon content of the source water, are also not considered in Table 1. A detailed discussion of THM formation with Delta source source water can be found in Lange and Kawczynski[1].

Figure 1 (page 5) is a plot of total THM concentration versus chloride concentration. Figure 1 illustrates that, even with the ability to alter disinfection processes to reduce THM formation, higher chlorides in raw water at the Bollman plant result in higher total THM production. With chloride concentrations above 50 mg/l, standard disinfection procedures at the Bollman plant can produce THM concentrations above the 50 µg/l total THM standard that is the least stringent of the currently proposed standards. At higher chloride levels, individual THM samples have exceeded 100 µg/l, although CCWD has been able to meet the current THM standard, which is a four quarter running average requirement.

Figure 2 (page 5) presents chloroform versus chloride concentration. Figure 2 illustrates that chloroform formation at the Bollman plant has been inversely related to the raw water chloride concentration, and that chloroform levels are low enough to meet future standards.

Brominated THM formation at the Bollman plant is more strongly related to raw water chloride concentration. Figure 3 (page 6) presents the historical Bollman plant brominated THM data. Bromide has been found to vary directly with chloride in sea water by a

variety of researchers. Figure 4 (page 6), for example, presents some results developed by Al Lange, CCWD Superintendent of Purification, in 1979. Each data point in Figure 4 represents a different location in the Delta or a Delta tributary waterway. The lowest bromide and chloride values were found in water sampled at the Sacramento River at Walnut Grove. The highest values were found in water sampled in the Delta adjacent to Frank's Tract. Other bromide values measured at the Bollman plant yield a bromide/chloride ratio of approximately 0.0038. Figure 4 and related work show that higher chloride raw water implies higher bromide raw water at the Bollman plant.

Information on the chemical kinetics of the bromide-disinfectant-THM precursor reaction can be found elsewhere (e.g. McGuire and Krasner, and Daniel in Appendix A of this report). The chloride-bromide relationship and the kinetics of the bromide-disinfectant-THM precursor reaction readily explain the historical from the Bollman plant presented in Figure 3.

The domination of brominated THM species at higher chloride concentrations is of concern to CCWD and other water purveyors because recent evidence suggests that the ingestion of brominated THMs may be more a more serious human health concern than was previously believed (see Clark, and Orme in Appendix A).

In conclusion, measured data collected over the past four years show that THM levels in the CCWD distribution system increase with increasing raw water chloride (and thus bromide) concentrations. Even with flexible disinfection options and a treatment approach often governed by a desire to minimize THM formation, CCWD has not been able to negate the effect of increased chloride concentrations on THM formation. Historical data suggest that the existing Bollman facility will have difficulty meeting the 50 µg/l total THM standard, which is the least stringent of the currently proposed standards, if future raw water quality is similar to historical raw water quality.

[1] Lange, A.L. and Kawczynski, E., "Controlling Organics: The Contra Costa County Water District Experience", Journal of the American Water Works Association, November, 1978, pp. 653-660.

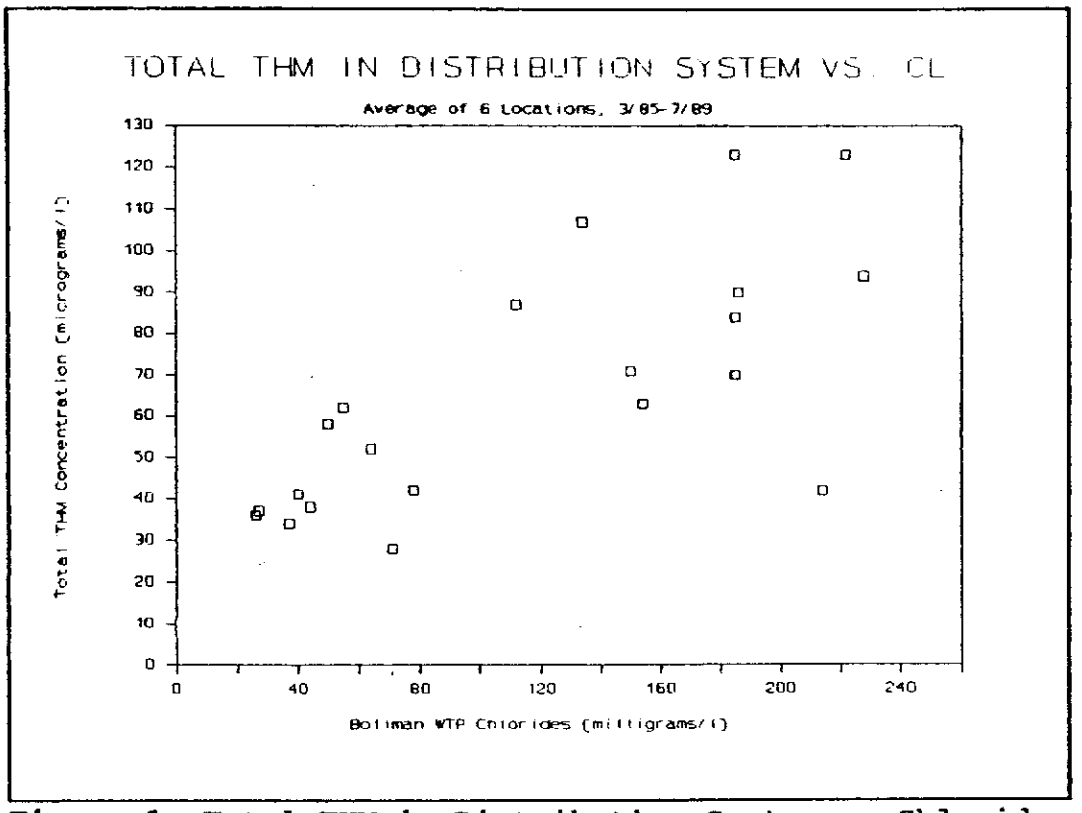


Figure 1 Total THM in Distribution System vs Chloride

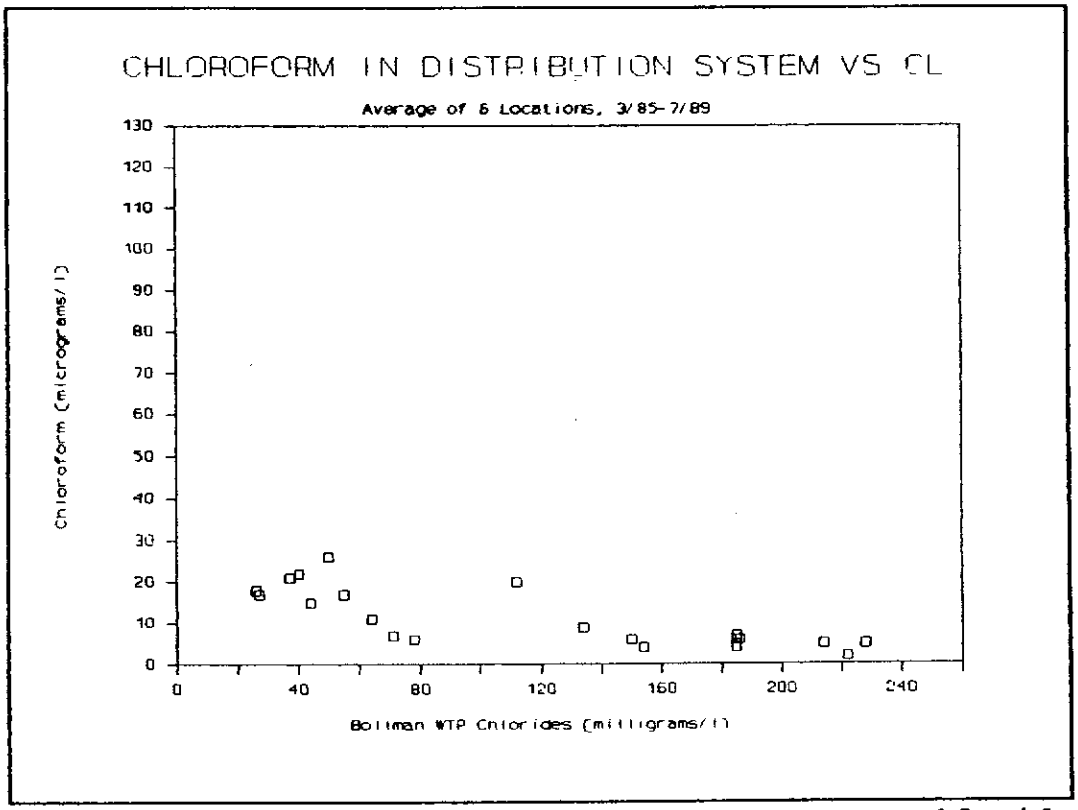


Figure 2 Chloroform in Distribution System vs Chloride

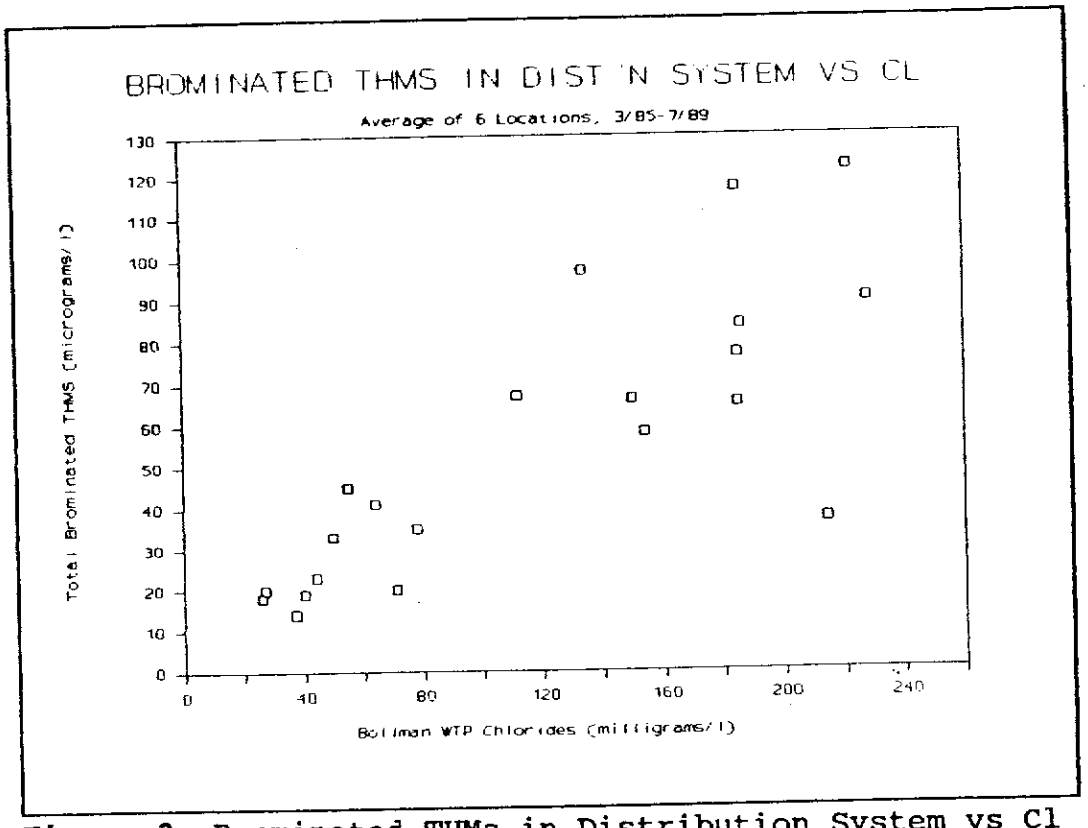


Figure 3 Brominated THMs in Distribution System vs Cl

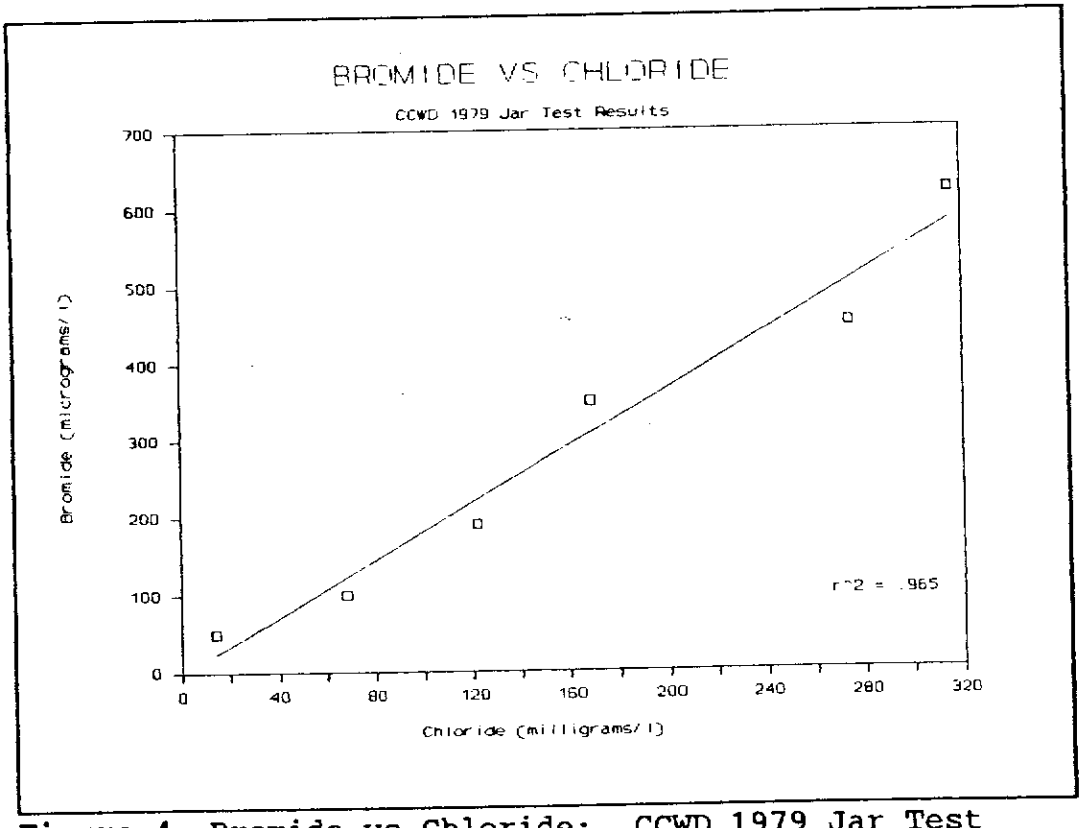


Figure 4 Bromide vs Chloride: CCWD 1979 Jar Test Results

13. THM Data from the Los Angeles Department of Water and Power.

RECEIVED
OCT 9 1989

Department of Water and Power the City of Los Angeles

September 28, 1989

Mr. Gregory Gartrell, Chair
Bay Delta Municipal and Industrial Workgroup
Contra Costa Water District
P.O. Box H20
Concord, California 94524

Dear Mr. Gartrell:

Impact of Bromides from Sacramento Delta on
Los Angeles Drinking Water Quality

As a follow up to my letter of September 15, I am resubmitting a new figure for inclusion in your report to the State Water Resources Control Board on the impact of bromides from the Sacramento Delta on drinking water quality in Los Angeles. We feel that this new figure more clearly depicts this impact than those previously submitted.

The attached figure clearly shows that as the percent of State Water Project (SWP) water increases, trihalomethanes (THM) increase by about six times. When SWP water was 60% of total flow treated at our Los Angeles Aqueduct Filtration Plant (LAAFP) during August - November 1988 and March - August 1989, THM increased about six times from 10-15 ppb to 60-80 ppb. Total THM were measured six miles from our LAAFP. Also, the brominated species of total trihalomethanes increased as more SWP water was received into our city, suggesting that the bromide ions from the Delta are the primary cause.

The SWP water was treated either using ozone, direct filtration, and chlorination at the LAAFP or using conventional filtration and chloramination at Metropolitan Water District's Jensen Filtration Plant.

111 North Hope Street, Los Angeles, California ☐ *Mailing address:* Box 111, Los Angeles 90051-0100
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Because we anticipate purchasing more State Water Project water to supplement our supplies in the future, the above results indicate that the City of Los Angeles may experience higher THM levels up to six times its present levels even more frequently in this area of the city. Our overall city average of 30-40 ppb will rise significantly as well. This is highly undesirable since EPA is planning to reduce the THM MCL from 100 ppb to the 25-50 ppb range.

From the above results, we request that your Workgroup recommend to the Board alternatives that minimize bromide levels in flows entering the SWP. The use of both state-of-the-art and conventional water treatment technology is unable to maintain THM levels at acceptable levels when SWP water with high bromides is treated. It becomes necessary to minimize the generation of THM by controlling the available amount of bromides at the source of supply, the Sacramento Delta.

If you have any further questions, please call Mr. Hoover Ng of my staff on (213) 481-3144.

Sincerely,

Bruce W. Kuebler/RG

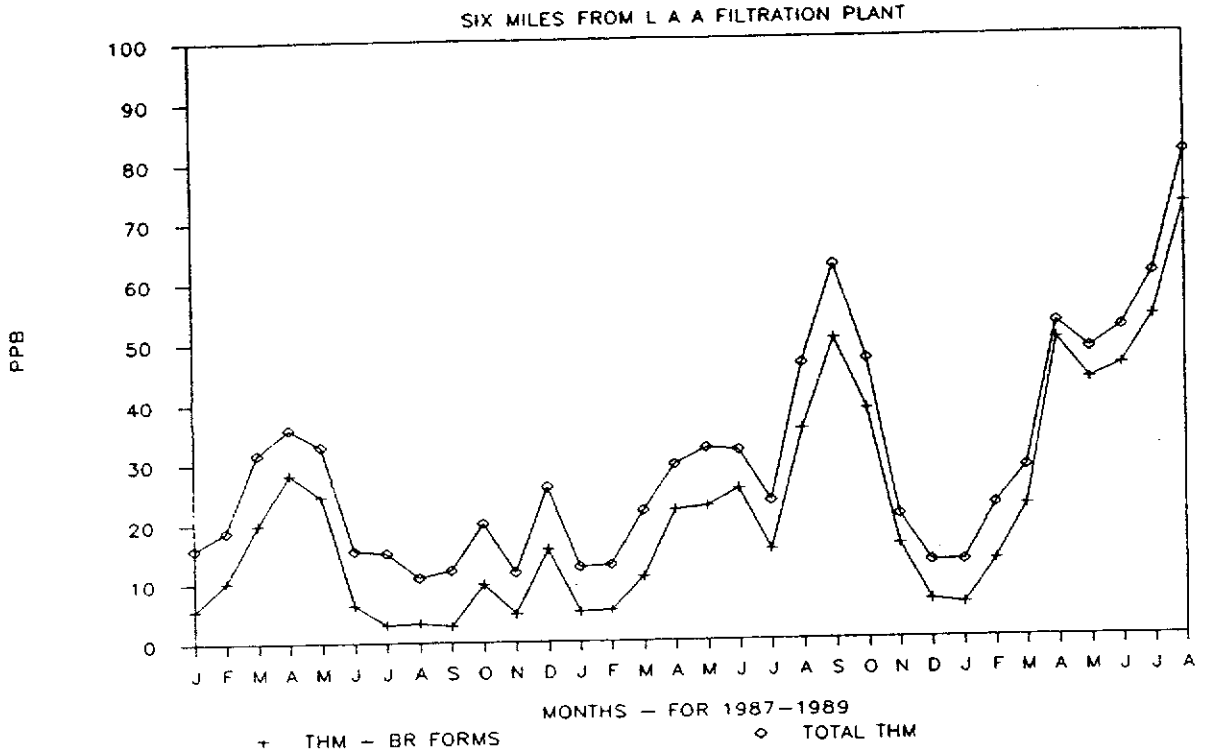
BRUCE W. KUEBLER
Engineer in Charge
Water Quality Division

Enclosure

c: Mr. Michael McGuire, MWD
Mr. Hoover Ng

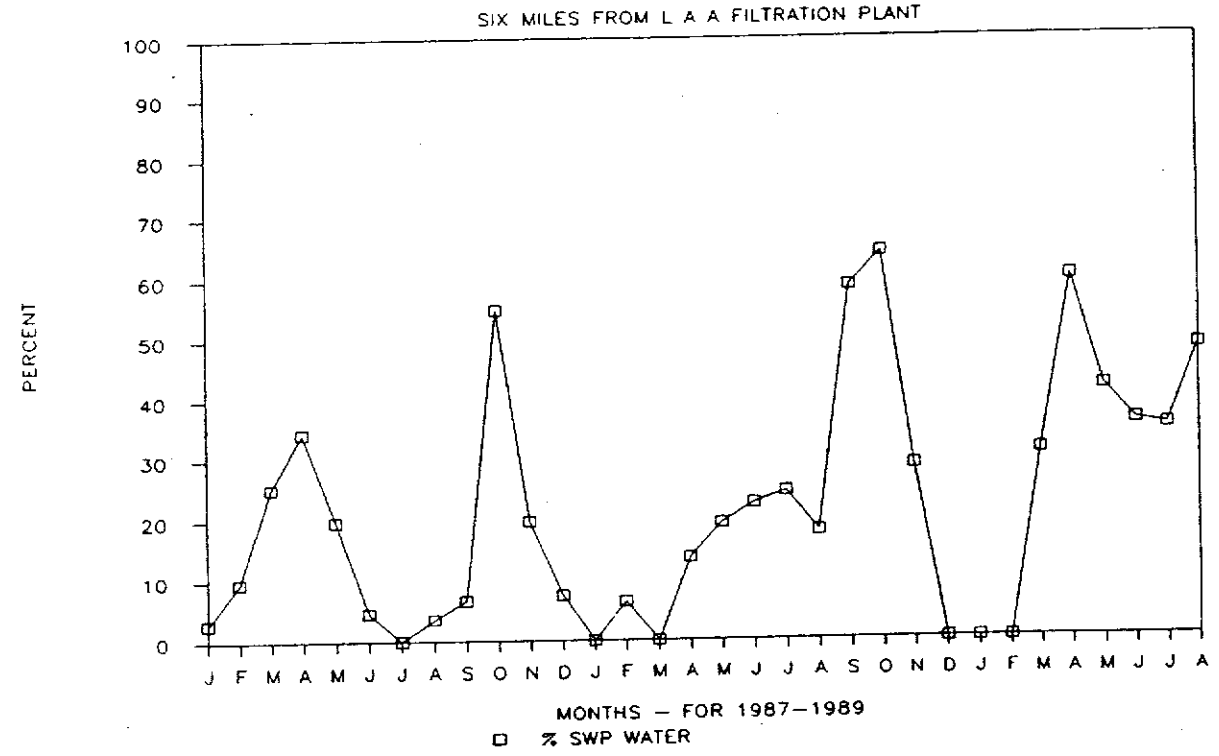
BROMINATED AND TOTAL THM

SIX MILES FROM L A A FILTRATION PLANT



STATE WATER PROJECT FLOW INTO LA

SIX MILES FROM L A A FILTRATION PLANT



14. Science Advisory Board Drinking Water Committee Meeting of October 11, 1989 Discussion of Strawman Rule for Disinfectants and Disinfection By-Products by Stephen W. Clark, USEPA, dated September 22, 1989.

SCIENCE ADVISORY BOARD DRINKING WATER COMMITTEE

Meeting of October 11, 1989

SEP 22 1989

DISCUSSION OF STRAWMAN RULE FOR DISINFECTANTS AND DISINFECTION BY-PRODUCTS

Stephen W. Clark
Criteria and Standards Division
Office of Drinking Water

I. OVERVIEW OF KEY POINTS IN THE STRAWMAN RULE

A. Set Maximum Contaminant Level Goals (MCLGs) and Maximum Contaminant Levels (MCLs) for the following:

1. Lead option

   a. Total trihalomethanes (TTHMs)
   b. Haloacetic acids
   c. Chloride dioxide, chlorite, chlorate
   d. Chlorine and chloramine

2. Potential add-ons

   a. Chloropicrin
   b. Cyanogen chloride
   c. Hydrogen peroxide, bromate, iodate
   d. Formaldehyde

B. Set treatment technique requirements or provide guidance for the following:

1. MX (as a surrogate for mutagenicity).

2. Total oxidizing substances (as a surrogate for organic peroxides and epoxides).

3. Assimillable organic carbon (AOC) (as a surrogate for microbiological quality of oxidized waters).

C. Require monitoring

1. Segmented by the treatment process used (see Table 4).

2. Reduce monitoring requirements to one per quarter at system discretion; one per year at State discretion based on system history.

D. List Best Available Technologies

1. Precursor removal (50% removal of TTHM-formation potential) using:

   a. Conventional treatment modifications.

   b. Granular Activated Carbon up to 30 minutes empty bed contact time and 3 months regeneration.

   c. GAC is not universally feasible due to water quality conditions.

   d. Membranes may not be BAT due to lack of full-scale experience.

2. Alternate oxidants

   a. Assuming MCLG values are met for disinfectants.

   b. Chlorine dioxide and chlorite residue removal and chloramines.

   c. Ozone plus chloramines.

   d. TTHM MCL of 25 µg/L is lowest that allows continued use of free chlorine.

3. By-product removal:

   a. Aeration (maybe for some).

   b. GAC adsorption (not for most chlorination by-products; ozone unknown).

   c. Reducing agents for MX, total oxidizing substances, possibly chloropicrin and cyanogen chloride.

   d. Reducing agents or free chlorine for hydrogen peroxide.

   e. Bromate and iodate -- uncertain.

   f. Caveat ozone use with possible future need for post-GAC treatment for controlling AOC (bio-assimilation) or removal of other by-products by adsorption.

E. Lead options are:

1. MCLs for TTHMs of 50 µg/L or 25 µg/L.

2. Other MCLs based on analyses of feasibility similar to TTHMs.

II. BACKGROUND

A. Interim total trihalomethane (TTHM) regulation.

1. Based on carcinogenicity of chloroform in laboratory animals and the possibility that the brominated analogues would have similar effects.

2. Goal was to reduce human exposure to animal carcinogens while not compromising microbiological safety.

3. Major changes in treatment practices implemented for compliance were moving the point of chlorination to after the settling process (precursor removal) and use of chloramines as a residual disinfectant (alternate oxidant).

4. Compliance has been good; systems serving less than 10,000 people are not required to comply due to low exposure and concern with compromising disinfection in small communities.

5. Generally, this standard has worked well and the current questions include:

   a. Should the standard be lowered?

   b. Should other compounds be added?

B. Current regulatory environment.

1. Congress, in the Safe Drinking Water Act Amendments of 1986, has placed a new emphasis on microbiological safety by requiring standards for filtration of surface waters and disinfection of all vulnerable waters.

2. Disinfection, including the maintenance of a residual in the distribution system, is mandatory for surface water systems. Disinfection requirements will also be set for ground water although variances will be allowed for good quality source waters. Both of these requirements raise concerns about increased exposure to disinfectants and disinfection by-products.

3. EPA developed working lists of disinfectants, chlorination and ozonation by-products (see Tables 1 - 3).

4. EPA could set maximum contaminant levels (MCLs) or treatment technique requirements for some or all of the contaminants in Tables 1 - 3. The most cost-effective regulatory approach would be to set

MCLs for a few contaminants which would serve as surrogates of the overall chemical safety of the water. The TTHM standard is an example of this.

C. Need for a strawman rule.

1. This is a very complex problem, requiring a multidisciplinary approach to simultaneously evaluate health, occurrence, analytical chemistry, monitoring, treatment, economic, and compliance issues.

2. There is a large amount of information available, some of which is the result of recent research -- further research and analysis needs to be focused so as to meet the EPA goal of proposing a rule in the Federal Register by the Fall of 1991.

3. There is a sincere desire to seek input from all affected parties early in the process of developing a proposal.

4. The strawman is by definition very flexible and can be re-oriented given new data or other inputs.

D. Limitations of the strawman.

1. The strawman was developed by people in the Office of Drinking Water and the Office of Research and Development who have first hand knowledge of the various technical and policy aspects of this problem.

2. However, full support documentation is not available; this limits the information available -- for instance, while MCLGs have been calculated for most contaminants, health effects analyses for some are incomplete and most risk assessments have not been verified by the proper EPA workgroups. Therefore, there are no MCL goal numbers available for discussion at this time.

3. The major thrust of this rule will be monitoring requirements and MCLs for compounds that are designed to lower overall human exposure to disinfectants and their by-products. This will be accomplished by changes in water treatment practice discussed in the best available technology section.

E. Expectations for the strawman

1. Create a document that will stimulate dialogue with the SAB, the EPA regulatory workgroup, the Drinking Water Advisory Council, States, Regions, and interested citizens and organizations.

2. The strawman is designed to help focus research, data gathering and analysis. Further, this document along with appropriate comments will serve as a guide to developing the proposed regulation.

3. More details will be inserted in later versions as new information becomes available.

III. DETAILED DISCUSSION OF ISSUES -- HEALTH

A. Issue: High dose versus low dose extrapolation for oxidants -- i.e., disinfectants.

Discussion: There is some tentative evidence that the chemistry in the gastrointestinal tract may be significantly different for high dose animal experiments versus the low doses seen in typical human exposure. Examples include demonstration of a chlorine demand in saliva and formation of different chloramine species at various doses of chloramine reacted with rat gastric juices in vitro. The differences in effects seen at high dose versus low dose could be due to differences in chemical species seen by the target organ. More needs to be known about the chemical kinetics and pharmacokinetics of chlorine and chloramines and other oxidants before the final maximum contaminant level goals are set for these compounds.

Resolution: The National Toxicology Program (NTP) bioassays may provide additional animal data for chlorine and chloramines at high doses. EPA has met with NTP officials to discuss the critical nature of these data. Outside expert consultants have been retained to advise ODW on the possible significance of different chemical species reaching the target organs at high versus low doses.

The Health Effects Research Laboratory (HERL) has also been asked to conduct experiments to help resolve this issue.

B. Issue: Determining the relative source contribution factor (RSC) for disinfectants and DBPs.

Discussion: A 20% RSC factor is used when insufficient data are available or a significant portion of exposure is due to sources other than water. For the residual disinfectants and chlorination by-products, the working hypothesis is that drinking water is the dominant source of human exposure. Therefore, an RSC factor of at least 80% will be used. For aldehydes, other exposure sources such as fruit juices are likely to be significant, so a lower RSC factor (perhaps 20%) will be used if they are regulated.

Resolution: The occurrence/human exposure document will present and analyze data to resolve this issue. A draft of this document will be available in September, 1990.

C. Issue: Should the total trihalomethane (TTHM) standard (MCLG) be based on an estimate of their toxicity as a group as in the interim standard or should individual risk assessments be presented currently?

Discussion: Chloroform is considered a B2 carcinogen by EPA. The bromine substituted analogues do not have the extensive testing results available for chloroform. There seem to be two major issues: (1) the carcinogenicity of chloroform based on rat kidney tumor data and (2) potential differences in pharmacokinetics of bromine analogues versus chloroform.

Resolution: The issue of differences in pharmacokinetics of the bromine analogues will require that short-term animal studies be conducted by HERL. ODW is currently negotiating to have this critical need met.

D. Issue: Strategy needs for future health effects research on ozonation by-products.

Discussion: Currently available data may be adequate for risk assessments for aldehydes of interest (esp., formaldehyde and acetaldehyde). However, long-term research is planned to identify other by-products for which health effects may be a concern. Another approach would be to conduct additional bioassays on concentrates from ozonized natural waters.

Resolution: We want to emphasize the approach using extracts/concentrates and screening them for biological activity using several in vitro and in vivo techniques. New analytical techniques need to be developed to identify and quantitate ozonation by-products. Studies of this type are underway in the Denver and Tampa water re-use projects. Extraction techniques for concentrating samples for instrumental analysis could be adapted for use in developing concentrates for toxicity studies. However, the chemistry of the extraction/concentration process needs to be better understood. In the case of MX, the bioassay was helpful in isolating and identifying the specific compound responsible for the mutagenic effect. This could be a possibility for ozonation by-products, although mutagenicity might not be the significant endpoint since most studies to date of ozonated products indicate low activity.

E. Issue: The toxicity data for cyanogen chloride are inadequate to determine if it behaves similar to hydrogen cyanide. If the pharmacokinetics are similar then the MCLG analysis could be analogous to that for hydrogen cyanide.

Discussion: The toxicity of hydrogen cyanide is well understood. One hypothesis is that cyanogen chloride behaves *in vivo* similar to hydrogen cyanide.

Response: ODW has requested that HERL conduct pharmacokinetics studies on cyanogen chloride. ODW has sought out expert advice on the chemistry in the digestive tract and possible high dose versus low dose differences. The literature in this area will be thoroughly reviewed.

F. Issue: Possible carcinogenicity or other use limiting toxicity endpoints for chloramines.

Discussion: Chloramines are a useful residual disinfectant for maintaining microbiological quality in the distribution system. They have the advantages of being more persistent than free chlorine and producing much lower levels of TTHMs and other chlorination by-products. Current use is in the range of 1-2 mg/L concentration at the tap. An MCL lower than this would preclude the use of chloramines by many systems, since the microbiological efficacy would be compromised.

An MCL in the range of 0.1 mg/L or lower could have the additional problem of poor specificity of the available analytical method. The current method for total chloramines is not specific for the species of interest, monochloramine. In some waters, especially those with high natural organic material content, the method for chloramine could detect 0.1 mg/L chloramine even though free chlorination is practiced. This would occur because organic chloramines are formed and are a source of false positive results in the chloramine analysis. Very high levels of chlorination could destroy them, but TTHMs and other by-product levels would be increased.

The use of chloramines is also the most cost-effective means of meeting current and future chlorination by-product standards. Not being able to use chloramines would result in many more systems having to use costly precursor removal treatment to meet current or lower standards.

Response: As discussed earlier, NTP and other health data are being obtained. The reactivity of chloramines in the digestive tract and the relationship of this to the dose-response interpretation are also being investigated.

Treatment and chemistry research are also concentrating on alternatives that include not relying on chloramines as the residual disinfectant of choice. If chloramines are safe, the most cost-effective means of simultaneously meeting disinfection and by-product requirements is to use ozone as a primary disinfectant followed by chloramines.

Resolution of the chloramine toxicity issue is of primary importance in deciding the outcome of this regulation.

G. Issue: Setting MCLGs for individual by-products.

Discussion: Most of the compounds of interest will have adequate data for calculation of an MCLG or cancer risk number by this Fall. ODW will then obtain concurrence on the risk assessments from the Agency's Reference Dose (RfD) Workgroup for noncarcinogenic endpoints and the CRAVE workgroup for the carcinogen classification. Compounds with particular concerns like cyanogen chloride and chloramines have been discussed earlier.

IV. OCCURRENCE

A. Use of occurrence data:

1. Selecting key indicator compounds for regulation.

2. Determining human exposure and relative source contribution (RSC) factor.

3. Developing an adequate data base for the economic impact assessment (EIA); this is a non-statutory requirement.

B. Examples of data available:

1. TTHMs: EPA and State data, plus McGuire and Meadow in Journal AWWA, January 1988. Singer and Chang in Journal AWWA, August 1989.

2. Other chlorination by-products: Krasner et al. in Journal AWWA, August 1989, plus EPA data.

3. Ozonation by-products: Glaze et al. in Journal AWWA, August 1989, plus EPA data.

4. Disinfectant levels: AWWA utility survey or assessment of generally accepted practices.

5. Secondary by-products of ozone plus chlorine or chloramines (ongoing work by Al Stevens et al., USEPA).

C. Important analyses:

1. Distribution of TTHM occurrence by system size, geographically by region, by water source (ground vs. surface), and treatment type (esp., disinfection practices).

2. Correlation of various DBPs and other parameters (e.g., treatment, pH, TOX, etc.) -- are a few compounds good surrogates for the rest? Under what circumstances?

3. Comparison of occurrence to MCLG values -- is regulation necessary if occurrence is well below MCLG?

4. National projections for economic impact analysis -- TTHMs are especially important since the most comprehensive data are available for them.

D. Current conclusions based on evaluation of health and occurrence:

1. On a weight basis the rank order of occurrence of chlorination by-products is (see Krasner et al.):

TTHMs
haloacetic acids
haloacetonitriles
chloral hydrate
chloropropanones
cyanogen chloride
chloropicrin
chlorophenols

2. Of these, the concentrations of TTHMs and haloacetic acids seem to be the most significant in comparison to potential health effects from consumption of chlorinated waters. There also appears to be a pH effect with TTHMs favored at higher pH and some haloacids favored at lower pH.

3. Cyanogen chloride concentrations seem to be higher in chloraminated waters although low overall. More health information is needed to determine the significance of this.

4. Chloropicrin could be a concern in chlorinated waters, especially if ozonation is also practiced -- awaiting health data to determine the significance of exposure to this compound.

5. MX should remain as a candidate for regulation or guidance, pending further data analysis although rapid in vivo detoxification is indicated.

6. The other chlorination by-products occur in low enough concentration in comparison to what was judged to be levels of health concern that considering the cost of monitoring (which could be substantial), these compounds will not be considered for regulation as part of this strawman.

7. The residual disinfectants are relevant for regulation, including chlorite and chlorate.

8. Based on limited data the following compounds are currently of interest in ozonated waters: formaldehyde, total oxidizing substances, bromate, iodate, and hydrogen peroxide. Alpha, beta unsaturated aldehydes and acids may also be of interest.

V. DISCUSSION OF ISSUES: ANALYTICAL CHEMISTRY

A. Status of Methods.

1. TTHMs -- OK; quantification is in the µg/L range.

2. Haloacetic acids -- simplification of method is likely to be accomplished shortly; this would reduce the cost of monitoring.

3. Multiple samples/analyses required for chlorination by-products because of differences in preservation (e.g., chloral hydrate if an MCL is needed requires ascorbic acid which is not good for the others).

4. Cyanogen chloride is unstable -- must be analyzed within a few days; need to resolve preservation issue in order to regulate.

5. No methods for MX or N-organochloramines.

6. Disinfectants; OK except the quantification levels need to be verified for some (esp., chlorite and chlorate).

7. Ozonation; aldehyde methods should be ready for survey work in FY 90.

8. Hydrogen peroxide method currently has poor performance; but chlorine converts it to water.

B. Methods issues requiring resolution.

1. Preservation of cyanogen chloride (if MCL is required).

2. Aldehyde standard method (if MCL is required).

3. Simplified method for haloacetic acids.

4. Obtain expert consultant advice on a method for total oxidizing substances as a surrogate for organic peroxides and epoxides.

5. Interference of organic chloramines with chloramine/chlorine residual testing (see health effects discussion).

6. Practical quantification limits for inorganics.

C. Conclusions regarding analytical methods:

1. Methods are or will be available for a proposed regulation in Fall of 1991.

2. The current method for haloacetic acids is more difficult than for TTHMs, but no more difficult than that currently used for the chlorophenoxy herbicides which have been regulated since 1975.

VI. DISCUSSION OF ISSUES -- MONITORING

A. Feasibility and cost of monitoring.

1. Using methods currently available, monitoring for chlorination by-products could cost up to $640 per sample.

2. On a national level this would range up to $157 million per year if four quarterly samples per year are required for all chlorinating systems similar to TTHM requirement.

3. Examining feasibility of formation potential or simulated distribution system samples for compliance purposes.

B. Issue -- number of samples.

1. Range of four as in the TTHM requirement to one at the end of the distribution system.

2. Frequency ranges from quarterly as in TTHM requirement to one during the peak season (demonstrated by previous quarterly monitoring).

3. Formation potential or simulated distribution system sample; one sample analyzed after holding time at specified temperature and other conditions.

C. Lead option.

1. Segment monitoring requirement by disinfection practices (see Table 4).

2. Allow option to monitor at one point per year (or quarterly, depending on State discretion); system could increase monitoring and average result if they like -- depends on how far below the MCL they are and treatment in place.

3. Goal is to reduce monitoring cost without placing administrative burden on the States.

VII. DEVELOPING A CANDIDATE LIST FOR DISCUSSION OF TREATMENT ISSUES

A. Background.

1. Currently regulating TTHMs as a surrogate for overall risks of chlorination by-products.

2. Need to assure that ozonation and other alternative disinfectants are safe in terms of by-product concentrations. Chlorine dioxide residual control is also an important consideration.

3. Need to consider surrogates; possible 200-300 compounds in GC-MS library for chlorination; ozonation has many possible by-products too, but analytical methods are less well developed.

4. Approach needs to consider selecting a cost-effective approach that uses a few key surrogates to manage overall risk.

B. Analysis.

1. Compare occurrence with MCLG; note that the occurrence values were worst case with TTHM values ranging up to 300-400 µg/L.

2. In this case TTHMs seem to be a good choice because: they represent about 50% of the total mass of chlorinated organics; chloroform is a B2 carcinogen; seem to represent chlorination by-products in general, but are formed in higher concentrations at higher pH; have good, inexpensive analytical method; can be controlled using a

variety of treatment technologies; have been regulated since 1979 and are relatively well understood.

3. The group of contaminants with the next highest concentration are the chlorinated (brominated) acetic acids which account for about 25% of the mass of chlorination by-products that can be measured; the di- and tri- chloroacetic acids may be animal carcinogens; trichloroacetic acid formation seems to be more favored at pH ≤7 versus pH 9.4; the analytical method is available although more difficult than TTHMs and may be about the same level of difficulty as the chlorophenoxy herbicides; there is a good chance that the haloacetic acid method will be simplified bringing its cost down; samples can be preserved for at least three weeks; monitoring appears feasible; adding the haloacetic acids may have the advantage of removing the bias of maintaining a low pH in distribution [low pH has two disadvantages: (1) higher levels of TOX in most cases and (2) increased corrosivity in some cases]; treatment for control of haloacetic acids is similar to that for TTHMs when precursor removal using conventional treatment is considered (see Stevens et al., Journal AWWA, August 1989).

4. Chloral hydrate, if regulated, would have to be analyzed in a separate sample at increased cost; worst case occurrence appears to be below current estimate of MCLG; would appear to be controlled by setting appropriate levels for TTHMs and CAAs which would prompt treatment controlling all chlorinated DBPs.

5. Occurrence levels in comparison to levels of health concern (MCLGs) do not seem to warrant regulations for haloacetonitriles, chlorinated propanones, and chlorophenols; this could save a substantial amount in monitoring costs; overall levels are likely to come down when TTHMs and CAAs are controlled.

6. Chloropicrin could be a concern in waters that are ozonated then chlorinated or chloraminated; toxicity data are still pending; conclusion is to gather more data prior to making a decision; possible monitoring only for systems using ozone and chlorine/chloramines.

7. Cyanogen chloride occurrence seems to increase with use of chloramines; instability of sample, 1-2 day holding time, may make regulatory monitoring impractical; toxicity is not fully determined -- may be occurring at levels well below MCLG;

conclusion: (1) continue analytical chemistry and preservation studies and (2) determine appropriate MCLG value.

8. All the disinfectants can be controlled (although there are data needs for chlorite and chlorate), measured, and will likely have adequate health data; regulate chlorine, chloramines, and chlorine dioxide (plus anions).

9. Bromate, iodate, and hydrogen peroxide could be significant and work is continuing in all areas.

10. It is unlikely that any useful information will be available for regulation of N-organochloramines; EPA may be able to provide some general guidance; this will become a long-term research need, especially analytical methods development.

11. Continue work on MX; especially, understanding its lack of in vivo toxicity and chemistry under water treatment conditions; possible regulation (treatment technique) or guidance.

12. Chemical reduction using GAC, PAC, bisulfite or related liquid agents should be explored for control of oxidizing organic substances like peroxides and epoxides; this may also be useful to reduce concentrations of MX, chloropicrin and other chloro-organic compounds; measurement may be useful for control of chlorination and ozonation processes.

13. Aldehydes, especially formaldehyde, should continue to be explored as an indicator of quality/safety of ozonated waters, recognizing, also, that aldehydes are formed by other disinfection processes.

VIII. TREATMENT DISCUSSION OVERVIEW

A. Goal is to determine BAT for various groups of disinfection by-products and disinfectants.

B. Discussion will be divided into three major approaches: precursor removal, alternate oxidants, and by-product removal.

C. The Safe Drinking Water Act Amendments of 1986 require that GAC adsorption be considered in the analysis as a benchmark technology for synthetic organic chemicals.

IX. DETAILED DISCUSSION OF PRECURSOR REMOVAL

A. Assumptions

1. Examine performance in terms of meeting specific levels of TTHMs under current regulatory monitoring.

2. Free chlorine is added to meet surface water disinfection requirements.

3. Examine cost of various processes for large metropolitan size utilities (10-100 million gallons per day capacity); also assume relatively good raw water quality.

4. Assume systems will select precursor removal treatments in this rough order of priority:

   a. Move point of chlorination to further reduce by-products.

   b. Optimize conventional treatment; increase alum dose and decrease pH.

   c. Add GAC or possibly membranes.

5. The parameters and cost ranges discussed by the BAT peer review group are adequate for purposes of rule development.

6. AWWA-RF TTHM occurrence data (McGuire and Meadows, 1988) are currently adequate for a preliminary national economic impact assessment.

B. Conventional Treatment

1. Alum; pH <6, increased alum dose (40-90 mg/L) plus acid for high alkalinity waters.

2. Performance; approximately a 50% removal of TTHM-formation potential.

3. Sludge will increase in volume, but decrease in percent solids. Polyaluminum chloride seems to have a significant advantage in this respect.

4. Based on AWWA-RF data 75% of large systems can currently meet 50 µg/L (note: some use chloramines); this could be increased possibly to 85% if more practiced optimization for precursor removal; about 40% currently could meet a standard of 25 µg/L; unable to estimate how many could obtain this level, if optimization of conventional were practiced.

C. GAC Adsorption -- Precursor Removal

1. Performance based on GAC in a steady-state, precursor removal mode following conventional treatment; this conventional treatment would be either optimized or not depending on the local circumstances; design/operating parameters and cost per ORD field research and BAT peer review group; e.g., 15 min empty bed contact time, 6-month reactivation cycle, concrete, gravity contactors.

2. Performance defined in terms of conventional plus GAC plus chlorination to meet surface water disinfection requirements.

3. Some systems could meet a TTHM MCL of 25 µg/L using this arrangement; others could not do this because the precursor material would break through rapidly, on the order of a week; example of this is Miami, Florida; practical limit on reactivation is in the range of not less than every 3 months with a 15-30 minute empty bed contact time.

4. Costs were considered affordable by large metropolitan systems; with higher costs representing coincidence of high TOC and 25 µg/L and 50 µg/L TTHM MCL.

5. As the TTHM MCL moves from 100 to 50 to 25 µg/L, more systems are likely to install GAC; some systems will not be able to meet lower MCLs even with GAC due to poor adsorption characteristics of their particular precursor material.

D. Membranes -- Nanofiltration with a molecular weight cutoff of approximately 200; basis of discussion is EPA report by Taylor et al.

1. Both ground and surface water sources in central Florida have been studied with 90% removal TTHM-FP and 85% recovery of product water.

2. Limited data; may not be BAT due to lack of field-scale application; policy decision pending, with ORD looking for existing installations; problems could be found with pretreatment of surface water and recovery rates at lower water temperatures.

3. This technology has great potential for complete treatment although at much higher cost than other technologies, but it appears to be emerging.

E. Conclusions regarding precursor removal.

1. Both optimized conventional treatment and GAC adsorption would be considered BAT and capable of up to approximately 50% removal of TTHM-formation potential. MCLs of 50 µg/L or 25 µg/L are achievable using either of these technologies, but especially at lower level many systems will find meeting the new standard very difficult, when free chlorine is the only disinfectant.

2. Analysis would assume that individual water quality conditions would dictate the specific degree of conventional treatment optimization and design parameters for GAC adsorption.

3. GAC adsorption will not be cost-effective for all systems, depending on raw water quality and selected design parameters.

4. Analysis of data needs to be done to determine national level costs versus national level benefits of 50 µg/L versus 25 µg/L TTHMs.

X. DETAILED DISCUSSION OF ALTERNATE OXIDANTS

A. Major options are ozone or chlorine dioxide plus chloramines.

B. Use of alternate oxidants is dependent on:

1. MCLG value for chloramines, since ozone or ClO_2 plus free chlorine does not perform nearly as well.

2. Cost-effective removal of ClO_2 residuals (chlorite and chlorate).

3. No major restrictions on use of ozone as a disinfectant other than microbiological quality concern (assimilable organic carbon, AOC).

4. Possible MCLs for aldehydes, bromate, iodate, ClO_2, ClO_2^-, ClO_3^-, H_2O_2, and total oxidizing substances.

C. Conclusions concerning alternate oxidants.

1. Treatment is feasible, taking cost into consideration for 25 or 50 µg/L of TTHMs.

2. Lower limit of 25 µg/L TTHMs allows continued use of free chlorine, both in chloraminated systems and free chlorine systems (with low TOC).

XI. REMOVAL OF BY-PRODUCTS

A. Aeration needs to be evaluated; likely to be marginal for chloroform and not cost-effective for other DBPs; problem with reformation if free chlorine is used in the distribution system.

B. GAC is not likely to be cost-effective for TTHMs or CAAs or other chlorination by-products; need isotherm/minicolumn data for some; problems with surface reactions, chromatographic effects, dioxin emissions during reactivation, etc.

C. GAC or reducing agents may be cost-effective for MX, chloropicrin, total oxidizing substances, ClO_2, ClO_2^-, H_2O_2; small amounts of GAC required vs. adsorption mode.

D. Ozonated waters may require GAC treatment or other biological processes (e.g., slow sand) for removal of aldehydes, AOC, and possibly other by-products -- this would be a biologically activated carbon or BAC; few data on this; would require new research effort.

E. Reduction techniques and BAC are affordable by large, metropolitan systems.

F. Chlorine dioxide by-products.

1. Scheduled research project to determine if relatively pure chlorine dioxide can be applied to meet required disinfection conditions, then removing residual chlorine dioxide and chlorite using reducing agents; chlorate will be controlled using specific generation techniques and application conditions.

2. If research project is successful, BAT can be specified for meeting low levels of chlorine dioxide and its by-products. Chloramines would be a logical residual disinfectant with free chlorine as the other alternative.

3. The lower cost and decreased complexity of using chlorine dioxide versus ozone to meet by-product standards and disinfection requirements could make it quite attractive. Providing safe water using chlorine dioxide as a primary disinfectant does not seem to be an insurmountable problem.

XII. INTERACTION WITH OTHER RULES

A. Surface Water Treatment Rule.

1. Ct values used to project by-product levels.

2. Turbidity requirement must be met; concern for precursor removal and ozonation prior to filtration.

3. Residual of 0.2 mg/L in surface water distribution. If this is free chlorine, then important in DBP MCL determination.

4. Chloramine may not be universally applicable.

B. Lead.

1. pH >8 will favor THMs, suppress acids and others.

2. For free chlorine higher Ct's are required at higher pH.

3. Organic removal may improve corrosion control.

C. Synthetic organic chemicals.

1. Compatible definition of GAC as BAT.

2. Will biologically activated carbon (BAC) be BAT for ozone by-products?

3. Avoid chlorination prior to GAC.

4. Fate of chlorite/chlorate on GAC.

5. Is GAC the best BAT?

D. Disinfectant MCLs.

1. What is BAT for each, especially chlorine dioxide?

2. Chloramine MCLG may determine chlorination by-products MCLs.

E. Discussion -- Key issue is integrating all these requirements into the final rule.

XIII. SUMMARY

A. Determined that it was feasible to monitor for a limited number of parameters, depending on the disinfectants used at a particular water system.

B. Monitoring may vary from quarterly at four locations to annually at one location, depending on the contaminant and its historic level.

C. Health effects data are still being developed and will be provided when they are available. However, the approach of using a few key parameters as indicators of chemical safety will limit the required number of MCLGs and MCLs.

D. An MCL approach was selected over a treatment technique approach as a more cost-effective and flexible means of regulation.

E. A list of research and analytical needs was developed, which if accomplished will complement the rule proposal.

Table 1. Candidate Disinfectants

Chlorine
- Hypochlorite Ion
- Hypochlorous Acid

Chloramine
- Ammonia

Chlorine Dioxide
- Chlorite
- Chlorate

Table 2. Candidate Chlorination By-Products

Trihalomethanes
- Chloroform
- Bromodichloromethane
- Dibromochloromethane
- Bromoform

Halocacetic Acids
- Monochloroacetic Acid
- Dichloroacetic Acid
- Trichloroacetic Acid
- Monobromoacetic Acid
- Dibromoacetic Acid

Haloacetonitriles
- Trichloroacetonitrile
- Dichloroacetonitrile
- Bromochloracetonitrile
- Dibromoacetonitrile

Haloketones
- 1,1-Dichloropropanone
- 1,1,1-Trichloropropanone

Other
- Chloropicrin
- Chloral Hydrate

Chlorophenols
- 2-Chlorophenol
- 2,4-Dichlorophenol
- 2,4,6-Trichlorophenol

Cyanogen Chloride

MX [3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)furanone]

N-Organochloramines

Table 3. Candidate Ozonation By-Products

ORGANICS (Major Groups)

- Aldehydes (formaldehyde, acetaldehyde, hexanal, and heptanal
- Organic acids
- Ketones
- Epoxides
- Peroxides
- Nitrosamines
- N-Oxy compounds
- Quinones (polyhydroxyphenols)
- Bromine substituted compounds

INORGANICS

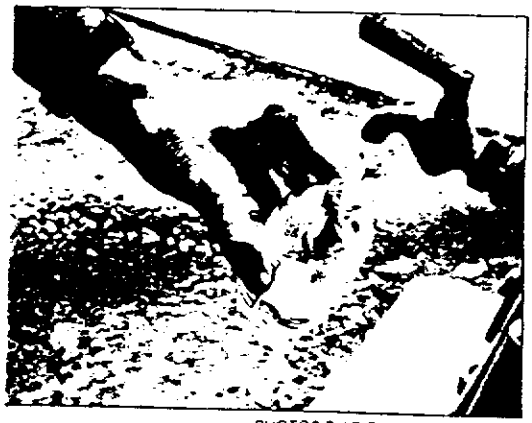
- Hydrogen peroxide
- Bromate
- Iodate
- Chlorate

Table 4. MONITORING REQUIREMENTS

Treatment Process	Monitoring Parameters
Chlorination	TTHMs Haloacetic Acids Total Organic Halides (?) Total Oxidizing Substances (?) Chloropicrin (?) Cyanogen Chloride (?) Total Chlorine Residual
Chloramination	TTHMs (?) Chloropicrin (?) Cyanogen Chloride (?) Total Chloramine Residual (?)
Chlorine Dioxide	Total Oxidizing Substances (?) Chlorine Dioxide Chlorite Chlorate
Ozonation	Formaldehyde (?) Total Oxidizing Substances (?) Bromate (?) Iodate (?) Hydrogen Peroxide (?)

15. Krasner, S.W., M.J. McGuire, J. G. Jacangelo, N.L. Patania, K.M. Reagan and E.M. Aieta, "The Occurrence of Disinfection By-products in US Drinking Water"

For complete copy, see the Journal of the AWWA vol. 81, no. 8, August 1989.



PHOTOS BY RICHARD RAVENSTINE

The Occurrence of Disinfection By-products in US Drinking Water

Stuart W. Krasner, Michael J. McGuire, Joseph G. Jacangelo, Nancy L. Patania, Kevin M. Reagan, and E. Marco Aieta

Data were gathered on the presence of disinfection by-products (DBPs) in drinking water and on the impact of treatment processes on DBP formation and control. Thirty-five water treatment facilities were selected to provide a broad range of source water qualities and treatment processes. Trihalomethanes were the largest class of DBPs detected (on a weight basis) in this study, with haloacetic acids being the next most significant DBP fraction. Formaldehyde and acetaldehyde, by-products of ozonation, were also demonstrated to be produced by chlorination. Cyanogen chloride was found to be preferentially produced in chloraminated water.

The US Environmental Protection Agency (USEPA) will be developing regulations to control disinfection by-products (DBPs) as a result of the 1986 amendments to the Safe Drinking Water Act (SDWA). Under these amendments, the USEPA is required to develop a priority list of chemicals that may be present in drinking water. Included on the list are trihalomethanes (THMs) and other DBPs.[1] If the provisions of the SDWA are to be met by the beginning of 1991, the presence and control of these DBPs must be fully understood. In September 1987, the USEPA's Office of Drinking Water entered into a cooperative agreement with the Association of Metropolitan Water Agencies (AMWA) to perform a study of the occurrence and control of DBPs. The AMWA contracted with the Metropolitan Water District of Southern California (MWD) to provide management services for the project and to perform the DBP analyses. Metropolitan subcontracted with James M. Montgomery Consulting Engineers Inc. to provide engineering services and some analyses for the study. In addition, the State of California Department of Health Services (CDHS), through the California Public Health Foundation (CPHF), contracted with MWD and James M. Montgomery to perform a similar study in California.

The USEPA study included 25 water utilities across the United States, and the CDHS study involved 10 water utilities in California. During the first year of this project, baseline data were gathered on all 35 water utilities. The DBPs under investigation included THMs; haloacetonitriles (HANs); haloketones (HKs); haloacetic acids (HAAs); chloropicrin (CHP); chloral hydrate (CH); cyanogen chloride (CNCl); 2,4,6-trichlorophenol; formaldehyde; and acetaldehyde (Figure 1). This article focuses on some of the significant preliminary findings of these DBP studies.

Experimental procedures

The sampling and analytical procedures utilized in these studies are described in detail elsewhere. Grab samples (Table 1) were collected at clearwell effluents (after final disinfection but prior to distribution). Total organic car-

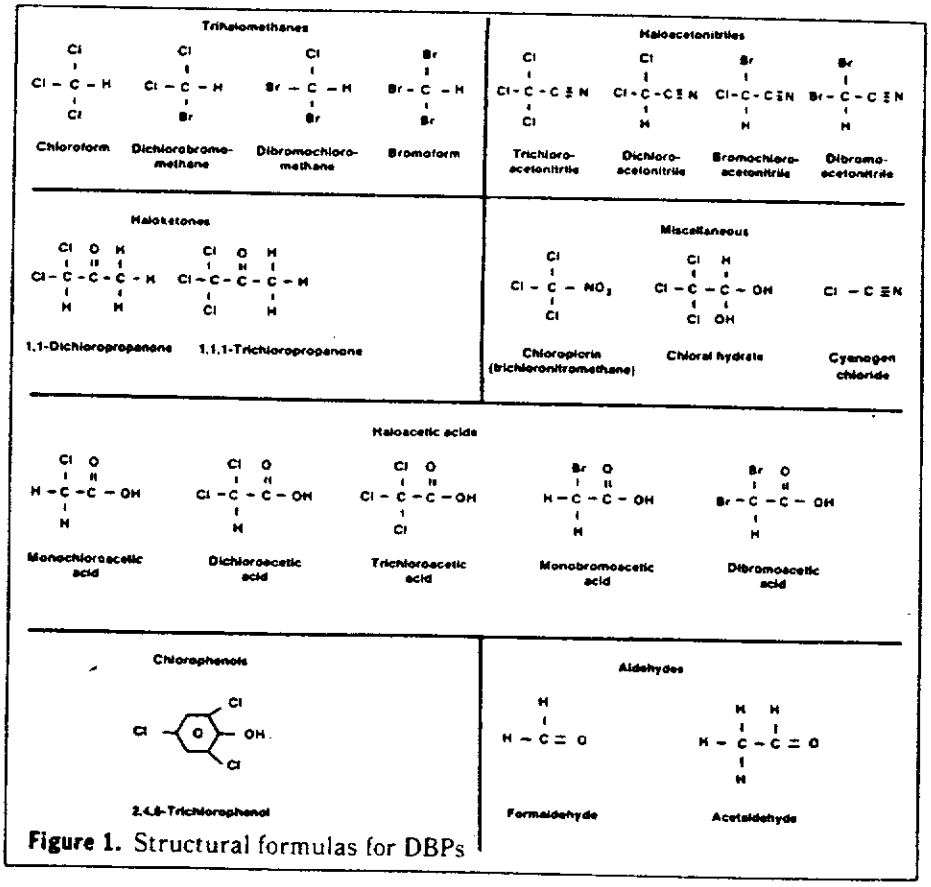


Figure 1. Structural formulas for DBPs

16. McGuire, M.J., M.K. Davis, C.H. Tate, E.M. Aieta, I.E. Wallace, J.C. Crittenden, "Evaluation of Granular Activated Carbon for Trihalomethane Control" Presented at the AWWA Research Foundation/U.S. EPA Conference, May 9-10, 1989, Cincinnati, Ohio.

EVALUATION OF GRANULAR ACTIVATED CARBON FOR TRIHALOMETHANE CONTROL

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INTRODUCTION

Recently enacted amendments to the Safe Drinking Water Act identify granular activated carbon (GAC) as a feasible treatment technique for synthetic organic chemicals [1]. Trihalomethanes (THMs) may be included as compounds for which GAC could be considered a feasible treatment technology. A number of recent actions by the U.S. Environmental Protection Agency (USEPA) virtually guarantee that the maximum contaminant level (MCL) for THMs will be lower in the future. The current drinking water standard for total THMs is 0.10 mg/L (100 µg/L).

On January 22, 1988, the USEPA issued a final priority list of disinfection by-products (DBPs), including THMs [2]. Proposed MCL goals and actual MCLs are expected to be issued in the early 1990s. At the present time, it is not known what these MCLs will be. The USEPA may choose to regulate THMs on an individual basis rather than combined as a total of the four compounds. The MCL could be as low as 5 µg/L and probably not higher than 50 µg/L (for a total of the four THMs). The THM treatment objectives assessed as part of this study were 5, 10, 20, and 50 µg/L; these goals were selected because they spanned the speculated new THM regulations.

The purpose of this paper is to present an overview of the significant findings of a study entitled "Optimization and Economic Evaluation of Granular Activated Carbon for Organic Removal" [3]. The full report and other publications will be referenced throughout this paper and should be consulted for important methodological details.

OBJECTIVES

The primary objectives of this study, which were directed toward the needs of Metropolitan and the water industry as a whole, were as follows:

- Optimization of GAC for meeting lower THM standards
- Estimation of the costs associated with optimized GAC treatment, both for Metropolitan and for six other water utilities across the country
- Identification of DBPs resulting from final disinfection of GAC-treated water with chlorine or chloramines
- Assessment of the ability of a mathematical model and/or bench-scale column test such as the rapid small-scale column test (RSSCT) to simulate total organic carbon (TOC) breakthrough curves from pilot-scale carbon contactors
- Development of helpful information and evaluation techniques which can be used by other utilities in evaluating GAC treatment for their facilities

SCOPE OF WORK

The scope of work for this study involved:

- Operating six post-filtration GAC contactors, with different empty-bed contact times (EBCTs) and GAC mesh sizes, to develop breakthrough profiles for the following parameters:
  - TOC
  - THMs
  - Total organic halogen (TOX) compounds
  - Other DBPs, including trichloroacetic acid (TCAA), dichloroacetic acid (DCAA), and dihaloacetonitriles (DHANs)
  - Simulated-distribution-system (SDS) THMs, TOC compounds, TCAA, DCAA, and DHANs associated with post-chlorination and post-chloramination
- Evaluating the impact of GAC treatment on the microbial quality of the treated water
- Developing cost estimates associated with GAC treatment for SDSTHM treatment goals of 5, 10, 20, and 50 μg/L
- Using mathematical models to simulate the pilot-column TOC breakthrough curves to predict the optimum EBCT

- Using an RSSCT to simulate TOC breakthrough profiles from pilot-scale carbon contactors
- Performing an RSSCT for six other water utilities around the country, measuring both the TOC and SDSTHM breakthrough profiles, so that cost estimates associated with GAC treatment could be prepared for these other utilities

BACKGROUND INFORMATION AND METHODS

Metropolitan's Treatment Facilities

Metropolitan's treatment system, which includes five treatment facilities to be expanded to a capacity of almost 3 billion gallons per day by the year 2000, is one of the largest in the world and supplies a majority of the treated water used in Southern California. The source waters for this system are Colorado River water (CRW) and State project water (SPW). The Robert A. Skinner, Robert B. Diemer, and F. E. Weymouth Filtration Plants can use both sources. The Henry J. Mills Filtration Plant uses only SPW from the East Branch, and the Joseph Jensen Filtration Plant uses only SPW from the West Branch. The process train employed at most of the plants includes pre-disinfection with chlorine, coagulation, flocculation, sedimentation, filtration, pH adjustment with sodium hydroxide, and final disinfection with chloramines. All of these plants are to be expanded within the next 7 to 10 years. Typical water quality characteristics of CRW and SPW are summarized in Table 1.

Pilot Treatment Facility

The pilot treatment facility (Figure 1) is located at Metropolitan's Weymouth plant in La Verne, California. It is a 6 gpm facility, constructed entirely of glass, stainless steel, and TFE/FEP, which is plumbed to receive 100 percent CRW, 100 percent SPW, or any blend of these two waters. The treatment train includes preoxidation (with chlorine dioxide), coagulation/flocculation (using alum and a cationic polymer), sedimentation, dual-media filtration, six GAC columns (operated in parallel), and laboratory-simulated post-chlorination or chloramination. The GAC column EBCTs tested during this study were 7.5 min, 15 min, 30 min, and 60 min. A commercial (12x40 mesh) size GAC (Filtrasorb 400, Calgon Carbon Corp., Pittsburgh, Pa.) was used for pilot-scale studies reported in this paper.

The breakthrough profile data obtained from each of the four carbon EBCTs are primarily representative of CRW. The latter part of the 60-min EBCT breakthrough curve is based on a blend of CRW and SPW. Limited data are presented on TOC and SDSTHM breakthrough curves for column 4, which only received SPW late in the study.

RSSCT Method

The RSSCT is a small-scale replica of a pilot- or full-scale fixed-bed carbon adsorber which is capable of producing breakthrough profiles similar to those from a larger scale

contactor. It uses a much smaller carbon particle size and carbon bed size and requires much less water and time to perform than its larger scale counterpart. As part of this study, RSSCTs were performed to simulate the TOC breakthrough profiles from the 15-, 30-, and 60-min pilot-scale carbon contactors.

The experimental setup and column packing for the RSSCT technique are shown on Figures 2a and 2b. The 12x40 mesh carbon (F400, Calgon) was crushed and sieved to the desired particle size. A previous publication by Crittenden [4] describes the RSSCT method in some detail. Experience gained in this study suggests that the cost to complete one RSSCT test is about 1/10 to 1/100 of the cost of a pilot-scale test depending on the complexity of the pilot study.

Analytical Methods

Table 2 summarizes the analytical methods used during this project [3, 5-7]. Where possible, outside references are listed; however, many of the methods were developed or modified specifically for this project, and these are available in Appendix A of the full report [3].

The SDS technique was used during this study to simulate, in the laboratory, DBP concentrations that would be expected to occur in Metropolitan's distribution system as a result of post-disinfection. The samples were spiked with either 1.0 mg free chlorine/L or 1.5 mg chloramines/L and incubated at 25°C for 5 days. The incubation temperature, 25°C, was selected because it is representative of reasonably high temperatures in Metropolitan's distribution system; the incubation time, 5 days, was selected because it approximates the maximum detention time through Metropolitan's distribution system. The disinfectant doses and the incubation temperature and time used for this SDS technique are specific to Metropolitan's system; these conditions may not be applicable to other utilities' distribution systems. The subscripts "Cl" and "NH" are used to distinguish between samples spiked with chlorine and chloramines, respectively.

METROPOLITAN'S PILOT-PLANT RESULTS

Breakthrough Profiles

The TOC and $SDSTHM_{Cl}$ breakthrough profiles for the different EBCTs tested are shown in Figures 3 and 4. Although breakthrough profiles were developed for other DBPs, those for TOC and $SDSTHM_{Cl}$ are included in this paper because they were the ones that were instrumental in preparing the cost estimates for GAC treatment. TOX breakthrough profiles are discussed later in this section. THMs were observed to be the predominant DBPs formed during post-disinfection. Because THMs predominated, using GAC to control THM concentrations should, at the same time, control the formation of other DBPs. According to the breakthrough profiles presented in Figures 3 and 4 (which represent essentially 100 percent CRW), the regeneration frequencies and effluent TOC concentrations corresponding to the different $SDSTHM_{Cl}$ treatment goals are as follows:

(μg/L)	(mg/L)	Regeneration Frequency for CRW (days) 7.5-min EBCT	15-min EBCT	30-min EBCT	60-min EBCT
5	0.16	0	3.1	10	32
10	0.25	2.8	9	30	56
20	0.44	5.5	19	42	90
50	1.00	13.8	35	83	--

Figure 5 shows, in more detail, the breakthrough of the 5 μg/L non-adsorbable $SDSTHM_{Cl}$ fraction during the first few days of operation for all four EBCTs. While this phenomenon has been noted by other researchers, its importance in meeting very low THM standards should be emphasized. If this phenomenon is confirmed in other GAC studies of precursor removal, it would limit the lower level of a future THM standard to about 10 μg/L.

The GAC in column 4 (EBCT = 15 min) was replaced with virgin carbon four times over the course of the study. As a result, separate breakthrough profiles were obtained from column 4 for 100 percent CRW, 100 percent SPW, and a blend of the two waters. Comparing these curves, shown in Figures 6 and 7, the following observations can be made:

- Very little difference was seen between the TOC breakthrough curves for 100 percent CRW and the CRW/SPW blend.
- The TOC breakthrough for 100 percent SPW occurred at a slightly slower rate than for 100 percent CRW.
- The THM precursor breakthrough was more rapid when treating 100 percent SPW than when treating 100 percent CRW. In other words, at essentially the same TOC concentration, SPW exhibited a higher potential for THM formation than did CRW. This is presumably the result of both SPW's higher bromide concentration and the presence of a different type of precursor than that found in CRW.

The GAC regeneration frequencies corresponding to the treatment of 100 percent SPW were determined to be as follows:

$SDSTHM_{Cl}$ (μg/L)	TOC (mg/L)	Regeneration Frequency for SPW (days) (EBCT = 15 min)
5	0.12	2
10	0.17	10
20	0.27	18
50	0.58	26

THM Formation as a Result of Chlorination Versus Chloramination

Post-disinfection of GAC-treated water with chlorine was shown to produce substantially higher SDSTHM concentrations in comparison with post-disinfection with chloramines.

Comparing the $SDSTHM_{Cl}$ breakthrough curves in Figure 4 and the $SDSTHM_{NH}$ breakthrough curves shown in Figure 8 illustrates this point. Note the very small concentrations--less than 4 μg THMs/L breaking through even the shortest EBCT. However, because of the microbiological concerns in GAC column effluents, it is unlikely that the use of chloramines as a primary disinfectant would be prudent downstream of GAC filters. However, a combination of a short contact time with free chlorine followed by conversion to chloramines could be a workable scenario.

TOC as a Surrogate Parameter for $SDSTHM_{Cl}$

Other researchers [8,9] have evaluated the use of surrogate parameters as indicators of other water quality parameters that are more difficult to measure, and they have shown that TOC can be used successfully as an indicator of THM formation potential. TOC serves as a good indicator of $SDSTHM_{Cl}$ because a significant portion of the organic compounds that constitute TOC are the precursors for the THM compounds. By comparison, the $SDSTHM_{Cl}$ analysis is much more difficult and requires substantially more time to perform than the TOC analysis. In a full-scale application, it would be impractical and very difficult to routinely monitor $SDSTHM_{Cl}$ in order to determine the appropriate time for carbon replacement and/or regeneration. The results of this study, shown in Figure 9, also demonstrate that ultraviolet (UV) absorbance is a suitable surrogate for TOC and therefore for $SDSTHM_{Cl}$. Because UV absorbance can be continuously monitored, it could be used, in a full-scale application, as an operational control parameter for $SDSTHM_{Cl}$ breakthrough.

The results of this study, presented in Figure 10, show that TOC will serve as an excellent indicator of $SDSTHM_{Cl}$ for CRW (provided that there is free-chlorine residual remaining in the SDS sample at the end of the incubation period). For both waters, the relationship between the two parameters is linear and can be described by the following equations (for this study only):

CRW: $SDSTHM_{Cl} = 58.89(TOC) - 2.30$
(valid for $0 \leq TOC \leq 0.75$)
$r^2 = 0.90$

SPW: $SDSTHM_{Cl} = 97.41(TOC) - 6.36$
(valid for $0 \leq TOC \leq 0.70$)
$r^2 = 0.96$

where the $SDSTHM_{Cl}$ and TOC concentrations are in units of μg/L and mg/L, respectively.

It is important to note that this relationship will be different for different waters and must be established for the specific water of interest. Depending on the organic

the season and/or time.

The $SDSTOX_{Cl}$ breakthrough profiles for the four different EBCTs studied are shown in Figure 11. As is readily apparent, these breakthrough curves are not nearly as smooth as the TOC and $SDSTHM_{Cl}$ breakthrough curves. This is presumably because of the inherent variability associated with the TOX analysis. With regard to EBCT, the $SDSTOX_{Cl}$ breakthrough profiles follow the expected trend of increasing time to breakthrough with increasing contact time.

RSSCT AND PILOT-PLANT BREAKTHROUGH PROFILES

The scaling equations used to set up the RSSCT are based on a dimensional analysis of the equations included in the dispersed-flow, pore-surface diffusion model [10], which is used to simulate adsorbate breakthrough from a full-scale contactor. This model allows for similarity between the small- and large-scale breakthrough profiles because it addresses the fundamental mechanisms driving the adsorption process in a fixed-bed system: advective flow, axial dispersion and diffusion, liquid-phase mass transfer resistance, surface diffusion, pore diffusion, adsorption equilibrium, and competitive equilibrium of solutes on the carbon surface. Dimensional analysis of the equations in the computer model results in six independent, dimensionless groups. In order to achieve similarity between the RSSCT and the full-scale adsorber, each of the six dimensionless groups must remain constant as the full-scale adsorber is scaled down. The scaling equations for sizing the RSSCT were obtained by setting the dimensionless groups for the large-scale adsorber equal to those for the small-scale contactor. As has been discussed by Crittenden, et al. [4], equating these dimensionless groups results in three sets of scaling equations, which are dependent upon the functional relationship between the solute (in this case TOC) intraparticle diffusivity (surface and pore diffusivity) and the GAC particle size:

Set 1 - Intraparticle diffusivity is independent of particle size.
Set 2 - Intraparticle diffusivity is a linear function of particle size.
Set 3 - Intraparticle diffusivity is related to particle size, but by some other functionality.

The first step in performing the RSSCTs for this study was to select the appropriate scaling equations to be used in determining the correct mass of GAC and the surface loading rate for the RSSCT. Prior to the RSSCTs, a series of batch rate tests were conducted on both CRW and SPW which indicated that, for both waters, surface diffusivity was a linear function of particle size.

The comparison between the RSSCT-simulated TOC breakthrough profile and the pilot-scale breakthrough profile (100 percent CRW) for the 15-min EBCT contactor is shown in Figure 12. The fit between the two curves (in qualitative terms) is excellent. For the 30- and 60-min EBCT columns (results not shown), the RSSCT and pilot breakthrough curves

track one another at the lower effluent TOC concentrations, but the curves begin to deviate from one another at higher TOC concentrations. The comparison between the RSSCT and pilot-scale curves (EBCT = 15 min) for 100 percent SPW was also good, but not as good as for 100 percent CRW.

To provide a national perspective to the study, six utilities from across the United States were selected to participate in this project. RSSCTs were performed for these six participating water utilities in order to estimate the costs associated with using carbon adsorption as a means of THM precursor control for waters with different qualities. The following utilities agreed to participate in this study and supplied Metropolitan with 60 gallons of water for the test:

- Atlanta Water Bureau
- Cincinnati Water Works
- East Bay Municipal Utility District
- Jefferson Parish Water District
- Palm Beach County Water Utilities
- Philadelphia Water Department

Three of these six utilities--Cincinnati, Jefferson Parish, and Philadelphia--had previously performed pilot-scale GAC adsorption studies. As a means of validating the accuracy of the RSSCT, the TOC breakthrough profiles obtained from those earlier pilot studies were used for comparison with the RSSCT-simulated breakthrough curves.

The RSSCT curves are compared with the pilot-scale curves for Cincinnati, Jefferson Parish, and Philadelphia in Figures 13, 14, and 15, respectively. As shown, good to excellent comparisons were attained for Cincinnati and Jefferson Parish. The Cincinnati pilot-plant TOC data, shown in Figure 13, were taken from a pilot study performed by Cincinnati in the same seasonal time period in which the RSSCT was performed. These pilot data, however, were collected in 1980, whereas the RSSCT data were collected in 1987. The two Philadelphia curves, on the other hand, do not compare well. A satisfactory RSSCT breakthrough curve was developed for Palm Beach, but no pilot data were available for comparison. As a result of the low influent TOC of Atlanta's and East Bay's water, TOC breakthrough profiles could not be developed using the available 60 gallons of water.

Based on the RSSCT/pilot-column comparative results for Metropolitan (for both CRW and SPW) and the six participating utilities, it can be concluded that, for some waters, the RSSCT provides an economical means of estimating pilot- or full-scale breakthrough profiles which can be used in making preliminary assessments of carbon utilization rates and feasibility level cost estimates. However, the limitations of the test are not yet well defined, and for some waters (using Philadelphia as an example) it appears that the comparability of the RSSCT and pilot-scale breakthrough curves may be inadequate.

COST ESTIMATES

Using the TOC breakthrough profiles and TOC/SDSTHM$_{Cl}$ relationships developed for both of Metropolitan's source waters--CRW

associated with implementing post-filtration GAC adsorption treatment were developed in relation to each of the $SDSTHM_{Cl}$ treatment goals (i.e., 5, 10, 20, and 50 $\mu g/L$).

Cost Estimation Methods

Cost equations used in calculating the GAC treatment cost estimates presented in this report are those developed by the USEPA from studies of field-scale systems [11]. More recent, modified versions [12] reflecting a reevaluation of the earlier equations in relation to newly obtained costs from completed field projects were incorporated into the final model. These equations were compiled in a spreadsheet cost model suitable for use on a personal computer. The cost equations include the most current USEPA estimates on all components of a GAC facility for water treatment. Details on these equations are contained in the noted references.

The two primary assumptions made in developing these costs involved the use of (1) gravity-flow concrete contactors for post-filtration GAC adsorption and (2) on-site carbon reactivation using fluidized bed furnaces. Other assumptions made for design and operating variables are listed in Table 3. As noted in the table, each of these values was determined from a different source. Those parameters specified by Metropolitan will change when the equations are applied to other utilities and other locations. Material costs and cost indices will also change in other locations.

Several steps were taken in developing the cost estimates for Metropolitan:

1. Determination of treatment parameters associated with the EBCTs used in the pilot study (i.e., 7.5, 15, 30, and 60 min) under the premise of simultaneous THM precursor breakthrough from all columns and, therefore, regeneration of all contactors at the same time. Simultaneous breakthrough/reactivation is one of the assumptions incorporated into the USEPA cost model [12] and the GAC cost estimates.

2. Using one of two approaches--either (1) mathematical model simulation, using the plug-flow, pore and surface diffusion model, or (2) graphical estimation based on pilot contactor breakthrough curves--calculations were made of regeneration frequencies for several intermediate EBCTs (i.e., EBCTs not tested in the pilot study) at the four $SDSTHM_{Cl}$ treatment goals and of treatment costs associated with each.

3. A plot of total annual cost versus EBCT was made for each of the treatment goals. From this plot, a determination of the optimum EBCT associated with each treatment objective was conducted.

4. For each of the optimum EBCTs determined from step 3 above, the costs of GAC treatment were reevaluated assuming effluent blending and staggered regeneration instead of assuming that all contactors are regenerated at once.

Using these steps, final cost estimates were developed for all of Metropolitan's treatment plants. A comparison between the blended and unblended effluent cases, for an example treatment plant with a capacity of 400 million gallons per day (MGD), is shown in Figure 16. As indicated, a substantial savings is realized for the blended effluent case.

The reason for using a blended case is that it represents a more realistic scenario than assuming regeneration of all contactors at once. In actual operations, regeneration would be on a staggered basis, as is filter backwashing in conventional plants. Since the effluent from all parallel contactors is blended prior to final disinfection, storage, and distribution, control of regeneration should be based on the effluent TOC concentration of the blended plant effluent rather than the effluent concentration from an individual contactor. Under this assumption, the useful life of individual contactors is extended, thus reducing costs.

Cost Estimates for Metropolitan

It has been proposed that Metropolitan's treatment system capacity be expanded to 2,970 MGD by the year 2000. This capacity was used in preparing the GAC treatment cost estimates for Metropolitan's treatment system as a whole. Cost estimates were also evaluated for the individual treatment facilities, as reported in the main body of the final report for this project [3].

Assessment of the optimum EBCTs for the four $SDSTHM_{Cl}$ treatment goals, along with the associated regeneration frequencies for blended effluent, indicated the following:

$SDSTHM_{Cl}$ ($\mu g/L$)	Optimum EBCT (min)	Regeneration Frequency for Blended Effluent (days)
5	60	42
10	30	47
20	15	32
50	7.5	30

The resultant treatment costs (i.e., capital, operation and maintenance, and unit annual costs) for Metropolitan's total system are summarized in Table 4. The unit annual cost is the sum of the annual O&M cost and the annualized capital cost shown on the basis of a unit volume of water (e.g. 1000 gals or 1 acre-foot).

Table 4 illustrates that GAC is an expensive means of THM control in Metropolitan's system. In Southern California, a family of five uses about 1 acre-foot of water per year. Metropolitan currently wholesales untreated water to its member agencies for $197 per acre-foot. A treatment surcharge of $33 per acre-foot is added for wholesale treated water. Table 4 shows that the treatment surcharge would

have to be increased by an amount ranging from 290 to 14,500 percent, depending on the target THM MCL. Overall, the annual cost of water to a typical family in Southern California would increase by 40-210 percent.

Cost Estimates for Participating Utilities

A major objective of this study was to prepare cost estimates for the six participating utilities. Because only one RSSCT was performed for each utility, simulating a full-scale contactor EBCT of 15 min, the optimum EBCTs related to the different treatment goals could not be determined. However, in all cases, effluent blending was evaluated. Because inadequate breakthrough curves resulted for Atlanta and the East Bay Municipal Utility District, cost estimates could not be calculated for these two utilities. The resultant capital and unit annual costs developed for the remaining four utilities are summarized in Table 5. The cost data in Table 5 also show that GAC would be an expensive means of meeting low THM standards. Palm Beach County, with its relatively high TOC levels, would be a particularly expensive place to control THMs with GAC.

These results confirm several of the findings published in a recent compilation of USEPA-funded GAC research that took place in the late 1970s and early 1980s [13]. While these studies were not designed to capture early TOC/$SDSTHM_{Cl}$ breakthrough, and their results were somewhat confounded by chlorination of the GAC filter influents, similarly high GAC treatment costs were determined to control THMs to levels of 10, 25, and 50 $\mu g/L$. Cincinnati was not representative of the other utilities, and the cost developed in that study--0.149/1000 gallons to meet a THM standard of 25 $\mu g/L$--can be compared to a cost of $0.30/1000 gallons to meet a 20 $\mu g/L$ standard in this study.

SUMMARY AND CONCLUSIONS

The principal conclusions that can be drawn from the data presented in this report are listed below.

TOC/$SDSTHM_{Cl}$ Breakthrough Curves

- CRW and SPW exhibited nonadsorbable TOC fractions of approximately 0.2 and 0.1 mg/L, respectively. These nonadsorbable TOC concentrations corresponded to $SDSTHM_{Cl}$ concentrations of approximately 5 $\mu g/L$ for both waters. Because the lowest achievable THM concentration is fixed by the $SDSTHM_{Cl}$ potential of the nonadsorbable TOC, this in turn fixes the lowest THM level achievable. Allowing for some variability in influent conditions, the lowest allowable THM concentration in a GAC plant effluent would be about 10 $\mu g/L$.

- The $SDSTHM_{Cl}$ technique proved to be an excellent means of simulating THM formation in the distribution system.

- TOC served as a suitable surrogate for $SDSTHM_{Cl}$ for both CRW and SPW; however, the relationship between

$SDSTHM_{Cl}$ and TOC was different for the two sources. UV absorbance was an excellent surrogate for predicting TOC breakthrough.

Cost Estimates

- GAC adsorption is an expensive means of THM control. If Metropolitan were to implement GAC adsorption as a unit process for THM precursor removal, the capital costs would range from $730 to $3900 million (based on a capacity of 2,970 MGD), depending on whether the upcoming regulations are set at 50 μg/L or 5 μg/L.

- Based on the RSSCTs performed for the participating utilities, the cost of implementing GAC adsorption would range from $0.30/1000 gallons to $3.06/1000 gallons for a $SDSTHM_{Cl}$ treatment goal of 20 μg/L. The cost would range from $3.38/1000 gallons to $19.06/1000 gallons for a goal of 5 μg/L. For an $SDSTHM_{Cl}$ treatment goal of 50 μg/L, cost estimates could only be developed for Palm Beach County, for which the implementation cost was estimated to be $2.21/1000 gallons.

- Optimizing the GAC cost model to include effluent blending is a much more realistic approach to developing cost estimates than assuming simultaneous GAC regeneration for all columns.

DBPs

- The THMs are the predominant DBPs formed during post-disinfection of GAC effluents with chlorine or chloramines. Control of the THM concentration by GAC should, at the same time, control the concentration of other DBPs in the distribution system. Breakthrough profiles for $SDSTOX_{Cl}$ appeared to track breakthrough of $SDSTHM_{Cl}$ and thus support the use of THM control by GAC as an indication of the control of other DBPs.

- Substantially higher SDSTHM concentrations were formed during post-chlorination than during post-chloramination.

RSSCTs

- The RSSCT was shown to be an economical means of estimating pilot-scale TOC breakthrough profiles, which can be used in making preliminary assessments of carbon utilization rates and feasibility level cost estimates.

- If the RSSCT is used in lieu of pilot-scale adsorption tests, the user should understand that the limitations of the test have not yet been clearly defined. However, two limitations are now known:

  - An RSSCT is performed over a short period of time, and, by comparison, a pilot study requires much more time. Therefore, if the influent adsorbate concentration is not relatively constant, the RSSCT

may not be able to produce a breakthrough profile that would be comparable to a pilot-scale profile.

- Selection of the appropriate scaling equations to use in sizing the RSSCT is dependent upon the functional relationship between surface diffusivity and GAC particle size. Therefore, it is strongly recommended that this relationship be evaluated prior to performing the RSSCT.

o If a pilot-scale evaluation is not an option, the RSSCT is a much more appropriate means of developing cost estimates than using either isotherm data or no adsorption at all.

ACKNOWLEDGMENTS

The authors are grateful to the American Water Works Association Research Foundation for its support and direction in this study and to the members of the Project Advisory Committee for their thorough review of the project report. The authors also wish to acknowledge and thank the six participating water utilities for their assistance in the RSSCT phase of this project.

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TABLE 1

Typical water quality of CRW and SPW during Metropolitan's GAC pilot studies

Source Water	Water Quality Parameter	Concentrations Measured During Study		
		Mean	Max.	Min.
CRW	Temperature	12.5°C	15.0°C	11.5°C
	Turbidity	1.6 NTU		
	Conductivity	805 μmho	854 μmho	400 μmho
	Bromide	0.06 mg/L	0.12 mg/L	0.05 mg/L
	Total alkalinity	129 mg/L as $CaCO_3$		
	TOC	2.64 mg/L	2.97 mg/L	2.31 mg/L
	TOX	25 g/L	49 g/L	12 g/L
SPW	Temperature	24.0°C	25.0°C	22.5°C
	Turbidity	2.3 NTU		
	Conductivity	474 μmho/cm	522 μmho/cm	452 μmho/cm
	Bromide	0.17 mg/L	0.19 mg/L	0.14 mg/L
	Total alkalinity	76 mg/L as $CaCO_3$		
	TOC	2.52 mg/L	2.82 mg/L	2.27 mg/L
	TOX	19 μg/L	29 μg/L	12 μg/L

TABLE 2

Analytical methods used in the AWWARF GAC project

Parameter	Method	Reference
THMs	LLE/GC/ECD; USEPA Method 501.2	[3], p. A-9
DCAA/TCAA	LLE (Derivatization)/GC/ECD	[3], p. A-17
DHANs	LLE (salt)/GC/ECD	[3], p. A-30
SDS	1.0 mg/L Cl_2/1.5 mg/L chloramines, pH = 8.2, 5 days, 25°C	[3], P. A-49 [5];
TOX	SW 846 Method 9020	[3], p. A-57 [6], p. 309;
Free/combined Chlorine	DPD Method, DR1/A Colorimeter	[3], p. A-8 [7];
Chlorine dioxide, Chlorite, chlorate	Amperometeric titration	[3], p. A-8 [6], p. 511,
TOC	Persulfate-ultraviolet oxidation	[3], p. A-8
Bromide	Ion chromatography	[3], p. A-7
UV absorbance	Measured at 250 nm, Lambda 5 Perkin Elmer UV spectrophotometer	[3], p. A-9
pH, turbidity, specific conductance	Standard Methods	[6]; [3], p. A-7

TABLE 3

Basic Cost Model Input Data

	Criteria Category	Value
*	Filter bed depth	10 ft
*	Filter surface area	1,500 sq ft
+	GAC loss rate	11 percent
*	GAC cost	$1.10/lb
*	GAC bulk density	26 lb/cu ft
+	Fluid bed reactivator capacity	50,000 lb/day
#	Utility water rate	$0.71/1000 gal
+	Reactivation water use	21 gal/lb GAC
+	Reactivator uptime	75 percent
+	On-site GAC transport labor	0.4 hr/1000 lb GAC
+	On-site GAC transport water use	2 gal/lb GAC
#	Electricity cost	$0.075/kwh
#	Labor cost	$30/hr
*	Diesel fuel cost	$0.90/gal
§	Construction cost index	5448
§	Producer's price index	297.6
#	Engineering/administration	18 percent
#	Contractor's overhead and profit	12 percent
#	Contingencies	15 percent
#	Interest rate	8 percent
#	Amortization period	20 years
*	Cost adjustment factor (yard piping, 10%; low lift pumping, 8%; other site items, 8%; residuals handling, 4%)	1.3
#	Average/design capacity factor	54 percent

* Assumed design values.
\+ Design/operating values specified by cost model developers.
\# Parameters specified by Metropolitan.
§ Published indices.

TABLE 4

Total Metropolitan system cost estimates
(total capacity, 2970 MGD)

Cost Category	SDSTHM (μg/L)/TOC (mg/L)*			
	5/0.16	10/0.25	20/0.44	50/1.0
Capital ($ million)	3,900	1,980	1,300	730
O&M ($ million/yr)	430	200	140	76
Unit annual‡ ($/1000 gallons)	1.46	0.68	0.47	0.29
Unit annual‡ ($/acre-foot)	480	220	150	95

* SDSTHM/TOC relationship is extrapolated from experimental data for TOC concentrations >0.75 mg/L.

‡ Includes annual amortized capital and O&M costs.

TABLE 5

Cost summary table for other utilities

Capital Costs
($million)

Utility	SDSTHM (μg/L)			
	5	10	20	50
Cincinnati (235 MGD[a])	689	149	74	---*
Jefferson Parish (70 MGD)	482	184	33	---*
Palm Beach Co. (16 MGD)	148	42	31	26
Philadelphia (320 MGD)	634	152	---*	---*

[a] plant capacity = 235 MGD; GAC capacity = 175 MGD

Unit Annual Costs
(includes annual amortized capital and O&M costs)
($/1000 gallons)

Utility	SDSTHM (μg/L)			
	5	10	20	50
Cincinnati	5.34	0.93	0.30	---*
Jefferson Parish	13.40	4.82	0.52	---*
Palm Beach County	19.06	4.42	3.06	2.21
Philadelphia	3.38	0.58	---*	---*

* No value reported because breakthrough was not reached during the RSSCT test for this SDSTHM.

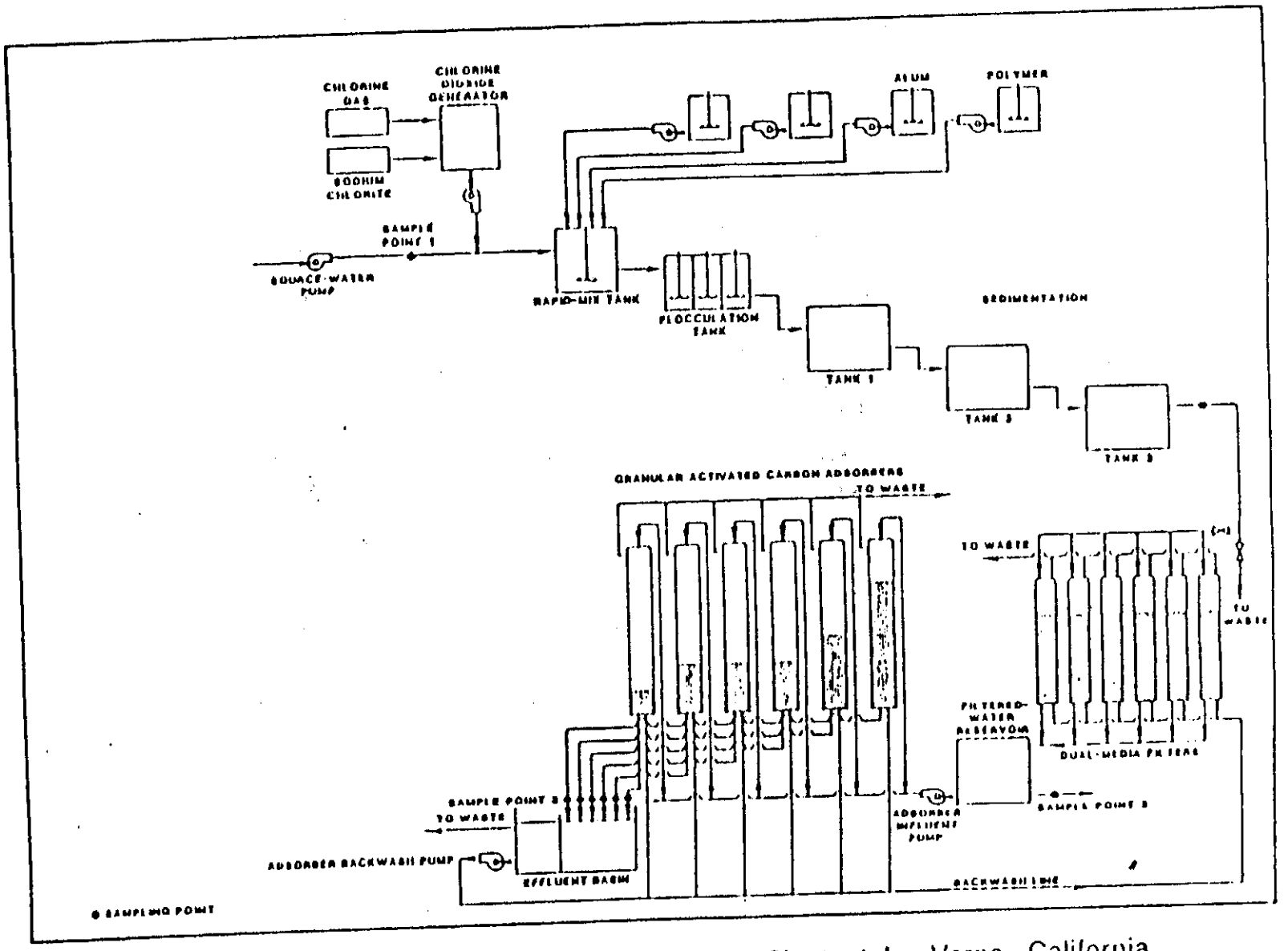

Figure 1 Metropolitan Water District Pilot Plant at La Verne, California

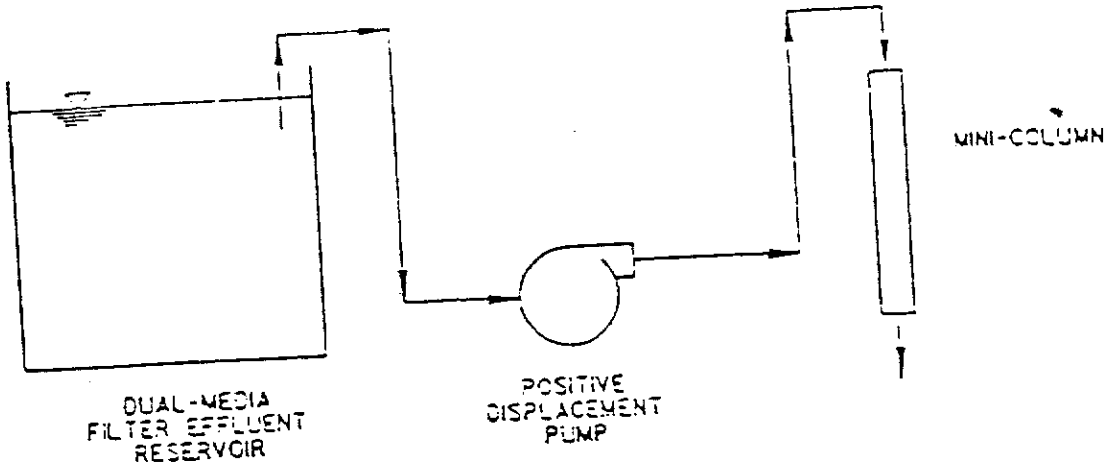

Figure 2a Setup for Rapid Small Scale Column Test

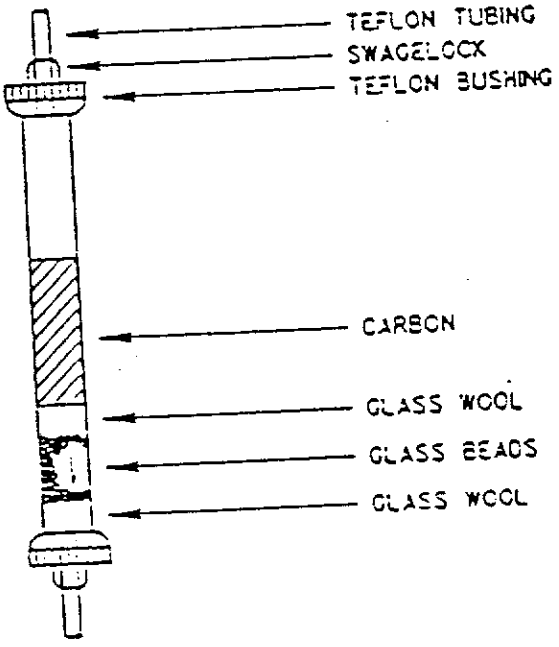

Figure 2b Packing for RSSCT Mini-Column

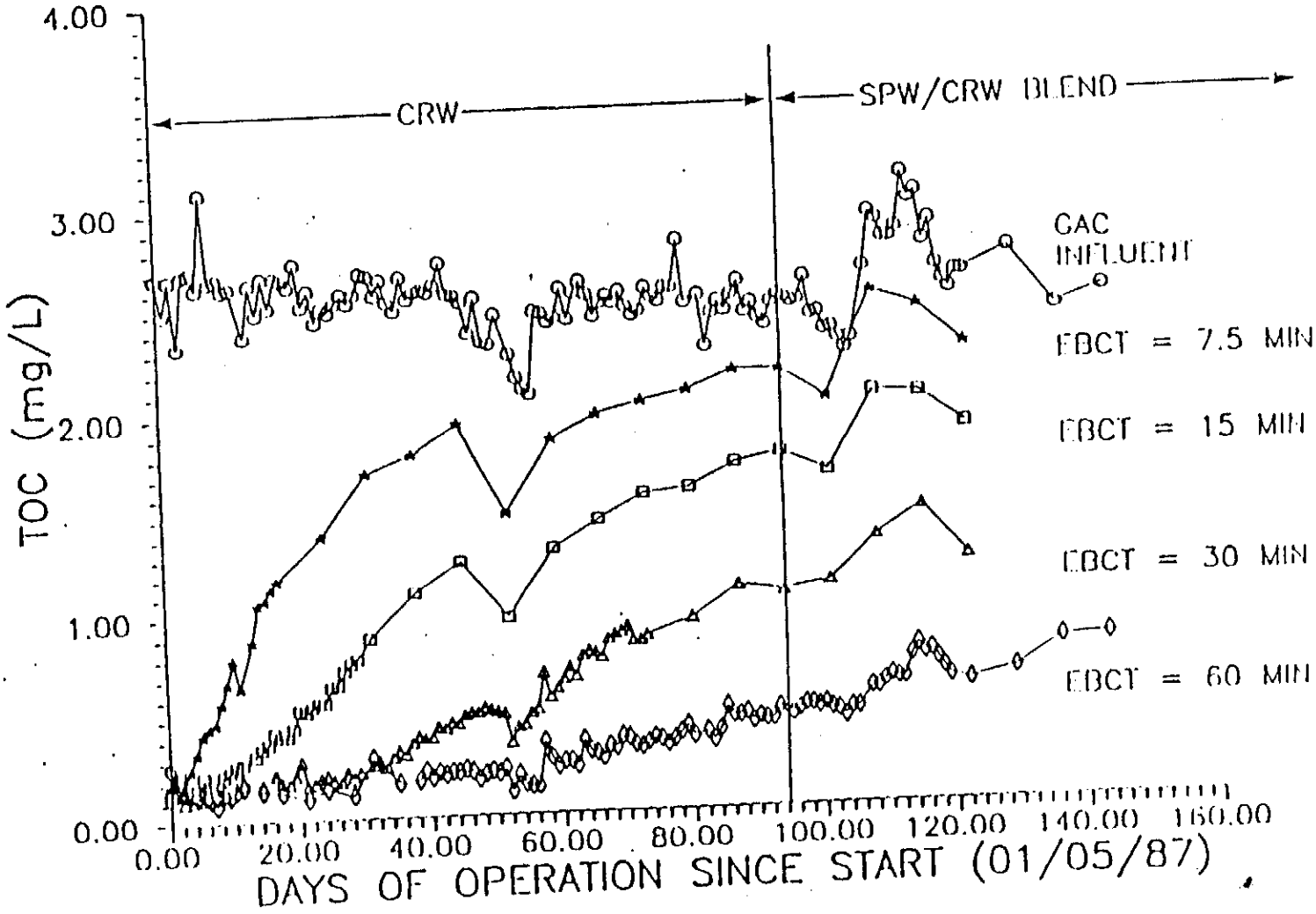

Figure 3 GAC Column Influent TOC Concentrations and TOC Breakthrough Profiles for Columns 1,2,5, and 6

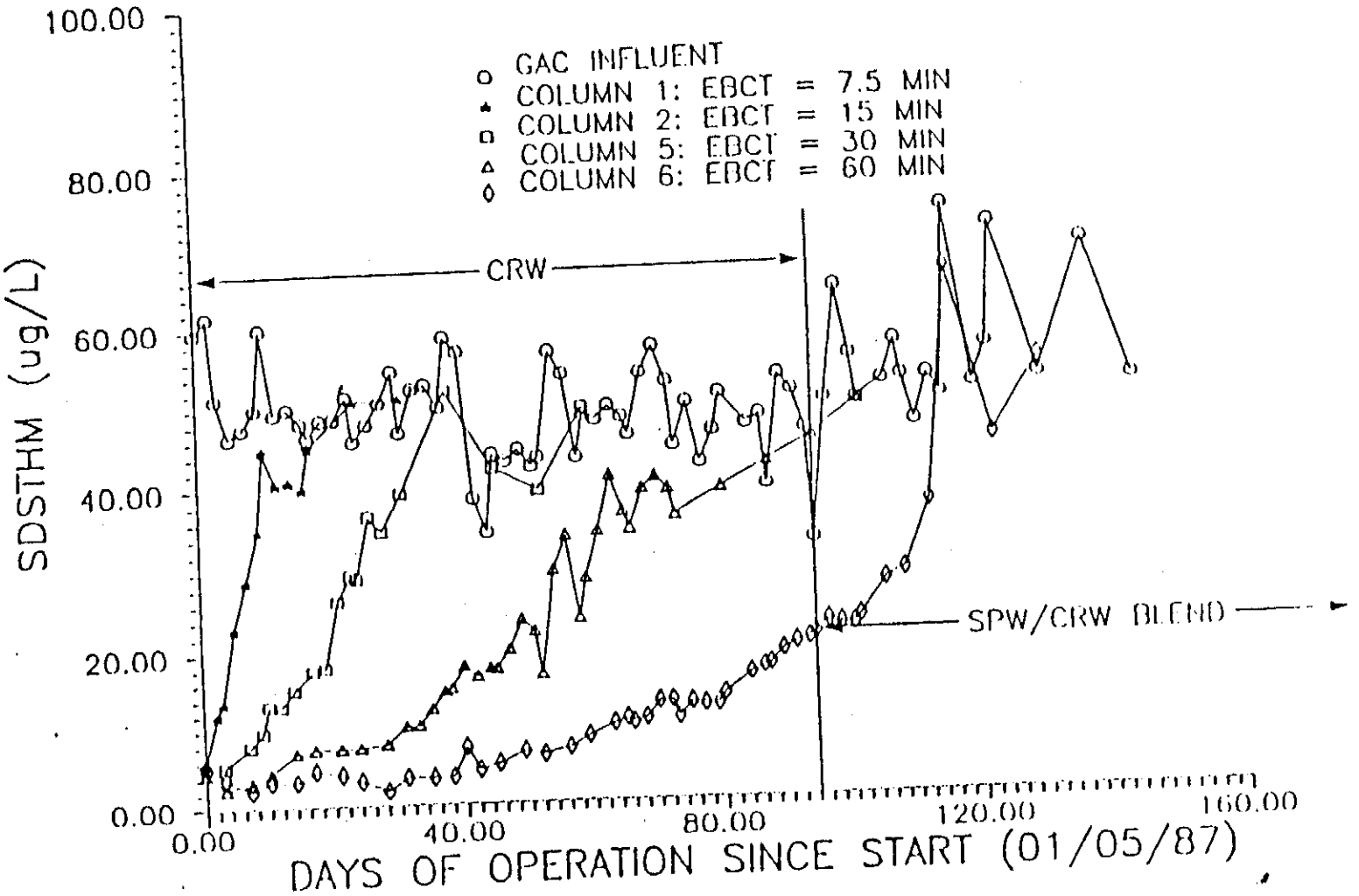

Figure 4 GAC Column Influent SDSTHM$_a$ Concentrations and SDSTHM$_a$ Breakthrough Profiles for GAC Columns 1,2,5 and 6

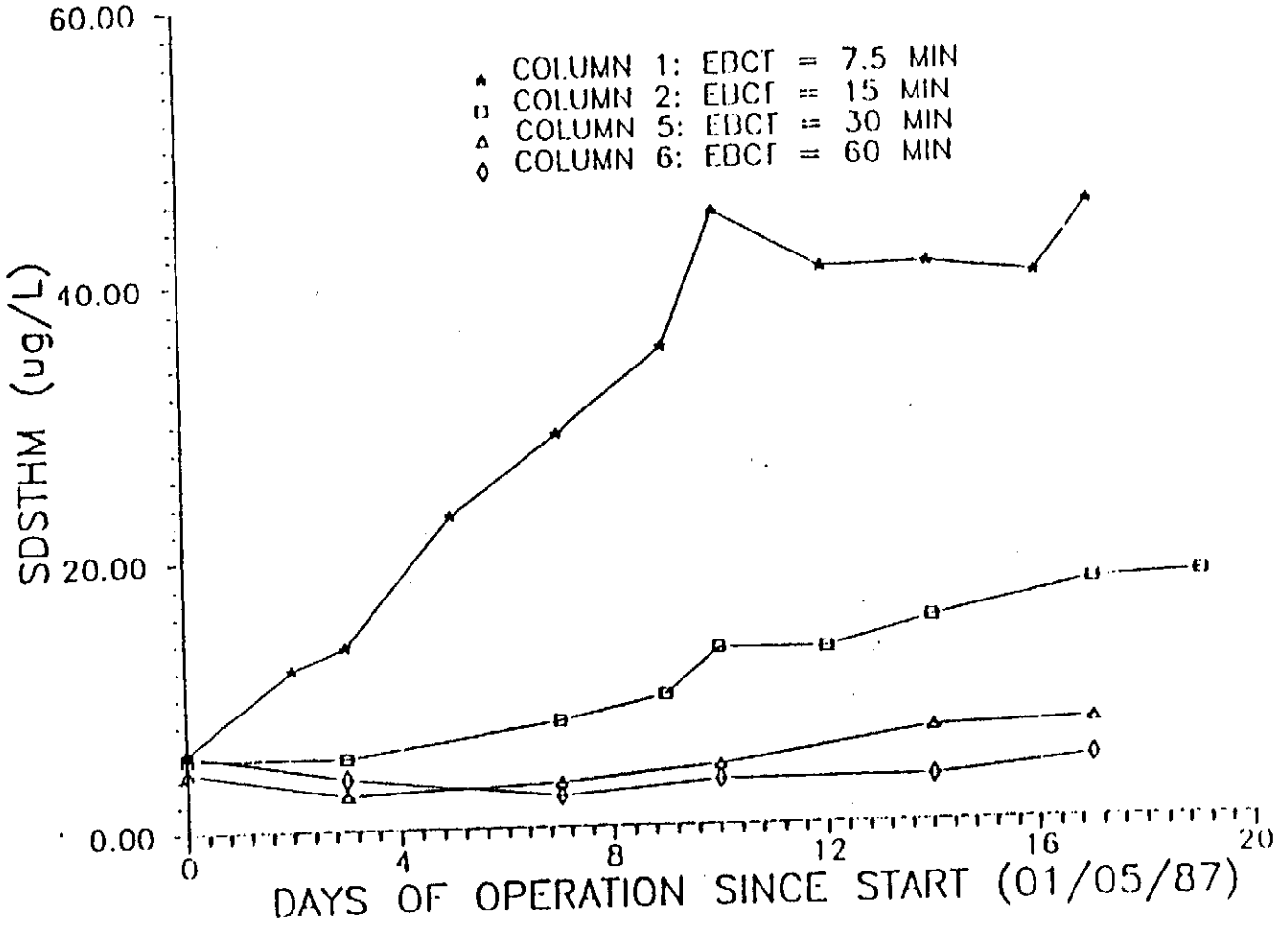

Figure 5 GAC Column Influent $SDSTHM_0$ Concentrations and $SDSTHM_t$ Breakthrough Profiles for GAC Columns 1,2,5 and 6. (First 20 days of Column Operation.)

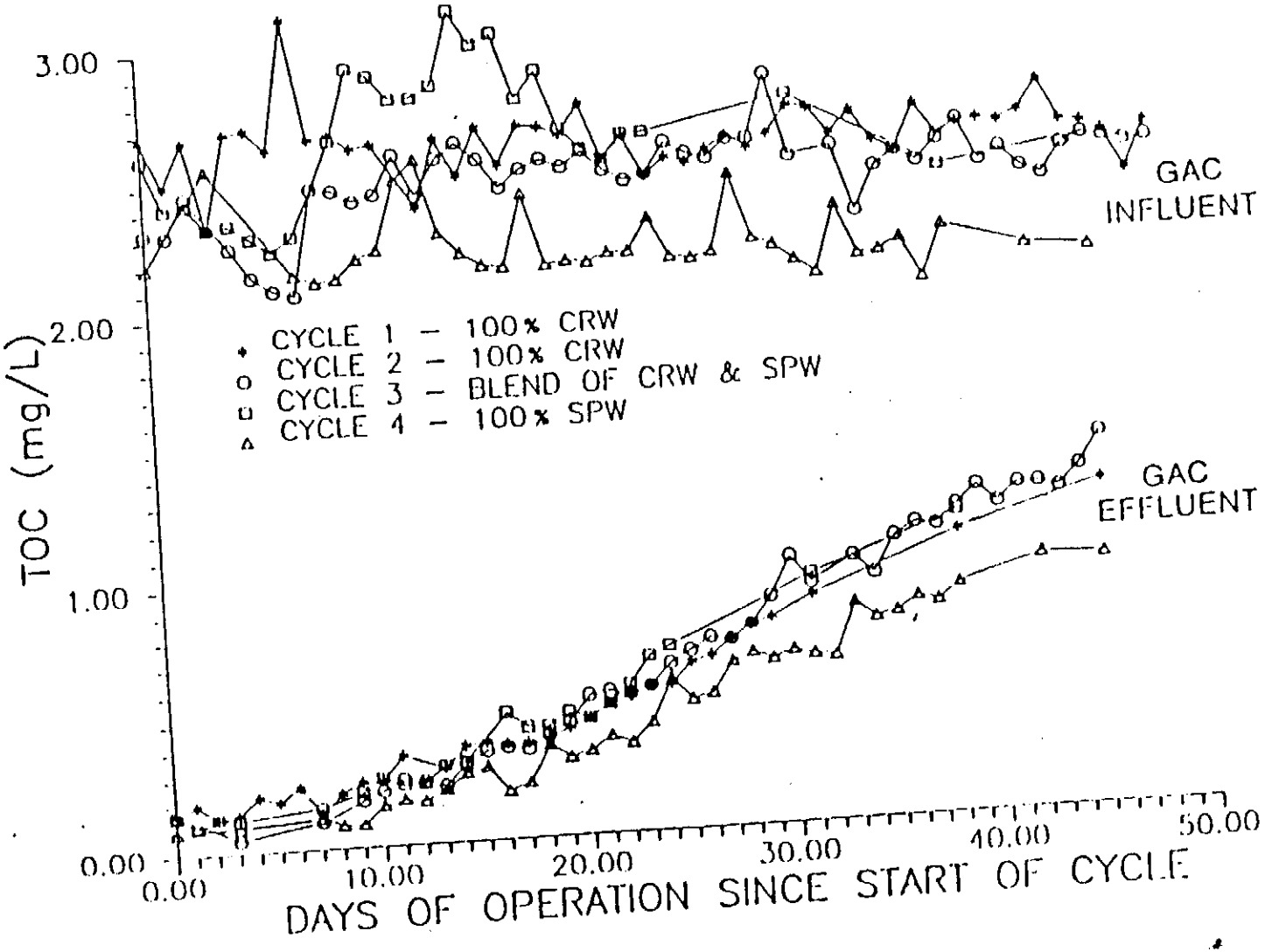

Figure 6 TOC vs. Time for Column #4 - Cycles 1,2,3,4

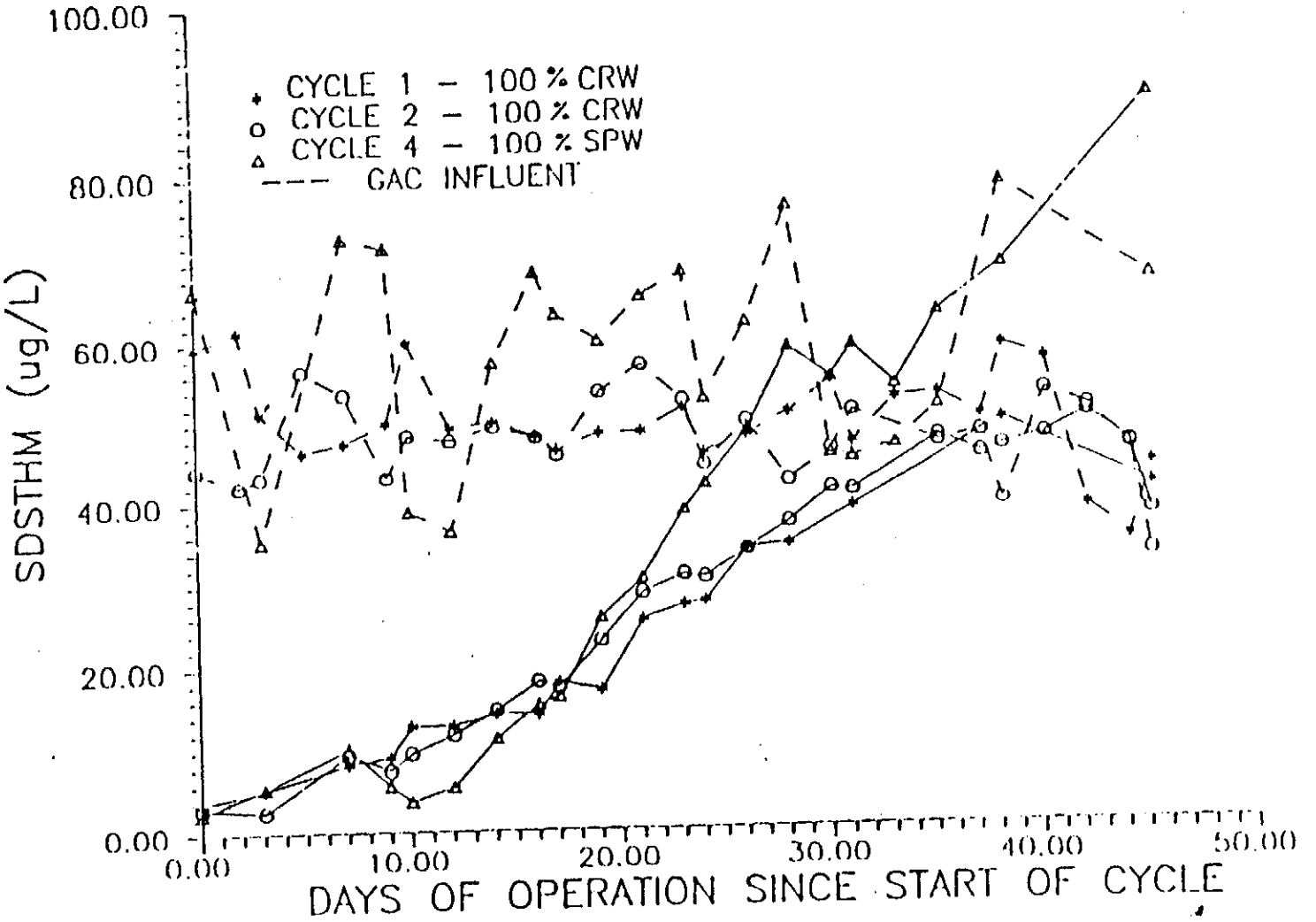

Figure 7 SDSTHM$_a$ Breakthrough Profiles for GAC Column 4 - Cycles 1,2 and 4

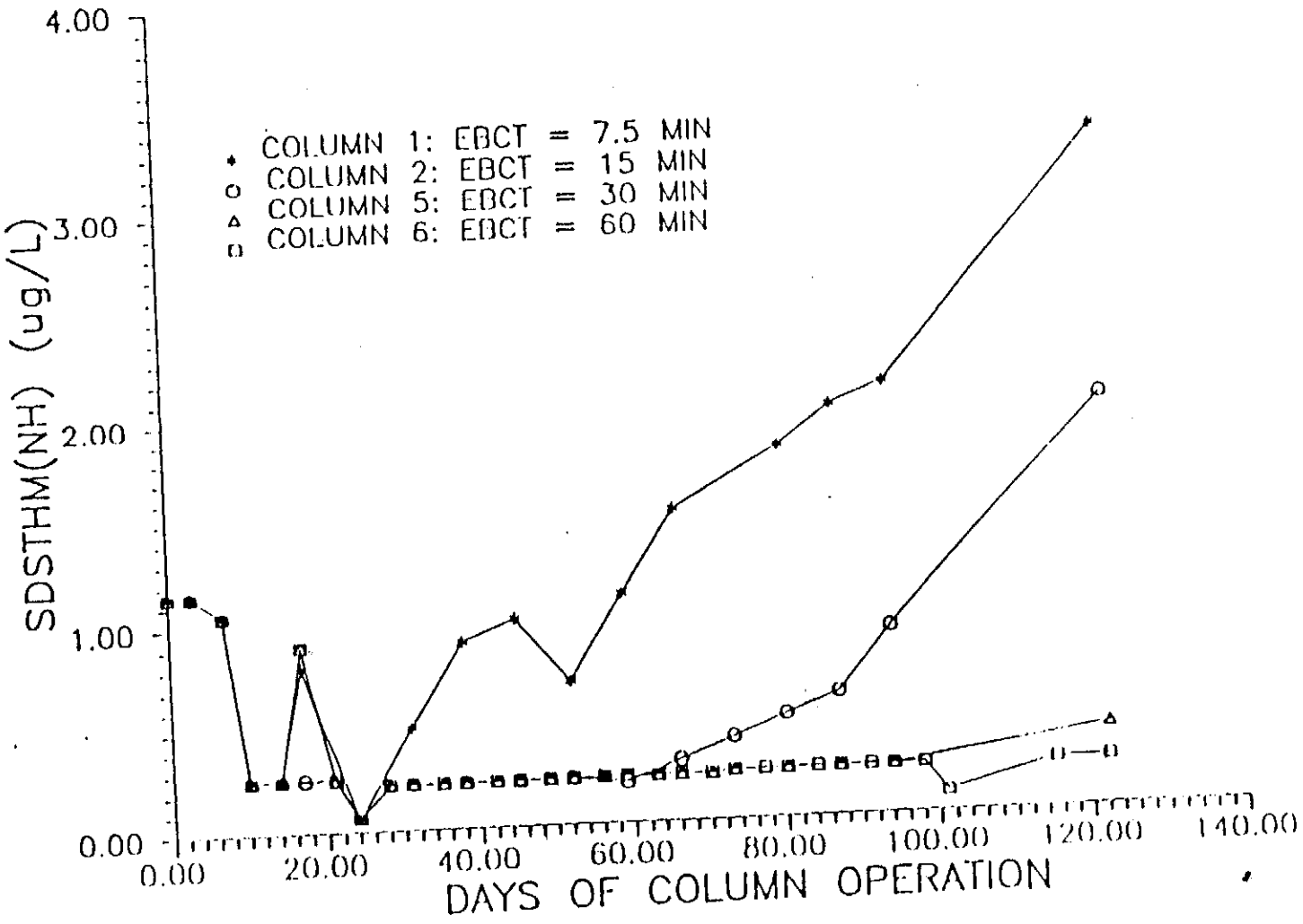

Figure 8 SDSTHM$_{NH}$ Breakthrough Profiles for GAC Columns 1,2,5 and 6

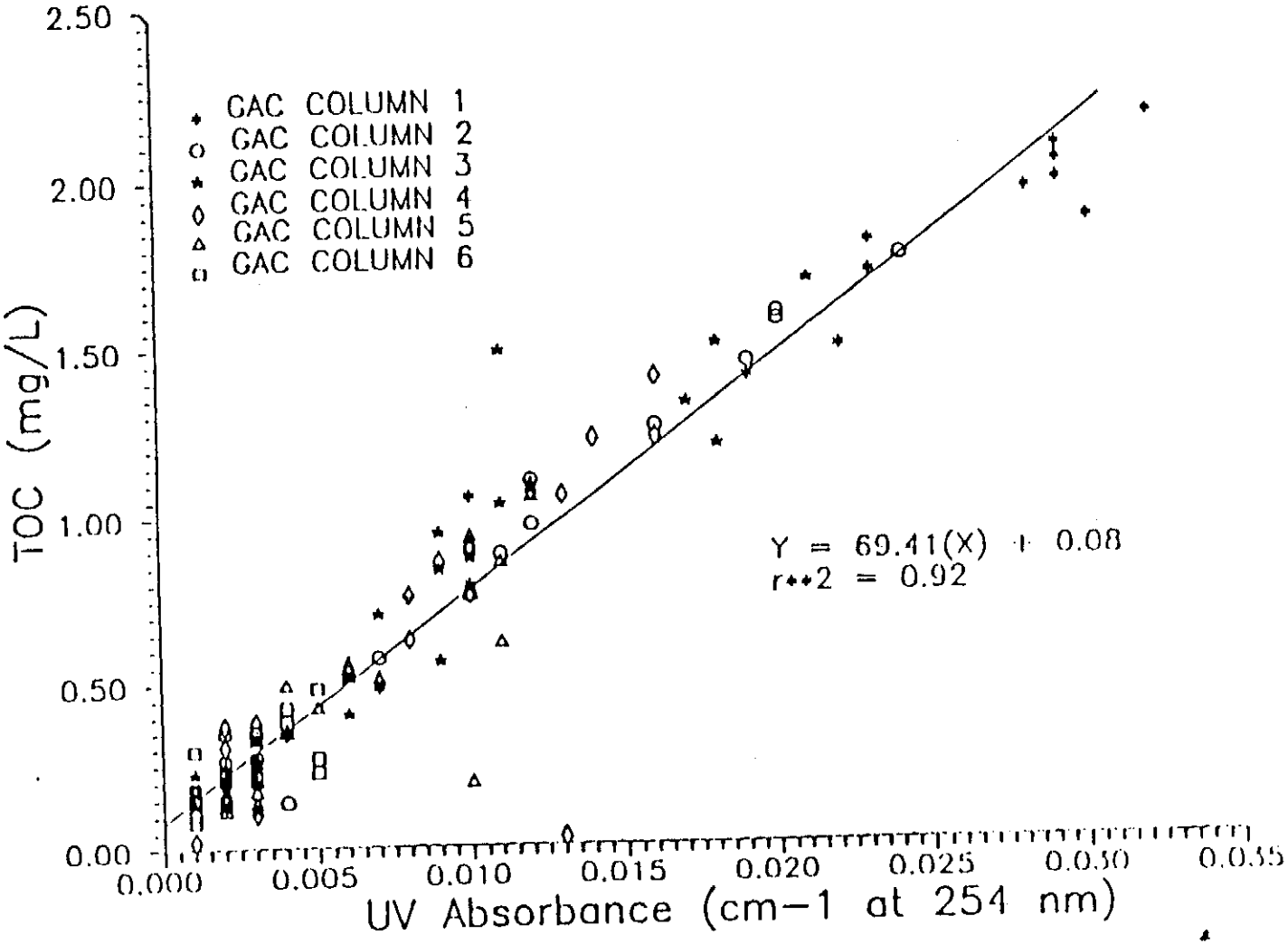

Figure 9 Linear Relationship Between TOC and UV-Absorbance (100% CNW; Carbon Columns 1,2,3,4,5 and 6)

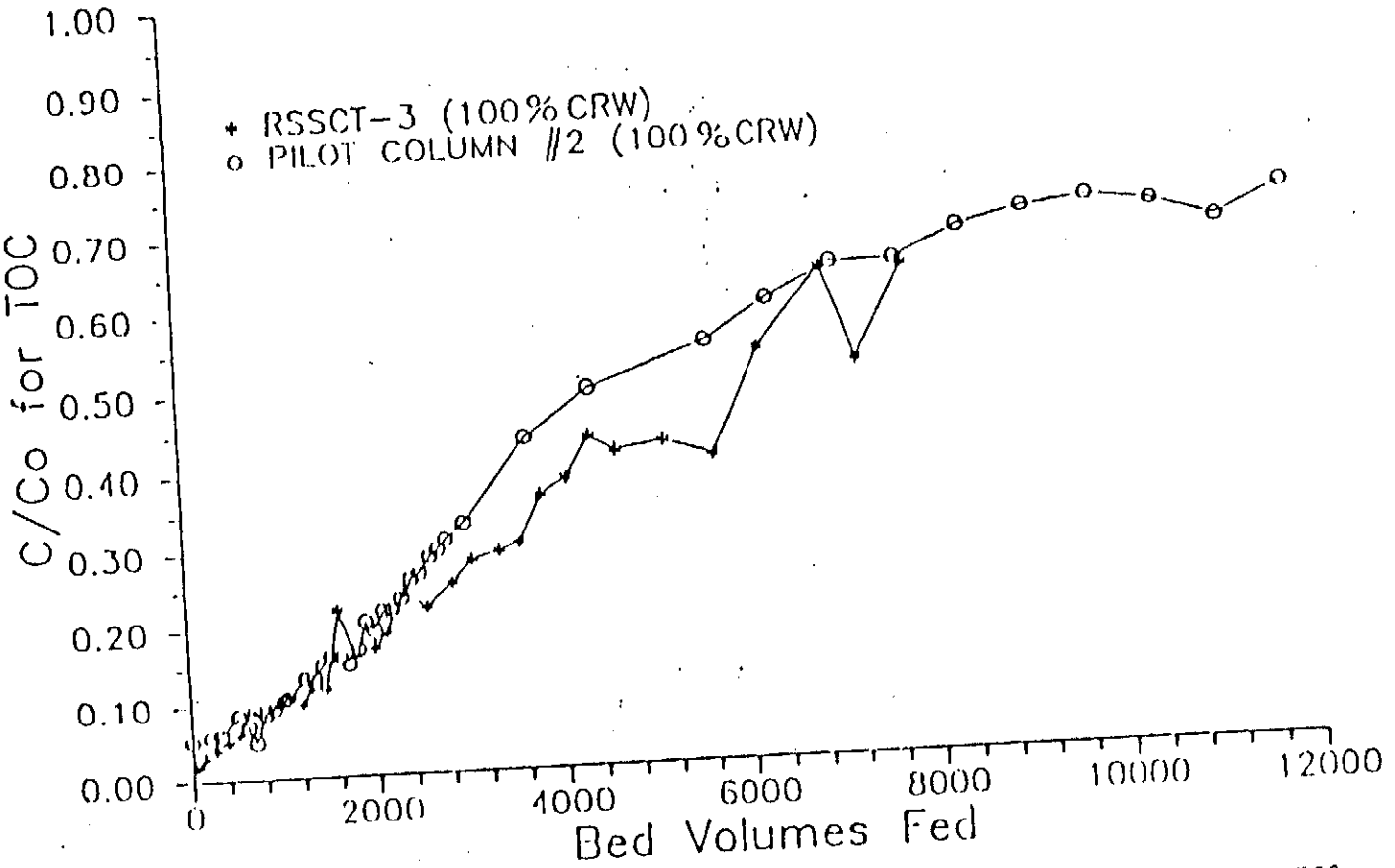

FIGURE 12 COMPARISON OF THE TOC BREAKTHROUGH PROFILE FROM RSSCT-3 WITH THE TOC BREAKTHROUGH PROFILE FROM PILOT GAC CONTACTOR #2. THE SETUP FOR RSSCT-3 ASSUMED INTRAPARTICLE DIFFUSIVITY TO BE A LINEAR FUNCTION OF GAC PARTICLE SIZES.

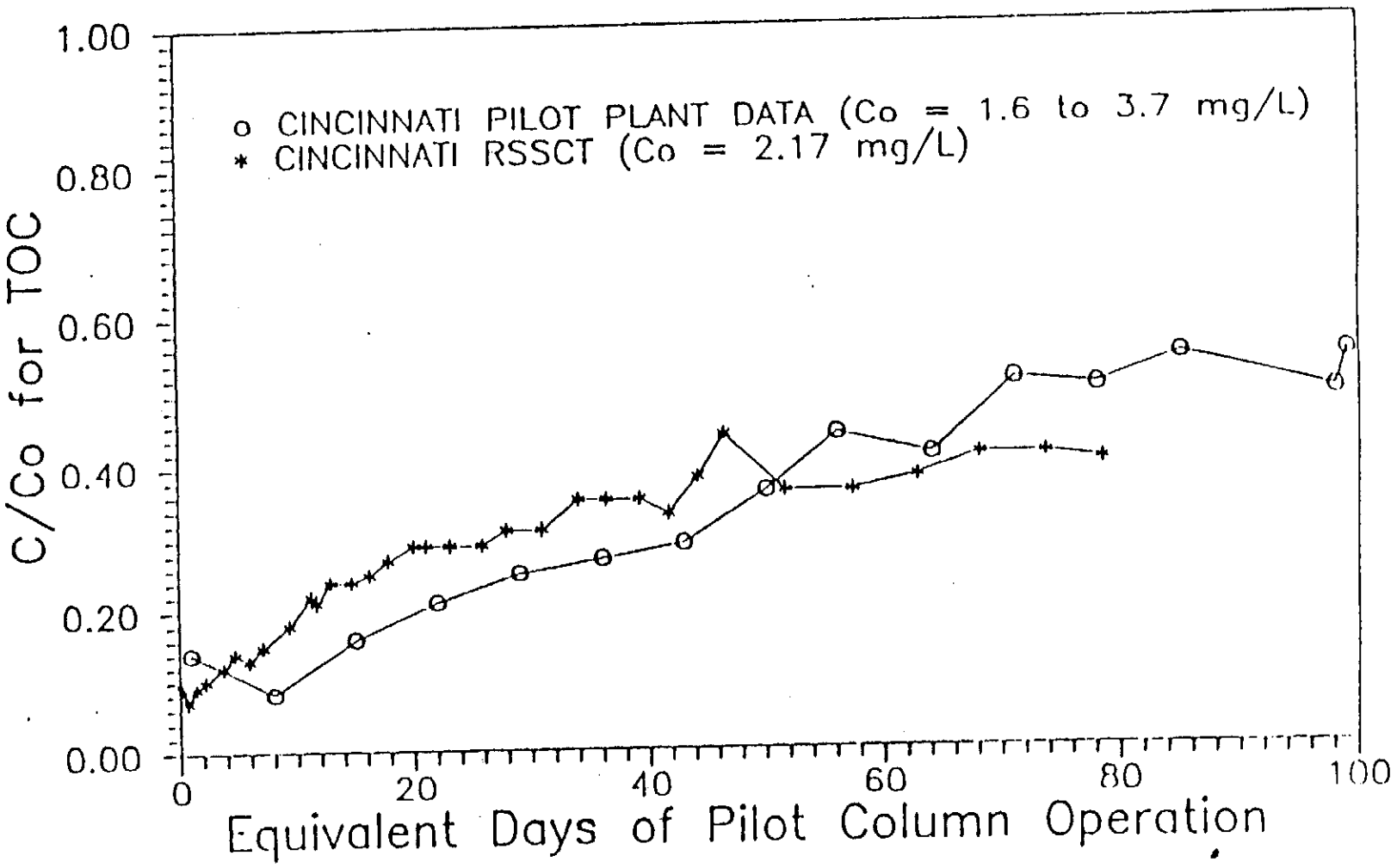

Figure 13 Cincinnati RSSCT vs. Cincinnati Pilot Plant TOC Breakthrough Profiles (EBCT = 15 min).

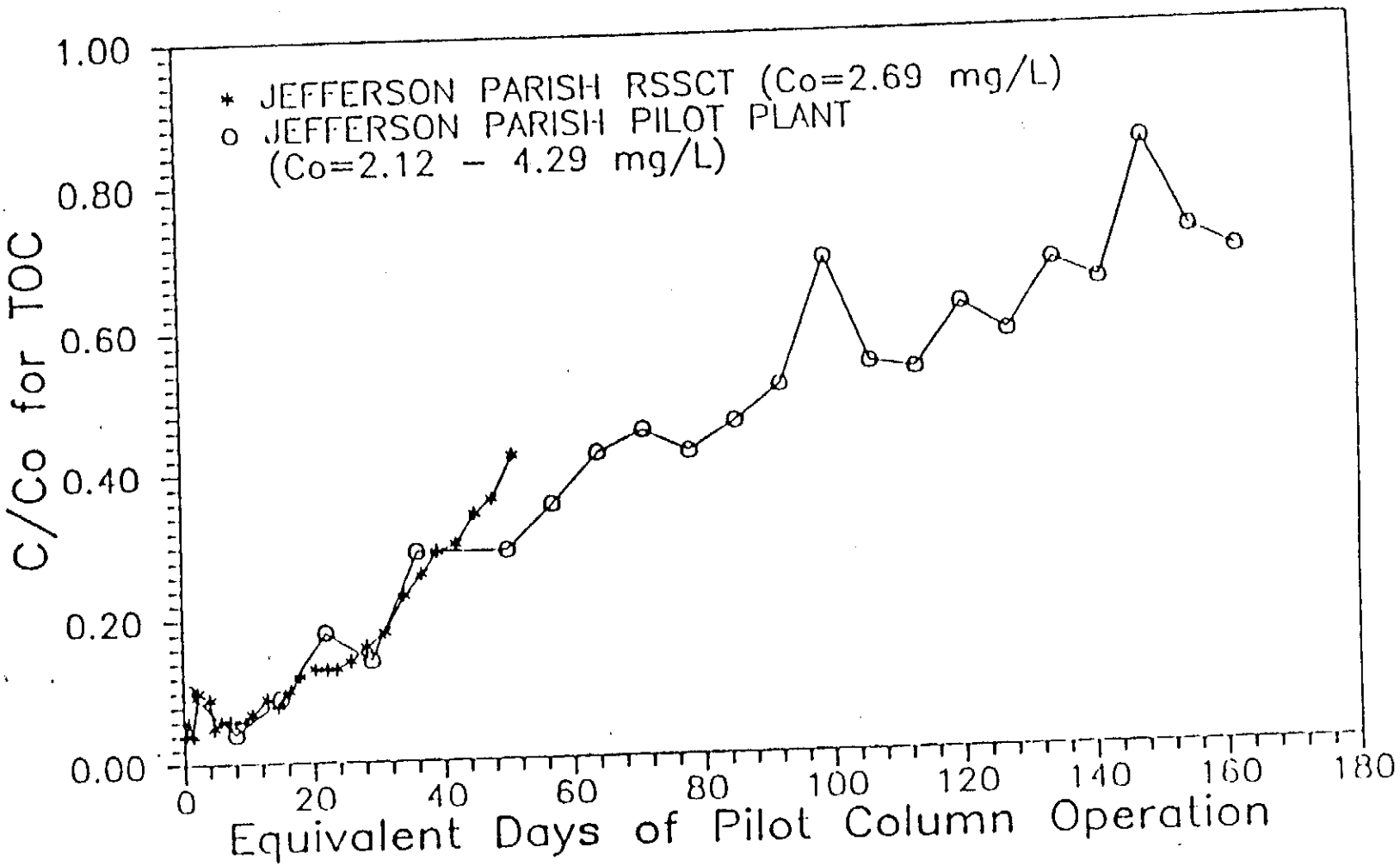

Figure 14 Comparison of RSSCT and Pilot Plant TOC Breakthrough Profiles for Jefferson Parish Water District (RSSCT EBCT = 15 min; Pilot EBCT = 20 min; Pilot Run #3).

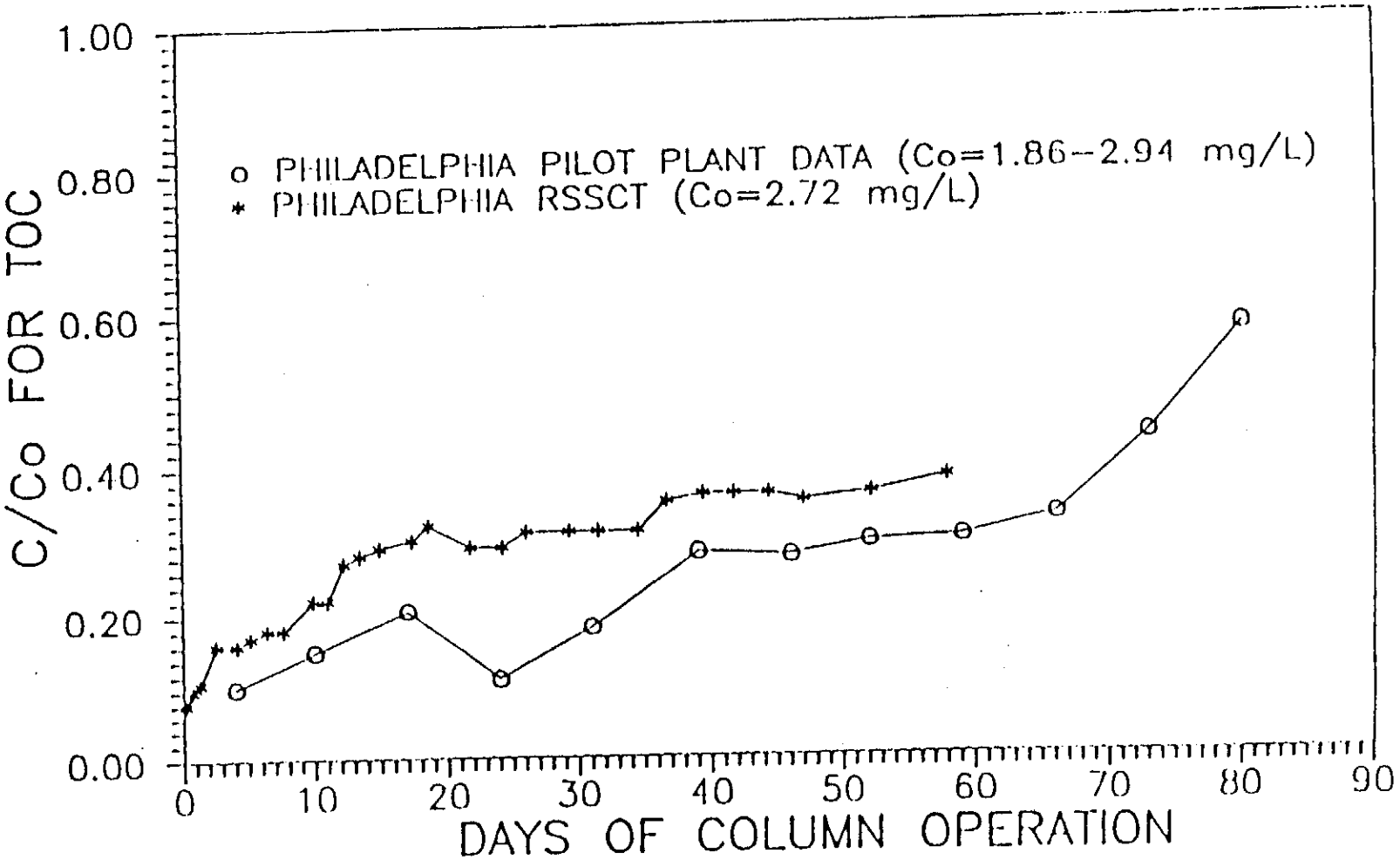

Figure 15 Comparison of RSSCT and Pilot Plant TOC Breakthrough Profiles for Philadelphia Water Department (RSSCT and Pilot EBCTs = 15 min).

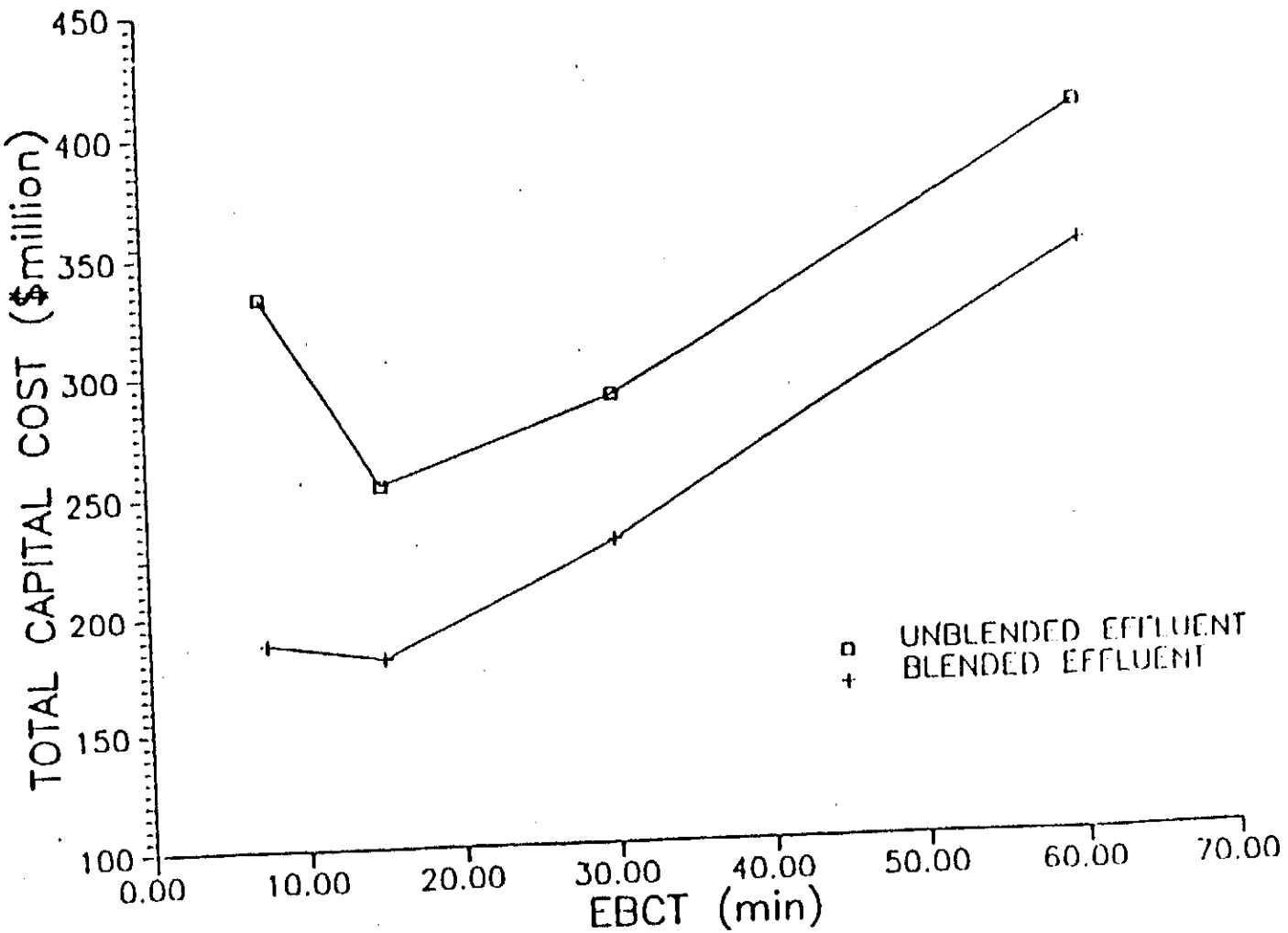

Figure 16 Total Capital Cost Comparison Between Blended and Unblended Effluent Cases for Example Metropolitan Treatment Plant (Capacity = 400 MGD; $SDSTHM_{CL} = 20 \mu g/L$).

17. Brown and Caldwell, Delta Drinking Water Quality Study, May, 1989 prepared for the California Urban Water Agencies

For copies, contact Brown and Caldwell in their Sacramento Office.