State of New Jersey
Department of
Environmental Protection
Division of Water Resources

Special Water Treatment Study
Phase I
Final Report

February 1983

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June 10, 1983

General William Whipple, Administrator
Water Supply and Watershed Management
Administration
Department of Environmental Protection
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File 1307.0010

Dear General Whipple:

We are pleased to submit three (3) copies of the Final Report for Phase I of the Special Water Treatment Study. This report, together with the Phase II Scope of Work sent to you 9 May 1983, fulfills the contractual requirements of Contract WR-1-2-0, between James M. Montgomery, Consulting Engineers, Inc. and the New Jersey Department of Environmental Protection dated 14 September 1982.

This completed report consists of six sections, and includes changes in the draft report requested by you in your letter of 13 April 1983. The first two sections of the report contain an introduction and executive summary, respectively. The next section summarizes the results of data gathering efforts and data evaluation of organic contamination of surface waters and groundwaters in New Jersey. Alternative unit processes for the treatment of drinking waters for control and removal of organic compounds are discussed in the fourth section. The fifth section discusses alternative disinfectants for maintenance of microbiological protection with a minimum of by-product formation. Finally, the report concludes with a discussion of costs of several feasible treatment process combinations to meet present and proposed finished water quality goals.

Should you have any questions concerning the attached report, or the Phase II Scope of Work for the Special Water Treatment Study, please do not hesitate to contact us. We look forward to an opportunity to work with you and your staff again.

Very truly yours,

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SECTION I

SECTION I

INTRODUCTION

This report presents the findings of the first phase of a special water treatment study investigating organic contamination of surface and groundwater supplies used for drinking water sources in the State of New Jersey conducted by James M. Montgomery, Consulting Engineers, Inc. (JMM), for the New Jersey Department of Environmental Protection (DEP). In addition to the review of existing water quality data, this project included a review of treatment processes for the control and removal of organic contaminants from both ground and surface water sources. The findings of this study were used to draft a scope of work for the Phase II of the Special Water Treatment Study, which was submitted to the DEP as a separate document.

This section describes the project background, authorization and scope, and general plan of approach.

BACKGROUND

The recent drought in New Jersey focused public attention on the issues of water quality in unprotected surface water sources of the state. Recent reports by the New Jersey DEP and others have described contamination of the state's surface and groundwaters. Many of these reports have included recent data on levels of organic compounds, which were often found at levels which may pose health risks to consumers. One major finding was the increasing occurence of contamination of groundwater supplies, which had been thought to be one of the safest potable water sources.

In response to these issues, the voters of the state passed the 1981 Water Supply Bond Act. This act authorized the expenditure of $350,000,000 for "projects to rehabilitate, repair or consolidate antiquated, damaged or inadequately operating water supply facilities; and to plan, design, acquire and construct various state water supply facilities" as set out in the New Jersey Statewide Water Supply Master Plan of April 1982.

One of the technical recommendations for the plan of action to meet the problems of water supply as described in the April 1982 Master Plan was a Special Water Treatment Study. The study's goal was to "provide a sounder basis for management decisions regarding treatment processes on rivers of marginal water quality."

AUTHORIZATION AND SCOPE

JMM was contracted by the New Jersey DEP to complete the first phase of the Special Water Treatment Study in a contract dated 14 September 1982. The goal of this phase of the project was to prepare a scope of work for Phase II, which would address specific problems faced by water purveyors in the state related to control and removal of organic contaminants. In addition, consideration was to be given to purveyors using groundwater supplies, as well as those purveyors using surface water supplies.

The project approach consisted of review and summary of available organic water quality data on raw and finished waters for those purveyors included among the 25 largest purveyors as listed in the Statewide Water Supply Master Plan. Eleven of these purveyors were visited to collect organic monitoring data. Sources of data within the DEP were also utilized. Researchers at Rutgers and Drexel Universities were visited to obtain results of their water quality investigations. These efforts provided the basis for a summary of organic water quality data, as of January 1983, for the group of purveyors mentioned.

To provide a basis for interpretation of the concentrations of organic compounds detected in New Jersey surface and groundwaters, existing regulations for organic contaminants in the United States, at both federal and state levels, and those of other countries were summarized. Current regulations for microbiological parameters were also summarized, as these must be considered in the selection of alternative disinfectants. In addition, pending future regulations for organics in the United States and New Jersey were summarized.

A literature review was conducted on alternative unit processes for the control and removal of organic contaminants from surface and groundwaters. Alternative disinfectants were summarized based on suitability for control or reduction of trihalomethanes (THMs), a by-product of disinfection with free chlorine. This review focused on the controlling parameters (and associated design variables) and efficiency of organics removal for each unit process. Disinfection alternatives were evaluated in terms of efficiency of microbiological protection, by-product formation, and potential health effects of by-products.

SECTION II

SECTION II

EXECUTIVE SUMMARY

This section describes the scope of this report and presents a summary of the major conclusions.

The remainder of this report is organized as follows:

- Section III Drinking Water Regulations
- Section IV Organic Contamination in New Jersey Water Supplies
- Section V Treatability of Organic Contaminants: Problem Description and Process Alternatives
- Section VI Alternative Disinfection Processes for Water Treatment Applications
- Section VII Process Configurations and Associated Costs for the Control and Removal of Organic Compounds

The major conclusions of this report are as follows:

- Only a small number of organic compounds found in drinking water are currently regulated in the United States. These compounds consist of four pesticides, two herbicides, and four compounds comprising the trihalomethane (THM) group. Some states have set more stringent standards by setting lower maximum contaminant levels (MCLs) than the federal regulations and/or by expanding the number of regulated compounds. Health effects data have been collected for a slightly larger group of compounds. The procedures used to extrapolate potential lifetime health risks for ingestion by humans of compounds found in drinking water are highly uncertain. As a result, the regulation of organic compounds found in drinking waters is undergoing major changes.

- Pending actions by the EPA and by the New Jersey Legislature will increase the number of organic compounds included in the National Interim Primary Drinking Water Regulations.

- Several surface sources have levels of total organic carbon (TOC) which, in the presence of free chlorine, may produce trihalomethane (THM) levels in excess of the current maximum container level (MCL) of 0.1 mg/l. Technical solutions are generally available to meet the standard, however, without major alterations to existing water treatment facilities. Some utilities have already instituted such solutions to comply with current regulations (e.g., the conversion to ozone at the Hackensack Water Company). In some cases, more extensive process changes may be required to meet the MCL for THMs.

- Surface water contamination throughout the state with volatile organic chemicals (VOCs) was found to be limited, even under drought conditions based on the 1980-81 drought water quality sampling program. Additional treatment of surface sources for removal of these compounds to meet possible MCLs for VOCs may not be necessary.

- Several surface sources are subject to significant contamination from point and non-point discharges under drought conditions, however. This has resulted in high levels of organic carbon (TOC), nitrogen species (NH_3-N and organic nitrogen), and the potential for levels of unknown and unidentifiable organic compounds with unknown health risks.

- Existing monitoring data of organic contaminants in surface sources in New Jersey are inadequate to determine the full extent of this organic contamination. Additional monitoring of unprotected surface sources near water intakes subjected to high levels of municipal and industrial discharges is recommended. Such monitoring should be of sufficient frequency and of sufficient breadth to measure a wide spectrum of organic fractions, in addition to VOCs. The variations of the levels of these compounds with time also needs to be determined.

- A brief review of data summaries indicates much higher levels of VOCs in groundwater than are found in surface waters within the state. Levels found in a small number of wells tested exceeded concentrations which are being considered as MCLs for these compounds.

- It may be expected, however, that organic contamination problems in groundwater may become more serious in the future. The VOCs are transported through the subsurface more rapidly than more hydrophobic compounds, which tend to be retarded by the soil. Thus, a broader spectrum of organic compounds may threaten groundwater resources than is indicated by current water quality data. These other compounds may only be detected years after the first signs of contamination have appeared.

- Several agencies are currently collecting data on organic contamination in ground and surface waters, and in finished drinking waters. These data are, for the most part, difficult to obtain and evaluate. A data base management system for collection, statistical evaluation, and report preparation would be of great assistance to the Bureau of Potable Water, and other divisions of DEP for management of the organic contamination problems in New Jersey waters.

- Of the unit processes available for treatment of VOCs found in groundwater, air stripping using packed towers is the least expensive, especially when compared to adsorption processes. Air stripping is currently being used by several purveyors in New Jersey for the removal of volatile organics from groundwaters. However, the secondary effects of air stripping (e.g., contamination by airborne particulates, microbiological growth in packed tower media, air pollution from organics emissions) and the range of applicability of this process for less volatile compounds need to be investigated.

- The technology for control of some additional synthetic organic chemicals (SOCs) found in untreated ground and surface water supplies has been well demonstrated in laboratory, pilot, and full-scale investigations in the United States and Europe. Full-scale applications of current organics control technology are more widespread in Europe, where experience indicates that this technology can meet stringent drinking water standards for organic compounds. Thus, additional demonstrations of alternative treatment technologies under New Jersey water quality conditions may not be necessary. However, because of the site-specific nature of the degree and extent of organic contamination, bench and/or pilot scale studies are recommended to obtain design and operating data to ensure that a given process is a technically feasible and cost effective solution to meet finished water quality goals.

- The technology for control of chlorination by-products, through the use of alternative disinfectants, has been well tested in the United States, and is now being widely used to meet the current MCL for THMs. Additional demonstrations of this technology are not needed, although intensive monitoring of microbiological quality of those plants planning to use an alternative disinfectant(s) is highly desirable. At those plants using an alternative disinfectant(s), continued monitoring of microbiological quality throughout the distribution system is recommended.

- The relative cost of alternatives for the treatment of surface waters with high levels of TOC to minimize THM formation increases in the order: chloramines < ozone and chloramines < granular activated carbon (GAC) and chlorine < Mulheim process (a combination of unit processes, including GAC and ozone, used at the Mulheim waterworks in West Germany). With the exception of the Mulheim process, the alternatives listed above were considered to be "add-on" processes to existing filtration plants. The incremental total cost of these alternatives (i.e., additional cost above the range for conventional filtration of between 5.9¢/day per capita and 9.8¢/day per capita for a 10 mgd plant, assuming per capita consumption of 150 gal/day), again with the exception of the Mulheim process, ranges from negligible for chloramines to between 6.6¢/day per capita and 10.8¢/day per capita for GAC and chlorine, for a 10 mgd plant. Economies of scale resulted in lower costs for a 100 mgd plant.

- GAC was the only technically feasible option for the treatment of surface waters contaminated with non-volatile SOCs. The total cost of this option is dependent upon the adsorption capacity of GAC for the compounds of interest, which directly affects the required regeneration frequency. Thus, the per capita incremental costs for these unit processes ranged from between 6.6¢/day and 10.8¢/day to between 22.7¢/day and 37.5¢/day, for a 10 mgd plant, dependent upon regeneration frequency. Again, economies of scale resulted in lower costs for a 100 mgd plant.

- The relative cost of alternatives for the treatment of groundwaters contaminated with volatile SOCs increases in the order: packed tower aeration and chlorine < GAC and chlorine < packed tower aeration, GAC, and chlorine. The per capita incremental total costs for these options ranged from between 1.5¢/day and 2.4¢/day for packed tower aeration and chlorine disinfection to between 8.4¢/day and 14.0¢/day for packed tower aeration, GAC, and chlorine disinfection, depending upon the required regeneration frequency, for a 1 mgd plant.

- More refined cost estimates can be made by detailing the types and concentrations of organics in untreated waters, and specific treatment goals.

A scope of work for Phase II of the Special Water Treatment Study, was written based on the conclusions listed above. The Phase II Scope of Work has been submitted to the DEP as a separate document.

SECTION III

SECTION III

DRINKING WATER QUALITY REGULATIONS

Drinking water regulations in the United States and elsewhere around the world have undergone extensive changes in the last decade. Modifications which are relevant to the New Jersey Department of Environmental Protection in its Special Water Treatment Study are (1) more extensive reliance on health effects data as the basis for setting standards and (2) addition of several new water quality parameters, including organic chemicals, to the list of regulated or soon-to-be regulated parameters. The emphasis on regulation of organic chemicals has resulted from improvements in analytical techniques, widespread occurrences of numerous organics in both ground and surface waters, systematic determinations of health effects of various organics, and development of engineering solutions for removal of the contaminants.

This chapter describes current national and state regulations for organic parameters in drinking water. Current national and state regulations for the microbiological quality of drinking water are also described. Proposed or potential regulations for organics are described, based on information available as of January 1983, to show which direction future statewide activities may take. For comparison to the control of organics and microbiological parameters in New Jersey, approaches taken in other domestic or overseas jurisdictions are summarized. Approaches to setting water quality goals for the State of New Jersey are then presented, along with advantages and disadvantages of each approach.

BASIS FOR CURRENT REGULATIONS

A brief review of current regulations for organics and microbiological parameters in drinking water will serve as background for describing proposed or potential regulations.

CHARACTERISTICS

Until recently, drinking water treatment regulations assumed that water was provided from the best available source. Those potable water sources that are available today are more likely to be contaminated with synthetic organic chemicals (SOCs) as a result of controlled or uncontrolled discharge of chemicals from industrial, agricultural, and urban uses. In some cases, naturally occurring organics compound the problem. Although not harmful in themselves, they react with disinfectants such as chlorine to produce undesirable byproducts.

Both surface and ground waters have been affected by organic chemical contamination. As shown in Chapter III of this report, natural waters used as potable water supplies within the State of New Jersey are not immune from this problem. Surface waters typically contain naturally occurring humic acids, which react with chlorine to produce trihalomethanes and other by-products which may have adverse health consequences. In addition, surface waters are often vulnerable to contamination from industrial, agricultural, and municipal discharge of a wide variety of SOCs. Groundwaters, long thought to be free from chemical or microbiological contaminants attributable to human activities, are now known to be susceptible to contamination.

An important aspect of current regulations is their applicability to treated water, not raw water. As a result, treatment practices in use today reflect the requirements of the drinking water regulations. For example, surface waters are typically treated by processes designed to remove suspended solids (through coagulation, flocculation, sedimentation, filtration) and to inactivate microorganisms (through chlorination). In addition, many groundwaters and surface waters in New Jersey are treated for iron and manganese removal and corrosion control. Ground water supplies are typically treated by chlorination, or undergo no treatment at all. Whatever control and/or removal of organics which results from these treatment processes is usually incidental. If more stringent regulations existed for control of synthetic organics, treatment practices would, in many cases, require modifications.

As a starting point, current regulations are summarized below, followed by a discussion of proposed or potential regulations for organics which have been or could be developed to respond to the drinking water supply quality situation as we understand it today.

CURRENT REGULATIONS

Current drinking water regulations apply to a limited number of organic and microbiological parameters.

Organic Parameters

A few organics are currently regulated through the federal Safe Drinking Water Act (PL 93-523) under the U.S. Environmental Protection Agency's primary and secondary drinking water regulations. New Jersey, like many states, has adapted the federal regulations as appropriate and applied them to its own needs through the New Jersey Safe Drinking Water Act and subsequent policies of the Department of Environmental Protectionination throughout the state with volatile organic chemicals (VOCs) was found to be limited, even under drought conditions based on the 1980-81 drought water quality sampling program. Additional treatment of surface sources for removal of these compounds to meet possible MCLs for VOCs may not be necessary.

- Several surface sources are subject to significant contamination from point and non-point discharges under drought conditions, however. This has resulted in high levels of orggulations (EPA, 1975) were published as the agency's initial attempt to respond to the requirements of the 1974 Safe Drinking Water Act. Accordingly, they represented a continuation or reaffirmation of existing U.S. Public Health Service recommended limits rather than a major step forward in establishing new standards. The NIPDWR contained maximum contaminant levels (MCLs) for four organic pesticides and two herbicides, as summarized in Table III-1. Drinking water purveyors typically do not have problems meeting the MCLs for these six compounds, as some of these pesticides/herbicides are no longer widely used in the U.S.

TABLE III-1

NATIONAL INTERIM PRIMARY DRINKING WATER STANDARDS
ORGANIC CHEMICALS

Parameter	Maximum Contaminant Level, mg/l
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP Silvex	0.01
Total trihalomethanes	0.10

In 1979, the EPA (EPA, 1979a) added total trihalomethanes (THMs) to its list of regulated organics as an amendment to the NIPDWR. This action followed findings that chlorine used as a disinfectant reacted with naturally occurring organic precursors to produce the THMs. Furthermore, the EPA determined that THMs produced adverse health effects, based on National Cancer Institute rodent tests and a number of epidemiological studies. The MCL for total THMs (the sum of concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform) is 0.10 mg/l or 100 ug/l.

Monitoring requirements are also attached to these regulations. The six organic pesticides/herbicides are to be monitored no less frequently than at three year intervals and sampled during the period of the year designated by the State as the period when contamination by pesticides is most likely to occur. The foregoing requirement applies to community water supplies using surface water sources. For community supplies which rely only on ground water sources, frequency of analysis is as specified by the State. Compliance is based on samples collected at the consumer's tap.

For total THMs, monitoring requirements are more complex because experience has shown that THMs fluctuate seasonally and spatially throughout the distribution system. Quarterly monitoring is required. For each water source, the supplier must sample at least four distinct sites in the distribution system, one of which must be at the system extreme. Compliance with the 0.10 mg/l MCL is determined by averaging the results from the four or more sites during a given quarter, then calculating a running annual average of the quarterly averages.

The THM regulations also implicitly require monitoring for total organic carbon (TOC), an organic indicator. Before a water purveyor makes a significant modification to the existing treatment processes to control THMs, it must submit to the State a monitoring plan. As a minimum, the baseline water quality survey in the distribution system should include TOC samples.

The effective date for compliance for the six herbicides/pesticides was June 24, 1977. Compliance with the THM regulations is a function of the size of the community water supplier. Those community water systems serving more than 75,000 persons were to comply by November 29, 1981. Those serving between 10,000 and 74,999 are to comply by November 29, 1983.

The EPA at one time proposed national regulations for control of synthetic organics which would have required use of granular activated carbon (GAC) for water supplies vulnerable to industrial contamination (EPA, 1978). These proposed regulations were never promulgated in that form. Instead of considering such a sweeping approach to organics control, EPA is now considering a more orderly approach, such as that for control of volatile organic chemicals proposed in 1982 and discussed later in this section.

National Secondary Drinking Water Regulations. In contrast to primary regulations, secondary regulations are not based on health effects, but rather on public welfare, consumer acceptance, and perceptions of taste, odor, and color. Unlike the EPA primary regulations, secondary regulations are not mandatory. They are offered to the States as guidance. Maximum contaminant levels are only recommended, not enforceable.

EPA's secondary regulations (EPA, 1979b) were published in 1979. Like the initial primary regulations published by EPA, the initial secondary regulations followed closely the levels previously recommended by the Public Health Service. The secondary maximum contaminant levels recommended by the EPA for organics are listed in Table III-2. Note that odor and color may be due to natural or synthetic organic or inorganic compounds.

TABLE III-2

EPA SECONDARY MAXIMUM CONTAMINANT LEVELS
FOR ORGANICS

Parameter	Secondary MCL
Color	15 color units
Foaming agents	0.5 mg/l
Odor	3 threshold odor number

Compliance with the secondary MCLs is left to the discretion of individual states.

New Jersey Safe Drinking Water Act. Like many states, New Jersey has accepted primacy, or primary enforcement responsibility from the EPA for drinking water regulations. Under the Federal Safe Drinking Water Act, each state's standards must be at least as stringent as the EPA's, but may be more stringent.

With respect to organics, New Jersey to date has adopted the EPA requirements for primary standards with few changes. The MCLs shown in Table III-1, for pesticides and herbicides, apply to New Jersey water purveyors. Monitoring for community water systems utilizing surface sources is to be repeated no less frequently than at three-year intervals, the same frequency specified in the federal regulations. The State has specified the period of sampling pesticides and herbicides, when concentrations are likely to be highest, to be from April 1 to September 30 (NJDEP, 1979).

Under Section 4(a) of the New Jersey Safe Drinking Water Act, the State set secondary drinking water regulations. These standards "may be required to be met by any water supply when the administrative authority having jurisdiction over the water supply finds a need therefore." Secondary standards for organics in the State are summarized in Table III-3. As before, note that color, odor, and taste may be caused by natural or synthetic inorganic or organic compounds.

TABLE III-3

NEW JERSEY SECONDARY DRINKING WATER REGULATIONS FOR ORGANICS

Parameter	Recommended Upper Limit
Color	10 color units (Standard Cobalt Scale)
Odor	3 threshold odor number
Taste	no objectionable taste
ABS/LAS*	0.5 mg/l

* alkyl benzene sulfonate and linear alkyl sulfonate or similar methylene blue reactive substances contained in synthetic detergents

If one of the parameters above in a given water supply fails to fall below the recommended upper limit, this "may constitute grounds for unacceptability of the water supply, if in the judgement of the authority having jurisdiction, such substances either singly or in combination, would render the water unduly corrosive, unpalatable, or aesthetically objectionable."

Note that the New Jersey secondary regulations are more restrictive than the EPA recommendations. In particular, the State limit for color is 5 color units less than the 15 color units in the Federal regulations. Also, the State regulations contain a requirement that taste not be objectionable, a factor which is not considered in the Federal criteria. Like odor and color, taste may be caused by either organic or inorganic compounds as well as microorganisms.

Regulations in Other States. Some discussion of the organics control policies of other states may be helpful to the New Jersey Department of Environmental Protection in selecting strategies for the future.

On the matter of THM control, at least two states have requirements more stringent than the EPA regulations. Discussions with officials of the New York Department of Health revealed that New York state has a 100 ug/l total THM maximum contaminant level, which follows the EPA regulation. However, New York has added the provision that no single THM species can exceed 50 ug/l. The state is considering lowering the limits for individual THM species.

In California, the Department of Health Services has extended the monitoring requirement for THMs to cover utilities serving less than the EPA-regulated population limit of 10,000. California has also developed extensive monitoring requirements for utilities which plan to change from chlorine to other disinfectants. An additional organic parameter, maximum total THM potential, is to be analyzed once per month for the treatment plant finished water.

Synthetic organic chemical concentrations in drinking waters are also being controlled in varying degrees by the states. Some states have relied on the data available in the EPA Office of Drinking Water health advisories on individual organics and have established procedures to control risks to consumers to some designated level. These levels may vary from state to state.

For example, the California Department of Health Services (California DOHs, 1980) has set "action levels" corresponding to the one in a million incremental lifetime cancer risk, as calculated by the EPA, for two volatile organics. These "action levels" are 5 ug/l for trichloroethylene (TCE) and 4 ug/l for tetrachloro ethylene (PCE or perchloroethylene).

When either or both of these chemicals exceed the action level, California requires that the utility take steps to meet the action levels at the consumer's taps. Action steps may include:

1. Resampling to verify TCE/PCE levels.
2. Locating an uncontaminated alternative source.
3. Blending water from more than one source.
4. Curtailing use of the contaminated source.
5. Treatment.

If TCE or PCE occurs at concentrations greater than 10 times the action level, the source must not be used at all. If concentrations of TCE and/or PCE are above the action level, but no more than 10 times these levels, restricted use is allowed such that the net risk to the consumer is still one in a million or below. For example, if the contaminant concentrations are 1-2 times the action level, the source, which is typically a well, can be used up to 6 months during the year. If concentrations are 8-10 times the action level, the well can be used no more than 30 days per year. Similar calculations permit use for 3 months at 2-4 times the action level and for 1.5 months at 4-8 times the action level. California has been successfully implementing this plan since 1980.

Other Federal Criteria. There are a number of other federal actions which have influenced the control of organics in drinking water. They differ from the regulations described above in that they are not binding on water suppliers or state agencies. In essence, this body of information and advice falls under the realm of recommendations which states can implement as they see fit.

The EPA Office of Drinking Water, Criteria and Standards Division in Washington, D.C. has developed a series of advisory documents for organic chemicals known as "health advisories," "informal guidance levels," or "SNARLs (Suggested No Adverse Response Levels)". These constitute advice on unregulated contaminants.

If the contaminant is not a carcinogen, the EPA calculates a SNARL essentially based on the methodology developed by the National Academy of Sciences in the series "Drinking Water and Health". The EPA has elected to calculate the SNARLs based on the 10 kg child, using safety factors for acceptable daily intake of 10, 100, or 1000 as judged appropriate based on availability and quality of data. The SNARLs are calculated based on varying durations of exposure, which are typically 1 day, 7 or 10 days, and long term, or chronic, exposure. The SNARLs indicate that the EPA does not condone the presence of these constituents in drinking water, but they do provide guidance on what levels can be tolerated from infrequent contamination such as spills. If the compound is both toxic and carcinogenic, the carcinogenic factor is not considered in developing the short-term SNARLs.

If EPA judges the compound to be a carcinogen, the health advisories use state-of-the-art techniques to estimate incremental lifetime cancer risks from exposure to drinking water with given concentrations of the organic compound. The EPA Office of Drinking Water relies primarily on a risk assessment methodology developed by the National Academy of Sciences based on a linear extrapolation of doses used in rodent tests assuming a human consumption of 2 l/day over 70 years. In certain cases, estimates from the EPA Cancer Assessment Group (CAG) are given for comparison. Although the EPA Office of Drinking Water takes no position in its health advisories on acceptable risk, it typically shows concentrations in drinking water which correspond to cited incremental lifetime cancer risks of 1 in 10,000, 1 in 100,000, and 1 in 1,000,000. The degree of confidence in the cited risk levels is generally recognized to be quite low in most cases, as the methodology relies on some yet unproven assumptions. Selection of appropriate risk levels is left to the individual states.

Table III-4 summarizes the information available to date on organic chemicals from the EPA Office of Drinking Water health advisories. Concentrations are shown which would result in 1 in 1,000,000 incremental lifetime cancer risks for

TABLE III-4

EPA OFFICE OF DRINKING WATER HEALTH ADVISORIES FOR ORGANICS SUMMARY OF INFORMATION

Parameter (All Concentrations in ug/l)	Carcinogenic Levels[1]		Non-Carcinogenic Levels SNARL for:			
	NAS	EPA-CAG	1 day Exposure	7 day	10 day	Long-term
Trichloroethylene	4.5	---	2000	---	200	75
Tetrachloroethylene	3.5	---	2300	---	175	20
Fuel Oil #2 (kerosene)	---	---	---	100	---	---
Benzene	---	1.5	---	350	---	---
Benzo(a)pyrene	PAH mixture carcinogenic; exact role of benzo(a)-pyrene is uncertain.		---	25	---	---
1,1,1-Trichloroethane	Not considered to be carcinogenic.		---	---	---	1000
Dichloromethane	Inconclusive evidence to date.		13000	---	1300	150
Chlordane	0.028	0.023	63	---	63	8
Formaldehyde	Some evidence of carcinogenicity.		---	---	30	---
Carbon Tetrachloride	4.5	---	200	---	20	---
1,2-Dichloroethane	0.7	0.95	None developed; Lack of satisfactory data.			

TABLE III-4 (Continued)

EPA OFFICE OF DRINKING WATER HEALTH ADVISORIES FOR ORGANICS SUMMARY OF INFORMATION

Parameter (All Concentrations in ug/l)	Carcinogenic Levels[1]		Non-Carcinogenic Levels SNARL for:			
	NAS	EPA-CAG	1 day Exposure	7 day	10 day	Long-term
Trans-1,2-Dichloroethylene	No studies completed.		27000	---	270	---
Cis-1,2-Dichloroethylene	No studies completed.		4000	---	400	---
1,1-Dichloroethylene	---	0.033	1000	---	---	70
Xylenes (Dimethylbenzenes)	No studies completed.		12000	---	1400	620
Methyl ethyl ketone	No studies found.		7500	---	750	---
n-Hexane	No studies found.		13000	---	4000	---
Ethylene glycol	No evidence to date.		19000	---	---	5500

---

[1] Levels for 1 in 1,000,000 incremental cancer risk, assuming lifetime consumption (70 years at 2 l/day).

carcinogens. For risks at 1 in 10,000 or 1 in 100,000, the listed concentrations should be multiplied by 100 or 10, respectively, as the risk assessment methodology assumes linearity of the dose/response relationship. Although the EPA Office of Drinking Water relies on the NAS cancer risk estimates, they sometimes cite the EPA Cancer Assessment Group estimates for comparison.

Although the EPA health advisories do not offer guidance to the states as to which risk level is appropriate, they do show concentrations corresponding to carcinogenic risk levels between 1 in 1,000,000 and 1 in 10,000, suggesting implicitly that something in this range is advisable. For perspective, the THM regulation, which was set on the basis of health effects and technical feasibility, corresponds to a carcinogenic risk of approximately 1 in 3000 (assuming each of the other three THMs has an equivalent risk per ug/l as chloroform). Thus, ultimate standards for other synthetic organics may, when taken individually, be lower than for the THMs.

The EPA Office of Drinking Water has issued these health advisories on individual organics found in water supplies since 1979. Other compounds are currently under consideration.

The priority pollutant list is another indication of organics for which EPA has a concern. The list, developed under a court-ordered consent decree, was made in response to an Environmental Defense Fund lawsuit charging EPA with not doing enough to regulate organics. Under the Clean Water Program, the EPA Office of Water Planning and Standards, Criteria and Standards Division (not to be confused with the Office of Drinking Water Criteria and Standards Division) developed water quality criteria for the list of priority pollutants (EPA, 1980).

For the priority pollutants, the EPA quality criteria serve as guidance only; they are not mandatory standards. They contain ambient water quality criteria for aquatic life (both fresh water and saltwater) and human health. Under the category of human health, the criteria for carcinogens and non-carcinogens are determined differently. Non-carcinogens have guidance levels based on health or organoleptic factors (tastes or odors) under two sets of assumptions:

- The compound is ingested through contaminated aquatic organisms alone.
- The compound is ingested through drinking water as well as the contaminated aquatic organisms.

No calculations are made for ingestion from drinking water alone. Concentrations of carcinogenic compounds are shown for risks of 1 in 10,000, 1 in 100,000 and 1 in 1,000,000 using a slightly different risk extrapolation model than the NAS. Again, the two sets of assumptions are used.

The organics included in the EPA priority pollutants are listed in Table III-5. Since the EPA Office of Drinking Water is not relying on these estimates to develop its own health advisories, presumably because the priority pollutant estimates use a slightly different risk extrapolation approach than the NAS, different assumptions are made on the ingestion of aquatic life are made, and

TABLE III-5

ORGANIC PRIORITY POLLUTANTS AS SPECIFIED BY EPA (EPA, 1979)

Halogenated methanes (1 carbon)

Methyl bromide
Methyl chloride
Methylene chloride (dichloromethane)
Bromoform (tribromomethane)
Chloroform (trichloromethane)
Bromodichloromethane
Dibromochloromethane
Dichlorodifluoromethane
Carbon tetrachloride (tetrachloromethane)

Chlorinated (2 carbon)

Chloroethane (ethyl chloride
Chloroethylene (vinyl chloride)
1,2-Dichloroethane (ethylene dichloride)
1,1-Dichloroethane
1,2-*trans*-Dichloroethylene
1,1-Dichloroethylene (vinylidene chloride)
1,1,2-Trichloroethane
1,1-Trichloroethane (methyl chloroform)
Trichloroethylene
Tetrachloroethylene
1,1,2,2-Tetrachloroethane
Hexachloroethane

Chlorinated (3 carbon)

1,2-Dichloropropane
1,3-Dichloropropylene

Chlorinated (4 carbon)

Hexachlorobutadiene

Chlorinated (5 carbon)

Hexachlorocyclopentadiene

Chloroalkyl ethers

Bis(chloromethyl)ether
Bis(2-chloroethyl)ether
Bis-(2-chloroisopropyl)ether
2-Chloroethylvinyl ether
Bis(2-chloroethoxy)methane

TABLE III-5 (Continued)

ORGANIC PRIORITY POLLUTANTS AS SPECIFIED BY EPA (EPA, 1979)

Pesticides

Aldrin
Dieldrin
Chlordane
α-Endosulfan
Endrin
Endrin aldehyde
Heptachlor
Heptachlor eopxide
α-BHC
β-BHC
γ-BHC (lindane)
δ-BHC
4,4'-DDT
4,4'-DDE (p, p'-DDX)
4,4'-DDD (p, p'-TDE)
Toxaphene

Nitrosamines

N-Nitrosodimethylamine
N-Nitrosodiphenylamine
N-Nitrosodi-n-propylamine

Miscellaneous

Acrolein
Acrylonitrile
Isophorone

Aromatics

Benzene
Toluene
Ethyl benzene

Polyaromatics

Napthalene
Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene (1,2-benzathrancene)
Benzo(a)pyrene (3,4-benzopyrene)
3,4-Benzofluoranthene
Benzo(k)flouranthene (11,12-benzofluoranthene)
Benzo(ghi)-perylene (1,12-benzoperylene)
Chrysene

TABLE III-5 (Continued)

ORGANIC PRIORITY POLLUTANTS AS SPECIFIED BY EPA
(EPA, 1979)

Dibenzo(a,h)anthracene(1,2,5,6-dibenzanthracene)
Fluorene
Fluoranthene
Indeno(1,2,3-cd)pyrene(2,3-o-phenylenepyrene)
Phenanthrene
Pyrene

Chloroaromatics
Chlorobenzene
o-Dichlorobenzene
p-Dichlorobenzene
m-Dichlorobenzene
1,2,4-Trichlorobenzene
Hexachlorobenzene

Chlorinated polyaromatic
2-Chloronaphthalene

Polychlorinated biphenyls
Arochlor 1016
Arochlor 1221
Arochlor 1232
Arochlor 1242
Arochlor 1248
Arochlor 1254
Arochlor 1260

Phthalate esters
Bis(2-ethylhexyl)phthalate
Butylbenzyl phthalate
Di-n-butyl phthalate
Di-n-octyl phthalate
Diethyl phthalate
Dimethyl phthalate

Nitroaromatics
Nitrobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene

Benzidines
Benzidine
3,3'-Dichlorobenzidine
1,2-Diphenylhydrazine

TABLE III-5 (Continued)

ORGANIC PRIORITY POLLUTANTS AS SPECIFIED BY EPA (EPA, 1979)

<u>Phenols</u>
Phenol
2,4-Dimethylphenol

<u>Nitrophenols</u>
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitro-o-cresol

<u>Chlorophenols</u>
2-Chlorophenol
4-Chloro-m-cresol
2,4-Dichlorophenol
2,4,6-Trichlorophenol
Pentachlorophenol
TCDD(2,3,7,8-Tetrachlorodibenzo-p-dioxin)

<u>Haloaryl ethers</u>
4-Chlorophenylphenyl ether
4-Bromophenylphenyl ether

no treatment is assumed, the human health water quality criteria are not listed in this table. Interested readers are referred to the Federal Register for more details.

Since the list of priority pollutants is more extensive than the list of compounds for which EPA has drinking water health advisories, it is logical to assume that the Office of Drinking Water will continue to expand the number of health advisories. It is anticipated that the EPA Office of Drinking Water will prepare five to ten new health advisories per year (Cotruvo, Personal Communication, 1983). In addition, New Jersey has added other organic compounds to the EPA priority pollutant list in its industrial waste survey to reflect organics of particular concern within the state.

The response on the part of the states to the EPA Office of Drinking Water health advisories has up until now been a voluntary one. EPA (EPA, 1981) has offered guidance to assist the states in the type of responses they make to findings of organic contamination.

In this draft document, the EPA has identified four categories of concern for acute and chronic toxic effects, concentrations of individual compounds which correspond to these four categories, and suggested responses. The categories are:

Category I-Acute Concern Level, High Risk: responses are emergency action, such as resampling and verification of the concentration levels, identifying the contaminant source and rectifying the problem if possible, and ban on water consumption for humans (cooking and drinking purposes.)

Category II-Subacute Concern Level: responses are immediate action, such as resampling and verification, identification of the contaminant source and rectifying the problem if possible, ban on water consumption for up to 10 days, and serious consideration of alternate sources or treatment.

Category III-Chronic Exposure Concern Level: responses as soon as possible, such as resampling and verification, identification or the contaminant source and rectifying the problem if possible, initiating long term surveillance monitoring, and altering treatment or considering alternate sources.

Category IV-Taste and Odor Detections: responses depend on whether taste and odor are from contamination which also causes health risk; identifying the source and corrective action are recommended.

Concentrations of selected organic chemicals corresponding to these four categories are summarized in Table III-6. Studies are underway to obtain values for the following chemicals:

Bromobenzene
o-Chlorotoluene
p-Chlorotoluene
1,1-Dichloroethylene
1,1-Dichloroethane
Cis-1,2-Dichloroethylene

TABLE III-6

CONCENTRATION LEVELS FOR SELECTED CHEMICALS, BASED ON TOXICITY OTHER THAN CARCINOGENESIS[1]

Parameter (All Concentration in mg/l)	I Acute	II Short-term	III Chronic	IV Taste and Odor
Benzene	0.35			2
Carbon tetrachloride	0.2	0.02		
Chlorobenzene			0.072[2]	0.1
Dichlorodifluoromethane	100[3]	43[3]	1.6[3]	
1,2-Dibromo-3-chloro-propane			0.00005	
1,2-Dichlorobenzene				0.01
1,3-Dichlorobenzene				0.02
1,4-Dichlorobenzene			0.13[3]	0.0003
1,2-Dichloroethane				29
1,2-Dichloropropane				0.0014
Ethylbenzene				0.1
Methylene chloride	13	1.3	0.15	
Isopropylbenzene				0.1
Styrene			1.3[3]	0.05
Tetrachloroethylene	2.3	0.18	0.02	0.3
Toluene	120[3]	10[3]	0.10[3]	1.0
1,1,1-Trichloroethane	140[3]	20[3]	1.1[3]	
Trichloroethylene	2	0.2	0.075	0.5
Trichlorofluoromethane	25[3]	2.2[3]		
m-Xylene	6.1[3]	3.2[3]		1.1
o-Xylene mixture				1.8
p-Xylene				0.5

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[1] EPA ODW, "Guidance to Response to Contamination Detected in the Survey,"Draft, 1981.

[2] Numbers calculated from Water Quality Criteria for a 10 kg child consuming 1 liter water/day.

[3] Numbers calculated from NAS Drinking Water and Health for a 10 kg child consuming 1 liter water/day.

Trans-1,2-Dichloroethylene
n-Propylbenzene
1,1,2,2-Tetrachloroethylene
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane

For those organic compounds which pose potential carcinogenic risks, the EPA also has four categories of concern, along with suggested responses. They are:

Category I-Projected Lifetime Exposure Risk Larger than 1 in 10,000: high priority situation with immediate action warranted, such as resampling and verification of concentration levels, identifying source and rectifying problem if possible, consideration of switching to alternate source or banning water consumption.

Category II-Projected Lifetime Exposure Risk between 1 in 10,000 and 1 in 100,000: expeditious actions suggested, such as resampling and verifying concentrations, identifying source and rectifying problem if possible, reducing human exposure, and initiating frequent monitoring.

Category III-Projected Lifetime Exposure Risk Between 1 in 100,000 and 1 in 1,000,000: actions should be taken as resources permit, such as resampling and verifying concentration levels, identifying source and rectifying problem if possible,and considering long range surveillance monitoring.

Category IV-Projected Risk less than 1 in 1,000,000: represents negligible risk and merit low priority.

The organic carcinogens which the Office of Drinking Water has identified, along with concentrations corresponding to the four categories described above, are shown in Table III-7.

International Regulations. Some of the more important international regulations for organics are the World Health Organization guidelines and the European Community (EC or Common Market) directive. Many of the individual countries have their own standards, but in most cases they are derivatives of the WHO or EC regulations.

The WHO European Standards (WHO, 1970) are advisory in nature. WHO International Standards (WHO, 1971) were established for non-European countries and are also advisory in nature. Organics criteria in the two WHO regulations are summarized in Table III-8.

The WHO regulations were developed more than a decade ago. Consequently, they do not address the issue of synthetic organics other than as indicator groups. Therefore, they offer little guidance. WHO standards are currently under revision and should be available soon.

In contrast, the EC directives (Knoppert, 1980), also summarized in Table III-8, are more current in their approach to synthetic organics in drinking water. Most noteworthy are the guidance levels of 1 ug/l for organo-chlorine compounds (other than pesticides) and the requirement that THMs should be as low

TABLE III-7

CONCENTRATION LEVELS FOR SELECTED POTENTIAL CARCINOGENS[1]

Parameter (All Concentrations in ug/l)	Method	I (10^{-4} Risk Level)	II (10^{-5} - 10^{-4})	III (10^{-6} - 10^{-5})	IV ($<10^{-6}$)
Carbon tetrachloride	NAS [2]	450	45-450	4.5-45	4.5
	CAG [3]	40	4-40	0.4-4	0.4
1,2-Dichloroethane	NAS	71	7.1-71	0.71-7.1	0.71
	CAG	95	9.5-95	0.95-9.5	0.95
1,2-Dibromoethane	NAS	5.5	0.55-5.5	0.055-0.55	0.055
	CAG				
Tetrachloroethylene	NAS	350	35-350	3.5-35	3.5
	CAG	90	9-90	0.9-9	0.9
Trichloroethylene	NAS	450	45-450	4.5-45	4.5
	CAG	280	28-280	2.8-28	2.8
1,1,2-Trichloroethane	NAS				
	CAG	61	6.1-61	0.61-6.1	0.61
1,1,2,2-Tetrachloroethane	NAS				
	CAG	17	1.7-17	0.17-1.7	0.17

TABLE III-7 (Continued)

CONCENTRATION LEVELS FOR SELECTED POTENTIAL CARCINOGENS[1]

Parameter (All Concentrations in ug/l)	Method	I (10^{-4} Risk Level)	II (10^{-5} - 10^{-4})	III (10^{-6} - 10^{-5})	IV ($<10^{-6}$)
Vinyl chloride	NAS	100	10-100	1-10	1
	CAG	200	20-200	2-20	2
Benzene	NAS	67	6.7-67	0.67-6.7	0.67
	CAG				

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[1] EPA ODW, "Guidelines to Response to Contamination Detected in the Groundwater Survey," Draft, 1981.

[2] NAS: Calculated by EPA/ODW using carcinogenic risks specified by the Safe Drinking Water Committee, National Academy of Sciences.

[3] CAG: Calculated by EPA/ODW using carcinogenic risks specified by EPA's Carcinogen Assessment Group. Modification made to reflect carcinogenic risks associated with lifetime exposure to drinking water. The contribution from fish/seafood has been excluded.

TABLE III-8

INTERNATIONAL REGULATIONS FOR ORGANICS

Parameter	WHO-European	WHO-International Highest Desired	WHO-International Maximum Permitted	EC Guidance Level	EC Maximum Permitted
Color (Pt-Co units)	---	5	50	1	20
Odor (by dilution)	---	unobjectionable	unobjectionable	0	3
Tastes (by dilution)	---	unobjectionable	unobjectionable	0	3
TOC (mg/l)	---	---	---	Reason for any increase above usual concentrations must be investigated.	
Chloroform extractable substances (mg/l)	0.5	---	---	0.1	---
Anionic detergents (mg/l)	0.2	0.2	1.0	---	0.2
Phenolic compounds (mg/l)	0.001	0.001	0.002		0.0005
Mineral oils (mg/l)	---	0.01	0.3	---	0.01
Polycyclic aromatic hydrocarbons (ug/l)	0.2	---	0.2	---	0.2
Pesticides and related compounds (ug/l)					
- Total	---	---	---	---	0.5
- Individual compound	---	---	---	---	0.1
Total Trihalomethanes (ug/l)	---	---	---	As low as possible	---
Other organochlorine compounds (ug/l)	---	---	---	1	---

as possible. Although the Europeans have not gone through the detail that U.S. regulatory agencies have on estimating health risks for individual contaminants, the net effect is similar. Current guidelines suggest that purveyors keep concentrations very low.

As with our federal standards and the discretion allowed the states to be more stringent, the EC directives allow each member country to be more restrictive. For example, the Federal Republic of Germany has a criteria of 25 ug/l for total organic halogen. This parameter includes the THM group of compounds as well as other, higher molecular weight, organo-halides. The West German standards are apparently based on achieveability rather than health effects estimates.

Wastewater reclamation and subsequent potable reuse are practiced in South Africa. For example, the Windhoek facility uses a blend of 25% treated wastewater and groundwater as its potable supply. However, South Africa has no statutory standards for potable water. The South Africa Bureau of Standards has "Specifications for Water for Domestic Supply", which must be met where water is used in the manufacture or processing of edible products which bear the SABS mark. However, SABS recommended parameters are generally used as guidelines. For organics, SABS limits are shown in Table III-9.

TABLE III-9

SABS LIMITS FOR ORGANICS

Parameter	Units	Recommended Limit	Maximum Allowable
Odor	Odor number	Unobjectionable	Unobjectionable
Color	Color units	1	10
Phenolic compounds	mg/l	0.001	0.002
Anionic surfactants	mg/l	0.5	0.5

In addition to using SABS limits as guidelines, the National Institute for Water Research developed lower hazard limits (LHL) for a number of organics "after consideration of available and suggested water quality standards, compounds found in water elsewhere, toxicological data and other relevant publications." These LHLs are summarized in Table III-10.

Disinfection Requirements

Current disinfection standards do not mandate maximum concentrations of specific microbiological contaminants. They are typically based on concentrations of indicator organisms, such as coliform bacteria, in the distribution system.

National Regulations. The EPA National Interim Primary Drinking Water Regulations do not refer specifically to disinfection requirements, but do require monitoring for coliform bacteria. The standard essentially requires that coliforms should not be detectable in the distribution system. With the currently available standard analytical techniques, these detection limits are 1 organism per 100 ml using the membrane filter technique and 2 organisms per 100 ml using the multiple tube fermentation (MPN) technique. Monitoring requirements, based on population served, and allowable frequency of positive counts are discussed in the regulations.

The THM regulations (EPA, 1979) also affect disinfection practice. The EPA indicates that utilities planning to change disinfectants must submit a plan to the primacy agency which, as a minimum, contains a baseline water quality survey of the distribution system. Coliforms, fecal coliforms, fecal streptococci, and standard plate counts (at both 20° and 35°C) are to be monitored, but no acceptable limits are defined by the EPA. If chlorine dioxide is used, the monitoring program must include analyses of chlorite, chlorate, and chlorine dioxide. The purveyor should be able to demonstrate an active disinfectant residual throughout the distribution system at all times during and after any change in disinfectant.

TABLE III-10

LOWER HAZARD LIMITS FOR ORGANICS USED IN SOUTH AFRICA

	Lower Hazard Limits (ug/l)	
Organic Compound Groups	**Individual Compound**	**Group**
Volatile Halogenated hydrocarbons (VHH)		50
Trihalomethanes (chloroform, bromoform, bromodichloromethane, dibromochloromethane), tetrachloromethane	1-10	
Chlorinated hydrocarbons/pesticides (CHP)		1
Lindane, chlordane, dieldrin, endrin, (bis)-chloroisopropylether, hexachloroobutadiene, hexachlorobenzene, PCBs, DDT-complex, endosulfan	0.1	
Dichlorobenzene, chloroethers	1	
Chlorophenols (CPHEN)		10
Di-, tri-, tetra- and pentachlorphenols	1	
Polynuclear aromatic hydrocarbons (PAH)		
Benzo(a)anthracene, benzo(b) and (k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene	0.1	
Phenolic compounds (PHEN)		10
Phenol, cresols, xylenols, beta-naphthol, etc.	1	
Other compounds (DIV)		
Dibutylphthalate, diphenylether, nitrotoluene	1	
Unidentified compounds to be identified by GC-MS		>1
CHP and PAH	0.1	

The EPA (EPA, 1978) in its original proposed THM regulations had outlined specific restrictions on the use of alternative disinfectants. Although the regulations were not adopted in that form, many in the industry are still using the proposed restrictions as guidelines. The 1978 proposal stated that chlorine dioxide may be used as a primary disinfectant in drinking water provided that the amount added did not exceed 1 mg/l. This was in response to EPA findings of possible adverse health effects of chlorine dioxide and its inorganic byproucts. Furthermore, the proposal stated that chloramines should not be used as a primary disinfectant, but could be used to maintain a residual in the distribution system. The latter restriction was due to the EPA thinking that chloramines are not as effective for disinfection as chlorine. These suggestions should be followed with discretion, particularly as more information becomes available on the health effects of chlorine dioxide and as more sophisticated techniques are available for evaluating disinfection effectiveness (see Section V).

State Regulations. Disinfection requirements within individual states tend to be judged on a case by case basis rather than mandated through written regulations. Some states, or local health departments, for example, require maintenance of a specific amount of disinfectant residual at the extremes of the system.

New Jersey requirements for coliform monitoring are more stringent than the EPA regulations. The State does not allow reductions in the monitoring frequency for coliforms and chlorine residual allowed under certain cases in the EPA standards.

Certain states have detailed monitoring requirements for disinfectants, byproducts, and microorganisms when water suppliers change disinfectants to minimize THM formation. For example, California requires the following:

Parameter	Monitoring Frequency	Monitoring Location
Chlorine demand	once/3 mo.	Filtered water prior to chlorination
Chlorine residual	once/week	Treated water and distribution system sampling points
Coliforms and plate counts	once/week	Raw, treated, and distribution system sampling points

If chloramines are used, weekly samples of treated water at the plant and throughout the distribution system are required for ammonia nitrogen, nitrite, taste, and odor. If chlorine dioxide is used, weekly samples are to be collected for residual oxidants (i.e., chlorine dioxide, chlorite and chlorate.)

International Regulations. The WHO European standards suggest that 95% of the samples should have coliforms below the detection limit, no two consecutive samples should be positive, and more than 100 samples should be collected during the year. For viruses, the standards state that if less than one plaque forming unit of virus is found per liter of water, the water is assumed to be safe to drink. Furthermore, they state that in practice 0.5 mg/l of free chlorine for 1 hour (0.4 mg/l of ozone for 4 minutes is considered equivalent) should be sufficient to inactivate virus. Standards mention other organisms which should be monitored in drinking water.

The WHO International standards offer guidance in that organisms which are considered to be of possible fecal origin should be absent. Recommended standards are:

- 95% of samples should have no detectable coliforms.
- E. coli should not be present in any sample.
- No sample should have more than 10 coliforms per 100 ml.
- Coliforms should not be detected in 2 consecutive samples. International recommendations on viruses are the same as in the European standards.

EC requirements, as summarized in Table III-11, cover more types of microorganisms than U.S. standards.

TABLE III-11

EUROPEAN COMMUNITY STANDARDS FOR MICROORGANISMS

			Maximum Acceptable	
Parameter	Units	Guideline	Membrane Filter	MPN
Total coliform	No./100 ml	---	0	<1
Fecal Coliform	No./100 ml	---	0	<1
Fecal Streptococci	No./100 ml	---	0	<1
Clostridium (sulfur reducing)	No./20 ml	---	0	<1
Total Count	No./ml			
22°C		10	---	---
37°C		100	---	---

PROPOSED OR POTENTIAL REGULATIONS FOR ORGANICS

POTENTIAL LEGISLATION IN NEW JERSEY

The New Jersey legislature is currently considering a proposed amendment to the Safe Drinking Water Act, New Jersey Assembly Bill 280 (NJ, 1983), which would require extensive regulation of hazardous chemicals, particulary synthetic organics. A Drinking Water Quality Institute would be formed and would initially establish MCLs for the following:

Trichloroethylene
Tetrachloroethylene
Carbon tetrachloride
1,1,1-trichlorethane
1,2-dichloroethane

Vinyl chloride
Methylene chloride
Benzene
Chlorobenzene
Dichlorobenzene(s)
Trichlorobenzene(s)
1,1-dichloroethylene
Cis-1,2-dichloroethylene
Trans-1,2-dichloroethylene
Polychlorinated biphenyls (PCBs)
Xylenes
Ethylene glycol
Chlordane
Kerosene
Formaldehyde
n-hexane
Methyl ethyl ketone

The Commissioner of the DEP would be charged with developing MCLs for additional compounds which, within the limits of medical, scientific, and technological feasibility, may cause death, behavioral abnormalities, cancer, genetic mutations, physiological malfunction, or physical deformity. For carcinogens, MCLs are to be set for each chemical at the 1 in 1,000,000 incremental lifetime risk level. This proposal, currently being debated, would cause considerable changes in the regulatory requirements for drinking water in the State of New Jersey. The proposed legislation does not include a requirement to evaluate the economic impact of meeting these regulatory goals. Increased treatment costs, which would ultimately be passed on to the consumer, would most likely be a result of this legislation.

EPA ADVANCE NOTICE OF PROPOSED RULEMAKING (ANPRM) FOR VOLATILE ORGANIC CHEMICALS

The EPA (EPA, 1982) is considering regulating a number of volatile organic chemicals which have frequently been detected in groundwater around the U.S. Many of these constituents are also frequently found in New Jersey, so the future actions of the EPA with respect to volatiles have a direct bearing on the State. The EPA is considering three options:

1. Establishing MCLs
2. Establishing Recommended MCLs
3. Requiring monitoring now and waiting to establish MCLs

Based on comments collected on the ANPRM, the EPA is currently in the process of developing proposed regulations. Discussions with health officials suggest EPA may propose a combination of MCLs and RMCLs. For example, the MCL for trichloroethylene may be 50 ug/l, with the RMCL at 5 ug/l.

The range of MCLs which EPA is considering, according to the ANPRM, is summarized in Table III-12. For 1,1,1-trichloroethane, the assumed basis for the MCL is the long-term SNARL. The other compounds are believed to be carcinogens, and the range of MCLs corresponds to concentrations associated with incremental lifetime cancer risks between 1 in 1,000,000 and 1 in 10,000.

TABLE III-12

POTENTIAL MCLs FOR VOLATILE SYNTHETIC ORGANICS UNDER CONSIDERATION BY EPA

Parameter	Potential MCL (ug/l)
Trichloroethylene	5-500
Tetrachloroethylene	5-500
Carbon tetrachloride	5-500
1,1,1-Trichloroethane	1000
1,2-Dichloroethane	1-100
Vinyl chloride	1-100

There are a number of other volatile organics which are frequently detected in groundwater, as cited in the ANPRM. However, EPA did not suggest any MCLs for these compounds in the 1982 publication.

FUTURE PROJECTIONS

There are a number of possibilities for future regulatory actions at the federal level for synthetic organic chemicals. These include:

- Lowering the MCL for THMs
- Increasing the number of SOCs under regulatory consideration by EPA
- Changing from monitoring requirements to MCLs
- Changing from advisory statements to MCLs or RMCLs
- Reducing the lower limit on population served for applicability of regulations
- Including surrogate parameters, such as TOX, or groups of compounds, to regulated lists
- Development of the Revised Primary Drinking Water Regulations in the near future.

LIMITATIONS OF REGULATIONS

This section summarized current and imminent regulations for microbiological parameters and a range of organic compounds in drinking waters. No attempt was made in this study to set treatment goals for those organic compounds found in New Jersey ground and surface waters. Thus, subsequent discussions of the technical feasibility and costs of alternative unit processes for the control of trace organic compounds is compared to the range of finished water MCLs required in the U.S. and abroad.

The determination of potable water regulations requires the combined efforts of scientific and public policy decision makers. The current state-of-the-art does not allow an assessment of the overall safety of drinking water. Current regulations have been set for a small fraction of the organic compounds found in drinking water. Determination of the risk from these individual compounds is a time consuming process which assumes an unproven linear extrapolation of dose/response data. Current drinking water regulations also do not address the issues of source quality, potentially harmful compounds which are difficult to detect given current analytical capabilities, and use of surrogate parameters, such as TOC and TOX. Thus, ultimate decisions on regulations are often made in light of changing scientific data and method of approach.

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——"National Interim Primary Drinking Water Regulations, Control of Trihalomethanes in Drinking Water," Federal Register 44:231, 68624-68707, November 29, 1979a.

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New Jersey Department of Environmental Protection, Division of Water Resources, "Safe Drinking Water Act Regulations, N.J.A.C. 7:10-1 through 7:10-11.13, Subchapters 4 through 7, Disinfection, Primary and Secondary Standards, Variances and Exemptions," July, 1979.

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SECTION IV

SECTION IV

ORGANIC CONTAMINATION IN NEW JERSEY WATER SUPPLIES

This section presents a summary review of the organic water quality data made available during the four month course of this study. Factors considered in the evaluation of the data included the compounds analyzed, analytical detection limit, and frequency of sampling. Concentrations of organic compounds in New Jersey water supplies, as indicated in this review, are compared to MCLs for currently regulated organic compounds, and those concentrations determined to pose health risks as summarized in Section III.

DESCRIPTION OF NEW JERSEY PURVEYORS

DATA SOURCES

Several data sources were used in preparing the summary of New Jersey drinking water purveyors. The Public Water System Inventory (PWSI) is a computerized database containing such information as population served, plant average production, plant design capacity and plant maximum production. A printout of relevant information for all 619 community water supplies throughout the state was obtained from the Bureau of Potable Water (BPW). Information was also obtained from the BPW Statewide Evaluation Inspection Forms, which contained more detailed information obtained by the BPW during on-site inspections. Additional information was obtained through visits to the following purveyors:

- Hackensack Water Company
- New Jersey Water Company
- Newark Water Department
- Jersey City Water Department
- Trenton Water Department
- New Brunswick Water Department
- Passaic Valley Water Commission
- North Jersey District Water Supply Commission
- Elizabethtown Water Company
- Monmouth Consolidated Water Company
- Camden City Water Department
- Atlantic City Water Department
- Rockaway Township Water Department

Phone interviews were also conducted with the remaining purveyors among the top 25 who use surface supplies.

STATEWIDE SUMMARY OF PURVEYORS

Figures IV-1 and IV-2 show the distribution of water purveyors based on population served and average daily usage, respectively. Note that the majority of purveyors serve less than 10,000 people and have an average daily usage of less than 1 mgd. As illustrated in Figure IV-1, there are 118 purveyors which serve between 10,000 and 75,000 persons. This group of purveyors must come into compliance with the federal THM regulations by November of this year.

Figures IV-3 and IV-4 show the distribution of water purveyors based on groupings used in the THM regulations. The purveyors were segregated into three groups depending on the population served. In Figure IV-3 the circle represents the total number of purveyors, which is 619. In Figure IV-4 the circle represents the population of New Jersey, which is approximately 7,365,000. The first group of purveyors, those serving less than 10,000 persons, represents 80% of the total number of purveyors. However, these purveyors serve only 10% of the population. The third group of purveyors, those serving more than 75,000 persons, represents only 1% of the total number of purveyors, yet serves 53% of the population.

Potable water supplies in New Jersey consist of 61% surface and 39% groundwater. Figure IV-5 shows the location of existing surface water intakes throughout the state.

SUMMARY OF 25 LARGER PURVEYORS

Table IV-1 contains a listing of the 25 larger purveyors as given in the Statewide Water Supply Master Plan (NJDEP, 1982a). Note that some purveyors have several divisions, and thus the table contains 36 listings. They are arranged according to the water supply planning region in decreasing order of population served within the region. The raw water source(s) for each purveyor is listed as well as the persons contacted, if a visit was made.

SOURCES OF WATER QUALITY DATA

The sources of water quality data with respect to organic contamination are discussed below. The data sources can be characterized as either statewide studies or purveyor-specific studies. For the statewide studies, data was only obtained for those purveyors listed among the top 25 in Table IV-1.

STATEWIDE STUDIES

The statewide studies from which data was obtained during this study are listed in Table IV-2. Listed are the types of samples analyzed in each study as well as the organic fractions measured. The specific compounds analyzed in each study as well as the related detection limits are reviewed in more detail below. Results are summarized and discussed in the following sections.

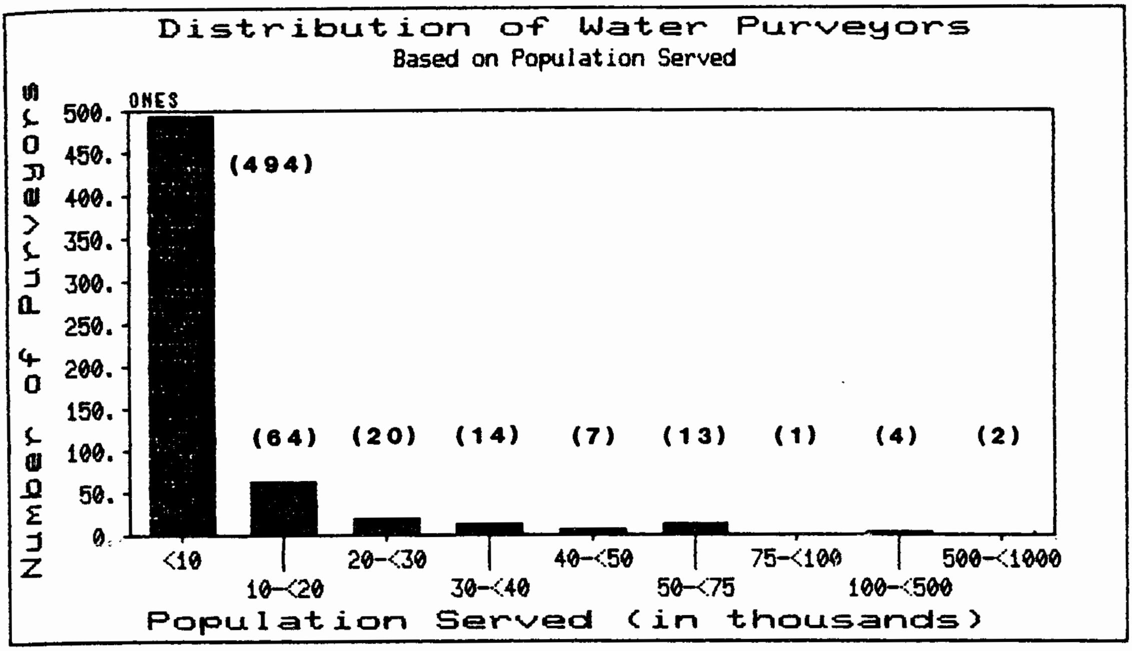

FIGURE IV-1. DISTRIBUTION OF NEW JERSEY WATER PURVEYORS BASED ON POPULATION SERVED

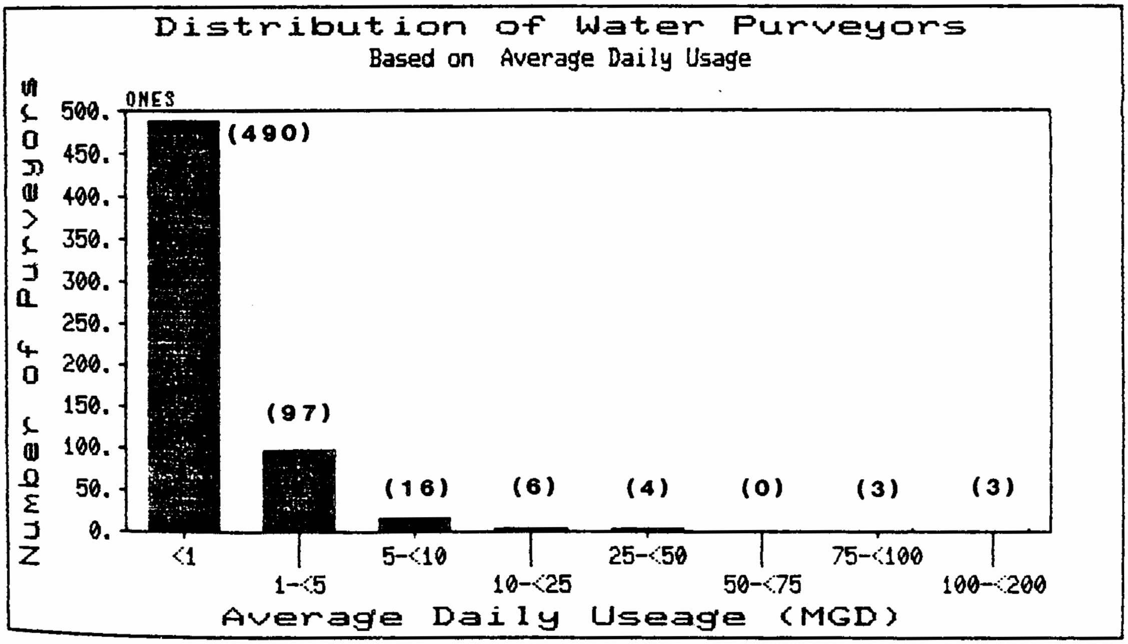

FIGURE IV-2. DISTRIBUTION OF NEW JERSEY WATER PURVEYORS BASED ON AVERAGE DAILY USAGE

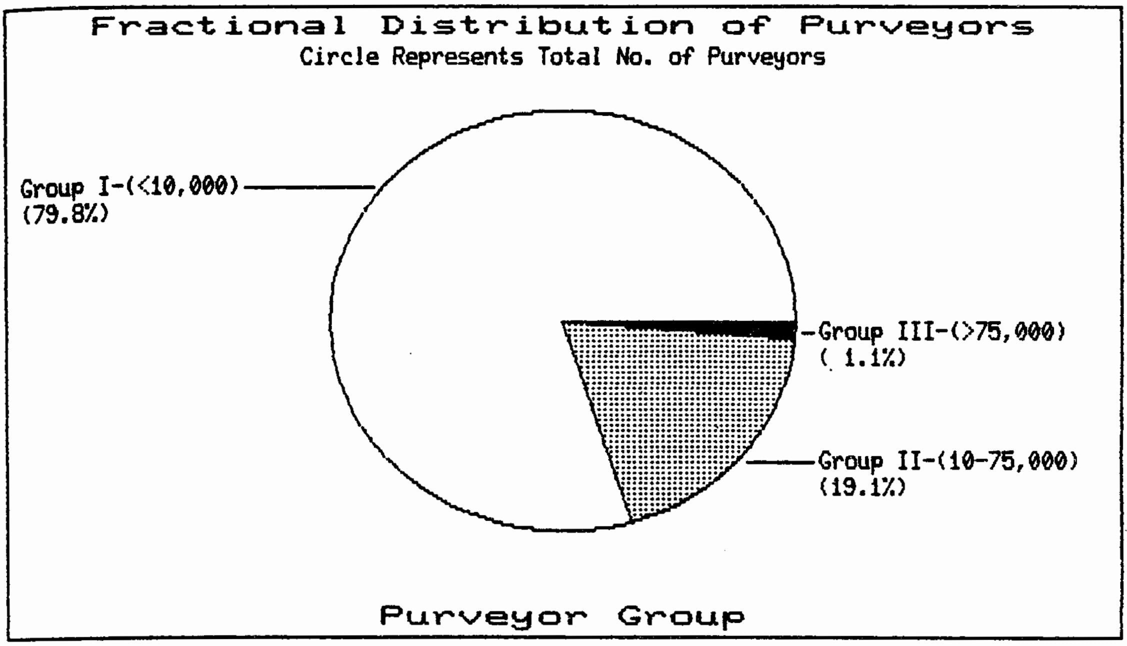

FIGURE IV-3. FRACTIONAL DISTRIBUTION OF NEW JERSEY WATER PURVEYORS BASED ON NUMBER OF PURVEYORS

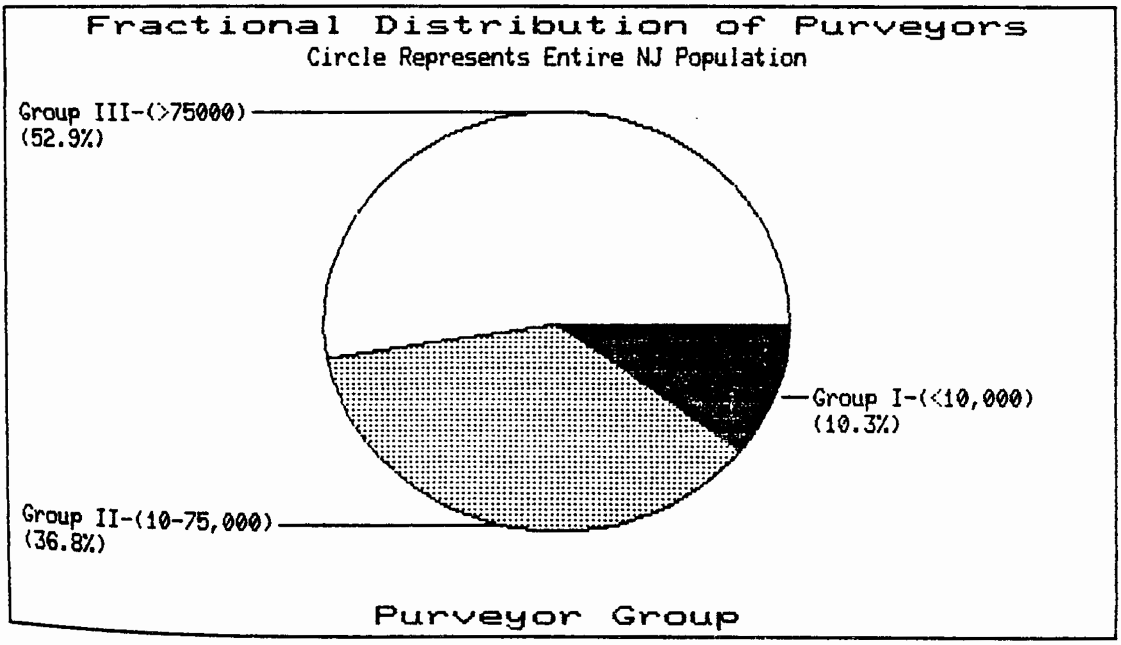

FIGURE IV-4. FRACTIONAL DISTRIBUTION OF NEW JERSEY WATER PURVEYORS BASED ON TOTAL POPULATION

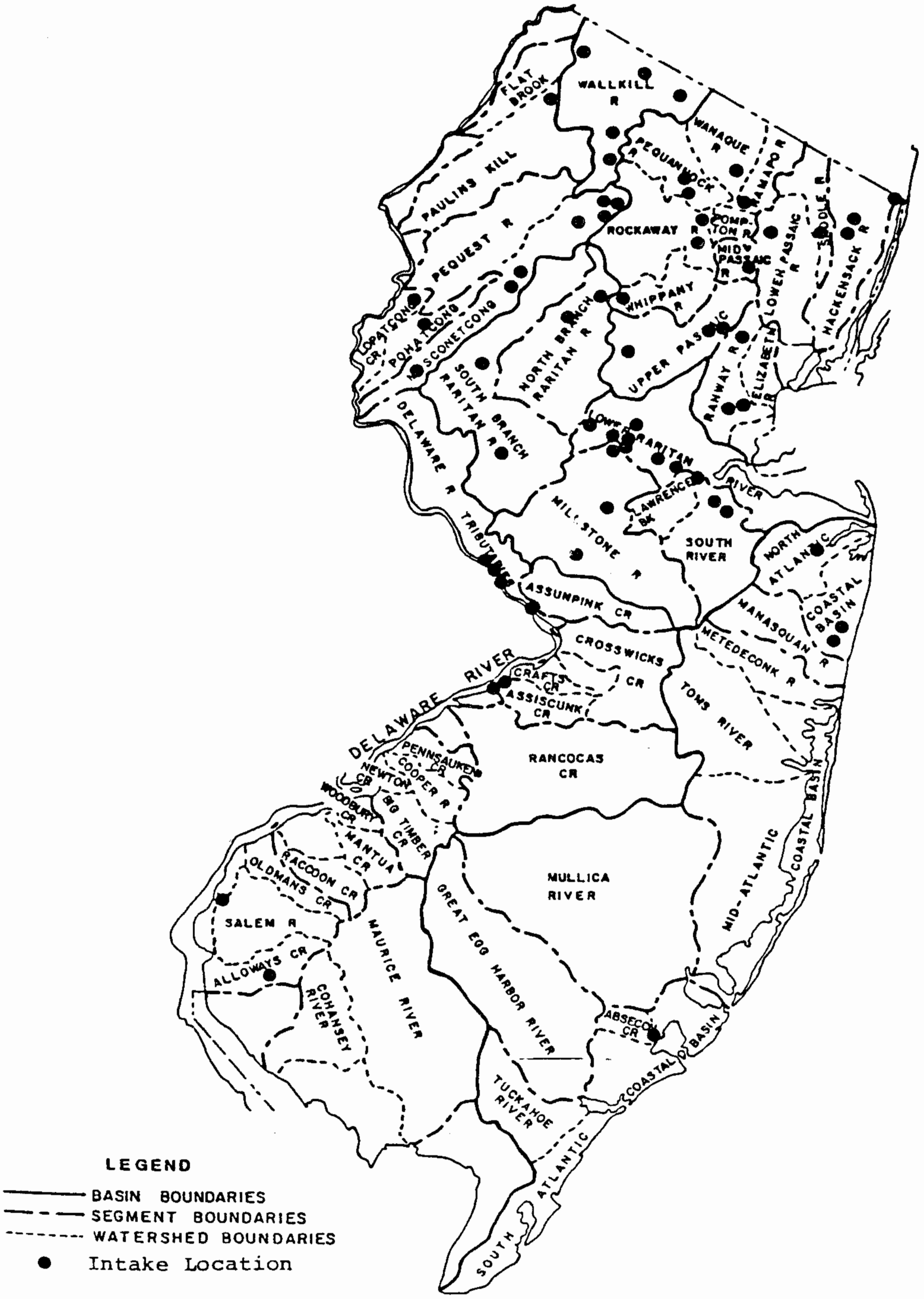

FIGURE IV-5. LOCATION OF EXISTING SURFACE WATER INTAKES (FROM NJ DEP, 1982)

TABLE IV-1

TOP 25 WATER PURVEYORS IN NEW JERSEY (FROM NEW JERSEY STATEWIDE WATER SUPPLY MASTER PLAN, APRIL 1982)

Purveyor	Population Served	Average Production (mgd)	Raw Water Source(s)	Person(s) Contacted
Region I - Northwest				
Hackensack Water Company	800,000	85.3	Oradell Reservoir, groundwater	George Haskew Leo Fung
North Jersey District Water Supply Commission	750,000	108.1	Wanaque Reservoir	Dean Noll
Elizabethtown	457,142	104.0	Millstone River, Raritan River, Delaware-Raritan Canal, groundwater	Glenn Johansen
Newark Water Department	382,400	80.1	Pequannock Watershed from Charlottsburg Reservoir, NJDWSC	Daniel Berardinelli Jim Connoly Andrew Pappachen
Passaic Valley Water Supply Commission	287,316	98.0	Passaic River	Wendel Inhoffer Richard Robie
Jersey City Water Department	240,000	191	Boonton Reservoir	Charles Catrillo Tom Neilan Al Dzydzora
Commonwealth Water Company	222,000	36.06	Passaic River, Canoe Brook, groundwater	Art Sherman (American Water Works Service Co.)
Middlesex Water Company	179,000	25.4	Robinsons Branch, Delaware-Raritan Canal, groundwater	

TABLE IV-1 (Continued)

TOP 25 WATER PURVEYORS IN NEW JERSEY
(FROM NEW JERSEY STATEWIDE WATER SUPPLY MASTER PLAN, APRIL 1982)

Purveyor	Population Served	Average Production (mgd)	Raw Water Source(s)	Person(s) Contacted
East Orange Water Department	78,000	9.94	groundwater	
Parsipanny-Troy Hills Water Department	68,000	5.0	groundwater	
Ridgewood	62,000	7.33	groundwater	
SE Morris County Municipal Utilities Authority	62,000	7.38	Clyde Potts Reservoir, groundwater	
New Brunswick Water Department	42,000	12.5	Lawrence Brook, Delaware-Raritan Canal	
Perth Amboy Water Department	41,000	6.0	groundwater	
Elizabethtown Water Company - Princeton Division	35,000	6.53	groundwater, Delaware-Raritan Canal	
Orange Water Department	32,000	3.29	Rahway River, groundwater	
Rahway Water Department	30,000	5.9	Rahway River, groundwater	
Garden State Water Company - Hamilton Square Division	22,300	1.68	groundwater	
Hawthorne Water Department	22,000	2.5	groundwater	
Boonton Water Department	10,000		Taylortown Reservoir, groundwater	

TABLE IV-1 (Continued)

TOP 25 WATER PURVEYORS IN NEW JERSEY (FROM NEW JERSEY STATEWIDE WATER SUPPLY MASTER PLAN, APRIL 1982)

Purveyor	Population Served	Average Production (mgd)	Raw Water Source(s)	Person(s) Contacted
Region II - Ocean and Monmouth Counties				
Monmouth Consolidated Water Company	259,497	25.4	Swimming River Reservoir, Jumping Brook, Shark River, groundwater	Herb Brown Art Shearman (AWWS Co)
Toms River Water Company	72,733	6.0	groundwater	
New Jersey Water Company - Lakewood District	25,750	2.75	groundwater	
Region III - Atlantic and Cape May Counties				
New Jersey Water Company - Atlantic County District	41,557	4.74	groundwater	
Atlantic City Water Department	40,000	12	Doughty Pond Reservoir, groundwater	Bill McLees
New Jersey Water Company - Ocean City District	18,000	3.07	groundwater	
Region IV - Salem and Cumberland Counties				
Vineland Water Department	30,000	6.72	groundwater	
Region V - Burlington, Camden, and Gloucester Counties				
New Jersey Water Company - Haddon Division	201,861	19.89	groundwater	

TABLE IV-1 (Continued)

TOP 25 WATER PURVEYORS IN NEW JERSEY
(FROM NEW JERSEY STATEWIDE WATER SUPPLY MASTER PLAN, APRIL 1982)

Purveyor	Population Served	Average Production (mgd)	Raw Water Source(s)	Person(s) Contacted
Camden Water Department	70,240	23.6	groundwater	Mike Vena
New Jersey Water Company - Delaware Valley District	69,274	7.1	groundwater	
Merchantville - Pennsauken Commission	50,000	6.59	groundwater	
Willingboro MUA	50,000	3.6	groundwater	
New Jersey Water Company - Camden District	39,550	3.91	groundwater	
Garden State Water Company - Blackwood Division	29,188	2.15	groundwater	
Region VI - Northwest				
Trenton Water Department	250,000	31.2	Delaware River	Richard Russo Joseph Bella
Garden State Water Company - Phillipsburg District	27,000	4.4	groundwater	

NOTE: Information compiled from NJDEP "Compliance Evaluation Inspection" form, Public Water System Inventory Subsystem data, and purveyor contacts.

TABLE IV-2

SUMMARY OF STATEWIDE WATER QUALITY SURVEYS WITH RESPECT TO ORGANIC COMPOUNDS IN NEW JERSEY

Designation	Time Period	Type of Sample	Organic Fraction(s) Measured
Public Water System Inventory Database	on-going	Finished Water, Distribution System	Pesticides (in finished water), THMs (in distribution system)
BPW/OCTSR Potable Water Survey	1978-1980	Untreated Surface Water, Untreated Groundwater, Finished Water, Distribution System	Volatile organics, base/neutrals, phenols, PCBs, pesticides
OCTSR Groundwater Survey	1979-81	Untreated Groundwater	Volatile organics, pesticides, PCBs
OCTSR Surface Water Survey	1978-79	Untreated Surface Water	Volatile organics, pesticides, PCBs
BPW Drought Water Quality Survey	Sept. 1980-Jan. 1981	Finished Water	Volatile organics, PCBs
USGS Water Quality Monitoring Network	on-going	Untreated Surface Water	TOC
EPA Region II Monitoring and Surveillance Program	1980-81	Finished Water	Volatile organics, pesticides
EPA National Groundwater Supply Survey	1981	Finished Water (from groundwaters)	Volatile organics, TOC

Public Water System Inventory Database

This database consists of analytical results for pesticides and THMs reported by each purveyor to the BPW. Sampling and reporting frequencies, for those purveyors regulated, are discussed in Section III.

BPW/Office of Cancer and Toxic Substances Research (OCTSR)

This survey, conducted in 1978 through 1980, analyzed samples of untreated surface water, untreated groundwater, finished water and distribution samples. Gas Chromatography/Mass Spectroscopy (GC/MS) analysis of several organic fractions was performed by the Department of Environmental Science at Rutgers University. The specific compounds analyzed are listed in Table IV-3 (Rutgers, undated). Detection limits (DLs) were not given in the Department laboratory manual which was prepared for the DEP. However, reference was made to analytical methodology specified by the EPA (EPA, 1979) for the analysis of priority pollutants. The DLs listed by the EPA ranged between 10 and 100 ug/L, depending upon the compound, are probably higher than those for the Rutgers Laboratory.

OCTSR Groundwater Study

This study, conducted between 1979 to 1981, analyzed samples of untreated groundwater for volatile organics, pesticides, and PCBs in 670 wells throughout the state. Grab samples were taken at wells used for monitoring and potable use, and represented samples from a small fraction of the 20,000 wells providing drinking water throughout the state. In some cases, grab samples were taken at the same sampling site over the course of the study. The specific compounds analyzed for by Gas Chromatography (GC) with an electron caputure detector, and detection limits, are listed in Table IV-4.

OCTSR Surface Water Study

This study analyzed grab samples of untreated surface waters throughout the state between 1978 and 1979. Sampling was not limited to only those surface waters used for potable water supplies. From one to three samples were taken at each sampling site over these two years. Similar analytical methodology was used in this study as was used in the OCTSR Groundwater Study. Table IV-5 lists those compounds analyzed for and detection limits, where given, in this study.

BPW Drought Water Quality Survey

This study was conducted by the BPW during the period of the recent drought, September 1980 through January 1981. Grab samples of finished water for 25 purveyors throughout the state were analyzed for volatile organics and PCBs. Sampling frequency ranged from 3 to 8 samples taken over the period from September 1980 through January 1981. Analyses were performed by the New Jersey Department of Health laboratories. The compounds analyzed for by GC and detection limits are listed in Table IV-6.

TABLE IV-3

ORGANIC COMPOUNDS ANALYZED IN BPW/OCTSR POTABLE WATER SURVEY

Compound
VOLATILE ORGANICS
Chloromethane
Dichlorodifluoromethane
Bromomethane
Vinyl chloride
Chloroethane
Methylene chloride
Trichlorofluoromethane
1,1-Dichloroethylene
1,1-Dichloroethane
Trans-1,2-dichloroethylene
Chloroform
1,2-Dichloroethane
(Freon 113)1,1,2-Trichlorofluoroethane
1,1,1-Trichloroethane
Carbon Tetrachloride
Bromodichloromethane
Bis-chloromethyl ether
1,2-Dichloropropane
Trans-1,3-dichloropropene
Trichloroethylene
Dibromochloromethane
Trans-1,2-dichloropropene
Cis-1,3-dichloropropene
Cis-1,2-dichloroethylene
1,1,2-Trichloroethane
1,2-Dibromoethane
Benzene
2-Chloroethylvinyl ether
Bromoform
Diiodomethane
1,1,2,2-Tetrachloroethene
1,1,2,2-Tetrachloroethane
Toluene
Chlorobenzene
Ethylbenzene
o-Xylene
m-Xylene
p-Xylene
Acrolein
Acrylonitrile

TABLE IV-3 (Continued)

ORGANIC COMPOUNDS ANALYZED IN BPW/OCTSR POTABLE WATER SURVEY

Compound
BASE NEUTRALS
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Hexachloroethane
1,2-Dichlorobenzene
Bis(2-chloroisopropyl)ether
Hexachlorobutadiene
1,2,4-Trichlorobenzene
Naphthalene
Bis(2-chloroethyl)ether
Hexachlorocyclopentadiene
Nitrobenzene
Bis(2-chloroethoxy)methane
2-Chloronaphthalene
Acenaphthylene
Acenaphthene
Isophorone
Fluorene
2,6-Dinitrotoluene
1,2-Diphenylhydrazine
2,4-Dinitrotoluene
N-Nitrosodiphenylamine
Hexachlorobenzene
4-Bromophenyl phenyl ether
Phenanthrene
Anthracene
Dimethylpthalate
Diethylpthalate
Fluoranthene
Pyrene
Di-n-butylphthalate
Benzidine
Butyl Benzylphthalate
Chrysene
Bis(2-ethylhexyl)phthalate
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Ideno(1,2,3-cd)pyrene

TABLE IV-3 (Continued)

ORGANIC COMPOUNDS ANALYZED IN BPW/OCTSR POTABLE WATER SURVEY

Compound
BASE NEUTRALS (Cont)
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
N-Nitrosodimethylamine
N-Nitrosodi-n-propylamine
4-Chloro-phenyl-phenyl ether
3,3'-Dichlorobenzidine
2,3,7,8-Tetrachlorobenzo-p-dioxin
Bis(chloromethyl)ether
PHENOLS
Pentachlorophenol
2,4-Dinitrophenol
p-Chloro-m-cresol
2,4,6-Trichlorophenol
2,4-Dichlorophenol
2,4-Dimethylphenol
Phenol
2-Nitrophenol
4-Nitrophenol
2-Chlorophenol
4,6-Dinitro-o-cresol
PCBs
Arochlor 1016
Arochlor 1221
Arochlor 1232
Arochlor 1242
Arochlor 1248
Arochlor 1254
Arochlor 1260
PESTICIDES
α-BHC
β-BHC
γ-BHC (Lindane)
Heptachlor
Δ-BHC
Aldrin
Heptachlor epoxide
Endosulfan I
p,p'-DDE

TABLE IV-3 (Continued)

ORGANIC COMPOUNDS ANALYZED IN BPW/OCTSR POTABLE WATER SURVEY

Compound
PESTICIDES (Cont)
Dieldrin
Endrin
p,p'-DDD
Endosulfan II
p,p'-DDT
Endrin aldehyde
Chlorodane
Toxaphene

NOTE: Analyses performed by Environmental Science Department, Cook College, Rutgers University.

TABLE IV-4

ORGANIC COMPOUNDS ANALYZED IN OCTSR GROUNDWATER SURVEY

Compound	Detection Limit ug/l
VOLATILE ORGANICS	
Methylene chloride	90
Methyl chloride	6.0
Methyl bromide	1.0
Chloroform	0.8
Bromoform	1.0
Trichloroethylene	0.3
1,1,2,2-Tetrachloroethane	0.3
1,1,2-Trichloroethane	1.0
Dibromochloromethane	0.1
Trifluoromethane	0.5
Carbon tetrachloride	0.1
1,2-Debromoethane	0.1
1,2-Dichloroethane	1.6
1,1,1-Trichloroethane	2.0
Vinyl chloride	0.5
Tetrachloroethylene	0.1
o-Dichlorobenzene	2.2
m-Dichlorobenzene	1.3
p-Dichlorobenzene	1.3
Trichlorobenzene	2.0
Diiodomethane	0.3
Dichlorobromomethane	0.5
PESTICIDES AND RELATED COMPOUNDS	
PCBs	0.06
Arochlor 1016	0.06
Arochlor 1242	0.06
Arochlor 1248	0.01
Arochlor 1254	0.01
α-BHC	0.01
β-BHC	0.01
Lindane (γ-BHC)	0.01
Heptachlor	0.01
Aldrin	0.01
Dieldrin	0.01
Chlorodane	0.01
Toxaphene	0.06

TABLE IV-4 (Continued)

ORGANIC COMPOUNDS ANALYZED IN OCTSR GROUNDWATER SURVEY

Compound	Detection Limit ug/l
PESTICIDES AND RELATED COMPOUNDS (Cont)	
Methoxychlor	0.08
Mirex	0.02
Endrin	0.01
o,p-DDT	0.04
p,p'-DDT	0.04
o,p-DDE	0.01
p,p'-DDD	0.02

TABLE IV-5

ORGANIC COMPOUNDS ANALYZED IN OCTSR SURFACE WATER SURVEY

	Detection Limit (ug/l)
Fluoroform	0.5
Methyl Chloride	6.0
Methyl Bromide	1.0
Vinyl Chloride	0.5
Methylene Chloride	90
Chloroform	0.8
1,2-Dichloroethane	1.6
1,1,1-Trichloroethane	2.0
Carbon Tetrachloride	0.1
Trichloroethylene	0.3
Dichlorobromomethane	0.5
1,1,2-Trichloroethane	1.0
Dibromochloromethane	0.1
1,2-Dibromoethane and Tetrachloroethylene	ng
Bromoform	1.0
1,1,2,2-Tetrachloroethane	0.3
Diiodomethane	0.3
m-Dichlorobenzone	1.3
p-Dichlorobenzene	1.3
o-Dichloroebenzene	2.2
1,2,4-Trichlorobenzene	2.0
1,1-Dichloroethylene	ng
Dibromomethane	ng
trans-Dichloroethylene	ng
Arochlor 1016	0.06
Arochlor 1242	0.06
Arochlor 1248	0.01
Arochlor 1254	0.01
α-BHC	0.01
β-BHC (Lindane)	0.01
γ-BHC	0.01
Heptachlor	0.01
Aldrin	0.01
Heptachlorepoxide	0.01
γ-chlordane	0.01
p,p'-DDE	0.01
Dieldrin	0.01
Endrin	0.01
o,p'-DDT	0.04
p,p'-DDD	0.04
p,p'-DDT	0.02
Mirex	0.02
Methoxychlor	0.08
Toxaphene	0.06

TABLE IV-5 (Continued)

ORGANIC COMPOUNDS ANALYZED IN OCTSR SURFACE WATER SURVEY

	Detection Limit (ug/l)
Benzo(x)pyrene	ng
Perylene	ng
Chrysene	ng
Fluoranthene	ng
TOC	ng

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ng - Not Given

USGS Water Quality Monitoring Network

In an on-going survey, the USGS reports water quality data for many surface stations throughout the state in yearly volumes of Water Resources Data. These data were obtained for water years 1976 through 1981. The only organic parameter reported in these volumes is total organic carbon (TOC). Several other indicator parameters which are indicative of upstream sewage discharges were evaluated. The data from those stream stations, located close to surface water intakes for the top 25 purveyors as listed in Table IV-1, were evaluated in this study. The twelve stream stations in this category are listed in Table IV-7.

EPA Potable Water Quality Monitoring

Region II - Monitoring and Surveillance Plan. In summer 1980 and 1981, EPA Region II obtained random grab samples of finished water at several water treatment plants throughout the state and analyzed for volatile organics and pesticides by GC. Those compounds analyzed and detection limits are listed in Table IV-8 (Kahn, 1982, personal communication).

National Groundwater Supply Survey. In 1981 the EPA conducted a national survey of finished waters from groundwater supplies and analyzed single grab samples for volatile organics by GC and for TOC. Those compounds analyzed and detection limits are listed in Table IV-9 (Kahn, 1982, personal communication).

Rutgers University Delaware and Raritan Canal Study

Several sampling programs were conducted between August 1979 and July 1980 by Rutgers University as part of their assessment of water quality in the Delaware and Raritan Canal (Rutgers, 1982). Monthly samples at twelve sites along the canal from the Delaware River inlet to New Brunswick were analyzed for conventional water quality parameters, including TOC. Samples were collected once at all twelve sites and analyzed for VOCs, pesticides and PCBs by GC. Similar analyses were conducted on samples collected every other month at five of the sites. Additional infrequent sampling at some sites during storm events investigated the effects of high runoff on the levels of these compounds. One sample at each of the five sites was also subjected to a more rigorous GC/MS analysis for all organic priority pollutants.

PURVEYOR-SPECIFIC STUDIES

These studies include monitoring of untreated water supplies by the purveyor, as well as other studies aimed at investigating the organic water quality of untreated and finished waters for specific purveyors. In many cases, much additional information was not available primarily to two factors. First, current drinking water regulations only required the analysis of finished waters and samples taken in the distribution system. Second, many purveyor laboratories were not equipped to perform organic analyses. The cost of frequent analyses of untreated water supplies by an outside laboratory can be high. Many of the larger purveyors contacted have recently purchased gas

TABLE IV-6

ORGANIC COMPOUNDS ANALYZED IN BPW POTABLE WATER SAMPLING

Compound	Detection Limit (ug/l)
Methylene Chloride	2
Trichlorofluoromethane	2
1,1-Dichloroethene	2
1,1-Dichloroethane	2
1,2-Dichloroethene	2
Chloroform	2
1,2-Dichloroethane	2
1,1,1-Trichloroethane	2
Carbon Tetrachloride	2
Bromodichloromethane	2
1,2-Dichloropropane	2
1,3-Dichloropropene	2
Trichloroethene	2
Dibromochloromethane	2
1,1,2-Trichloroethane	2
Benzene	2
2-Chlorethylvinyl ether	2
Bromform	2
1,1,2,2-Tetrachloroethene	2
1,1,2,2-Tetrachloroethane	2
Toluene	2
Chlorobenzene	2
Ethylbenzene	2
Acrylonitrile	100
Acrolein	100

Note: Analyses performed by NJ Department of Health.

TABLE IV-7

LOCATION OF USGS SURFACE WATER QUALITY MONITORING STATIONS ANALYZED IN THIS STUDY

Station Number	Location	Period of Record of Streamflow Data	Period of Record of Water Quality Data Used
01377000	Hackensack River at Rivervale (4.6 mi upstream from Oradell Dam)	WY 1943-1981	WY 1976-1981
01379500	Passaic River near Chatham (3.0 mi upstream from Canoe Brook)	WY 1905-1981	WY 1976-1981
01389000	Pompton River at Two Bridges	No data available	WY 1976-1979
01389500	Passaic River at Little Falls	WY 1899-1981	WY 1978-1981
01391500	Saddle River at Lodi (3.2 mi upstream from mouth)	WY 1925-1981	WY 1976-1981
01394500	Rahway River at Springfield (1.5 mi south of Springfield)	WY 1940-1981	WY 1979-1981
01395000	Rahway River at Rahway (0.9 mi upstream of Robinsons Branch)	WY 1923-1981	WY 1979-1981
01400500	Raritan River at Manville (1.4 mi upstream from Millstone River)	WY 1905-1981	WY 1976-1981
01405030	Lawrence Brook at Westons Mills (200 ft downstream from Westons Mill Pond outflow)	No data available	WY 1976-1981
01407500	Swimming River near Red Bank (50 ft upstream from dam on Swimming River Reservoir)	WY 1925-1981	WY 1976-1981
01407705	Shark River near Neptune City (0.3 mi downstream of Robins Swamp Brook)	WY 1968-1981	WY 1976-1981
01463500	Delaware River at Trenton	WY 1914-1981	WR 1976-1981

TABLE IV-8

ORGANIC COMPOUNDS ANALYZED IN EPA REGION II MONITORING AND SURVEILLANCE PLAN

Compound	Detection Limit ug/l
VOLATILE ORGANICS	
Benzene	0.1
Carbon Tetrachloride	0.1
Chlorobenzene	0.1
1,2-Dichloroethane	0.1
1,1,1-Trichloroethane	0.1
1,1-Dichloroethane	0.1
1,1,2-Trichloroethane	0.1
1,1,2,2-Tetrachloroethane	0.1
Chloroethane	0.1
Bis(Chloromethyl)ether	0.1
2-Chloroethyl vinyl ether	0.1
Chloroform	0.1
1,1-Dichloroethylene	0.1
1,2-trans-Dichloroethylene	0.1
1,2-Dichloropropane	0.1
1,3-Dichloropropylene	0.1
Ethylbenzene	0.1
Methylene chloride	0.1
Methyl chloride	0.1
Methyl bromide	0.1
Bromoform	0.1
Dichlorobromomethane	0.1
Trichlorofluoromethane	0.1
Dichlorodifluoromethane	0.1
Chlorodibromomethane	0.1
Tetrachloroethylene	0.1
Toluene	0.1
Trichloroethylene	0.1
Vinyl chloride	0.1
Acrolein	0.1
Acrylonitrile	0.1
PESTICIDES	
γ-BHC	0.04
Endrin	0.2
Methoxychlor	0.6
2,4,D	0.06
Toxaphene	1.2
Silvex(2,4,5,TP)	0.09

TABLE IV-9

ORGANIC COMPOUNDS ANALYZED IN EPA NATIONAL GROUNDWATER SUPPLY SURVEY

Compound	Detection Limit (ug/l)
Chloroform	0.2
Bromodichloromethane	0.2
Dibromochloromethane	0.5
Bromoform	1.0
Dichlorodidomethane	1.0
Vinyl chloride	1.0
Methylene chloride	1.0
1,1-Dichloroethylene	0.2
1,1-Dichloroethane	0.2
Cis- and/or trans-1,2-dichloroethylene	0.2
1,2-Dichloroethane	0.5
1,1,1-Trichloroethane	0.2
Caron tetrachloride	0.2
1,2-Dichloropropane	0.2
Trichloroethylene	0.2
1,1,2-Trichloroethane	0.5
1,1,1,2-Tetrachloroethane	0.2
Tetrachloroethylene	0.2
1,1,2,2-Tetrachloroethane	0.5
Chlorobenzene	0.5
1,2-Dibromo-3-chloropropane	5.0
Benzene	0.5
Toluene	0.5
Ethylbenzene	0.5
Bromobenzene	0.5
Isopropylbenzene	0.5
m-xylene	0.2
Styrene	0.5
o- and p-xylene	0.2
n-propylbenzene	0.5
o-chlorotoluene	0.5
p-chlorotoluene	0.5
m-Dichlorobenzene	0.5
o-Dichlorobenzene	0.5
p-Dichlorobenzene	0.5

chromatographs, or plan to in the near future, and will be conducting systematic monitoring of untreated water supplies to measure certain trace organic compounds, principally volatile organics. In those cases where data were available, the specific compounds analyzed and detection limits are discussed below in the sections dealing with individual purveyors.

SUMMARY OF DATA

The data obtained during the course of this study are summarized below. Discussed first are the results of statewide studies followed by the results of purveyor-specific studies. The data presented below have several limitations. First, the small number of grab samples taken in most studies may not provide a representative indication of the extent of organic contamination at a given location. More frequent sampling and statistical analysis of the data are necessary to provide a better indication of the types and concentrations of compounds present. Generally the data summarized below were too limited to warrant statistical evaluation. Second, the analytical methodology used in the studies described in the above sections allowed for the identification of primarily volatile organics and pesticides, and, in some cases, other higher molecular weight, less polar compounds (e.g., those in the base/neutral fraction).

STATEWIDE SUMMARIES

BPW/OCTSR Potable Water Survey

Those compounds detected in untreated surface waters of the top 25 purveyors as listed in Table IV-1 are presented in Table IV-10. As can be seen, low concentrations of volatile organics, PCBs and pesticides were found. As observed in many other studies, phthalates were detected in nearly all samples in the Potable Water Survey. However, subsequent sampling with stainless steel equipment and analysis in a phthalate-free lab indicated that observed phthalate concentrations were most likely due to contamination (Hunter, personal communication, 1983).

Those compounds detected in seven untreated groundwaters sampled are listed in Table IV-11. At two locations grab samples were taken on two separate occasions, and at one location three grab samples were taken. Only one grab sample was taken at each of the other four sites. Compared to the results shown in Table IV-10 for surface water, the concentrations of several volatile organics were higher for those seven groundwaters. Concentrations of organics detected at the sites where two or three samples were taken illustrate the variability with time.

Table IV-12 lists those compounds detected in the finished waters from 20 water treatment plants using both groundwater and surface water. One to three samples were taken at each location. For those trace organics not removed by the treatment process, the finished water levels are representative of levels found in raw water. Low concentrations of THMs were observed in untreated ground and surface waters, but higher concentrations of these

TABLE IV-10

ORGANIC COMPOUNDS DETECTED IN UNTREATED SURFACE WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Date	Organic Fraction	Compounds(s) Detected	Concentration (ug/l)
Hackensack Water Co., Oradell Reservoir	12/5/79	Pesticide	p,p'-DDE	0.01
Commonwealth Water Company, Canoe Brook Reservoir #1	10/11/78	VO	Methylene Chloride	11.7
			1,1,1 Trichloroethane	20.5
			Toluene	2.4
		Phenol	p-chloro-m-cresol	0.10
			2,4,6-Trichlorophenol	0.20
			2,4-Dichlorophenol	0.15
			2-Chlorophenol	< 0.20
		Pesticide	α-BHC	< 0.01
			β-BHC	0.02
			γ-BHC	0.082
			Heptachlor epoxide	< 0.01
Jersey City Water Department, Boonton Reservoir	9/29/80	VO	Methylene Chloride	1.05
			Toluene	0.54

TABLE IV-10 (Continued)

ORGANIC COMPOUNDS DETECTED IN UNTREATED SURFACE WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Date	Organic Fraction	Compounds(s) Detected	Concentration (ug/l)
New Brunswick Water Department, Lawrence Brook	10/16/78	VO	Methylene Chloride	0.5
			Chloroform	5.2
			1,1,1 Trichloroethane	1.2
			Bromodichloromethane	3.5
			Dibromochloromethane	1.3
		Phenol	Pentachlorophenol	4.4
			2,4,6-Trichlorophenol	1.2
			2,4-Dichlorophenol	0.6
		Pesticide	Δ-BHC	0.01
			Heptachlor epoxide	<0.01
Passaic Valley Water Commission, Passaic River	10/16/79	VO	Toluene	0.7
	10/2/80	VO	Methylene chloride	1.56
			Chloroform	0.59
			1,1,1-Trichloroethane	0.48
			Trichloroethene	0.63
			1,1,2,2-Tetrachloroethene	0.28
			Toluene	0.15
		Base/neutral	Bis (2-ethylhexyl) phthalate	21.9
		Pesticide	α-BHC	0.03
			Δ-BHC	1.57

TABLE IV-10 (Continued)

ORGANIC COMPOUNDS DETECTED IN UNTREATED SURFACE WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Date	Organic Fraction	Compounds(s) Detected	Concentration (ug/l)
North Jersey District Water Supply Commission, Wanaque Reservoir	12/27/79	VO	Benzene	0.52
		Pesticide	α-BHC	>0.01
			Δ-BHC	0.11
			p,p'-DDE	>0.01
Rahway Water Department, Rahway River	10/1/80	VO	Methylene Chloride	1.44
			Chloroform	0.63
			1,1,1-Trichloroethane	0.69
			Trichloroethylene	0.82
			Toluene	0.32
		PCB	Arochlor 1016	< 0.06
		Pesticide	α-BHC	0.02
			γ-BHC (lindane)	> 0.01

TABLE IV-11

ORGANIC COMPOUNDS DETECTED IN UNTREATED GROUNDWATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/23/78	7/26/79	10/17/79
New Jersey Water Company - Haddon District, Haddon Division, Haddon Heights Station	VO	Methylene chloride	0.9	nd	nd
		Chloroform	0.4	nd	nd
		1,1,1-Trichloroethane	2.6	nd	0.4
		Toluene	nd	5.8	2.0
	Phenol	Pentachlorophenol	2.4	nd	nd
	PCB	Arochlor 1248	nd	nd	0.146
	Pesticide	α-BHC	nd	nd	0.114
		β-BHC	0.11	nd	nd
		γ-BHC (lindane)	nd	nd	0.11
		Δ-BHC	0.011	nd	nd
		Endosulfane I	nd	nd	0.389
		p,p'-DDE	nd	> 0.01	nd
			10/12/78		
Perth Amboy Water Department, Runyon Plant Wells No. 3, 4, 5	VO	Methylene chloride	5.6		
		Trans-1,2-dichloroethylene	5.4		
		1,1,1-Trichloroethane	8.4		
		Trichloroethylene	0.6		
		1,1,2-Trichloroethane	2.1		
	Pesticide	α-BHC	< 0.010		
		β-BHC	0.015		
		Aldrin	< 0.010		

TABLE IV-11

ORGANIC COMPOUNDS DETECTED IN UNTREATED GROUNDWATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)	
			11/2/78	9/6/79
Ridgewood Water Department, Linwood Avenue Well	VO	Methylene chloride	4.0	65.2
		1,1,1-Trichloroethane	11.4	nd
		1,1,2,2-Tetrachloroethene	11.4	nd
		Toluene	nd	6.9
	Pesticide	β-BHC	<0.01	nd
		Δ-BHC	<0.01	nd
		Heptachlor epoxide	<0.01	nd
		Endosulfane I	0.028	nd
		Dieldrin	<0.01	<0.01
			10/23/78	
Camden City Water Department Well No. 5	VO	Trans-1,2-dichloroethylene	2.0	
		1,1,1-Trichloroethane	3.9	
		Trichloroethylene	15.7	
		Diiodomethane	0.7	
	Phenol	Pentachlorophenol	12.2	
		p-Chloro-m-cresol	1.1	
		4,6-Dinitro-o-cresol	5.1	
	Pesticide	Δ-BHC	<0.01	
		Heptachlor epoxide	0.011	

TABLE IV-11

ORGANIC COMPOUNDS DETECTED IN UNTREATED GROUNDWATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)	
			11/2/78	9/18/79
Parsippany-Troy Hills Water Company, Well No. 7	VO	Trichlorofluoromethane	40.4	40.9
		1,1,1-Trichloroethane	12.6	nd
		Trichloroethylene	0.8	9.9
		Toluene	nd	5.6
	Phenol	Pentachlorophenol	5.3	nd
	Pesticide	α-BHC	<0.01	nd
		β-BHC	<0.01	nd
		Δ-BHC	<0.01	nd
		p,p'-DDE	nd	>0.01
			10/13/78	
Toms River Water Company, Well No. 16	VO	Methylene chloride	8.7	
		1,1,1-Trichloroethane	5.8	
	Pesticide	β-BHC	0.017	
		Δ-BHC	0.022	
			10/30/78	
Garden State Water Company - Phillipsburg District, Control Station, Well C	VO	Trans-1,2-dichloroethylene	1.6	
		Chloroform	1.6	
		1,1,1-Trichloroethane	3.5	
		Trichloroethylene	4.8	
	Phenol		(not measured)	
	Pesticide	α-BHC	<0.010	
		β-BHC	0.017	
		Δ-BHC	0.015	

compounds were observed in finished waters due to final disinfection with free chlorine.

OCTSR Surface Water Study

Table IV-13 lists the compounds detected in untreated surface waters during the OCTSR Surface Water Study. Data from only those sampling sites located near intakes for water treatment plants is included. Note that the concentration peaks for 1,2-dibromoethane and tetrachloroethane were not able to be separately quantified, and thus these two compounds are listed together in this table. As observed for several groundwater sampling sites described above, the concentrations of organics detected at those surface water sites where several grab samples were taken vary with time.

OCTSR Groundwater Study

Tables IV-14 and IV-15 summarize the results of the OCTSR groundwater study as discussed in a 1981 report (NJDEP, 1981). In the two year course of this study, 1,118 samples were taken at 670 well locations throughout the state. Note that these wells include those used for industry and monitoring purposes, public water supply, and individual domestic water supply. Detailed results of the analyses of these samples were not included in the report.

Table IV-14 lists those compounds most often detected at high concentrations in the groundwater samples. These eight volatile compounds were sometimes found at concentrations greater than 100 ug/l. Table IV-15 lists the remaining volatile compounds analyzed, the percentage of samples greater than the detection limit, and the maximum concentrations observed. Note that only five volatile compounds listed in Table IV-15 were found in concentrations greater than 10 ug/l.

EPA Region II, Monitoring and Surveillance Plan

Table IV-16 lists those volatile organics detected in the finished water of 14 treatment plants throughout the state (Kahn, 1982, personal communications). In most cases, grab samples were taken once in 1980 and once in 1981. The majority of the compounds detected are only those of the THM group. Trichloroethylene was the only other volatile compound found with concentrations greater than 1 ug/l.

EPA National Groundwater Survey

Table IV-17 lists those compounds detected in the treated groundwater supplies for three purveyors listed among the top 25 (Kahn, 1982, personal communication). No compounds were detected at levels exceeding 10 ug/l.

Rutgers University Delaware and Raritan Canal Study

The extent and degree of organic contamination detected at the sampling sites along the Delaware-Raritan Canal does not differ significantly, for the organic fractions measured, compared to the results of other surface water studies

TABLE IV-12

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			8/2/79	11/7/79	
Atlantic City Water Department Pleasantville Plant	VO	Chloroform	41.0	1.83	
		Bromodichloromethane	13.2	1.62	
		Dibromochloromethane	1.0	nd	
	PCB	Arochlor 1242	>0.06	nd	
	Pesticide	β-BHC	0.034	nd	
		Heptachlor	0.062	nd	
		Heptachlor epoxide	0.033	nd	
		Endrin	0.034	nd	
		p,p'-DDT	0.090	nd	
		Δ-BHC	0.213	nd	
			11/2/78	7/31/79	9/30/80
Hackensack Water Company New Milford Plant	VO	Methylene chloride	2.40	6.1	1.71
		Trans-1,2-dichloroethylene	nd	43.1	nd
		Chloroform	47.0	nd	35.73
		1,1,1 Trichloroethane	4.70	1.7	0.30
		Bromodichloromethane	24.1	nd	14.42
		Dibromochloromethane	7.7	6.0	3.20
		Benzene	nd	5.1	nd
		Toluene	nd	nd	2.48
	Base/neutral	Bis(2-chloroethyl)ether	nd	262	nd

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			11/2/78	7/31/79	9/30/80
Hackensack Water Company (cont)	Phenol	Pentachlorophenol	15.1	nd	nd
		2,4 Dinitrophenol	30.7	nd	nd
		p-Chloro-m-cresol	10.2	nd	nd
		2,4,6-Trichlorophenol	5.4	nd	nd
		2,4-Dichlorophenol	6.4	nd	nd
		2,4-Dimethylphenol	4.5	nd	nd
		Phenol	6.3	nd	nd
		2-Chlorophenol	4.1	nd	nd
		2,4-Dinitro-o-cresol	20.90	nd	nd
	Pesticide	α-BHC	nd	0.46	nd
		β-BHC	<0.01	nd	nd
		Δ-BHC	0.013	0.229	nd
		Heptachlor epoxide	<0.01	>0.01	nd
		Endosulfane I	0.019	0.025	nd
		p,p'-DDE	nd	0.082	nd
			7/26/79	10/11/79	
New Jersey Water Company Delaware Valley District	VO	Trichloroethylene	1.0	nd	
		Bromoform	nd	2.2	
	PCB	Arochlor 1016	nd	0.061	
		Arochlor 1248	>0.06	nd	
	Pesticide	γ-BHC (Lindane)	nd	0.172	
		Δ-BHC	0.161	nd	

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/23/78	7/26/79	10/17/79
Camden City Water Department Parkside Station Plant	VO	Methylene chloride	nd	6.0	4460
		Chloroform	nd	0.9	nd
		1,2-Dichloroethane	2.2	nd	nd
		1,1,1-Trichloroethane	1.9	8.1	nd
		Carbon Tetrachloride	nd	9.4	nd
		Trichloroethylene	12.4	22.1	21.5
		1,1,2,2-Tetrachloroethene	5.4	12.8	nd
		Chlorobenzene	0.4	nd	nd
	Phenol	Pentachlorophenol	13.5	nd	nd
	PCB	Arochlor 1248	nd	0.396	nd
	Pesticide	β-BHC	<0.010	nd	nd
		Δ-BHC	<0.010	nd	0.091
		Heptachlor epoxide	nd	2.039	>0.01
		p,p'-DDE	nd	nd	0.113
		Endrin	nd	0.251	nd
		p,p'-DDT	nd	0.556	nd
			10/25/78	7/26/79	
Merchantville-Pennsauken Commission Park Avenue Wellfield	VO	Methylene chloride	1.0	nd	
		1,1,1-Trichloroethane	2.6	nd	
		Trichloroethylene	3.0	7.0	

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/25/78	7/26/79	
Merchantville-Pennsauken Commission (cont)	Phenol	p-Chloro-m-cresol	7.4	nd	
		2,4,6-Trichlorophenol	3.6	nd	
		2,4-Dichlorophenol	3.1	nd	
		2-Chlorophenol	1.7	nd	
	PCB	Arochlor 1016	nd	> 0.06	
	Pesticide	β-BHC	<0.01	nd	
		Δ-BHC	<0.01	nd	
		Heptachlor epoxide	nd	> 0.01	
		p,p'-DDE	nd	>0.025	
			10/24/78	7/16/79	10/10/79
East Orange Water Department Millburn Pumping Station	VO	Methylene chloride	0.9	nd	nd
		1,1,1-Trichloroethane	5.1	nd	nd
		1,1,2,2-Tetrachloroethene	nd	nd	1.2
		Toluene	nd	nd	2.2
	Phenol	Pentachlorophenol	2.6	nd	nd
		2,4,6-Trichlorophenol	1.2	nd	nd
	PCB	Arochlor 1016	nd	>0.06	nd
	Pesticide	-BHC	0.01	nd	nd
		-BHC	0.01	nd	0.255
		Endosulfane I	0.023	nd	nd

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/11/78	7/16/79	
Commonwealth Water Company Canoe Brook Pump Station, Filter Plant No. 1	VO	Methylene chloride	1.5	nd	
		Chloroform	49.9	24.9	
		1,1,1-Trichloroethane	1.2	1.8	
		Bromodichloromethane	12.1	9.4	
		Dibromochloromethane	2.9	1.3	
	Pesticide	β-BHC	<0.01	>0.01	
		Heptachlor	nd	0.076	
		Δ-BHC	nd	0.094	
		Heptachlor epoxide	nd	0.013	
			9/30/80		
Newark Water Department Pequannock Watershed Plant	VO	Methylene chloride	1.20		
		Chloroform	21.77		
		1,1,1-Trichloroethane	0.31		
	Pesticide	-BHC (lindane)	0.01		
			10/24/78	7/16/79	10/2/80
Orange Water Department Beach Street Plant	VO	Methylene chloride	0.3	nd	nd
		Chloroform	1.4	0.9	0.55
		1,1,1-Trichloroethane	4.6	1.9	nd
		Carbon Tetrachloride	nd	2.7	nd
		Bromodichloromethane	nd	1.4	nd

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/24/78	7/16/79	10/2/80
Orange Water Department (cont)	VO	Dibromochloromethane	nd	1.8	1.25
		1,1,2,2-Tetrachloroethene	0.4	nd	0.16
	Phenol	Pentachlorophenol	7.6	nd	nd
		p-Chloro-m-cresol	2.4	nd	nd
		2,4,6-Trichlorophenol	1.2	nd	nd
		2,4-Dichlorophenol	1.2	nd	nd
		Phenol	2.7	nd	nd
	Pesticide	α-BHC	< 0.01	nd	nd
		β-BHC	0.028	nd	nd
		Δ-BHC	0.018	nd	nd
		Endosulfane I	0.016	nd	nd
			9/29/80		
Jersey City Water Department Boonton Reservoir Treatment Plant	VO	Methylene chloride	0.92		
		Chloroform	6.12		
		1,1,1-Trichloroethane	0.10		
		Dibromochloromethane	0.76		
			8/30/79	11/29/79	
Elizabethtown Water Company - Princeton Division Stoney Brook Plant	VO	Methylene chloride	nd	2.21	
		Chloroform	28.1	9.74	
		Bromodichloromethane	9.9	2.76	
		Dibromochloromethane	3.8	1.05	
		Benzene	19.4	nd	

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			8/30/79	11/29/79	
Elizabethtown Water Company (cont)	Pesticide	p,p'-DDE	>0.01	0.01	
			10/1/80		
New Brunswick Water Department	VO	Methylene chloride	1.00		
		Chloroform	11.10		
		1,1,1-Trichloroethane	0.18		
		Bromodichloromethane	3.98		
		Dibromochloromethane	1.12		
		Toluene	0.42		
			10/31/79		
Perth Amboy Water Department	VO	Chloroform	1.05		
Runyon Plant	Pesticide	p,p'-DDT	0.01		
			10/12/78	8/2/79	11/8/79
Monmouth Consolidated Water Company Swimming River Plant	VO	Methylene chloride	7.5	nd	2.28
		Chloroform	72.9	50.1	22.0
		1,1,1-Trichloroethane	9.5	nd	nd
		Bromodichloromethane	17.5	26.8	13.5
		Dibromochloromethane	2.9	2.9	2.0
	Phenol	Pentachlorophenol	5.3	nd	nd
		p-Chloro-m-cresol	1.4	nd	nd

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/12/78	8/2/79	11/8/79
Monmouth Consolidated Water Company (cont)	Phenol	2,4,6-Trichlorophenol	0.8	nd	nd
		Phenol	9.9	nd	nd
		4-Nitrophenol	nd	143	nd
	PCB	Arochlor 1242	nd	>0.06	nd
	Pesticide	α -BHC	<0.01	nd	nd
		β -BHC	< 0.01	nd	nd
		Δ -BHC	nd	nd	0.248
		Heptachlor epoxide	0.014	nd	nd
		Endosulfane I	nd	nd	>0.01
		p,p'-DDE	nd	nd	0.031
		Endrin	nd	0.015	nd
			11/2/78	9/18/79	10/10/79
Boonton Water Department Old Denville Road Wellfield Plant	VO	Methylene chloride	6.7	nd	nd
		Chloroform	1.5	nd	nd
		1,1,1-Trichloroethane	31.7	nd	nd
		Bromodichloromethane	1.3	nd	nd
		Dibromochloromethane	2.9	nd	nd
		Toluene	nd	2.4	nd
	Phenol	Pentachlorophenol	4.4	nd	nd
	Pesticide	α-BHC	< 0.01	nd	nd
		β-BHC	0.015	nd	nd
		Δ-BHC	0.012	nd	nd
		Endrin	nd	>0.01	nd
		p,p'-DDT	nd	> 0.06	nd

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)		
			10/13/78	8/1/79	11/7/79
Toms River Water Company Parkway Plant	VO	Chloroform	4.3	nd	nd
		1,1,1-Trichloroethane	24.8	nd	nd
		Benzene	nd	6.3	nd
	Phenol	Pentachlorophenol	3.3	nd	nd
		p-Chloro-m-cresol	1.0	nd	nd
		2,4,6-Trichlorophenol	0.6	nd	nd
		2,4-Dichlorophenol	0.5	nd	nd
	Pesticide	β-BHC	<0.01	nd	nd
		Δ-BHC	<0.01	nd	0.272
		p,p'-DDE	nd	0.14	0.052
		Endrin	nd	nd	0.025
			9/6/79		
Hawthorne Water Department Wagaraw Road Plant	VO	1,1,1-Trichloroethane	22.5		
		Trichloroethylene	150		
		Benzene	6.6		
		1,1,2,2-Tetrachloroethene	6.6		
		Toluene	1.3		
	Pesticide	α-BHC	0.036		
		Δ-BHC	0.079		

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)
			10/1/80
Passaic Valley Water Commission Little Falls Plant	VO	Methylene chloride	2.75
		Chloroform	21.0
		1,1,1-Trichloroethane	1.16
		Bromodichloromethane	9.74
		Trichloroethylene	1.20
		Dibromochloromethane	4.36
		1,1,2,2-Tetrachloroethene	0.65
	Pesticide	γ-BHC (lindane)	0.21
		Δ-BHC	2.06
		Heptachlor epoxide	0.01
		p,p'DDE	0.01
			9/30/80
North Jersey District Water Supply Commission Wanaque Plant	VO	Methylene chloride	5.11
		Chloroform	9.49
		1,1,1-Trichloroethane	0.19
		Carbon Tetrachloride	0.14
		Toluene	1.14

TABLE IV-12 (Continued)

ORGANIC COMPOUNDS DETECTED IN FINISHED DRINKING WATERS IN THE BPW/OCTSR POTABLE WATER SURVEY

Location	Organic Fraction	Compounds(s) Detected	Date and Concentration (ug/l)
			10/1/80
Rahway Water Department	VO	Methylene chloride	0.78
		Chloroform	29.81
		Bromodichloromethane	20.00
		Trichloroethylene	0.80
		Dibromochloromethane	6.72
		Toluene	0.42
	Pesticide	α -BHC	0.16

TABLE IV-13

COMPOUNDS DETECTED IN OCTSR SURFACE WATER STUDY

		Date and Concentration (ug/l)		
Location	Compound(s) Detected	8/18/78	11/9/78	3/29/79
Wanaque River (Wanaque River Basin)				
	Fluoroform	nd	<0.5	nd
	Methyl Chloride	nd	<6.0	nd
	Methylene Chloride	< 90	<90	nd
	Chloroform	0.97	<.8	nd
	1,1,1-Trichloroethane	<2.0	<2.0	< 2.0
	Carbon Tetrachloride	nd	0.3	nd
	Trichloroethylene	1.22	<0.3	nd
	Dichlorobromomethane	<0.10	<0.1	<0.1
	Dibromochloromethane	<0.10	nd	nd
	1,2-Dibromoethane and Tetrachloroethylene	0.59	0.72	<0.06
	Bromoform	< 1.0	1.00	nd
	1,1-Dichloroethylene	<10.0	nr	<10.0
	Dibromomethane	nd	nr	nr
	trans-Dichloroethylene	nd	nr	nr
	Arochlor 1248	nd	nd	0.334
	α-BHC	<0.01	<0.01	<0.01
	β-BHC	0.114	nd	nd
	Heptachlor	nd	<0.01	nd
	γ-Chlordane	<0.01	nd	<0.01
	p,p'-DDE	nd	nd	<0.02
	Dieldrin	<0.01	nd	nd
	o,p'DDT	nd	nd	<0.04
	p,p'-DDD	<0.02	nd	<0.02
	Mirex	<0.02	nd	nd
	TOC	4.7 mg/l	2.5 mg/l	2.8 mg/l

TABLE IV-13 (Continued)

		Date and Concentration (ug/l)		
Location	Compound(s) Detected	8/18/78	11/10/78	3/2/79
Jumping Brook (Shark River Basin)				
	Vinyl Chloride	nd	nd	10.08
	Methylene Chloride	743.33	< 90	nd
	Chloroform	<0.80	<0.8	nd
	1,2-Dichloroethane	1.61	nd	nd
	1,1,1-Trichloroethane	< 2.00	<2.0	< 2.0
	Carbon tetrachloride	nd	0.22	nd
	Trichloroethylene	<0.30	0.48	nd
	Dichlorobromomethane	nd	0.23	nd
	Dibromochloromethane	nd	0.27	nd
	1,2-Dibromoethane and Tetrachloroethylene	0.09	0.13	<0.06
	Bromoform	< 1.0	nd	< 1.0
	1,1-Dichloroethylene	nd	nr	16.03
	Dibromomethane	nd	nr	nd
	trans-Dichloroethylene	<10.0	nr	nd
	Arochlor 1242	nd	nd	0.272
	α-BHC	nd	nd	< 0.01
	γ-BHC (Lindane)	nd	<0.01	< 0.01
	β-BHC	0.106	0.1	nd
	Heptachlor	nd	0.048	nd
	Aldrin	< 0.01	< 0.01	< 0.01
	Heptachlor epoxide	< 0.01	nd	nd
	γ-Chlordane	< 0.01	0.022	< 0.01
	p,p'-DDE	nd	<0.02	< 0.02
	Dieldrin	nd	<0.01	nd
	p,p'-DDD	nd	<0.02	nd
	p,p'-DDT	nd	<0.04	nd
	Fluoranthene	nd	nd	112
	TOC	5.0 mg/l	4.0 mg/l	4.5 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l) 8/16/78	11/10/78	3/21/79
Shark River (Shark River Basin)				
	Vinyl Chloride	nd	nd	6.02
	Methylene Chloride	90	< 90	nd
	Chloroform	1965	< 0.8	nd
	1,1,1-Trichloroethane	2.0	< 2.0	< 2.00
	Carbon tetrachloride	nd	0.35	< 0.10
	Trichloroethylene	0.97	< 0.3	nd
	Dichlorobromomethane	nd	< 0.1	nd
	Dibromochloromethane	< 0.10	nd	nd
	1,2-Dibromoethane and Tetrachloroethylene	0.07	0.09	< 0.06
	Bromoform	nd	< 1.0	< 1.0
	1,1-Dichloroethylene	60.68	nr	< 10
	Dibromomethane	0.10	nr	nd
	trans-Dichloroethylene	nd	nr	nd
	α-BHC	< 0.01	< 0.01	< 0.01
	γ-BHC (Lindane)	nd	nd	< 0.01
	β-BHC	0.097	0.084	0.173
	Heptachlor	nd	0.013	nd
	Aldrin	nd	nd	< 0.01
	Heptachlor epoxide	< 0.01	nd	< 0.01
	γ-Chlordane	< 0.01	< 0.01	< 0.01
	p,p'-DDE	< 0.01	nd	nd
	Dieldrin	< 0.01	nd	< 0.01
	Endrin	< 0.01	nd	nd
	o,p'-DDT	< 0.04	nd	nd
	p,p'-DDD	< 0.02	nd	nd
	p,p'-DDT	< 0.04	nd	nd
	Mirex	< 0.02	nd	nd
	Chrysene	9.9	nd	nd
	Fluoranthene	2.3	nd	nd
	TOC	4.0 mg/l	4.5 mg/l	4.0 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l) 10/12/78	2/3/79	5/2/79
Tennent Brooke (South River Basin)				
	Methylene Chloride	< 90	<90	nd
	Chloroform	0.8	< 0.8	nd
	1,2-Dichloroethane	nd	2.88	nd
	1,1,1-Trichloroethane	<2.0	<2.00	nd
	Carbon tetrachloride	<0.01	<0.10	nd
	Trichloroethylene	nd	0.31	nd
	Bromoform	<1.0	nd	nd
	1,1,2,2-Tetrachloroethane	nd	0.488	nd
	1,1-Dichloroethylene	nr	< 10.0	nd
	Dibromomethane	nr	nd	nd
	trans-Dichloroethylene	nr	159.93	nd
	Arochlor 1248	nd	nd	< 0.06
	Arochlor 1254	nd	nd	0.272
	α-BHC	0.01	<0.01	< 0.01
	γ-BHC (Lindane)	nd	< 0.01	nd
	β-BHC	0.224	0.205	0.178
	Aldrin	nd	<0.01	nd
	Heptachlor epoxide	nd	<0.01	<0.01
	γ-Chlordane	<0.01	<0.01	<0.01
	p,p'-DDE	<0.01	nd	< 0.02
	Dieldrin	<0.01	nd	< 0.01
	Mirex	nd	<0.02	nd
	TOC	5.5 mg/l	1.4 mg/l	0.2 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l)		
		9/21/78	12/14/78	3/26/79
Lawrence Brook (Lawrence River Basin)				
	Fluoroform	nd	nd	nr
	Methyl Chloride	nd	nd	nr
	Methyl Bromide	nd	nd	nr
	Vinyl Chloride	nd	nd	nr
	Methylene Chloride	133.58	90.0	nr
	Chloroform	134.61	< 0.8	nr
	1,2-Dichloroethane	< 1.6	34.64	nr
	1,1,1-Trichloroethane	< 2.0	nd	nr
	Carbon tetrachloride	0.54	0.25	nr
	Trichloroethylene	0.51	< 0.30	nr
	Dichlorobromomethane	< 0.10	0.31	nr
	1,1,2-Trichloroethane	nd	nd	nr
	Dibromochlormethane	< 0.10	nd	nr
	1,2-Dibromoethane and Tetrachlorethylene	0.42	0.83	nr
	Bromoform	nd	nd	< 1.0
	1,1-Dichloroethylene	208.01	nd	nr
	Dibromomethane	< 0.10	< 0.10	nr
	trans-Dichloroethylene	< 10.0	nd	nr
	Arochlor 1242	nd	nd	0.262
	α-BHC	nd	nd	< 0.01
	γ-BHC (Lindane)	nd	< 0.01	< 0.01
	δ-BHC	0.126	< 0.01	0.047
	Heptachlor	nd	0.083	nd
	Aldrin	nd	< 0.01	nd
	Heptachlorepoxide	0.012	< 0.01	nd
	γ-chlordane	< 0.01	< 0.01	< 0.01
	p,p'-DDE	< 0.01	< 0.02	< 0.02
	Dieldrin	< 0.01	< 0.01	nd
	p,p'-DDT	nd	< 0.04	nd
	TOC	9.5 mg/l	6.4 mg/l	3.4 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l) 1/28/79
Delaware River (Delaware River Basin)		
	Methylene Chloride	< 90
	1,1,1-Trichloroethane	< 2.0
	Arochlor 1248	< 0.06
	γ-BHC (Lindane)	< 0.01
	p,p'-DDE	< 0.02
	TOC	4.0 mg/l

Location	Compound(s) Detected	8/31/78	12/13/78
Saddle River (Hackensack River Basin)			
	Methylene Chloride	< 90	< 90
	Chloroform	< 0.8	nd
	1,2-Dichloroethane	1.64	nd
	1,1,1-Trichloroethane	< 2.00	< 2.00
	Trichloroethylene	< 0.3	< 0.3
	1,2-Dibomoethane and Tetrachloroethylene	< 0.6	nd
	Bromoform	nd	< 1.0
	1,1-Dichloroethylene	< 10.0	nd
	Dibromomethane	< 0.10	nd
	trans-Dichloroethylene	< 10.0	nd
	α-BHC	nd	0.011
	γ-BHC (Lindane)	nd	< 0.01
	β-BHC	0.168	nd
	Heptachlor	nd	0.103
	Aldrin	nd	< 0.01

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l)		
		8/31/78	12/13/78	
Saddle River (Hackensack River Basin) (Continued)				
	Heptachlor epoxide	0.011	<0.01	
	γ-Chlordane	<0.01	<0.01	
	p,p'-DDE	<0.01	<0.02	
	Dieldrin	<0.01	<0.01	
	Endrin	nd	<0.01	
	o,p'-DDT	nd	<0.04	
	p,p'-DDD	nd	<0.02	
	p,p'-DDT	nd	<0.04	
	TOC	5.0 mg/l	7.5 mg/l	
		8/31/78	12/14/78	3/30/79
Rahway River (Rahway River Basin)				
	Methylene Chloride	<90.0	<90.0	nd
	Chloroform	<0.8	<0.80	<0.8
	1,1,1-Trichloroethane	5.06	< 2.0	<2.0
	Carbon tetrachloride	0.22	nd	nd
	Trichloroethylene	0.57	< 0.30	3.84
	Dichlorobromomethane	<0.10	0.56	<0.10
	1,2-Dibromoethane and Tetrachloroethylene	0.95	nd	0.10
	Bromoform	<1.00	nd	nd
	-dichlorobenzene	nd	nd	5.17
	1,1-Dichloroethylene	<10.0	nd	<10.0
	trans-Dichloroethylene	<10.0	nd	nd

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l) 8/31/78	12/14/78	3/30/79
Rahway River (Rahway River Basin) (Continued)				
	Arochlor 1242	nd	nd	0.276
	α-BHC	<0.01	<0.01	nd
	γ-BHC (Lindane)	<0.01	<0.01	nd
	β-BHC	0.167	0.219	nd
	Heptachlor	nd	0.298	0.044
	Aldrin	nd	< 0.01	nd
	Heptachlor epoxide	0.022	0.013	0.016
	γ-Chlordane	0.01	< 0.01	<0.010
	p,p'-DDE	<0.01	< 0.02	<0.020
	Dieldrin	<0.01	< 0.01	nd
	o,p'-DDT	<0.04	nd	nd
	p,p'-DDD	<0.02	< 0.02	nd
	p,p'-DDT	< 0.04	nd	nd
	TOC	4.2 mg/l	5.5 mg/l	7.5 mg/l

Location	Compound(s) Detected	9/22/78	3/1/79
Clyde Potts Reservoir (Whippany River Basin)			
	Methylene Chloride	<90.0	<90.0
	Chloroform	< 0.8	< 0.8
	1,1,1-Trichloroethane	<2.00	nd
	Carbon tetrachloride	< 0.10	nd
	1,2-Dibromoethane and Tetrachloroethylene	0.09	<0.06
	Bromoform	<1.00	nd

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l)	
		9/22/78	3/1/79
Clyde Potts Reservoir (Whippany River Basin) (Continued)			
	1,1-Dichloroethylene	10.0	nd
	trans-Dichloroethylene	10.0	nd
	γ-BHC (Lindane)	nd	< 0.01
	β-BHC	0.022	0.037
	Heptachlor epoxide	< 0.01	nd
	γ-Chlordane	nd	< 0.01
	TOC	2.5 mg/l	2.5 mg/l

		8/31/78	12/14/78	3/30/79
Robinsons Branch (Rahway River Basin)				
	Methylene Chloride	187.71	< 90.0	nd
	Chloroform	< 0.8	< 0.8	nd
	1,2-Dichloroethane	nd	1.67	nd
	1,1,1-Trichloroethane	< 2.0	nd	< 2.0
	Carbon tetrachloride	0.14	< 0.10	nd
	Trichloroethylene	< 0.3	nd	nd
	Dichlorobromomethane	nd	< 0.10	nd
	1,2-Dibromoethane and Tetrachloroethylene	> 0.12	> 0.44	nd
	Bromoform	< 1.0	nd	nd
	1,1-Dichloroethylene	< 10.0	nd	60.08
	Dibromomethane	nd	< 1.01	nr
	trans-Dichloroethylene	< 10.0	nd	nr

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l)		
		8/31/78	12/14/78	3/30/79
Robinsons Branch (Rahway River Basin) (Continued)				
	Arochlor 1242	nd	nd	0.401
	α-BHC	nd	<0.01	nd
	γ-BHC (Lindane)	nd	<0.01	<0.01
	β-BHC	0.626	0.379	nd
	Heptachlor epoxide	nd	0.039	nd
	γ-Chlordane	0.039	0.015	nd
	p,p'-DDE	<0.01	< 0.02	< 0.02
	Dieldrin	0.014	<0.01	< 0.01
	Endrin	<0.01	<0.01	nd
	o,p'-DDT	nd	< 0.04	nd
	p,p'-DDD	<0.02	< 0.02	nd
	p,p'-DDT	<0.04	nd	<0.04
	TOC	4.2 mg/l	4.0 mg/l	10.8 mg/l

Location	Compound(s) Detected	8/2978	12/19/73
Delaware and Raritan Canal (Lower Raritan River Basin)			
	Methylene Chloride	<90.0	<90.0
	1,2-Dichloroethane	3.09	nd
	1,1,1-Trichloroethane	<2.00	< 2.00
	Trichloroethylene	2.01	<0.30
	Dichlorobromomethane	nd	<0.10
	1,1,2-Trichloroethane	<0.10	nd
	Dibromochloromethane	<0.10	nd

TABLE IV-13 (Continued)

		Date and Concentration (ug/l)	
Location	Compound(s) Detected	8/2978	12/19/73
Delaware and Raritan Canal (Lower Raritan River Basin)			
	1,2-Dibromoethane and Tetrachloroethylene	> 0.15	nd
	Bromoform	< 1.0	nd
	Diodomethane	< 0.30	nd
	m-dichlorobenzene	< 1.25	nd
	1,1-Dichloroethylene	10.45	nr
	Dibromomethane	< 0.10	nr
	trans-Dichloroethylene	1248.98	nr
	α-BHC	< 0.01	nd
	γ-BHC (Lindane)	nd	0.132
	β-BHC	0.093	nd
	Heptachlor	0.033	nd
	Heptachlor epoxide	nd	< 0.01
	γ-Chlordane	nd	< 0.01
	p,p'-DDE	nd	< 0.02
	Dieldrin	< 0.01	< 0.01
	p,p'-DDT	nd	< 0.04
	TOC	2.0 mg/l	6.6 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l)	
		8/23/78	12/01/78
Delaware and Raritan Canal (Lower Raritan River Basin)			
	Methylene Chloride	nd	< 90
	Chloroform	< 0.8	< 0.8
	1,2-Dichloroethane	< 2.00	< 1.6
	1,1,1-Trichloroethane	< 0.1	< 2.0
	Carbon tetrachloride	< 0.3	< 0.1
	Trichloroethylene	< 0.1	< 0.3
	Dichlorobromomethane	nd	< 0.1
	1,2-Dibromoethane and Tetrachloroethylene	0.14	0.12
	Bromoform	< 1.0	nd
	1,1-Dichloroethylene	21.43	nd
	trans-Dichloroethylene	12.62	11.41
	Arochlor 1242	nd	0.185
	α-BHC	< 0.01	nd
	β-BHC	0.145	nd
	Heptachlor	0.067	0.018
	Aldrin	nd	< 0.01
	γ-Chlordane	< 0.01	< 0.01
	p,p'-DDE	< 0.01	< 0.02
	Dieldrin	< 0.01	nd
	Endrin	< 0.01	nd
	p,p'-DDD	< 0.02	nd
	p,p'-DDT	nd	< 0.04
	TOC	3.5 mg/l	7.9 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l) 8/30/78	12/21/78
Delaware and Raritan Canal (Millstone River Basin)			
	Methylene Chloride	< 90	< 90
	Chloroform	<0.8	nd
	1,1,1-Trichloroethane	<2.00	< 2.00
	Carbon tetrachloride	0.43	< 0.1
	Trichloroethylene	0.75	< 0.3
	Dichlorobromomethane	<0.10	1.03
	1,2-Dibromoethane and Tetrachloroethylene	> 0.30	0.10
	Bromoform	nd	<1.00
	1,1-Dichloroethylene	nd	<10.0
	trans-Dichloroethylene	< 10.0	13.06
	α-BHC	<0.01	<0.01
	γ-BHC (Lindane)	nd	<0.01
	β-BHC	0.518	nd
	Heptachlor	0.087	nd
	Aldrin	nd	<0.01
	Heptachlorepoxide	nd	<0.01
	γ-Chlordane	<0.01	<0.01
	p,p'-DDE	<0.01	< 0.02
	Dieldrin	<0.01	< 0.01
	o,p'-DDT	< 0.04	nd
	p,p'-DDD	< 0.02	nd
	p,p'-DDT	< 0.04	nd
	TOC	3.5 mg/l	4.5 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l)	
		9/12/78	1/26/79
Oradell Reservoir (Hackensack River Basin)			
	Methylene Chloride	<90	nd
	Chloroform	<0.8	<0.8
	1,1,1-Trichloroethane	<2.00	<2.00
	Trichloroethylene	1.81	<0.3
	Dichlorobromomethane	nd	<0.1
	1,1,2-Trichloroethane	<1.00	nd
	1,2-Dibromoethane and Tetrachloroethylene	0.27	<0.06
	1,1-Dichloroethylene	nd	nr
	Dibromomethane	0.17	nr
	trans-Dichloroethylene	17.49	nr
	Arochlor 1016	nd	nr
	Arochlor 1242	nd	nr
	Arochlor 1248	nd	nr
	Arochlor 1254	nd	nr
	α-BHC	nd	nr
	γ-BHC (Lindane)	nd	nr
	β-BHC	0.105	nr
	Heptachlor	nd	nr
	Aldrin	nd	nr
	Heptachlorepoxide	<0.01	nr
	γ-Chlordane	<0.01	nr
	p,p'-DDE	<0.01	nr
	Dieldrin	<0.01	nr
	Endrin	nd	nr
	o,p'-DDT	nd	nr
	p,p'-DDD	<0.02	nr
	p,p'-DDT	nd	nr
	Mirex	nd	nr
	Methoxychlor	nd	nr
	TOC	24.5 mg/l	7.8 mg/l

TABLE IV-13 (Continued)

Location	Compound(s) Detected	Date and Concentration (ug/l) 9/13/78	 2/15/79
Boonton Reservoir (Rockaway River Basin)			
	Methylene Chloride	<90	nd
	Chloroform	<0.8	nd
	1,1,1-Trichloroethane	<2.00	nd
	Carbon tetrachloride	1.63	< 0.3
	Trichloroethylene	< 0.3	nd
	Dichlorobromomethane	< 0.1	nd
	Dibromochloromethane	nd	0.16
	1,2-Dibromoethane and Tetrachloroethylene	0.07	nd
	1,1-Dichloroethylene	<10.0	<10.0
	trans-Dichloroethylene	25.37	nd
	α-BHC	<0.01	nd
	γ-BHC (Lindane)	nd	<0.01
	β-BHC	0.046	0.179
	Aldrin	nd	<0.01
	Heptachlorepoxide	<0.01	<0.01
	γ-Chlordane	nd	<0.01
	p,p'-DDE	nd	nd
	TOC	3.7 mg/l	2.1 mg/l

---

nd - not detected

nr - not reported

TABLE IV-14

MOST COMMON VOLATILE ORGANIC COMPOUNDS DETECTED IN OCTSR GROUNDWATER SURVEY

Compound	Percent of Samples > DL[1]	Number of Samples >10 ug/l[1]	Number of Wells[2] >10 ug/l	Number of Wells[2] >100 ug/l
Carbon tetrachloride	26.8%	6	5	2
Chloroform	14.5	24	24	3
1,2-Dichloroethane	5.8	22	18	0
Tetrachloroethylene	22.7	16	16	2
1,1,1-Trichloroethane	21.0	83	65	5
Trichloroethylene	26.4	52	27	12
Dichlorobenzene	4.8	8	8	2
Trichlorobenzene	1.5	4	4	1

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[1] Total number of samples = 1,118

[2] Total number of wells sampled = 670

TABLE IV-15

ADDITIONAL VOLATILE ORGANIC COMPOUNDS DETECTED IN OCTSR GROUNDWATER SURVEY

Compound	Percent of Samples $>$ DL[1]	Number of Samples $>$ 10 ug/l	Maximum Concentration Observed (ug/l)
Bromoform	1.5%	1	34.3
1,1,2-Trichloroethane	2.0	1	31.1
Dichlorobromomethane	7.0	1	43.0
Dibromomethane	0.5	2	44.9
1,2-Dibromoethane	3.6	4	48.8
Fluoroform	0.8	0	3.5
Methyl chloride	0.0	0	nd
Methyl bromide	0.3	0	7.4
Vinyl chloride	0.4	0	9.5
Dibromochloromethane	4.8	0	2.4
1,1,2,2-Tetrachloroethane	2.1	0	2.7
Diiodomethane	1.4	0	2.0

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1. Total number of Samples = 1,118
nd = Not detected

TABLE IV-16

ORGANIC COMPOUNDS DETECTED IN EPA REGION II MONITORING AND SURVEILLANCE PROGRAM

Purveyor	Date	Compound(s) Detected	Concentration (ug/l)
Commonwealth Water Company - Canoe Pump Station	7/22/80	Chloroform	88.0
		Dichlorobromomethane	13.0
		Chlorodibromomethane	2.1
	8/3/81	Chloroform	75.0
		Dichlorobromomethane	14.0
		Chlorodibromomethane	1.6
Elizabethtown Water Company - Baritan-Millstone Plant	7/22/80	Chloroform	45.0
		Dichlorobromomethane	9.0
		Chlorodibromomethane	2.0
	8/3/81	Chloroform	136.0
		Dichlorobromomethane	13.0
		Chlorodibromomethane	0.7
Elizabethtown Water Company - Stoney Brook Plant	7/22/80	Chloroform	29.0
		Dichlorobromomethane	7.2
		Chlorodibromomethane	1.3
Jersey City Water Department - Boonton Reservoir Plant	7/30/80	Chloroform	8.7
		Dichlorobromomethane	2.1
		Chlorodibromomethane	0.48
		Chlorobenzene	0.09
		1,3-Dichloropropylene	0.11
Middlesex Water Company	7/22/80	Chloroform	41.0
		Dichlorobromomethane	13.0
		Chlorodibromomethane	2.8
		2,4-D	0.31
	8/3/81	Chloroform	36.0
		Dichlorobromomethane	10.0
		Chlorodibromomethane	1.6
Monmouth Consolidated Water Company - Jumping Brook Plant	7/22/80	Chloroform	10.0
		Dichlorobromomethane	2.6

TABLE IV-16 (Continued)

ORGANIC COMPOUNDS DETECTED IN EPA REGION II MONITORING AND SURVEILLANCE PROGRAM

Purveyor	Date	Compound(s) Detected	Concentration (ug/l)
	8/3/81	Chloroform	33.0
		Dichlorobromomethane	13.0
		Chlorodibromomethane	5.0
Monmouth Consolidated Water Company - Swimming River Plant	7/22/80	Chloroform	37.0
		Dichlorobromomethane	12.0
		Chlorodibromomethane	2.9
	8/3/81	Chloroform	46.0
		Dichlorobromomethane	14.0
		Chlorodibromomethane	4.0
Newark Water Department	7/22/80	Chloroform	53.0
		Dichlorobromomethane	3.2
	8/3/81	Chloroform	46.0
		Dichlorobromomethane	6.0
		Chlorodibromomethane	0.6
North Jersey District Water Supply Comm.	7/21/80	Chloroform	29.0
		Dichlorobromomethane	4.3
	8/3/81	Chloroform	18.0
		Dichlorobromomethane	3.0
Passaic Valley Water Commission	7/22/80	Chloroform	77.0
		Dichlorobromomethane	33.0
		Chlorodibromomethane	8.0
		γ-BHC	0.0032
		2,4-D	0.18
	8/3/81	Chloroform	103.0
		Dichlorobromomethane	27.0
		Chlorodibromomethane	4.0
Perth Amboy Water Department - Runyon Wellfield Plant	7/22/80	Chloroform	1.4
	8/3/81	(nothing detected)	

TABLE IV-16 (Continued)

ORGANIC COMPOUNDS DETECTED IN EPA REGION II MONITORING AND SURVEILLANCE PROGRAM

Purveyor	Date	Compound(s) Detected	Concentration (ug/l)
Garden State Water Company	7/21/80	Chloroform	7.7
		Dichlorobromomethane	5.4
		Chlorodibromomethane	3.1
	8/3/81	Chloroform	12.0
		Dichlorobromomethane	8.0
		Chlorodibromomethane	5.0
		Trichloroethylene	1.8
Rahway Water Company	7/22/80	Chloroform	51.0
		Dichlorobromomethane	24.0
		Chlorodibromomethane	10.0
		Trichloroethylene	1.4
	8/3/81	Chloroform	58.0
		Dichlorobromomethane	16.0
		Chlorodibromomethane	4.0
		Trichloroethylene	2.0
Toms River Water Company - Holly Street Plant	7/22/80	(nothing detected)	
	8/3/81	(nothing detected)	

TABLE IV-17

ORGANIC COMPOUNDS DETECTED IN EPA NATIONAL GROUNDWATER SURVEY[1]

Purveyor	Date	Compound(s) Detected	Concentration (ug/l)
Merchantville - Pennsauken Commission	4/9/81	Cis- and/or Trans-1,2 dichloroethylene	0.57
		Trichloroethylene	7.2
		TOC	0.3 (mg/l)
Garden State Water Company - Phillisburg District	4/8/81	Chloroform	7.8
		Bromodichloromethane	4.7
		Dibromochloromethane	4.8
		Carbon tetrachloride	0.82
		Trichloroethylene	1.2
		TOC	1.3 (mg/l)
Camden Water Department	4/15/81	Chloroform	2.1
		Bromodichloromethane	0.9
		1,2-Dichloroethane	0.53
		1,2-Dichloropropane	1.7
		TOC	1.3 (mg/l)

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[1] For those purveyors listed in Table IV-1

summarized in this section (Rutgers, 1982). The most important finding of this study was the variation in organics concentration during storm events compared to average conditions. Concentrations of PCBs in samples taken after storms were higher than in average samples. The highest PCB concentrations were measured in the canal after passage through the conduits at Trenton. In addition, trihalomethane formation potential increased during storm events.

Public Water System Inventory Database

Quarterly THM concentrations for those purveyors serving more than 75,000 persons are listed in Table IV-18. Based on a running yearly average of sequential samples, the only purveyor exceeding the MCL of 100 ug/l was the Hackensack Water Company. A change in disinfection practices in the first quarter of 1982 has resulted in lower THM concentrations since then for this purveyor.

PURVEYOR-SPECIFIC SUMMARIES

Hackensack Water Company

Figures IV-6a, b, and c show the variation of TOC, color, ammonia nitrogen, total organic nitrogen (TON), fecal coliform, and fecal streptococci with stream flow for water years 1976 through 1981 at Riverdale, New Jersey (USGS, 1976-81). Relationships between streamflow and TOC have been investigated in Switzerland (Stumm and Morgan, 1981), and show decreasing TOC concentrations with increasing streamflow, which indicates that higher streamflows may have a dilution effect on background TOC levels. Similar relationships between streamflow and NH_3-N, TON, fecal coliform, and fecal streptococci can be expected. However, such a simple relationship will not be the case if runoff during high flow periods contributes to the background TOC concentration. These figures are presented to illustrate such relationships in the water supply for the Hackensack Water Company, and to illustrate typical background concentrations measured.

A statistical analysis of these parameters is presented in Table IV-19. For each parameter the number of samples, median, 90 percentile value, range, mean, standard deviation, geometric mean and geometric standard deviation are listed. The mean and standard deviation describe the characteristics of water quality parameters which are normally distributed, while the geometric mean and geometric standard deviation describe the characteristics of log-normally distributed data. Previous data suggests that the median value of TOC concentration measured over the period of record is an indication of the potential for the formation of THMs where free chlorine is used in water treatment. Assuming a 50 percent removal of TOC during treatment, water from the Hackensack River would have a median TOC concentration of 3 mg/l prior to disinfection. Experience indicates that generally, between 20 and 50 ug of THMs are formed per mg of TOC by disinfection with free chlorine. Thus, there is a potential for the formation of 90 to 150 ug/l of THMs in this water supply. Measured THM concentrations for the Hackensack Water Company prior to March 1982, before chloramines were instituted for disinfection, show a range of 38 to 280 ug/l.

TABLE IV-18

QUARTERLY THM CONCENTRATIONS FOR PURVEYORS SERVING MORE THAN 75,000 PERSONS

Purveyor	1981				1982			
	I	II	III	IV	I	II	III	IV
Hackensack Water Co.	197	150	277	38 (166)	29 (124)	78 (106)	86 (58)	nr
Commonwealth Water Co.	19	59	26	30 (34)	nr	nr	nr	nr
Newark Water Dept.	nr	nr	nr	nr	nr	nr	nr	nr
Jersey City Water Dept.	19	9	nr	40	nr	30	nr	nr
New Jersey Water Co. - Haddon District	nr	nr	0	2	1	nr	nr	nr
Trenton Water Dept.	nr	nr	nr	nr	nr	60	nr	nr
Monmouth Consolidated Water Company	nr	60	97	35	19 (53)	31 (46)	nr	nr
Passaic Valley Water Commission	nr	nr	73	47	37	42 (50)	66 (48)	54 (50)
North Jersey District Water Supply Commission	35	60	60	nr	nr	nr	nr	nr
Elizabethtown Water Co.	31	67	97	41 (59)	34 (59)	54 (63)	nr	nr
Middlesex Water Co.	30	30	30	30 (30)	30 (30)	20 (28)	nr	nr

Note: Figure in parentheses represents running yearly average based on four previous quarterly samples.
Concentrations in ug/l.
nr = not reported

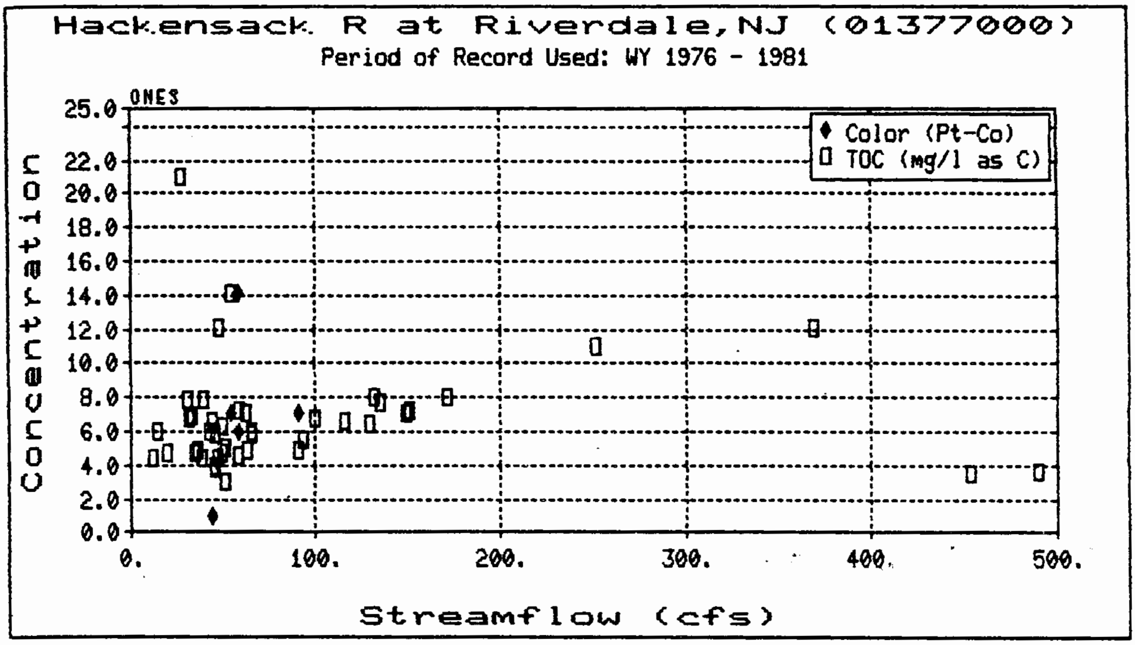

FIGURE IV-6a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, HACKENSACK RIVER AT RIVERDALE, NJ

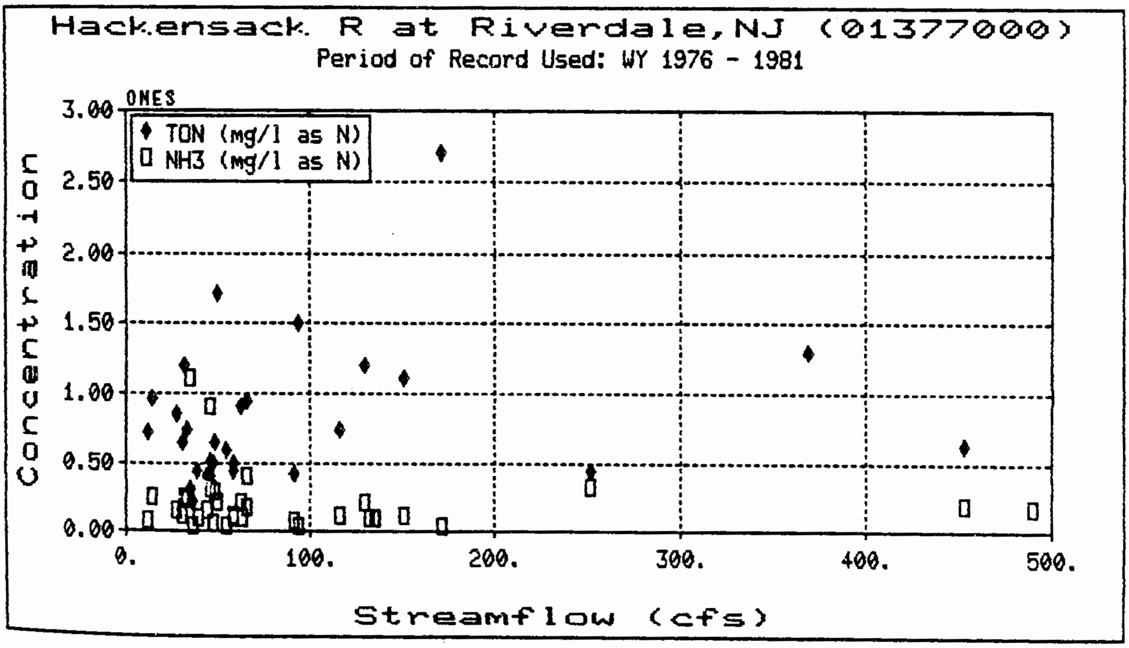

FIGURE IV-6b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, HACKENSACK RIVER AT RIVERDALE, NJ

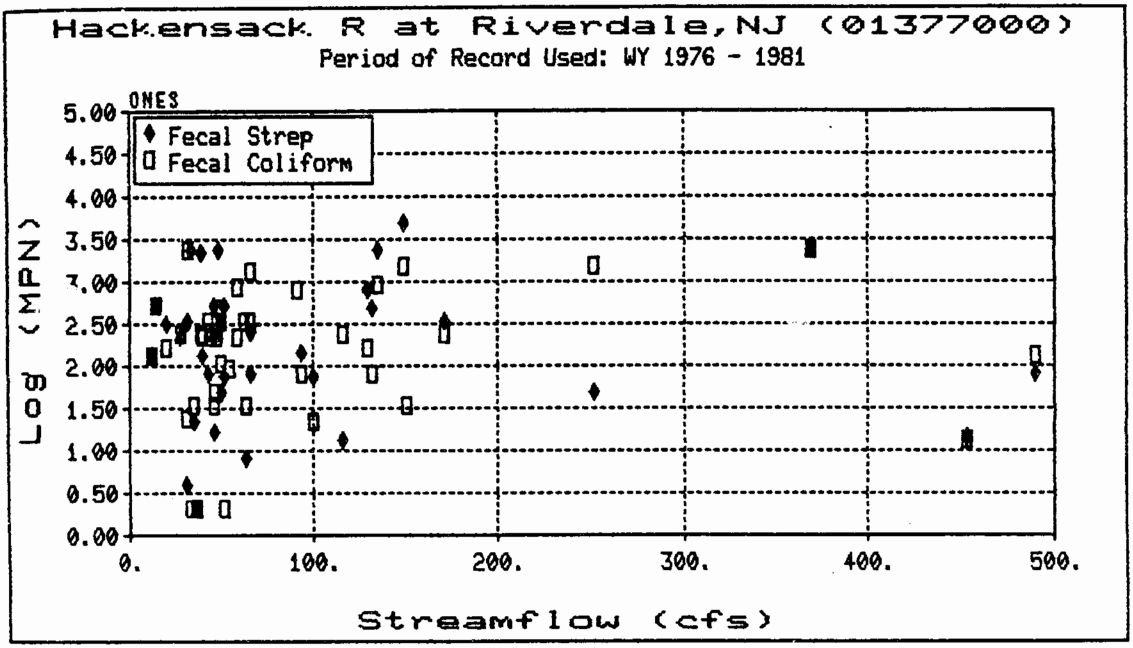

FIGURE IV-6c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, HACKENSACK RIVER AT RIVERDALE, NJ

TABLE IV-19

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - HACKENSACK RIVER AT RIVERDALE, NEW JERSEY

Period of Record Used: WY 1976 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	43	/	43
Median / 90th Pcnt.	6.0	/	11.0
Range	3.0	-	21.0
Mean / Std. Dev.	6.6	/	3.2
Geom. Mean / Std. Dev.	6.1	/	1.4

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	33	/	33
Median / 90th Pcnt.	.15	/	.31
Range	.02	-	1.10
Mean / Std. Dev.	.20	/	.22
Geom. Mean / Std. Dev.	.14	/	2.27

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	29	/	29
Median / 90th Pcnt.	.63	/	1.50
Range	.20	-	2.70
Mean / Std. Dev.	.81	/	.50
Geom. Mean / Std. Dev.	.69	/	1.74

Fecal Coliform (MPN)

Number Used/Number	42	/	42
Median / 90th Pcnt.	270	/	1300
Range	2	-	2400
Mean / Std. Dev.	418	/	594
Geom. Mean / Std. Dev.	145	/	5

Fecal Streptococci (MPN)

Number Used/Number	35	/	35
Median / 90th Pcnt.	211	/	2400
Range	2	-	5000
Mean / Std. Dev.	662	/	1074
Geom. Mean / Std. Dev.	167	/	6

TOC was the only organic compound analyzed in this monitoring program. The other parameters listed in Table IV-19 were chosen because they are indicative of upstream sewage contamination. Such contamination may affect drinking water treatment processes necessary to provide finished water of required organic quality and microbiological quality. When the concentration of a certain parameter was reported as less than a given value, that value was used in the analysis (e.g., "less than 1 mg/l" was included in the data base as "1 mg/l"). A similar approach was used for those parameters reported as "greater than" a certain value.

The concentration variations for six parameters with stream flow for the Saddle River near Lodi, which is used as a source by the Hackensack Water Company during low flow period, are shown Figure IV-7a, b, and c (USGS, 1976-81). A statistical analysis of these parameters is presented in Table IV-20. Note the higher median value for TOC in this water supply which indicates a higher potential for THM formation. Also, the Saddle River shows an order of magnitude higher mean ammonia concentration than the Hackensack River which suggests upstream discharges of municipal wastewater.

Table IV-21 lists the results of finished water monitoring at four times throughout the drought period. Note that the total THM concentration measured in the treatment plant effluent would likely be higher further out in the distribution system. Six other volatile organic compounds were measured in the study and are also reported in Table IV-20.

Figure IV-8 presents a more detailed picture of the relationship between TOC and stream flow. Influent TOC values were measured for an ozone pilot plant study from February through May of 1980 (Fung, 1982, personal communication). Average daily stream flows in the Hackensack River were obtained from New Jersey Water Resources Data (USGS, 1980). TOC concentrations ranged from 3 to 9.7 mg/l, while stream flows ranged from 14 to 808 cfs. These two parameters, as a function of time, are plotted in Figure IV-8. No clear relationship between stream flow and TOC is indicated at this location.

Two grab samples taken on 23 April and 13 May 1981 in the finished water were analyzed for organic priority polutants. Concentrations of organics in this category were reported as below detection limits (Fung, 1982, personal, communication).

North Jersey District Water Supply Commission

Six grab samples of the finished water at the Wanaque Reservoir water treatment plant were taken during the period of the recent drought. The results are shown in Table IV-22. The results are characterized by low concentrations of total THMs at the treatment plant. This was most likely due to lower temperatures during the winter months. Higher concentrations of THMs would be expected if a drought were to occur during the hotter summer months.

Trihalomethane formation potential (THMFP) was investigated in studies conducted by the EPA (EPA, 1980). Six samples were taken in Fall 1980, dosed

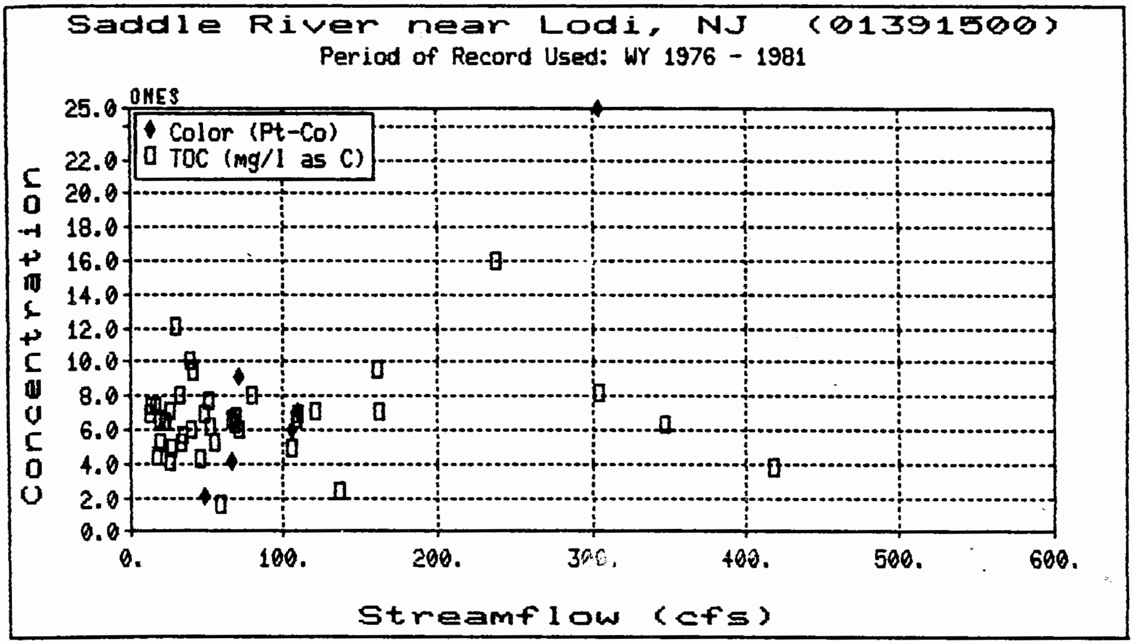

FIGURE IV-7a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, SADDLE RIVER NEAR LODI, NJ

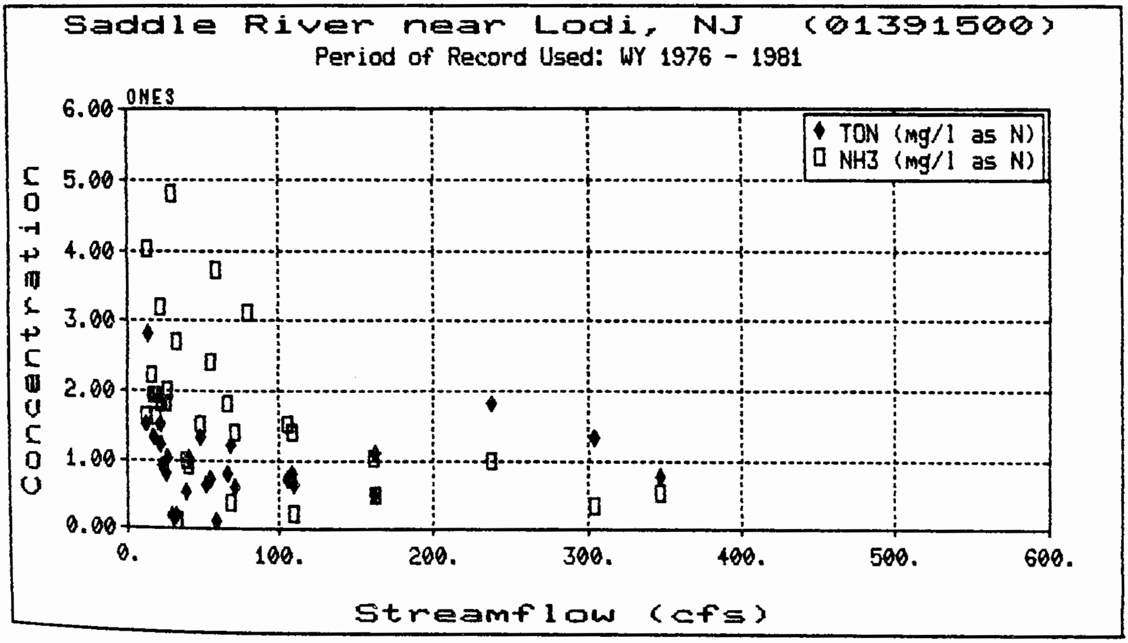

FIGURE IV-7b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, SADDLE RIVER NEAR LODI, NJ

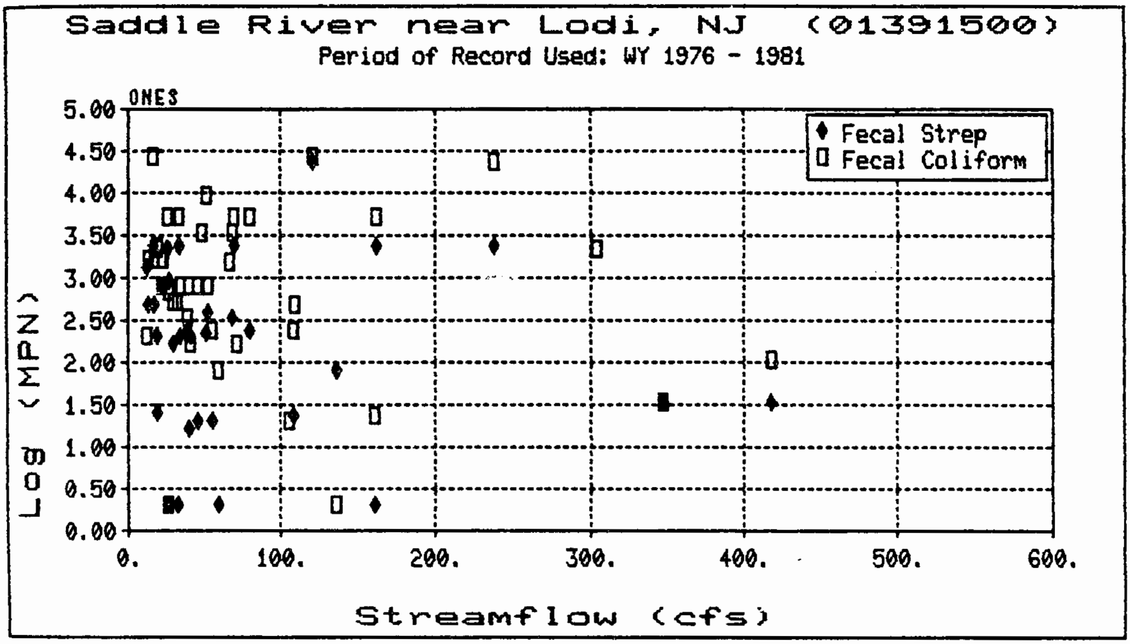

FIGURE IV-7c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, SADDLE RIVER NEAR LODI, NJ

TABLE IV-20

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - SADDLE RIVER NEAR LODI, NEW JERSEY

```
  Period Of Record Used: WY 1976 - WY 1981

      Total Organic Carbon - TOC (mg/l)

Number Used/Number          41     /      41
Median / 90th Pcnt.       6.5      /    9.5
Range                     1.6      -    16.0
Mean / Std. Dev.          6.7      /    2.5
Geom. Mean / Std. Dev.    6.3      /    1.4

        Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number          32     /      32
Median / 90th Pcnt.       1.6      /    3.20
Range                     .05      -    4.80
Mean / Std. Dev.          1.69     /    1.13
Geom. Mean / Std. Dev.    1.19     /    2.77

      Total Organic Nitrogen - TON (mg/l)

Number Used/Number          29     /      29
Median / 90th Pcnt.       .89      /    1.79
Range                     .10      -    2.79
Mean / Std. Dev.          1.00     /    .55
Geom. Mean / Std. Dev.    .82      /    2.00

             Fecal Coliform (MPN)

Number Used/Number          42     /      42
Median / 90th Pcnt.       790      /    9700
Range                     2        -    28000
Mean / Std. Dev.          4050     /    7431
Geom. Mean / Std. Dev.    792      /    9

           Fecal Streptococci (MPN)

Number Used/Number          36     /      36
Median / 90th Pcnt.       230      /    2400
Range                     2        -    24000
Mean / Std. Dev.          1348     /    3926
Geom. Mean / Std. Dev.    192      /    10
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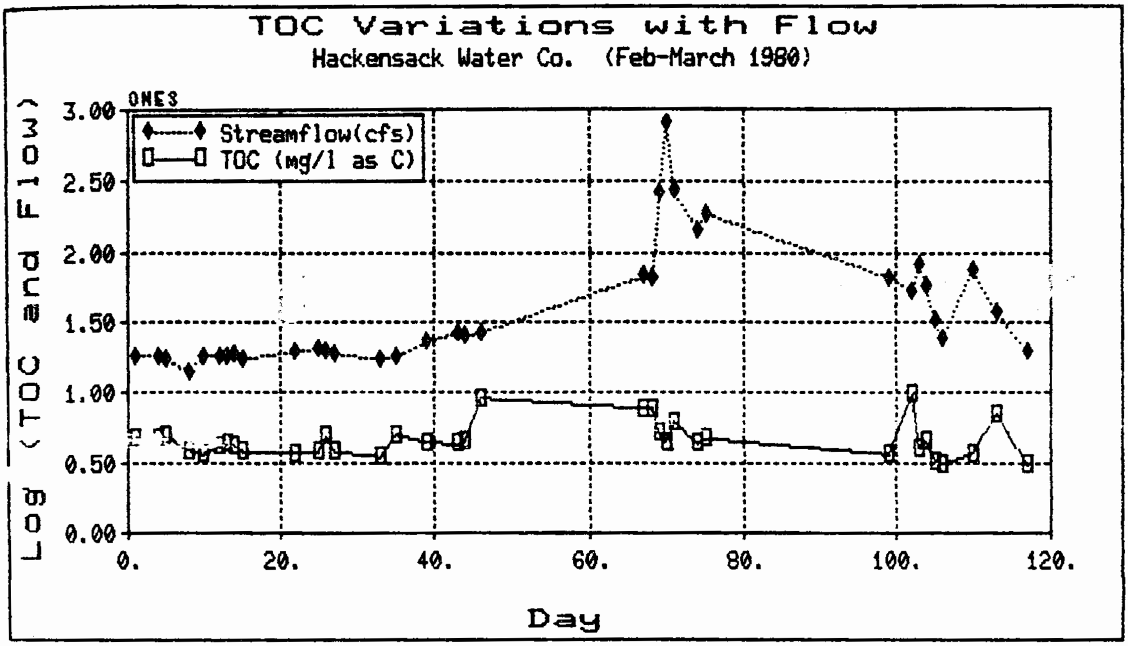

FIGURE IV-8. VARIATION OF STREAMFLOW AND TOC FROM FEBRUARY-MAY 1980 AT THE NEW MILFORD PLANT, HACKENSACK WATER COMPANY

TABLE IV-21

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT HACKENSACK WATER COMPANY DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	9/27/80	10/18/80	10/25/80	1/10/81
Chloroform	nr	64.4	64.3	38.3
Bromodichloromethane	nr	20.2	26.5	21.8
Dibromochloromethane	nr	nr	nr	7.8
Bromoform	nr	nr	nr	nd
Total THMs	111.7	84.6	90.9	67.9
Tetrachloroethylene	0.7	nr	nr	nd
Trichloroethylene	1.1	nr	nr	nd
1,1,1-Trichloroethane	0.8	nr	nr	nd
1,1-Dichloroethylene	nr	nr	nr	nd
1,2-Dichloroethylene	nr	2.8	22.0	nd
Carbon Tetrachloride	nr	nr	nr	nr

NOTE: nd = not detected
nr = not reported

TABLE IV-22

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT NORTH JERSEY DISTRICT WATER SUPPLY COMMISSION DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)					
Week Ending:	10/18/80	10/25/80	11/1/80	11/22/80	11/29/80	1/17/81
Chloroform	19.7	51.2	16.4	15.7	24.3	8.3
Bromodichloromethane	3.4	nr	16.3	nd	nd	3.1
Dibromochloromethane	nd	nr	nr	nd	nd	nr
Bromoform	nd	nr	nr	nd	nd	nd
Total THMs	23.1	51.2	16.3	15.7	24.3	11.4
Tetrachloroethylene	nd	nr	nr	nd	6.3	nd
Trichloroethylene	0.6	nr	nr	nd	6.3	nd
1,1,1-Trichloroethane	nd	nr	nr	nd	nd	nd
1,1-Dichloroethylene	nd	nr	nr	nd	6.9	nd
1,2-Dichloroethylene	10.6	20.5	16.3	24.2	nd	nd
Carbon Tetrachloride	nd	nr	nr	nd	nd	nd

NOTE: nd = not detected
nr = not reported

with chlorine at 30 mg/l at a pH between 6.9 and 7.3, and stored for six days. Terminal THM concentrations were measured at the end of this time and found to range from 49 to 81 ug/l. This indicates that THMs may not be a problem when treating this source.

Elizabethtown Water Company

Figure IV-9a, b, and c show the variation of six water quality parameters with stream flow for the Raritan River at Manville, one of the surface water supplies used by the Elizabethtown Water Company (USGS, 1976-81). Statistical analysis of these parameters is presented in Table IV-23. Table IV-24 presents the results of the analyses of three finished water samples during the drought period of 1980-1981.

Laboratory results for the analysis of untreated water from the Raritan River intake, Delaware-Raritan Canal intake, and Millstone River intake were provided for two grab samples obtained during January 1983 (Johansen, 1983, personal communication). The results for the January 5 grab sample, analyzed by EPA Method 601 (i.e., purge and trap GC analysis) (EPA, 1979), showed all compounds measured by this technique to be less than 1 ug/l in each of the three surface water samples. The January 21 grab sample, analyzed using the same technique, showed all concentrations of compounds measured by this technique to be less than 10 ug/l.

Newark Water Department

The results of five finished water samples analyzed during the drought of 1980-1981 are shown in Table IV-25. Laboratory results were obtained for the analysis of raw water and finished water for the past several months (Pappachen, 1983, personal communication). TOC concentrations measured in the five reservoirs in the Pequannock watershed ranged from less than 1 mg/l to 4.3 mg/l. The TOC in the finished water at the Charlottesburg Treatment Plant was 1 mg/l in Janaury 1983. THM concentrations in the finished water at the Charlottesburg Treatment Plant were 38.4 ug/l and 45.8 ug/l in November and December, 1982, respectively.

Passaic Valley Water Commission

The variations of five water quality parameters with stream flow for the Passaic River at Little Falls are presented in Figures IV-10a, b, and c (USGS, 1976-81). A statistical summary of water quality parameters for this location is shown in Table IV-26. Note the high median concentration of both TOC and ammonia nitrogen at this location. The variations of ammonia nitrogen with stream flow, as shown in Figure IV-10b are indicative of significant wastewater contamination upstream of Passaic Water Valley Commission's intake. This was documented in a report by the New Jersey DEP (NJ DEP, 1982b).

In contrast to the water quality shown at the existing Little Falls intake, the water quality with respect to these five parameters is superior at the Pompton River at Two Bridges. The intake for the Passaic Valley Water Commission will be moved to this location upon completion of the Wanaque South Project.

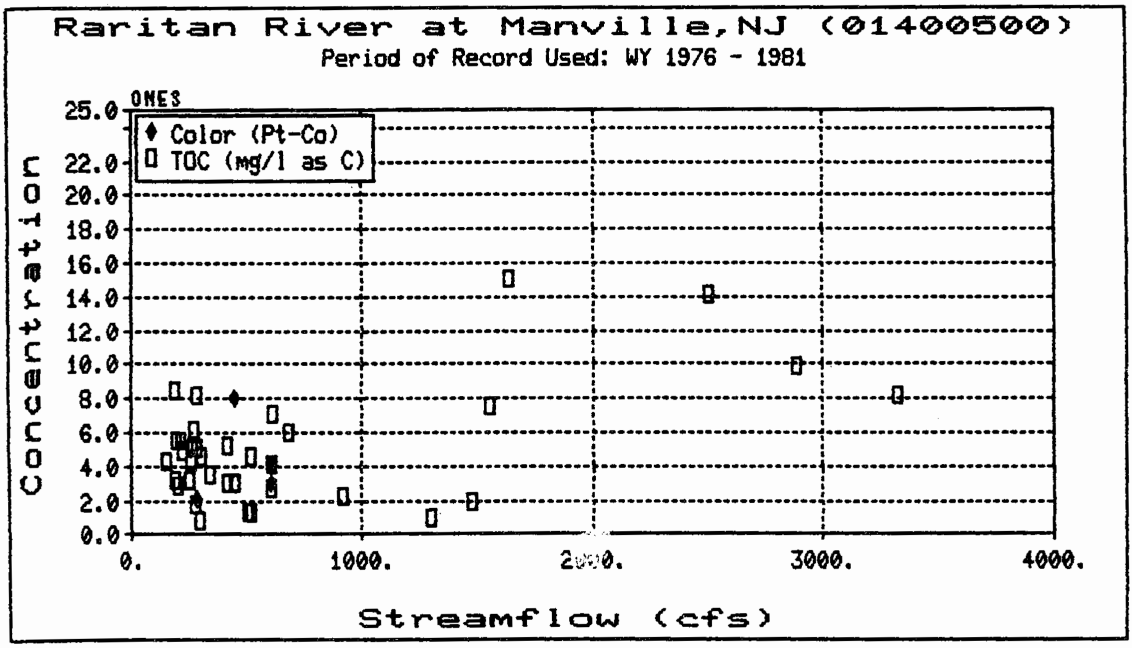

FIGURE IV-9a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, RARITAN RIVER AT MANVILLE, NJ

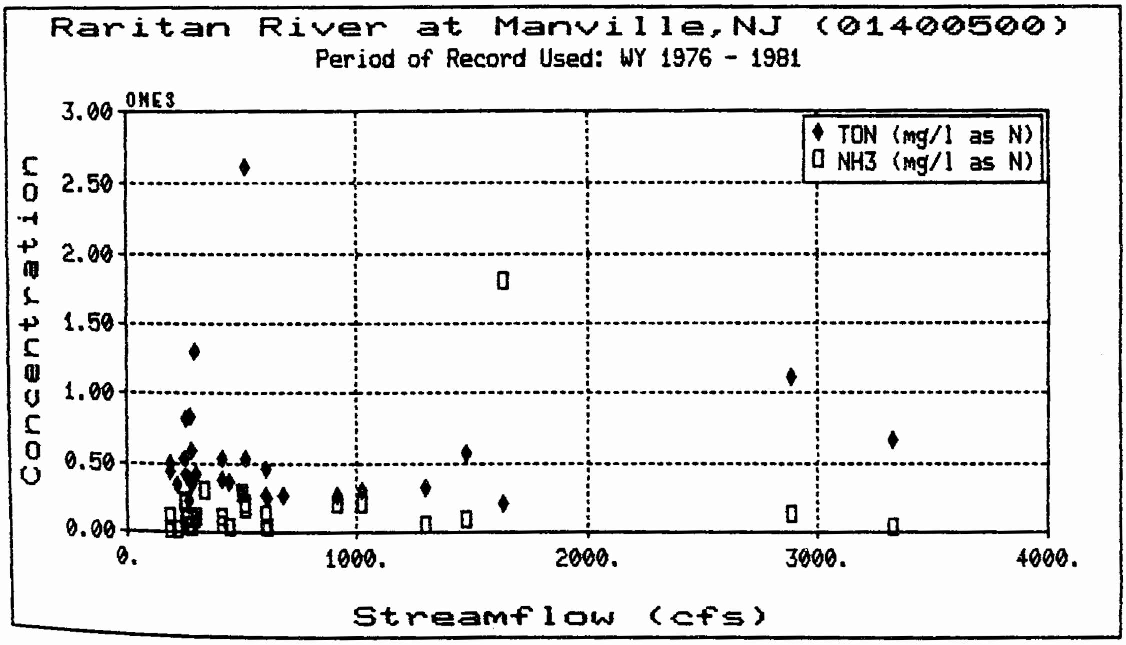

FIGURE IV-9b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, RARITAN RIVER AT MANVILLE, NJ

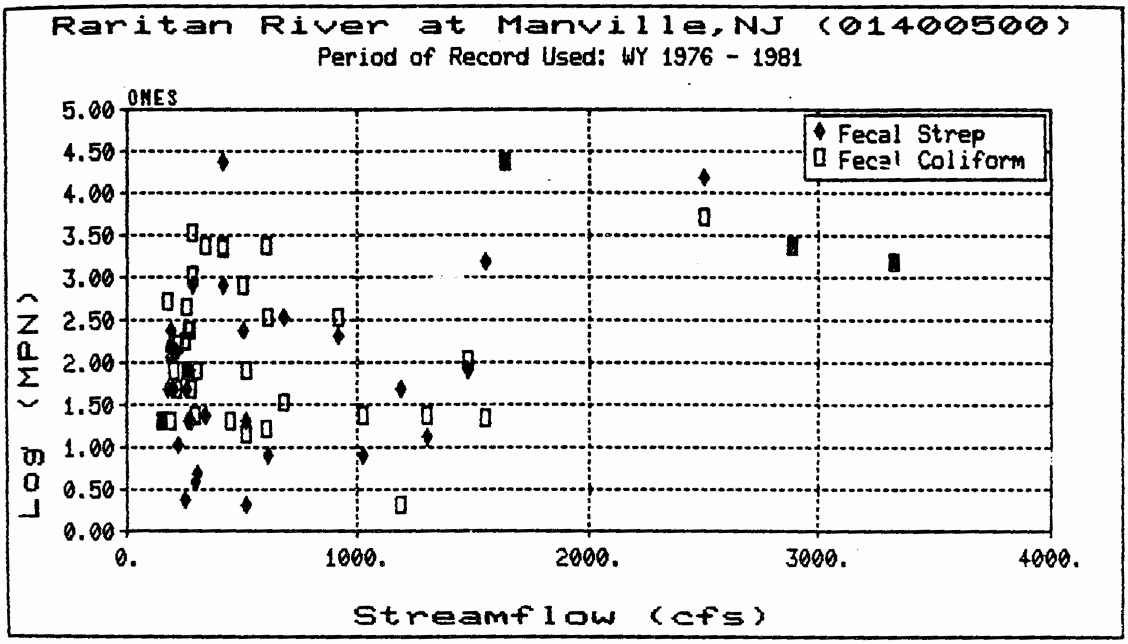

FIGURE IV-9c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, RARITAN RIVER AT MANVILLE, NJ

TABLE IV-23

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - RARITAN RIVER AT MANVILLE, NEW JERSEY

```
     Period of Record Used: WY 1976 - WY 1981


        Total Organic Carbon - TOC (mg/l)

   Number Used/Number         37     /      37
   Median / 90th Pcnt.       4.3     /     8.5
   Range                     .8      -     15.0
   Mean / Std. Dev.          4.8     /     3.1
   Geom. Mean / Std. Dev.    3.9     /     1.9


          Ammonia Nitrogen - NH3 (mg/l)

   Number Used/Number         31     /      31
   Median / 90th Pcnt.       .10     /     .21
   Range                     .00     -     1.79
   Mean / Std. Dev.          .16     /     .30
   Geom. Mean / Std. Dev.    .09     /     2.62


        Total Organic Nitrogen - TON (mg/l)

   Number Used/Number         29     /      29
   Median / 90th Pcnt.       .40     /     1.10
   Range                     .20     -     2.59
   Mean / Std. Dev.          .55     /     .461
   Geom. Mean / Std. Dev.    .45     /     1.74


              Fecal Coliform (MPN)

   Number Used/Number         40     /      40
   Median / 90th Pcnt.       130     /     2400
   Range                     2       -     24000
   Mean / Std. Dev.          1300    /     3818
   Geom. Mean / Std. Dev.    184     /     7


             Fecal Streptococci (MPN)

   Number Used/Number         36     /      36
   Median / 90th Pcnt.       79      /     2400
   Range                     2       -     24000
   Mean / Std. Dev.          2043    /     5940
   Geom. Mean / Std. Dev.    100     /     11
```

TABLE IV-24

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT ELIZABETHTOWN WATER COMPANY DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)		
Week Ending:	10/11/80	11/29/80	1/10/81
Chloroform	28.6	nr	18.6
Bromodichloromethane	9.1	nd	nd
Dibromochloromethane	3.6	nd	5.7
Bromoform	nr	nd	nd
Total THMs	41.3	nr	24.3
Tetrachloroethylene	nr	nd	nd
Trichloroethylene	nr	nd	nd
1,1,1-Trichloroethane	nr	nd	nd
1,1-Dichloroethylene	nr	nd	nd
1,2-Dichloroethylene	0.9	nd	nd
Carbon Tetrachloride	nr	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-25

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT NEWARK WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)				
Week Ending:	10/18/80	10/25/80	11/1/80	11/29/80	1/10/81
Chloroform	42	36.9	37.1	nr	25.1
Bromodichloromethane	3.1	6.7	6.9	nd	5.6
Dibromochloromethane	nr	nr	nd	nd	nd
Bromoform	nr	nr	nd	nd	nd
Total THMs	45.1	42.6	44.0	nr	30.7
Tetrachloroethylene	0.5	nd	nd	nd	nd
Trichloroethylene	nr	nr	nd	nd	nd
1,1,1-Trichloroethane	nr	nr	nd	nd	nd
1,1-Dichloroethylene	nr	nr	nd	nd	nd
1,2-Dichloroethylene	8.9	19.1	7.0	nd	nd
Carbon Tetrachloride	nr	nr	nd	nd	nd

NOTE: nd = not detected
nr = not reported

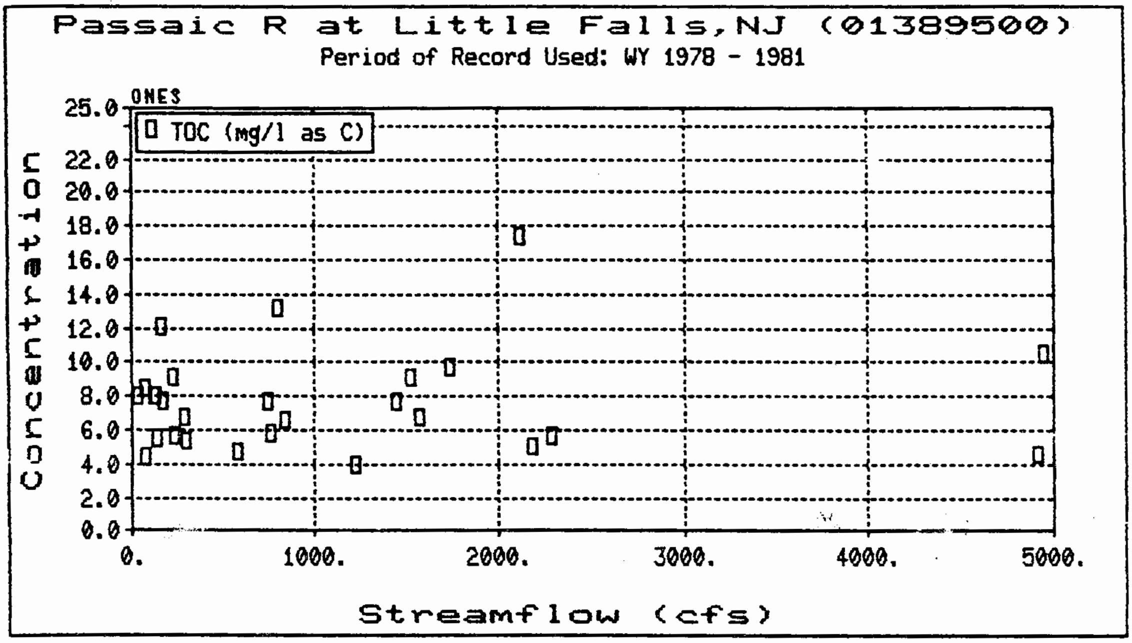

FIGURE IV-10a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, PASSAIC RIVER AT LITTLE FALLS, NJ

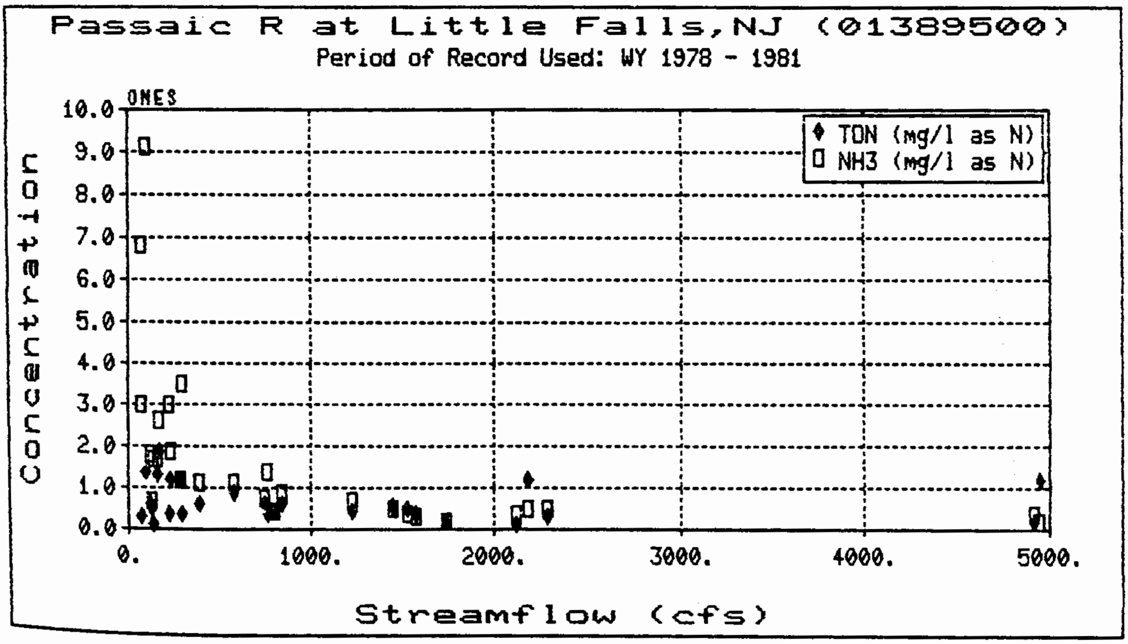

FIGURE IV-10b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, PASSAIC RIVER AT LITTLE FALLS, NJ

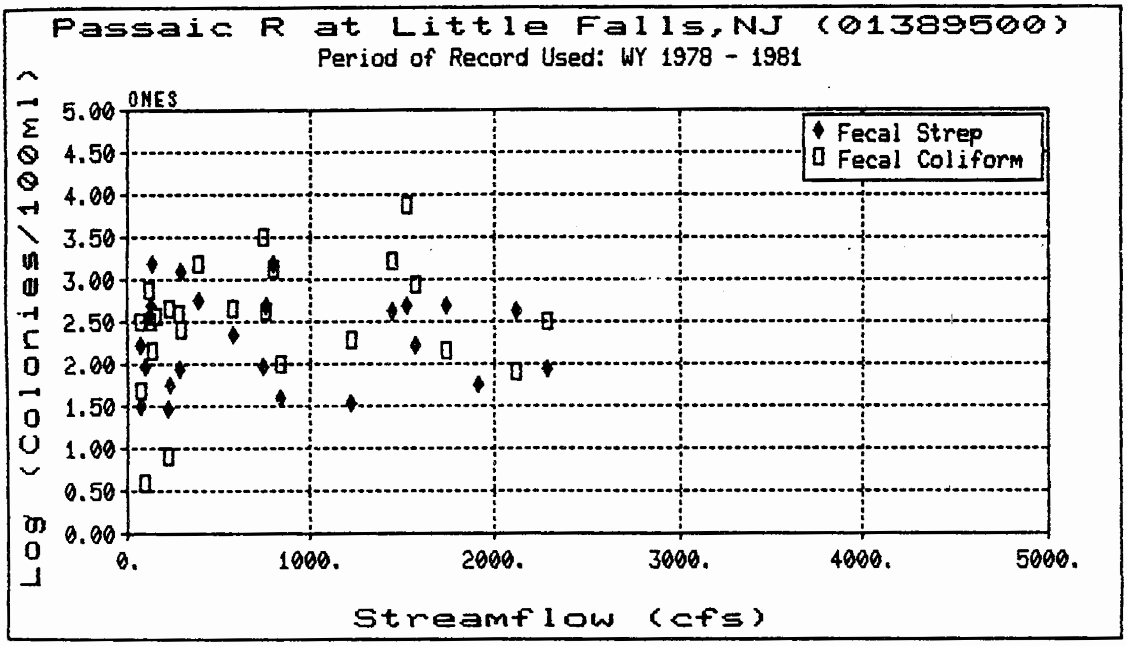

FIGURE IV-10c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, PASSAIC RIVER AT LITTLE FALLS, NJ

TABLE IV-26

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - PASSAIC RIVER AT LITTLE FALLS, NEW JERSEY

Period of Record Used: WY 1978 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	29	/	29
Median / 90th Pcnt.	7.5	/	17.2
Range	3.9	-	107.3
Mean / Std. Dev.	11.7	/	18.6
Geom. Mean / Std. Dev.	8.2	/	1.8

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	28	/	28
Median / 90th Pcnt.	.87	/	3.50
Range	.18	-	9.10
Mean / Std. Dev.	1.64	/	1.97
Geom. Mean / Std. Dev.	1.00	/	2.63

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	27	/	27
Median / 90th Pcnt.	.52	/	1.29
Range	.10	-	2.59
Mean / Std. Dev.	.69	/	.53
Geom. Mean / Std. Dev.	.52	/	2.12

Fecal Coliform (MPN)

Number Used/Number	24	/	24
Median / 90th Pcnt.	310	/	1700
Range	4	-	7800
Mean / Std. Dev.	879	/	1603
Geom. Mean / Std. Dev.	297	/	5

Fecal Streptococci (MPN)

Number Used/Number	24	/	24
Median / 90th Pcnt.	170	/	1200
Range	29	-	1600
Mean / Std. Dev.	384	/	439
Geom. Mean / Std. Dev.	196	/	3

Table IV-27 presents the results of a statistical analysis of five water quality parameters at this location. Note that the mean values of TOC and ammonia nitrogen are lower compared to those at the Little Falls location.

Table IV-28 presents the analytical results from seven samples of finished water at Passaic Valley during the period of drought in 1980-1981.

A significant amount of water quality data with respect to trace organics has been collected throughout the Passaic River watershed by the Passaic Valley Water Commission laboratory (Inhoffer, 1982, personal communication). Monthly samples have been collected and analyzed at 23 sites in the watershed since May 1981. The list of compounds analyzed and detection limits are shown in Table IV-29. Statistical analysis of six volatile organics at three sites was performed, and the results are shown in Tables IV-30 through IV-32. Table IV-30 presents a statistical summary of chloroform, bromodichloromethane, dibromochloromethane, 1,1-trichloroethane, trichloroethene, and tetrachloroethane concentrations at the treatment plant intake. For those compounds which were reported as non detectable, a concentration equal to one half the detection limit was used in the statistical analyses. In addition to the compounds listed in Table IV-30, the following compounds were detected at the plant intake. The compounds are listed by name followed by the number of times detected and number of samples in parentheses and the range of concentrations:

• Bromoform	(2/18)	ND-1.24 ug/l
• 1,2-Dichloroethene	(2/18)	ND-0.81 ug/l
• Carbon tetrachloride	(2/18)	ND-0.07 ug/l

Table IV-31 shows a statistical analysis for these six volatile organics at the confluence of Deepval Brook in the Passaic River approximately five miles upstream from the plant intake. In addition to those compounds listed in Table IV-31, the following compounds were detected at this location. The compound name is listed followed by the number of times detected in parentheses and the range of concentration.

• Methylene chloride	(3/17)	ND-42.03 ug/l
• Bromoform	(3/17)	ND-0.37 ug/l
• Carbon tetrachloride	(2/17)	ND-10 ug/l

Note that for each of these six volatile organic compounds listed in Table IV-30 and IV-31, the median concentrations are higher at Deepval Brook that at the plant intake five miles downstream. The ratio of the concentration at Deepval Brook to the concentration at the plant intake is not equal for all compounds, as would be expected if simple dilution were the only process occuring. In general, higher ratios were observed for those compounds with higher Honry's constants, a measure of volatility. This illustrates the removal of these compounds in surface waters through natural stream aeration.

Table IV-32 shows a statistical analysis for these six volatile organic compounds at the Pompton River at Two Bridges. In addition to those compounds listed in Table IV-32, the following compounds were also detected.

TABLE IV-27

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - POMPTON RIVER AT TWO BRIDGES, NEW JERSEY

```
   Period of Record Used: WY 1976 - WY 1979

      Total Organic Carbon - TOC (mg/l)

  Number Used/Number          24     /       24
  Median / 90th Pcnt.       5.0      /     8.6
  Range                     2.4      -     11.0
  Mean / Std. Dev.          5.7      /     2.1
  Geom. Mean / Std. Dev.    5.3      /     1.4

         Ammonia Nitrogen - NH3 (mg/l)

  Number Used/Number          18     /       18
  Median / 90th Pcnt.       .18      /     .33
  Range                     .00      -     .37
  Mean / Std. Dev.          .18      /     .10
  Geom. Mean / Std. Dev.    .14      /     2.37

      Total Organic Nitrogen - TON (mg/l)

  Number Used/Number          17     /       17
  Median / 90th Pcnt.       .47      /     1.29
  Range                     .23      -     2.29
  Mean / Std. Dev.          .61      /     .48
  Geom. Mean / Std. Dev.    .50      /     1.74

              Fecal Coliform (MPN)

  Number Used/Number          27     /       27
  Median / 90th Pcnt.       539      /     2400
  Range                     2        -     16000
  Mean / Std. Dev.          1483     /     3785
  Geom. Mean / Std. Dev.    379      /     6

             Fecal Streptococci (MPN)

  Number Used/Number          18     /       18
  Median / 90th Pcnt.       130      /     539
  Range                     8        -     2400
  Mean / Std. Dev.          293      /     536
  Geom. Mean / Std. Dev.    95       /     4
```

TABLE IV-28

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT PASSAIC VALLEY WATER COMMISSION DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)							
Week Ending:	9/27/80	10/18/80	10/25/80	11/1/80	11/22/80	11/29/80	1/10/81	1/17/81
Chloroform	nr	50.9	46.3	49.5	56.6	69.1	47.9	20.2
Bromodichloromethane	nr	23.1	16.0	17.0	22.2	28.2	7.7	17.3
Dibromochloromethane	nr	4.7	nr	nr	nd	nd	7.7	4.3
Bromoform	nr	nd	nr	nr	nd	nd	nd	nd
Total THMs	107.1	78.7	46.3	71.8	78.8	69.1	79.2	41.8
Tetrachloroethylene	4.5	1.8	nr	nr	6.4	7.1	nd	6.5
Trichloroethylene	3.9	1.1	nr	nr	nd	3.3	nd	3.7
1,1,1-Trichloroethane	1.1	0.9	3.3	nr	4.8	4.0	nd	3.9
1,1-Dichloroethylene	nr	nd	nr	nr	nd	7.5	nr	nd
1,2-Dichloroethylene	nr	10.4	9.7	17.0	22.4	nd	2.9	nd
Carbon Tetrachloride	0.8	nd	nr	nr	nd	nd	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-29

ORGANIC COMPOUNDS ANALYZED IN PASSAIC VALLEY WATER COMISSION WATERSHED MONITORING PROGRAM

Compound
Chloroform
Methylene chloride
Bromodichloromethane
Dibromochloromethane
Bromoform
1,1-Dichloroethane
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
1,1,1,2-Tetrachloroethane
Trichloroethene
Tetrachloroethene
1,1-Dichloroethene
1,2-Dichloroethene
1,3-Dichloropropene
1,2-Dichloropropane
Chlorobenzene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2,4-Trichlorobenzene
Carbon tetrachloride

Note: Detection limit for first 11 compounds listed is between approximately 0.1 and 1 ug/l, while the detection limit for the last 14 compounds is between 1 and 10 ug/l. (Goetz-Gebel, personal communication, 1983).

TABLE IV-30

STATISTICAL ANALYSES OF CONCENTRATIONS OF SIX VOLATILE ORGANICS - PASSAIC VALLEY WATER COMMISSION PLANT INTAKE

Passaic Valley Water Commission - Station 100 (Plant Intake)
(June 1981-November 1982)

Chloroform (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.57	/	1.12
Range	.05	-	3.24
Mean / Std. Dev.	.75	/	.69
Geom. Mean / Std. Dev.	.48	/	3.06

Bromodichloromethane (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.09	/	.36
Range	.025	-	.40
Mean / Std. Dev.	.13	/	.11
Geom. Mean / Std. Dev.	.08	/	2.68

Dibromochloromethane (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.025	/	.12
Range	.025	-	.17
Mean / Std. Dev.	.05	/	.04
Geom. Mean / Std. Dev.	.04	/	1.95

1,1,1-Trichloroethane (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.41	/	1.47
Range	.05	-	4.57
Mean / Std. Dev.	.79	/	1.03
Geom. Mean / Std. Dev.	.42	/	3.19

Trichloroethene (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.40	/	1.83
Range	.05	-	2.50
Mean / Std. Dev.	.85	/	.74
Geom. Mean / Std. Dev.	.45	/	3.66

Tetrachloroethene (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.12	/	.38
Range	.05	-	.46
Mean / Std. Dev.	.18	/	.11
Geom. Mean / Std. Dev.	.14	/	2.09

TABLE IV-31

STATISTICAL ANALYSES OF CONCENTRATIONS OF SIX VOLATILE ORGANICS - DEEPVAL BROOK

```
Passaic Valley Water Commission - Station 104 (Deepval Brook)
                (June 1981-November 1982)

                Chloroform (ug/l)

      Number Used/Number          17     /      17
      Median / 90th Pcnt.       6.69     /    27.52
      Range                      .05     -    33.84
      Mean / Std. Dev.          8.80     /    9.11
      Geom. Mean / Std. Dev.    4.49     /    4.33

               Bromodichloromethane (ug/l)

      Number Used/Number          17     /      17
      Median / 90th Pcnt.        .21     /    .80
      Range                      .025    -    .93
      Mean / Std. Dev.           .27     /    .24
      Geom. Mean / Std. Dev.     .19     /    2.39

               Dibromochloromethane (ug/l)

      Number Used/Number          17     /      17
      Median / 90th Pcnt.        .025    /    .11
      Range                      .025    -    .36
      Mean / Std. Dev.           .06     /    .07
      Geom. Mean / Std. Dev.     .04     /    2.04

               1,1,1-Trichloroethane (ug/l)

      Number Used/Number          17     /      17
      Median / 90th Pcnt.       9.30     /    26.45
      Range                      .05     -    30.89
      Mean / Std. Dev.          11.77    /    9.00
      Geom. Mean / Std. Dev.    7.09     /    4.15

                  Trichloroethene (ug/l)

      Number Used/Number          17     /      17
      Median / 90th Pcnt.       35.04    /    91.59
      Range                     4.30     -    165.75
      Mean / Std. Dev.          45.48    /    39.38
      Geom. Mean / Std. Dev.    30.92    /    2.54

                 Tetrachloroethene (ug/l)

      Number Used/Number          17     /      17
      Median / 90th Pcnt.       4.67     /    13.85
      Range                      .05     -    15.53
      Mean / Std. Dev.          6.32     /    4.31
      Geom. Mean / Std. Dev.    3.51     /    5.11
```

TABLE IV-32

STATISTICAL ANALYSES OF CONCENTRATIONS OF SIX VOLATILE ORGANICS - POMPTON RIVER AT TWO BRIDGES, NEW JERSEY

Passaic Valley Water Commission - Station 610 (Pompton R. at Two Bridges)
(June 1981-November 1982)

Chloroform (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.10	/	2.39
Range	.05	-	2.45
Mean / Std. Dev.	.51	/	.77
Geom. Mean / Std. Dev.	.18	/	4.06

Bromodichloromethane (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.075	/	.31
Range	.025	-	.67
Mean / Std. Dev.	.098	/	.15
Geom. Mean / Std. Dev.	.048	/	2.80

Dibromochloromethane (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.025	/	.14
Range	.025	-	.15
Mean / Std. Dev.	.043	/	.03
Geom. Mean / Std. Dev.	.033	/	1.83

1,1,1-Trichloroethane (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.05	/	.77
Range	.05	-	.93
Mean / Std. Dev.	.14	/	.70
Geom. Mean / Std. Dev.	.08	/	2.26

Trichloroethene (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.05	/	.61
Range	.05	-	5.80
Mean / Std. Dev.	.46	/	1.30
Geom. Mean / Std. Dev.	.13	/	3.46

Tetrachloroethene (ug/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	.10	/	.51
Range	.05	-	.64
Mean / Std. Dev.	.17	/	.16
Geom. Mean / Std. Dev.	.11	/	2.36

Methylene chloride	(1/18)	ND-11.0 ug/l
1,2-Dichloroethane	(1/18)	ND-0.62 ug/l
1,1,2-Trichloroethane	(1/18)	ND-0.59 ug/l
Carbon tetrichloride	(1/18)	ND-0.08 ug/l

Note the improved water quality at this location compared to the existing plant intake and Deepval Brook as measured by the median values of these six volatile organic compounds.

A report by Hunter and Sabatino (undated) summarizes the results of a study in the Passaic River watershed investigating sources of halogenated hydrocarbons in an urban water supply. The study was conducted from May 1976 to January 1980. These researchers found that during the summer months, chloroform was the dominant volatile organic compounds detected in the Passaic River watershed, while during the winter months methylene chloride was dominant. The presence of chloroform can be explained by chlorine disinfection of wastewater effluents discharged into the Passaic River tributaries and the faster rate of reaction and higher chlorine doses in the summer. Other compounds detected in this study, found in the concentration range of 0.1 to 10 ug/l included:

- 1,1,1-Trichloroethane
- 1,1,2,2-Tetrachloroethylene
- Bromodichloromethane
- 1,1,2-Trichloroethane
- 1,1,2,2-Tetrachloroethane
- Dibromochloromethane

Jersey City Water Department

Table IV-33 presents the results of seven finished water samples analyzed during the period of the recent drought in 1980-1981.

In November 1982, Jersey City had samples of water from the Boonton Reservoir and Rockaway River analyzed for volatile organics, base/neutral extractables, pesticides and acid extractables. These samples were analyzed according to EPA methods 608, 624 and 625 (EPA, 1979). The concentrations of all compounds analyzed in these methods was below the detection limits which range from 10 to 250 ug/l (Dzydzora, 1983, personal communication). Additional samples of Boonton Reservoir water were collected and analyzed for THMs in November 1980, June 1981, December 1981 and June 1982. The concentrations in these four samples were 0.77 ug/l, 11.28 ug/l, "not detected", and "not detected", respectively.

Drexel University has conducted a monitoring program during Summer 1981 at three sites on the Boonton Reservoir and Rockaway River (Suffet, 1982, personal communication). Using the resin concentration technique, they were able to tentatively identify 22 aromatic compounds and 17 other organic compounds. Of these compounds, 13 were found at concentration of approximately 1 ug/l. All others were at concentrations less than 1 ug/l.

TABLE IV-33

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT JERSEY CITY WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)							
Week Ending:	9/27/80	10/11/80	10/18/80	10/25/80	11/1/80	11/29/80	1/10/81	1/17/81
Chloroform	19.1	32.5	17.2	20.6	30.3	22.4	20.1	9.7
Bromodichloromethane	nr	15.2	5.7	9.2	10.1	nd	7.2	3.7
Dibromochloromethane	nr	4.8	nr	nr	nd	nd	nd	nd
Bromoform	nr	nr	nr	nr	nd	nd	nd	nd
Total THMs	30.4	52.5	22.9	29.8	40.4	22.4	27.3	13.4
Tetrachloroethylene	1.3	nr	nr	nr	6.4	nd	nd	nd
Trichloroethylene	0.3	0.5	nr	nr	nd	nd	nd	nd
1,1,1-Trichloroethane	nr	nr	nr	nr	nd	nd	nd	nd
1,1-Dichloroethylene	nr	nr	nr	nr	nd	nd	nd	nd
1,2-Dichloroethylene	nr	7.1	0.6	20.9	27.8	nd	nd	nd
Carbon Tetrachloride	nr	nr	nr	nr	nd	nd	nd	nd

NOTE: nd = not detected
nr = not reported

Commonwealth Water Company

Figures IV-11a, b and c shows the variation of six water quality parameters with stream flow at the Passaic River at Chatham, one of the sources used by the Commonwealth Water Company (USGS, 1976-81). Table IV-34 presents statistical analyses of each of these water quality parameters at this location.

Table IV-35 presents the results of four finished water samples taken during the drought of 1980-1981.

Laboratory analyses of untreated surface water at the Commonwealth Water Company, for the period 1980-1982, were provided for Canoe Brook Reservoir No. 2, Passaic River near Chatham and the Canoe Brook (King, 1983, personal communication). Pesticides and herbicides were analyzed in each of these samples, but were never detected in this period. TOC values in the March 1980 sample for the Passaic River were, 4.61 mg/l, and for the Canoe Brook, 3.88 mg/l.

Middlesex Water Company

Table IV-36 contains the analytical results of four finished water samples collected during the drought of 1980-1981.

Southeast Morris County MUA

Table IV-37 contains analytical results of four finished water samples collected during the period of the recent drought, 1980-1981.

New Brunswick Water Department

Table IV-38 shows the results of a statistical analysis for five water quality parameters at the USGS stream water quality monitoring station at Lawrence Brook. No stream flow data were available at this location (USGS, 1976-81).

Table IV-39 contains analyses of four finished water samples obtained during the drought of 1980-1981.

Orange Water Department

Figures IV-12a, b and c show the relationship between five water quality parameters and stream flow at the Rahway River near Springfield, a surface source used by the Orange Water Department (USGS, 1976-81). Table IV-40 contains a statistical analysis of these five water quality parameters at this location.

Table IV-41 contains the analytical results of three finished water samples obtained during the 1980-1981 drought.

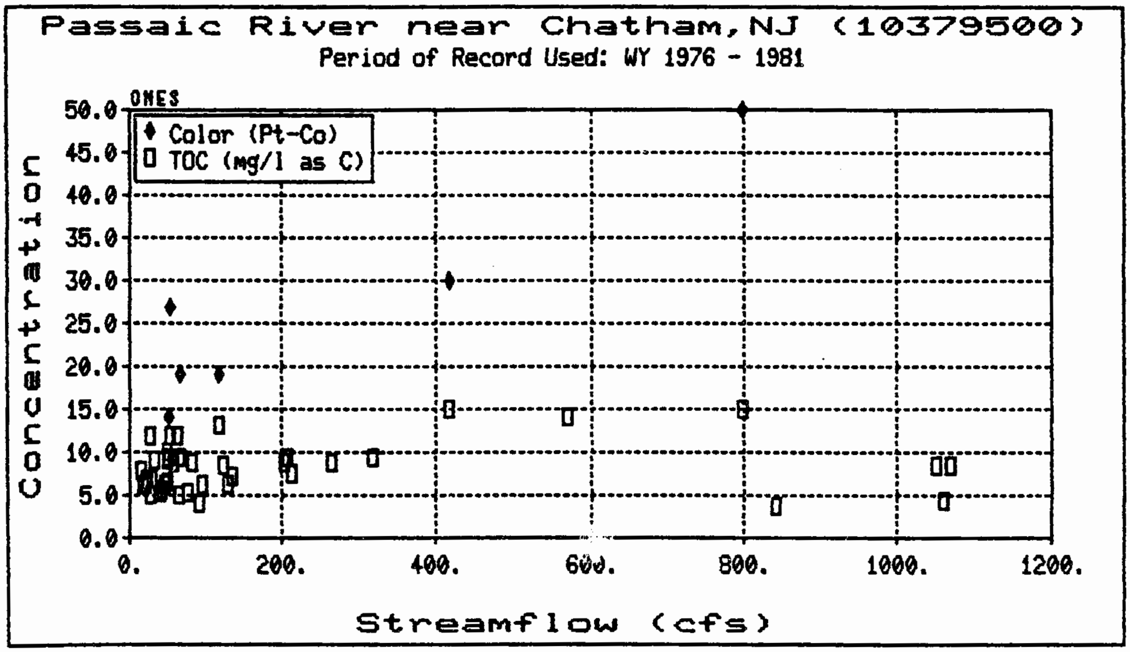

FIGURE IV-11a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, PASSAIC RIVER NEAR CHATHAM, NJ

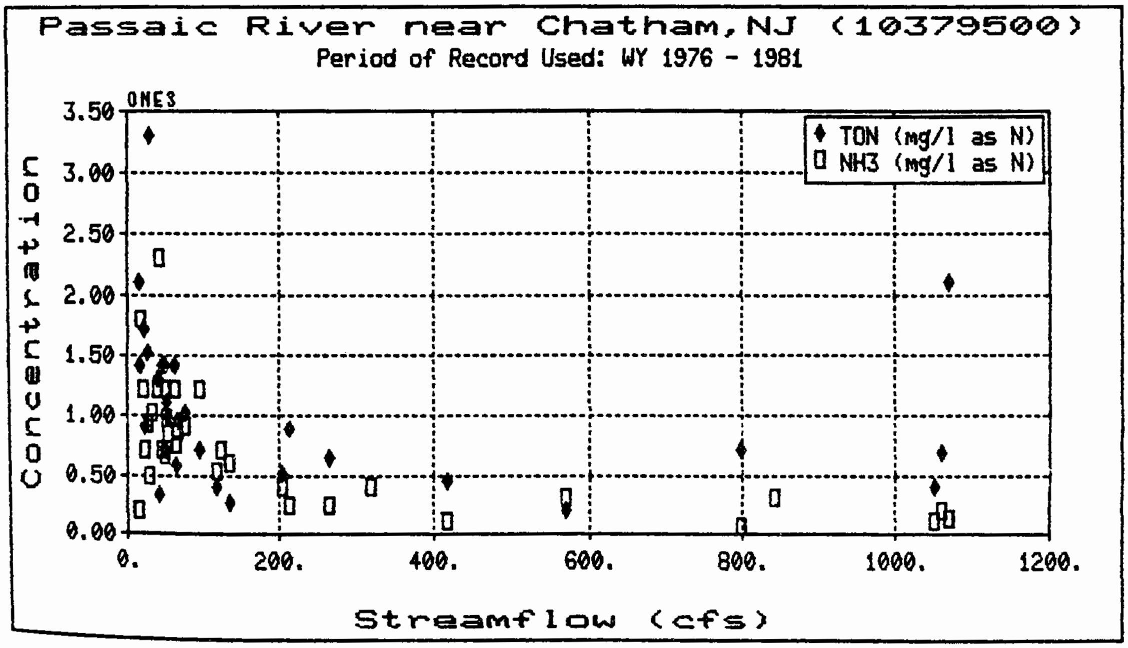

FIGURE IV-11b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, PASSAIC RIVER NEAR CHATHAM, NJ

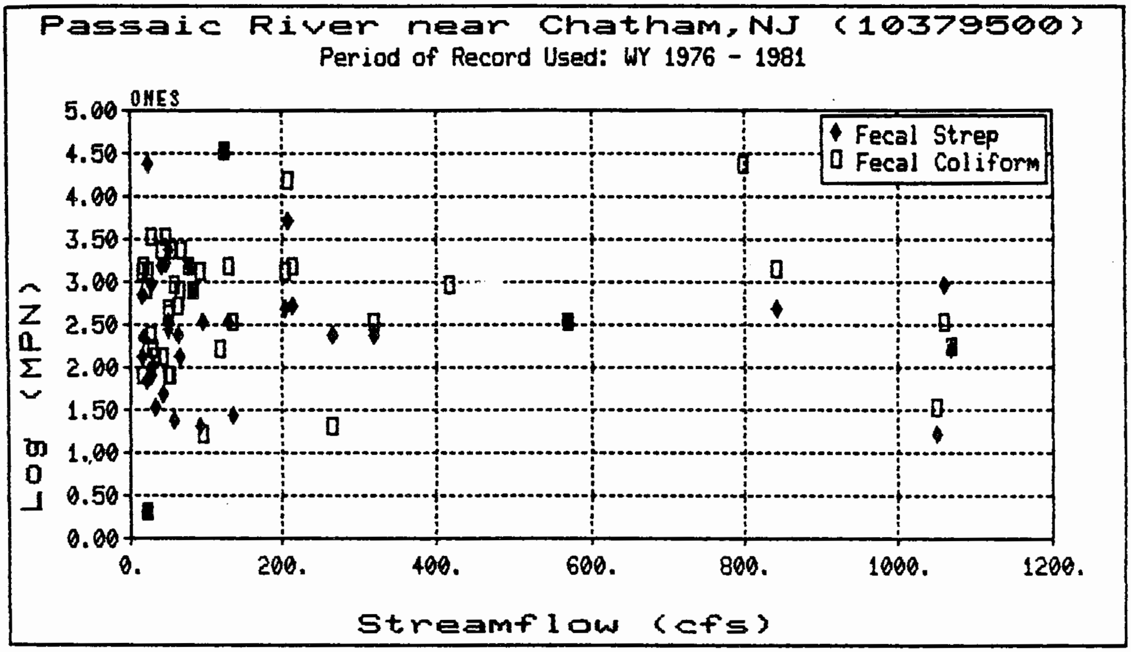

FIGURE IV-11c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, PASSAIC RIVER NEAR CHATHAM, NJ

TABLE IV-34

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - PASSAIC RIVER NEAR CHATHAM, NEW JERSEY

Period of Record Used: WY 1976 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	41	/	41
Median / 90th Pcnt.	7.6	/	12.0
Range	3.5	-	15.0
Mean / Std. Dev.	8.1	/	2.8
Geom. Mean / Std. Dev.	7.7	/	1.4

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	33	/	33
Median / 90th Pcnt.	.69	/	1.20
Range	.07	-	2.29
Mean / Std. Dev.	.70	/	.49
Geom. Mean / Std. Dev.	.52	/	2.36

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	29	/	29
Median / 90th Pcnt.	.89	/	2.09
Range	.20	-	3.29
Mean / Std. Dev.	1.02	/	.66
Geom. Mean / Std. Dev.	.84	/	1.91

Fecal Coliform (MPN)

Number Used/Number	41	/	41
Median / 90th Pcnt.	790	/	2400
Range	2	-	35000
Mean / Std. Dev.	2611	/	6682
Geom. Mean / Std. Dev.	520	/	6

Fecal Streptococci (MPN)

Number Used/Number	36	/	36
Median / 90th Pcnt.	269	/	2400
Range	2	-	35000
Mean / Std. Dev.	2215	/	6809
Geom. Mean / Std. Dev.	287	/	6

TABLE IV-35

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT COMMONWEALTH WATER COMPANY DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	10/18/80	10/25/80	11/29/80	1/10/81
Chloroform	5.3	10.5	nr	23.7
Bromodichloromethane	1.9	nr	nd	7.7
Dibromochloromethane	nr	4.6	nd	nd
Bromoform	nr	nr	nd	nd
Total THMs	7.2	15.1	nr	31.4
Tetrachloroethylene	nr	2.1	nd	nd
Trichloroethylene	1.3	1.9	nd	nd
1,1,1-Trichloroethane	nr	1.5	nd	nd
1,1-Dichloroethylene	nr	nr	nd	nd
1,2-Dichloroethylene	9.6	8.0	nd	nd
Carbon Tetrachloride	nr	1.0	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-36

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT MIDDLESEX WATER COMPANY DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	10/11/80	10/18/80	11/29/80	1/10/81
Chloroform	30.9	20.4	nr	7.4
Bromodichloromethane	10.2	8.6	nd	2.0
Dibromochloromethane	3.6	nr	nd	nd
Bromoform	nr	nr	nd	nd
Total THMs	44.7	29.0	nr	9.4
Tetrachloroethylene	1.0	nr	nd	nd
Trichloroethylene	nr	nr	nd	nd
1,1,1-Trichloroethane	nr	nr	nd	nd
1,1-Dichloroethylene	nr	nr	nd	nd
1,2-Dichloroethylene	nr	10.6	nd	nd
Carbon Tetrachloride	nr	nr	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-37

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT SOUTHEAST MORRIS COUNTY MUNICIPAL UTILITIES AUTHORITY DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	11/11/80	10/18/80	11/28/80	1/17/81
Chloroform	11.3	10.2	nr	3.6
Bromodichloromethane	2.5	1.6	nd	nr
Dibromochloromethane	nr	nr	nd	nd
Bromoform	nr	nr	nd	nd
Total THMs	13.8	11.8	nr	nr
Tetrachloroethylene	nr	nr	nd	nd
Trichloroethylene	nr	nr	nd	nd
1,1,1-Trichloroethane	nr	nr	nd	nd
1,1-Dichloroethylene	nr	nr	nd	nd
1,2-Dichloroethylene	1.1	8.0	nd	nd
Carbon Tetrachloride	nr	nr	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-38

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - LAWRENCE BROOK NEAR WESTON'S MILL, NEW JERSEY

Period of Record Used: WY 1977 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	30	/	30
Median / 90th Pcnt.	6.4	/	8.6
Range	3.0	-	9.6
Mean / Std. Dev.	6.4	/	1.7
Geom. Mean / Std. Dev.	6.1	/	1.3

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	29	/	29
Median / 90th Pcnt.	.10	/	.25
Range	.00	-	.30
Mean / Std. Dev.	.12	/	.07
Geom. Mean / Std. Dev.	.10	/	2.25

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	26	/	26
Median / 90th Pcnt.	.44	/	.92
Range	.15	-	2.09
Mean / Std. Dev.	.58	/	.39
Geom. Mean / Std. Dev.	.50	/	1.67

Fecal Coliform (MPN)

Number Used/Number	31	/	31
Median / 90th Pcnt.	70	/	1600
Range	2	-	2400
Mean / Std. Dev.	393	/	671
Geom. Mean / Std. Dev.	77	/	7

Fecal Streptococci (MPN)

Number Used/Number	31	/	31
Median / 90th Pcnt.	79	/	490
Range	2	-	2400
Mean / Std. Dev.	214	/	444
Geom. Mean / Std. Dev.	67	/	4.

TABLE IV-39

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT NEW BRUNSWICK WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	10/11/80	11/22/80	11/29/80	1/10/81
Chloroform	11.1	21.7	nr	7.3
Bromodichloromethane	4.5	15.1	nd	nd
Dibromochloromethane	2.3	nd	nd	nd
Bromoform	nr	nd	nd	nd
Total THMs	17.9	36.8	nr	7.3
Tetrachloroethylene	nr	nd	nd	nd
Trichloroethylene	nr	nd	nd	nd
1,1,1-Trichloroethane	nr	nd	nd	nd
1,1-Dichloroethylene	nr	nd	nd	nd
1,2-Dichloroethylene	0.7	nd	nd	nd
Carbon Tetrachloride	nr	nd	nd	nd

NOTE: nd = not detected
nr = not reported

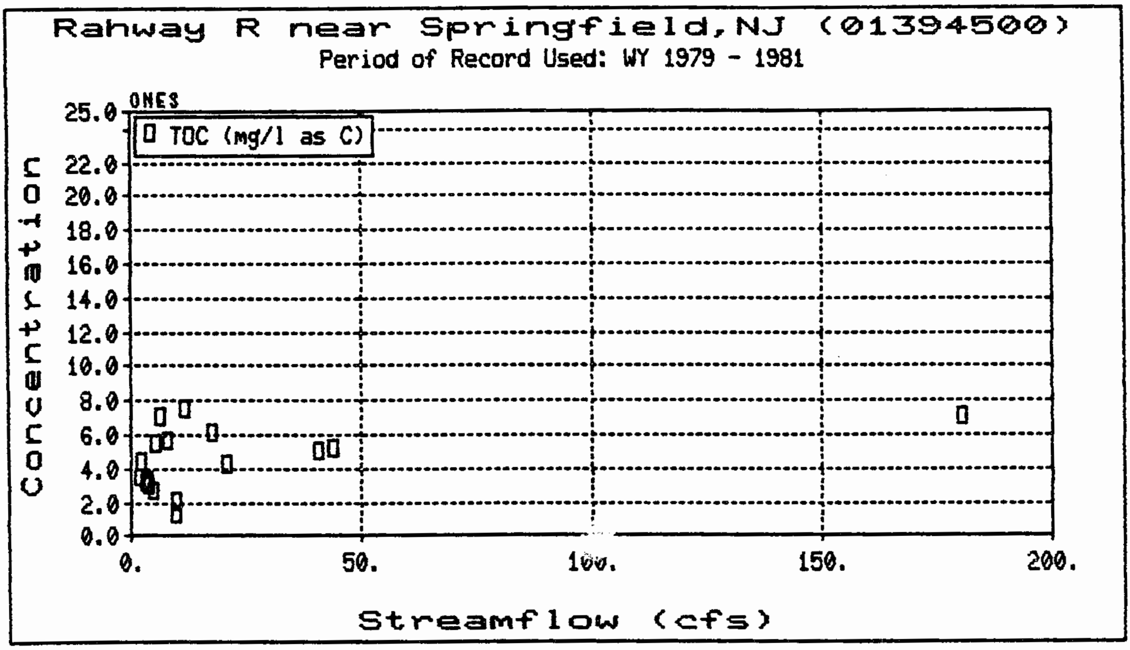

FIGURE IV-12a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, RAHWAY RIVER NEAR SPRINGFIELD, NJ

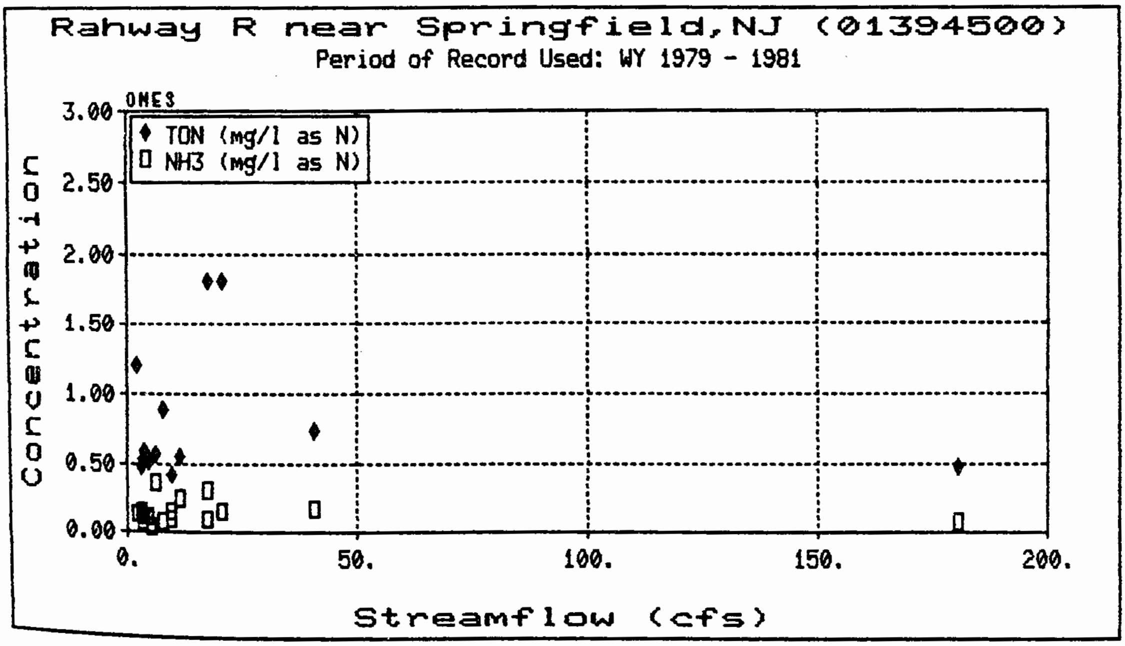

FIGURE IV-12b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, RAHWAY RIVER NEAR SPRINGFIELD, NJ

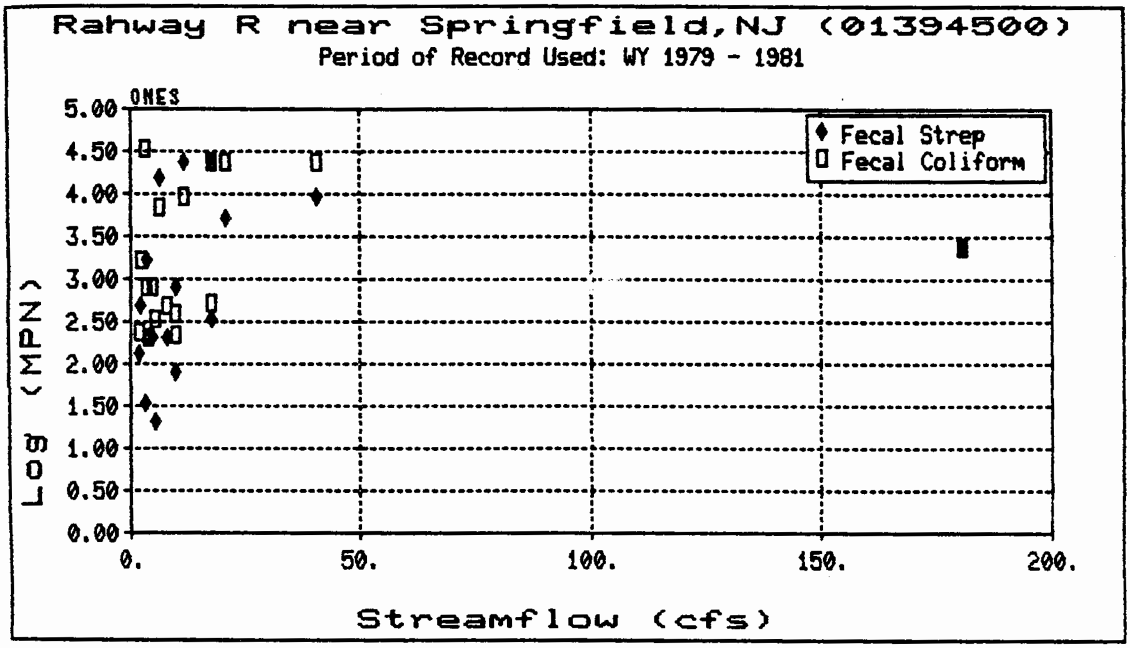

FIGURE IV-12c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, RAHWAY RIVER NEAR SPRINGFIELD, NJ

TABLE IV-40

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - RAHWAY RIVER NEAR SPRINGFIELD, NEW JERSEY

Period of Record Used: WY 1979 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	17	/	17
Median / 90th Pcnt.	4.4	/	7.0
Range	1.2	-	7.5
Mean / Std. Dev.	4.5	/	1.7
Geom. Mean / Std. Dev.	4.1	/	1.5

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	16	/	16
Median / 90th Pcnt.	.11	/	.30
Range	.02	-	.34
Mean / Std. Dev.	.14	/	.08
Geom. Mean / Std. Dev.	.12	/	1.79

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	13	/	13
Median / 90th Pcnt.	.56	/	1.79
Range	.41	-	1.79
Mean / Std. Dev.	.80	/	.47
Geom. Mean / Std. Dev.	.70	/	1.62

Fecal Coliform (MPN)

Number Used/Number	17	/	17
Median / 90th Pcnt.	800	/	24000
Range	33	-	24000
Mean / Std. Dev.	5667	/	8833
Geom. Mean / Std. Dev.	1212	/	6

Fecal Streptococci (MPN)

Number Used/Number	17	/	17
Median / 90th Pcnt.	490	/	24000
Range	20	-	24000
Mean / Std. Dev.	5011	/	8060.
Geom. Mean / Std. Dev.	778	/	9

TABLE IV-41

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT ORANGE WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)		
Week Ending:	10/18/80	11/29/80	1/10/81
Chloroform	2.5	nr	3.4
Bromodichloromethane	1.6	nd	3.0
Dibromochloromethane	nr	nd	4.2
Bromoform	nr	nd	nd
Total THMs	4.1	nr	10.6
Tetrachloroethylene	0.9	nd	nd
Trichloroethylene	nr	nd	nd
1,1,1-Trichloroethane	nr	nd	nd
1,1-Dichloroethylene	nr	nd	nd
1,2-Dichloroethylene	8.7	nd	nd
Carbon Tetrachloride	nr	nd	nd

NOTE: nd = not detected
nr = not reported

Rahway Water Department

Figures IV-13a, b and c show the relationship between five water quality parameters and stream flow at the Rahway River at Rahway, a source used by the Rahway Water Department (USGS, 1976-81). Statistical analyses of these five water quality parameters are shown in Table IV-42.

Table IV-43 shows the analytical results of five finished water samples obtained during the 1980-1981 drought. High concentrations of THMs were observed during this sampling.

Boonton Water Department

Table IV-44 provides a analytical results of four finished water samples obtained during the 1980-1981 drought.

Monmouth Consolidated Water Company

Figures IV-14a, b and c show the relationship between five water quality parameters and stream flow at the Swimming River near Redbank, one of the sources used by the Monmouth Consolidated Water Company (USGS, 1976-81). Table IV-45 provides a statistical summary for these five water quality parameters at this location. The relationship between these five water quality parameters and stream flow at the Shark River near Neptune City, another surface source used by the Monmouth Consolidated Water Company, is shown in Figures IV-15a, b and c (USGS, 1976-81). Statistical analyses of these five parameters are shown in Table IV-46.

Laboratory analyses of pesticides and herbicides, and TOC by Monmouth Consolidated Water Company for the period of 1980-1982 were provided (Burdan, 1983, personal communication). Samples analyzed during this period for pesticides and herbides for untreated waters in the Shark River, Jumping Brook, Glendola Reservoir, and Swimming River and treated waters from the Swimming River Treatment Plant were below the detection limit. TOC concentrations were analyzed in March 1980 for untreated waters from the Shark River, 2.80 mg/l; Glendola Reservoir, 3.71 mg/l; and the Swimming River, 1.64 mg/l.

Camden Water Department

The City of Camden differs from all other purveyors discussed in this section in that its water supply consists entirely of groundwater sources. Groundwater sources consist of several wells within the City limits as well as three well fields northwest of the City along the Delaware River. Table IV-47 summarizes the concentrations of trichloroethylene, tetrachloroethylene, carbon tetrachloride, and 1,1-dichloroethane in the three wells serving the Parkside Treatment Plant, located within the City limits during December 1979 to December 1980 (Vena, 1982, personal communication). Although the three wells are located within an approximately 1,000 ft radius of the plant, the concentrations of these compounds listed in Table IV-47 vary widely. Table IV-48 contains analytical results for these three wells as well as two additional

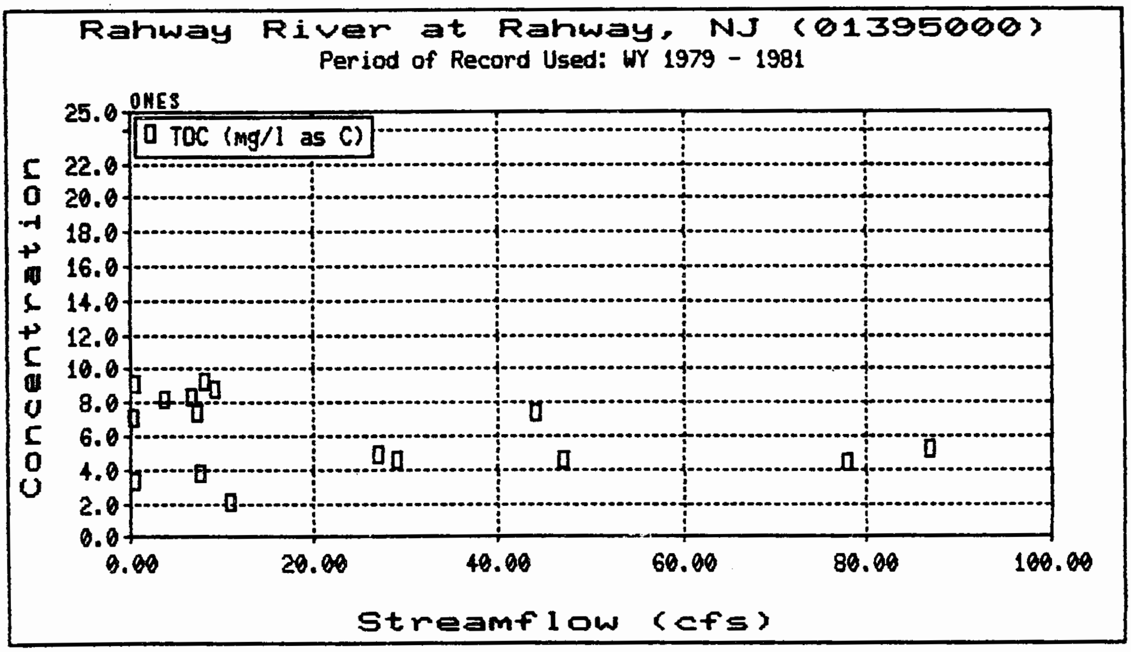

FIGURE IV-13a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, RAHWAY RIVER AT RAHWAY, NJ

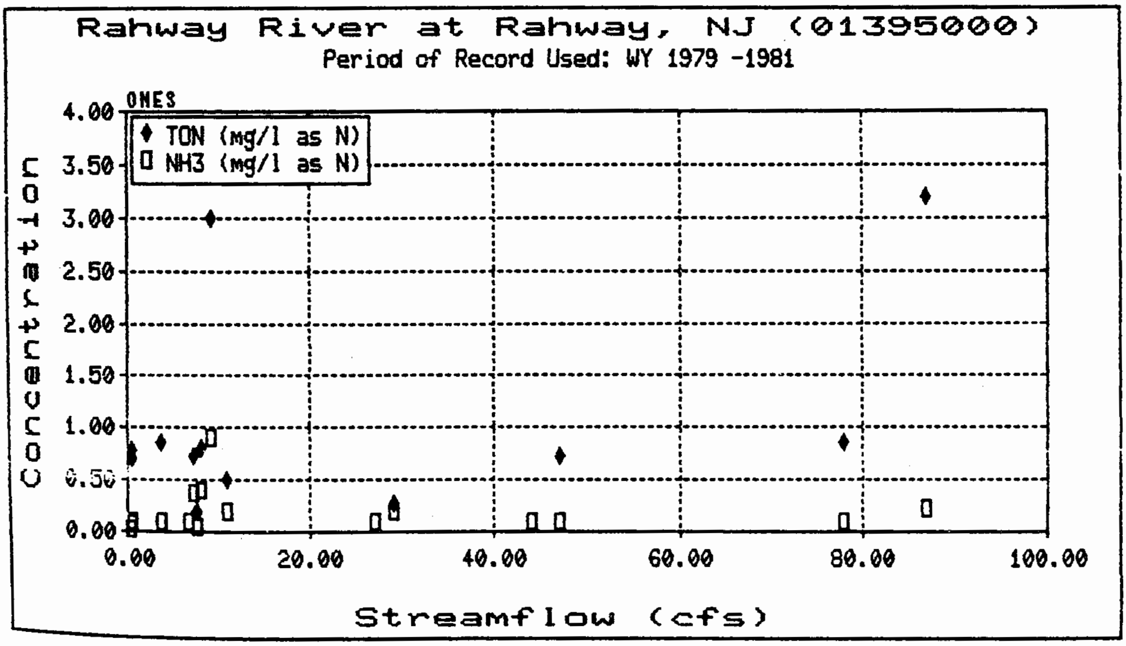

FIGURE IV-13b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, RAHWAY RIVER AT RAHWAY, NJ

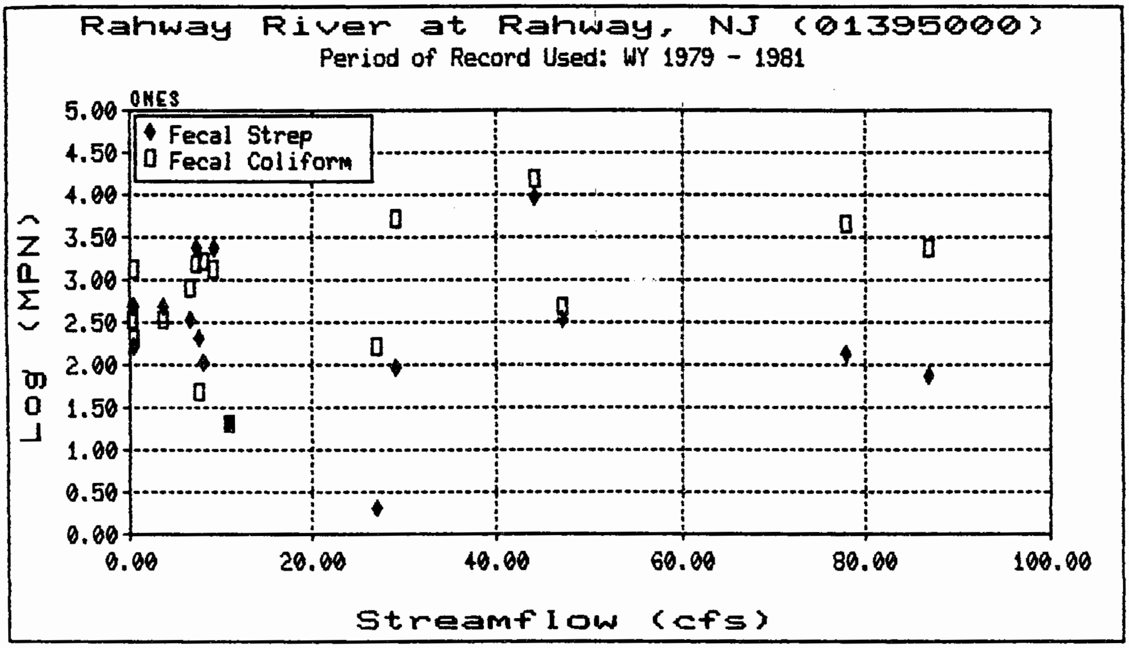

FIGURE IV-13c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, RAHWAY RIVER AT RAHWAY, NJ

TABLE IV-42

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - RAHWAY RIVER AT RAHWAY, NEW JERSEY

Period of Record Used: WY 1979 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	18	/	18
Median / 90th Pcnt.	4.8	/	9.1
Range	2.0	-	9.1
Mean / Std. Dev.	5.8	/	2.1
Geom. Mean / Std. Dev.	5.4	/	1.5

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	17	/	17
Median / 90th Pcnt.	.10	/	.38
Range	.02	-	.89
Mean / Std. Dev.	.19	/	.70
Geom. Mean / Std. Dev.	.13	/	2.17

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	13	/	13
Median / 90th Pcnt.	.73	/	3.00
Range	.20	-	3.20
Mean / Std. Dev.	1.01	/	.90
Geom. Mean / Std. Dev.	.76	/	2.06

Fecal Coliform (MPN)

Number Used/Number	18	/	18
Median / 90th Pcnt.	490	/	5399
Range	20	-	16000
Mean / Std. Dev.	2069	/	3691
Geom. Mean / Std. Dev.	628	/	5

Fecal Streptococci (MPN)

Number Used/Number	18	/	18
Median / 90th Pcnt.	170	/	2400
Range	2	-	9700
Mean / Std. Dev.	947	/	2122
Geom. Mean / Std. Dev.	194	/	6

TABLE IV-43

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT RAHWAY WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)				
Week Ending:	10/11/80	10/18/80	11/22/80	11/29/80	1/10/81
Chloroform	53.9	54.5	95.1	nr	24.1
Bromodichloromethane	17.4	22.6	41.6	nr	23.3
Dibromochloromethane	5.4	4.9	15.4	nd	14.5
Bromoform	nr	nr	nd	nd	nd
Total THMs	76.7	82	152.1	nr	61.9
Tetrachloroethylene	2.2	nr	nd	nd	1.6
Trichloroethylene	2.0	1.5	8.0	nd	11.1
1,1,1-Trichloroethane	0.6	nr	nd	nd	3.4
1,1-Dichloroethylene	nr	nr	nd	nd	nd
1,2-Dichloroethylene	nr	9.0	nd	nd	5.0
Carbon Tetrachloride	nr	nr	nr	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-44

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT BOONTON WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	10/11/80	11/22/80	11/29/80	1/17/81
Chloroform	2.5	37.0	nr	15.4
Bromodichloromethane	1.3	14.9	nd	14.6
Dibromochloromethane	nr	nd	nd	3.0
Bromoform	nr	nd	nd	nd
Total THMs	3.8	51.9	nr	33
Tetrachloroethylene	nr	nd	nd	nd
Trichloroethylene	nr	20.1	nd	17.1
1,1,1-Trichloroethane	nr	10.6	nd	nd
1,1-Dichloroethylene	nr	nd	nd	nd
1,2-Dichloroethylene	7.9	27.1	nd	nd
Carbon Tetrachloride	nr	nd	nd	nd

NOTE: nd = not detected
nr = not reported

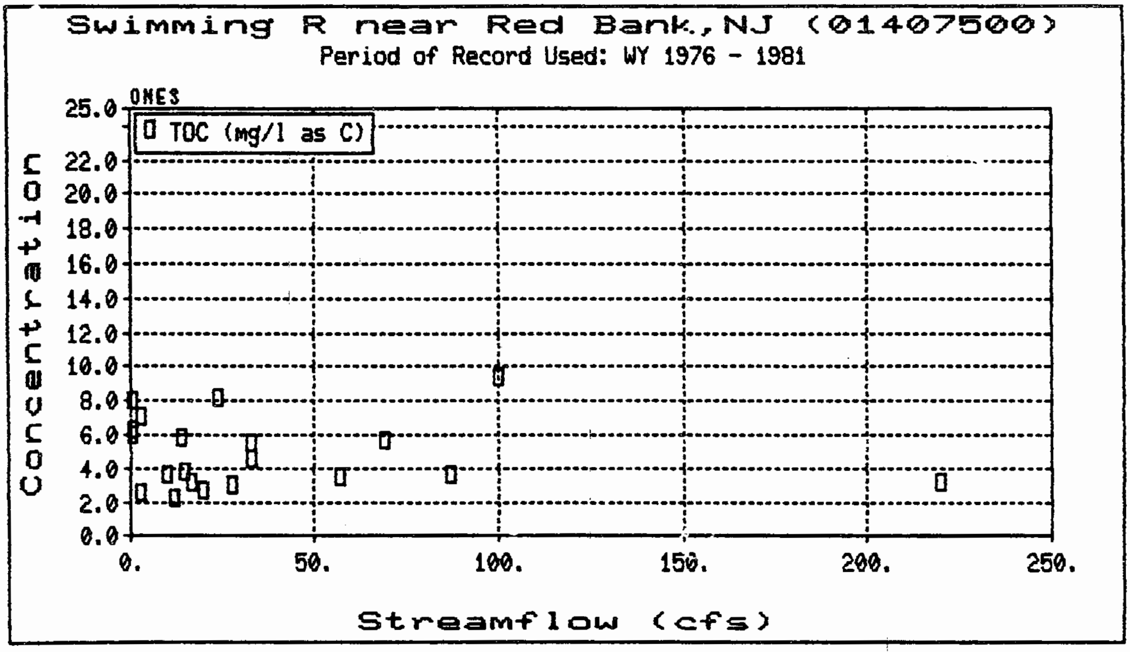

FIGURE IV-14a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, SWIMMING RIVER NEAR RED BANK, NJ

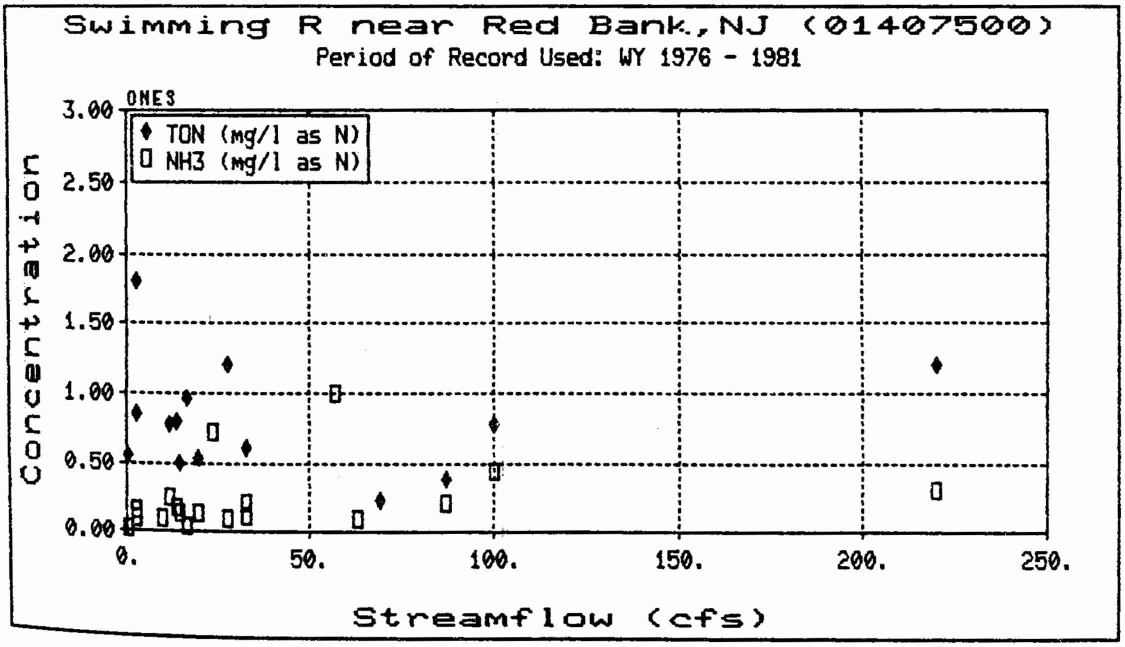

FIGURE IV-14b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, SWIMMING RIVER NEAR RED BANK, NJ

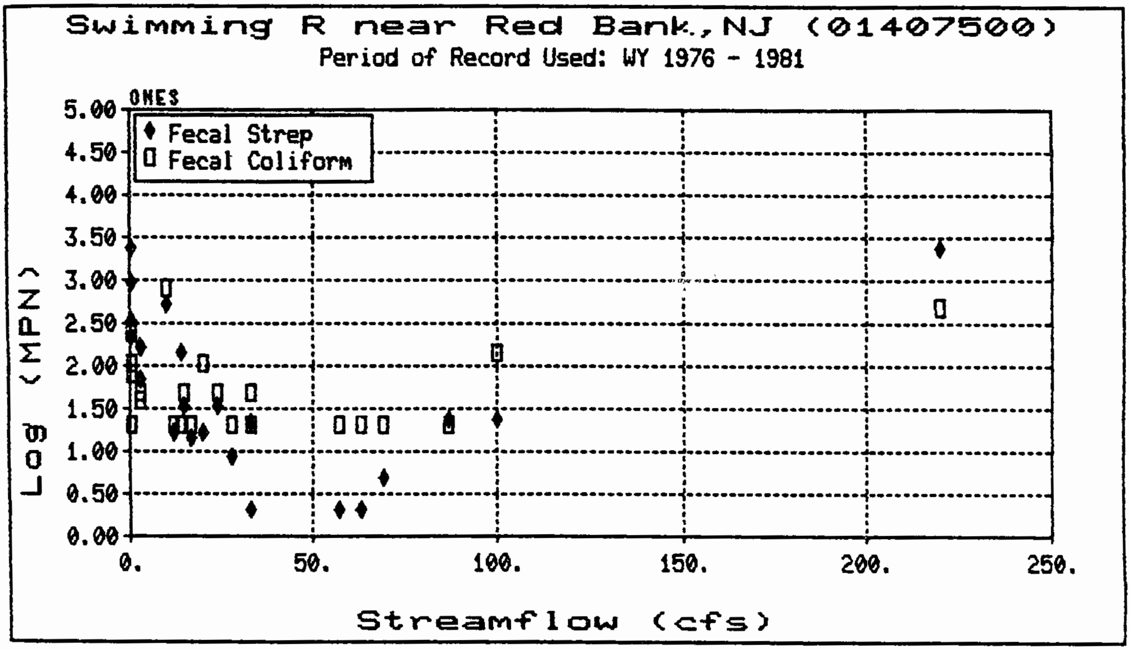

FIGURE IV-14c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, SWIMMING RIVER NEAR RED BANK, NJ

TABLE IV-45

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - SWIMMING RIVER NEAR RED BANK, NEW JERSEY

Period of Record Used: WY 1976 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	21	/	21
Median / 90th Pcnt.	4.5	/	8.1
Range	2.2	-	11.0
Mean / Std. Dev.	5.1	/	2.3
Geom. Mean / Std. Dev.	4.6	/	1.5

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	20	/	20
Median / 90th Pcnt.	.12	/	.43
Range	.01	-	1.00
Mean / Std. Dev.	.22	/	.23
Geom. Mean / Std. Dev.	.14	/	2.44

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	16	/	16
Median / 90th Pcnt.	.60	/	1.20
Range	.23	-	1.79
Mean / Std. Dev.	.75	/	.38
Geom. Mean / Std. Dev.	.66	/	1.63

Fecal Coliform (MPN)

Number Used/Number	24	/	24
Median / 90th Pcnt.	50	/	790
Range	20	-	9200
Mean / Std. Dev.	515	/	1824
Geom. Mean / Std. Dev.	70	/	4

Fecal Streptococci (MPN)

Number Used/Number	24	/	24
Median / 90th Pcnt.	33	/	970
Range	2	-	2400
Mean / Std. Dev.	316	/	661
Geom. Mean / Std. Dev.	49	/	7

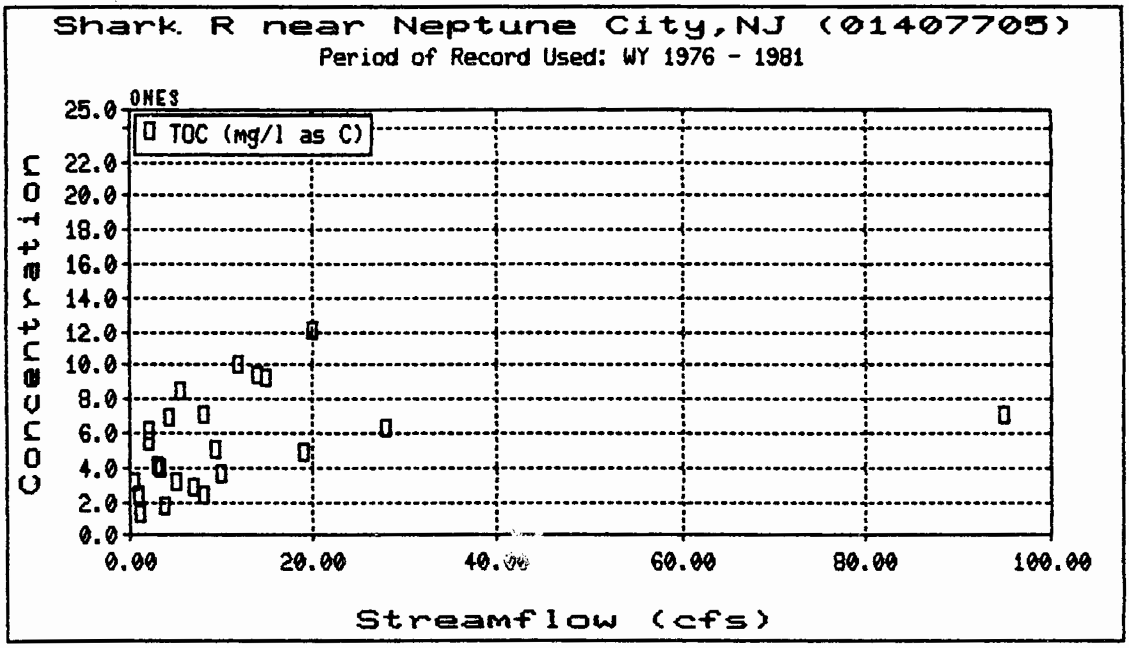

FIGURE IV-15a. VARIATION OF COLOR AND TOC WITH STREAM-FLOW, SHARK RIVER NEAR NEPTUNE CITY, NJ

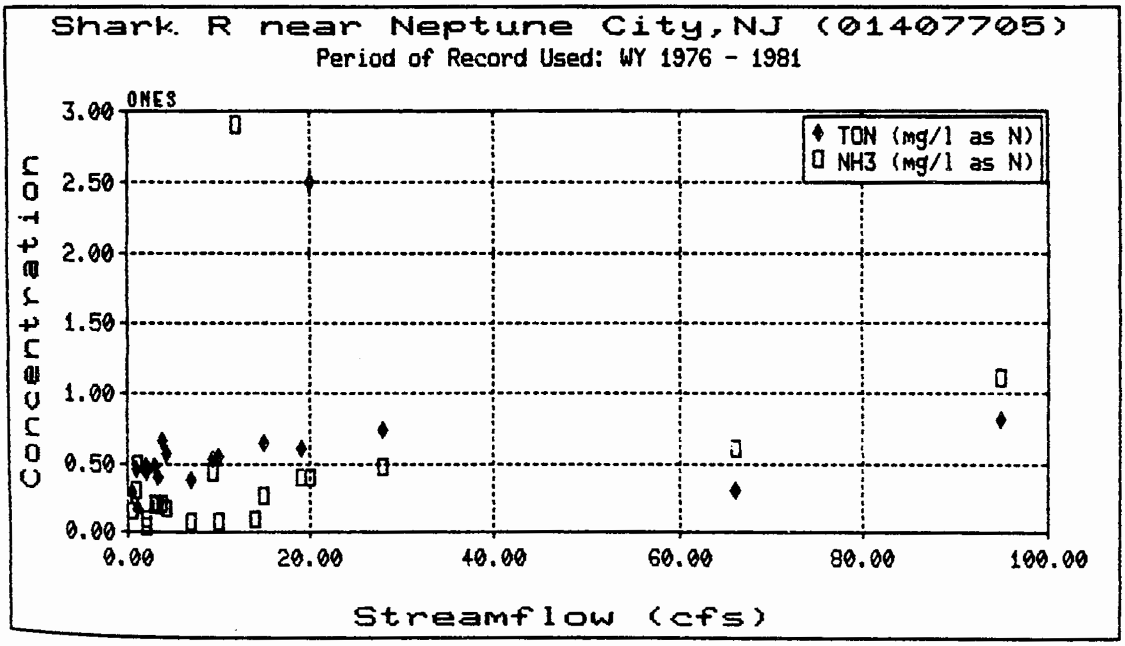

FIGURE IV-15b. VARIATION OF NH_3 AND TON WITH STREAM-FLOW, SHARK RIVER NEAR NEPTUNE CITY, NJ

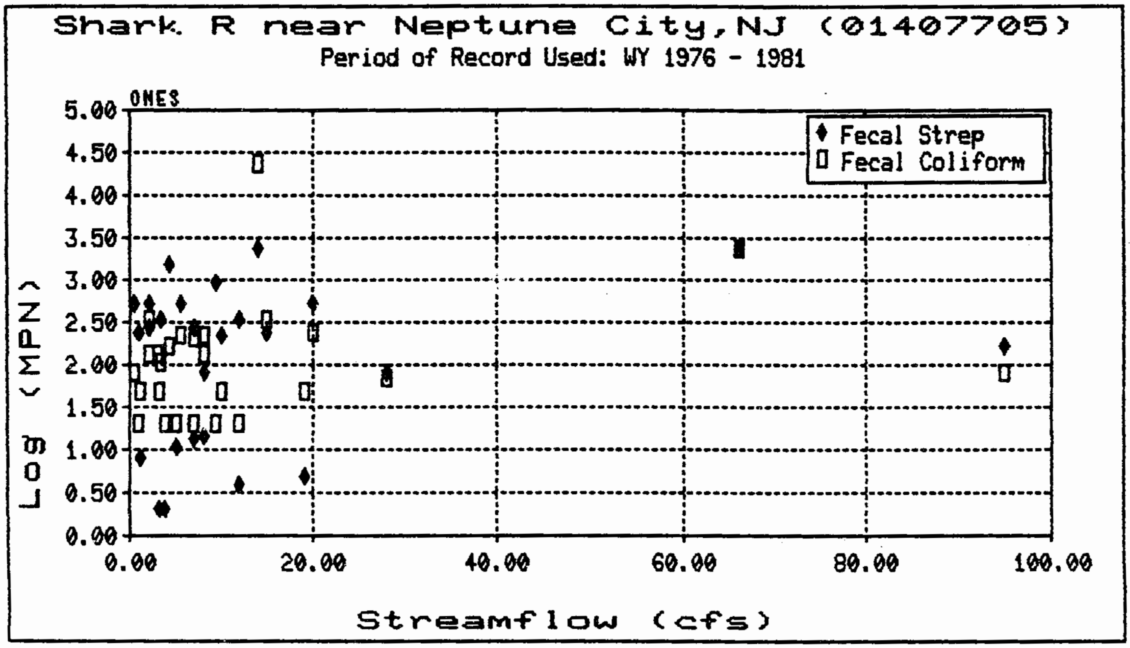

FIGURE IV-15c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, SHARK RIVER NEAR NEPTUNE CITY, NJ

TABLE IV-46

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - SHARK RIVER NEAR NEPTUNE CITY, NEW JERSEY

Period of Record Used: WY 1976 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	24	/	24
Median / 90th Pcnt.	4.8	/	9.3
Range	1.2	-	12.0
Mean / Std. Dev.	5.3	/	2.8
Geom. Mean / Std. Dev.	4.5	/	1.8

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	21	/	21
Median / 90th Pcnt.	.23	/	.60
Range	.03	-	2.90
Mean / Std. Dev.	.42	/	.60
Geom. Mean / Std. Dev.	.25	/	2.59

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	19	/	19
Median / 90th Pcnt.	.51	/	2.50
Range	.17	-	3.29
Mean / Std. Dev.	.74	/	.76
Geom. Mean / Std. Dev.	.56	/	1.94

Fecal Coliform (MPN)

Number Used/Number	28	/	28
Median / 90th Pcnt.	80	/	330
Range	20	-	24000
Mean / Std. Dev.	1046	/	4438
Geom. Mean / Std. Dev.	103	/	4

Fecal Streptococci (MPN)

Number Used/Number	27	/	27
Median / 90th Pcnt.	240	/	1600
Range	2	-	2400
Mean / Std. Dev.	440	/	651
Geom. Mean / Std. Dev.	108	/	8

TABLE IV-47

VOLATILE ORGANIC CONCENTRATIONS IN PARKSIDE PLANT RAW GROUNDWATER
(December 1979 - December 1980)

Compound	Average Concentration			Concentration Range		
	Well 13 ug/l	Well 17 ug/l	Well 18 ug/l	Well 13 ug/l	Well 17 ug/l	Well 18 ug/l
Trichloroethylene	28.6	37.1	11.9	8.8-39.5	10.8-61.7	8.3-24.8
Tetrachloroethylene	3.3	16.1	18.4	nd-5.6	4.4-27.8	16.1-22.7
Carbon tetrachloride	2.6	0.3	nd	1.4-3.5	nd-0.3	nd
1,2-Dichloroethane	15.2	2.2	2.0	7.5-20.7	0.9-2.9	0.9-3.3

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nd = not detected

(from Malcolm Pirnie, 1981)

TABLE IV-48

VOLATILE ORGANICS DETECTED IN FIVE WELLS AND FINISHED WATER IN CAMDEN (ug/l) (DEC 79 TO DEC 80)

Compound	12/26/80	1/31/80	2/29/80	4/3/80	5/2/80	6/3/80	7/2/80	8/11/80	9/3/80	10/3/80	11/5/80	12/2/80
City Well No. 5												
Chloroform	0.41	nd	5.97	5.23	nd	3.53	0.49	nd	nd	2.94	3.61	3.78
Bromodichloromethane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chlorodibromomethane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Bromoform	nd	nd	nd	nd	nd	0.11	nd	nd	nd	nd	nd	nd
1,2-Dichloroethane	2.62	3.73	3.09	2.47	2.79	2.39	3.41	2.63	2.12	2.28	2.42	2.56
Trichloroethylene	15.8	54.8	39.44	44.68	36.79	28.03	39.39	25.9	1.52	34.02	44.07	48.56
Tetrachloroethylene	1.01	1.33	0.99	2.50	1.25	1.14	1.88	0.78	nd	1.48	1.99	1.73
Carbon Tetrachloride	nm	nm	nd	nd	nd	nd	nd	nm	nd	nd	nd	nd
City Well No. 13												
Chloroform	4.27	4.80	nm	nm	nm	nm	2.84	5.09	2.74	3.58	3.56	3.02
Bromodichloromethane	nd	nd	nm	nm	nm	nm	nd	nd	0.82	nd	nd	nd
Chlorodibromomethane	nd	nd	nm	nm	nm	nm	nd	nd	nd	nd	nd	nd
Bromoform	nd	nd	nm	nm	nm	nm	nd	nd	nd	nd	nd	nd
1,2-Dichloroethane	14.2	18.7	nm	nm	nm	nm	17.98	20.7	7.47	15.54	16.01	11.10
Trichloroethylene	28.5	39.5	nm	nm	nm	nm	28.81	29.6	8.76	30.97	32.76	29.87
Tetrachloroethylene	3.88	5.55	nm	nm	nm	nm	1.81	2.40	nd	4.07	4.92	3.69
Carbon Tetrachloride	nm	2.57	nm	nm	nm	nm	2.52	3.52	1.35	2.69	2.85	2.70
City Well No. 17												
Chloroform	1.76	0.28	0.43	nd	0.47	0.91	nd	nd	0.36	0.70	0.25	0.27
Bromodichloromethane	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chlorodibromomethane	nd	0.45	0.04	nd	nd	0.51	0.32	0.23	nd	1.10	1.22	0.71
Bromoform	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,2-Dichloroethane	2.89	2.39	1.53	2.26	2.30	1.72	2.33	2.53	0.89	1.85	2.50	2.56
Trichloroethylene	51.9	61.7	15.22	48.3	37.05	10.80	27.68	34.9	23.84	40.46	42.20	44.49
Tetrachloroethylene	18.3	27.8	4.44	79.17	19.57	8.09	11.42	18.0	11.93	19.00	19.74	17.45
Carbon Tetrachloride	nm	0.15	nd	nd	nd	nd	nd	nd	nd	nd	0.32	0.33
City Well No. 18												
Chloroform	7.20	0.56	0.44	1.71	nm	0.73	0.69	nm	1.02	0.31	0.21	nm
Bromodichloromethane	nd	nd	nd	nd	nm	nd	nd	nm	nd	nd	nd	nm
Chlorodibromomethane	nd	nd	nd	nd	nm	0.30	0.86	nm	0.67	0.58	0.72	nm
Bromoform	nd	nd	nd	nd	nm	nd	nd	nm	nd	nd	nd	nm
1,2-Dichloroethane	3.29	1.35	0.94	1.40	nm	2.33	3.0	nm	1.91	2.04	2.12	nm
Trichloroethylene	8.33	8.60	24.75	12.60	nm	15.02	11.22	nm	8.69	9.07	9.12	nm
Tetrachloroethylene	21.30	21.8	15.46	16.63	nm	18.81	16.13	nm	17.00	18.19	22.70	nm
Carbon Tetrachloride	nm	nm	nd	nd	nm	nd	nd	nm	nd	nd	nd	nm

TABLE IV-48

VOLATILE ORGANICS DETECTED IN FIVE WELLS AND FINISHED WATER IN CAMDEN (ug/l) (DEC 79 TO DEC 80)

Compound	12/26/80	1/31/80	2/29/80	4/3/80	5/2/80	6/3/80	7/2/80	8/11/80	9/3/80	10/3/80	11/5/80	12/2/80
Parkside Treatment Plant - Finished Water												
Chloroform	0.87	1.20	nd	nd	0.60	0.59	1.13	1.28	1.11	0.81	0.87	1.13
Bromodichloromethane	nd	nd	0.74	0.03	nd	nd	nd	nd	nd	nd	nd	nd
Chlorodibromomethane	0.21	0.26	2.94	2.23	nd	0.94	0.38	0.18	1.71	1.29	1.37	0.38
Bromoform	nd	nd	1.79	4.00	nd	1.24	nd	nd	nd	nd	nd	nd
1,2-Dichloroethane	4.46	5.90	0.95	0.37	0.73	0.79	7.56	7.42	5.56	5.17	5.45	6.98
Trichloroethylene	16.0	20.0	11.26	10.45	6.62	1.16	16.46	13.9	13.78	12.07	12.92	17.05
Tetrachloroethylene	6.47	9.71	8.29	4.68	nd	1.28	5.66	5.40	5.68	5.15	5.70	3.83
Carbon Tetrachloride	nm	0.20	nd	nd	nd	nd	nd	nm	0.43	0.36	0.40	0.48
Well No. 4												
Chloroform	nm	nm	nm	nd	nd	25.81	nm	nm	nm	nm	nm	nm
Bromodichloromethane	nm	nm	nm	nd	nd	nd	nm	nm	nm	nm	nm	nm
Chlorodibromomethane	nm	nm	nm	19.96	14.95	21.42	nm	nm	nm	nm	nm	nm
Bromoform	nm	nm	nm	nd	nd	nd	nm	nm	nm	nm	nm	nm
1,2-Dichloroethane	nm	nm	nm	21.04	0.53	0.68	nm	nm	nm	nm	nm	nm
Trichloroethylene	nm	nm	nm	31.41	31.88	28.09	nm	nm	nm	nm	nm	nm
Tetrachloroethylene	nm	nm	nm	6.70	5.86	6.56	nm	nm	nm	nm	nm	nm
Carbon Tetrachloride	nm	nm	nm	nd	nd	nd	nm	nm	nm	nm	nm	nm

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nd = not detected
nm = not measured
Analysis performed by Techological Resources, Inc., Camden

City wells and finished water from the Parkside Treatment Plant from December 1979 through December 1980. Trihalomethanes and four volatile organic compounds were measured. This data points out not only the variations in trace organic contamination within a small area, i.e., City wells 13, 17 and 18, but also the variations observed in time. For example, tetrachloroethylene concentrations in City well no. 17 ranged from 4.4 ug/l to 79.2 ug/l over the period of a year.

Trenton Water Department

The variations of six water quality parameters with stream flow at the Delaware River at Trenton are shown in Figures IV-16a, b and c (USGS, 1976-81). Statistical analysis of these five parameters are presented in Table IV-49.

Analytical results for four finished water samples taken during the recent 1980-1981 drought are presented in Table IV-50.

COMPARISON OF AVAILABLE ORGANIC WATER QUALITY DATA TO PROJECTED HEALTH RISKS

Table IV-51 summarizes the concentrations of nine volatile organic compounds in untreated surface waters and finished waters, from both ground and surface water sources. Because data summaries only were available for the OCTSR Groundwater Study, and additional data was scarce, untreated groundwater data were not included. The table lists the number of times each compound was detected within the specified concentration ranges. These nine compounds, all VOCs, were selected because 10^{-6} incremental lifetime carcinogenic risk levels were available from the EPA. These risk levels are also listed in the table as a basis for interpretation. For example, the 10^{-6} risk level for trichloroethylene falls between 1 and 10 ug/l. Over half of the quantifiable samples have concentrations in this range or greater. Thus, for carbon tetrachloride, 1,2-dichloroethane, tetrachloroethylene, and trichloroethylene, a comparison of observed concentrations to 10^{-6} risk levels indicates potential health risks. Such comparisons were not possible for other compounds due to lack of monitoring data for compounds othe than VOCs and/or lack of health effects data.

WATER QUALITY UNDER DROUGHT CONDITIONS

The objective of this section is to estimate the possible levels of organic compounds under specified drought conditions in New Jersey surface waters. For the purposes of this discussion, organic compounds are separated into two categories. The first category consists of natural organics as measured by the surrogate parameter, TOC, which has been shown to correlate with levels of THMs subsequently formed with the use of free chlorine for disinfection. The secondary category consists of synthetic organic chemicals (SOCs) as measured in the volatile, base/neutral, acid extractable, or pesticide and herbicide fractions.

Numerous approaches can be used to estimate expected concentrations of organics in surface sources. One approach uses mass transport models which

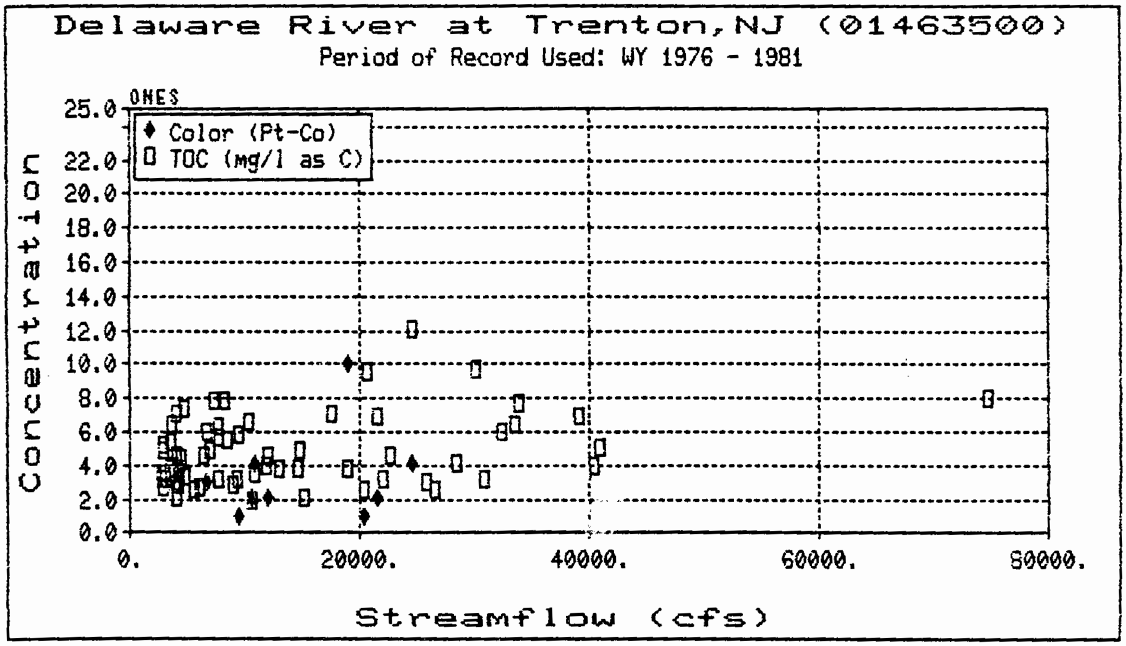

FIGURE IV-16a. VARIATION OF COLOR AND TOC WITH STREAMFLOW, DELAWARE RIVER AT TRENTON, NJ

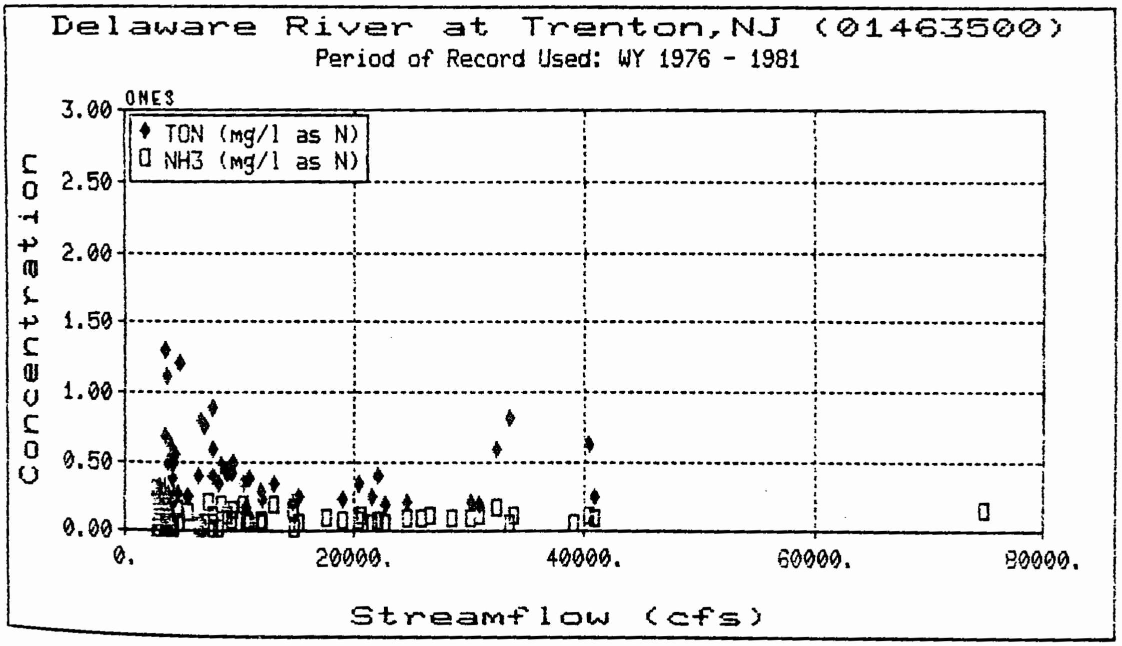

FIGURE IV-16b. VARIATION OF NH_3 AND TON WITH STREAMFLOW, DELAWARE RIVER AT TRENTON, NJ

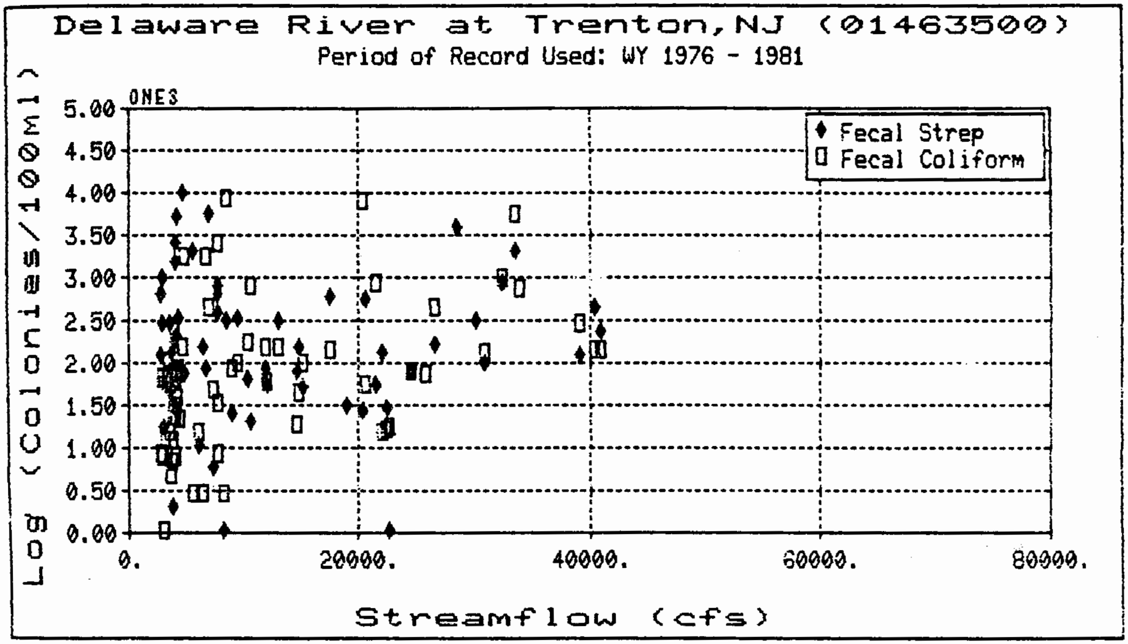

FIGURE IV-16c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH STREAMFLOW, DELAWARE RIVER AT TRENTON, NJ

TABLE IV-49

STATISTICAL ANALYSES OF FIVE WATER QUALITY PARAMETERS - DELAWARE RIVER AT TRENTON, NEW JERSEY

Period of Record Used: WY 1976 - WY 1981

Total Organic Carbon - TOC (mg/l)

Number Used/Number	68	/	68
Median / 90th Pcnt.	3.9	/	7.5
Range	.7	-	12.0
Mean / Std. Dev.	4.7	/	2.0
Geom. Mean / Std. Dev.	4.3	/	1.4

Ammonia Nitrogen - NH3 (mg/l)

Number Used/Number	63	/	63
Median / 90th Pcnt.	.07	/	.18
Range	.00	-	.34
Mean / Std. Dev.	.08	/	.06
Geom. Mean / Std. Dev.	.05	/	2.62

Total Organic Nitrogen - TON (mg/l)

Number Used/Number	53	/	53
Median / 90th Pcnt.	.34	/	.79
Range	.17	-	1.29
Mean / Std. Dev.	.42	/	.25
Geom. Mean / Std. Dev.	.36	/	1.68

Fecal Coliform (MPN)

Number Used/Number	64	/	64
Median / 90th Pcnt.	63	/	1000
Range	1	-	8550
Mean / Std. Dev.	568	/	1634
Geom. Mean / Std. Dev.	69	/	7

Fecal Streptococci (MPN)

Number Used/Number	62	/	62
Median / 90th Pcnt.	130	/	2000
Range	1	-	10000
Mean / Std. Dev.	718	/	1642
Geom. Mean / Std. Dev.	151	/	6

TABLE IV-50

VOLATILE ORGANICS DETECTED IN FINISHED WATER AT TRENTON WATER DEPARTMENT DURING BPW DROUGHT WATER QUALITY MONITORING

Parameter	Sampling Date and Concentration (ug/l)			
Week Ending:	10/11/80	11/22/80	11/29/80	1/10/81
Chloroform	20.0	33.6	nr	17.9
Bromodichloromethane	10.2	nr	nd	8.5
Dibromochloromethane	nd	nd	nd	nd
Bromoform	nd	nd	nd	nd
Total THMs	30.2	33.6	nr	26.4
Tetrachloroethylene	6.8	nd	nd	nd
Trichloroethylene	1.9	nd	nd	nd
1,1,1-Trichloroethane	nd	nd	nd	nd
1,1-Dichloroethylene	4.3	nd	nd	nd
1,2-Dichloroethylene	51.2	nd	nd	nd
Carbon Tetrachloride	nd	nd	nd	nd

NOTE: nd = not detected
nr = not reported

TABLE IV-51

SUMMARY OF OCCURENCE OF VOLATILE ORGANIC CHEMICALS (EXCLUDING THMs) IN UNTREATED SURFACE WATER SAMPLES AND FINISHED WATER SAMPLES

Compound	10^{-6} Incremental Lifetime Carcinogenic Risk Level	Number of Times Compound Detected in Specied Concentration Range			
		0.1-1 ug/l	1-10 ug/l	10-100 ug/l	100 ug/l
Carbon Tetrachloride	0.4[a], 4.5[b]	13	2	0	0
1,2-Dichloroethane	0.95[a], 0.71[b]	5	17	0	0
1,2-Dibromoethane	0.055[b]	0	0	0	0
Tetrachloroethylene	0.9[a], 3.5[b]	22	14	1	0
Trichloroethylene	2.8[a], 4.5[b]	23	25	6	1
1,1,2-Trichloroethane	0.61[a]	1	0	0	0
1,1,2,2-Tetrachloroethane	0.17[a]	1	0	0	0
Vinyl Chloride	2[a],1[b]	0	1	1	0
Benzene	0.67[b]	1	3	1	0

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a. Calculated by EPA/ODW using carcinogenic risks specified by EPA's Carcinogen Assessment Group. Modification made to reflect carcinogenic risks associated with lifetime exposure to drinking water. The contribution from fish/seafood has been excluded.

b. Calculated by EPA/ODW using carcinogenic risks specified by the Safe Drinking Water Committee, National Academy of Sciences.

provide estimates of the time and spatial distribution of selected components in river systems. For a given river segment a transport model can be constructed incorporating sinks and sources to predict concentrations of organics under selected hydraulic conditions. The sources of organic compounds consist of point source and non-point source discharges of pollutants.

A much simpler approach, and the one used based on available resources in this study, is based on steady-state mass balances assuming no sinks for the contaminants of interest. Contaminants are treated as conservative parameters with this approach.

The sections below discuss the data available for the estimation of possible levels of THM precursors and synthetic organic chemicals under low flow conditions. Hydrologic and water quality data obtained for the Passaic Valley Water Supply Commission intake on the Passaic River and the Elizabethtown Water Company intake on the Raritan River are used to illustrate one approach of estimating concentrations under low-flow conditions. Insufficient water quality data were available for water sytems using reservoir supplies to include them in the discussion.

ESTIMATION OF THM PRECURSOR LEVELS

The formation of THMs within the distribution system of a given water supply depends upon the influent water quality as well as the treatment process scheme. One measure of the potential for the formation of THMs is to dose a water sample with a given amount of chlorine and to store it under specified conditions for approximately one week. The conditions for the determination of the trihalomethane formation potential (THMFP) have not been standardized, so comparisons of this parameter from one site to another are limited. A parameter which has been measured at the USGS water quality monitoring stations throughout the state has been total organic carbon (TOC). As discussed in the sections above, industry experience indicates that TOC levels of 3 to 4 mg/l following a conventional filtration process has the potential for the formation of THMs at levels greater than the 0.1 mg/l standard when free chlorine is used.

However, this approach must be used with caution in predicting levels of THM concentrations based on TOC concentrations alone. The measured TOC consists of natural compounds which exhibit different yields of THMs per unit of equivalent weight. Several rivers in New Jersey are subject to significant discharges of industrial and municipal wastewaters (NJDEP, 1982a). Studies on the composition of soluble organics in secondary effluents have shown that from 35 to 45% of the total COD of these effluents is comprised of humic substances, over half of which is fulvic acid (Manka, et al, 1974). Thus, depending on the composition of natural organics in the river system, THM yields can be expected to vary considerably. Nonetheless, the approach described above provides a guide to the TOC levels which may present problems with respect to THMs.

ESTIMATION OF SYNTHETIC ORGANIC CHEMICAL CONCENTRATIONS

The concentration of SOCs to be expected during drought concentrations are more difficult to assess. Little monitoring has been done as a function of stream flow for surface waters throughout the state. In contrast to the concentrations of THM precursors, SOC concentrations are dependent upon point source discharges of treated muncipal wastewater and industrial wastewaters as well as non-point sources such as urban runoff. However, the monitoring of SOCs in point source discharges is not currently required under the discharge permit system. Predictions of expected concentrations of SOCs under drought conditions would most likely have to be made using a mass transport model incorporating sinks and sources. SOCs are subject to many natural transformation reactions which will affect their concentrations, over and above the effects of dilution. Such natural processes include aeration of volatile compounds, biotransformation, and adsorption onto natural particulates and subsequent settling. Volatile organics are very susceptible to natural aeration processes, as shown by Hunter and Sabatino (undated) in comparing upstream loadings of seven volatile organics with downstream concentrations observed in the Passaic River.

To illustrate the types of organics found in point source municipal wastewater discharges, Table IV-52 shows the occurrences of four organic compound fractions in three studies of municipal wastewater effluents (JMM, 1982). Acid extractable and pesticides/PCB compounds were not detected in any of the samples analyzed. A phthalate was the only base/neutral extractable compound detected in the samples analyzed, and ranged in concentration from "not detected" to 92 ug/l. In contrast to the previous three organic fractions, volatile organics were often detected in one or more of the three studies summarized. Note that the highest concentrations of volatile organics were observed for three compounds commonly used in industrial applications; 1,1,1-trichloroethane, tetrachloroethylene, and trichloroethylene.

A study investigating halogenated hydrocarbons in the Passaic Valley watershed (Hunter and Sabatino, undated) measured the concentrations of eight two-carbon halogenated compounds, and detected levels less than 100 ug/l in grab samples at seven municipal wastewater treatment plants sampled. Single grab samples were obtained at two wastewater treatment plants and analyzed for PCBs. One of the samples showed a high concentration of 198 ug/l. Based on this limited information available for the state, it is difficult to predict loadings of SOCs from municipal wastewater treatment plants, especially for the non-volatile fractions.

Loadings of SOCs from point source industrial discharges are even more difficult to predict. The types and concentrations of SOCs from industrial sources is very site specific. Monitoring of these discharges will be required in the future in order to assess the effects of SOCs on downstream surface water intakes.

TABLE IV-52
ORGANIC PRIORITY POLLUTANTS DETECTED IN MUNICIPAL WASTEWATER EFFLUENTS (FROM JMM, 1982)

	Blue Plains Priority Pollutant Study				COE - EEWTP Study				EPA 20-Plant Study			
	No. of Samples Analyzed	Frequency of Detection %	Minimum[a] ug/l	Maximum ug/l	No. of Samples Analyzed	Frequency of Detection %	Minimum[a] ug/l	Maximum ug/l	No. of. Samples Analyzed	Frequency of Detection %	Minimum[a] ug/l	Maximum ug/l
BASE/NEUTRAL EXTRACTABLE COMPOUNDS (47)												
Di-N-butyl Phthalate	4	0	--	--	4	25	--[b]	3.6	129	59	1	92
ACID EXTRACTABLE COMPOUNDS (11)												
(none detected)												
PESTICIDES/PCB COMPOUNDS (25)												
(none detected)												
VOLATILE ORGANIC COMPOUNDS (31)												
Benzene	15	73	37	144	8	0	--	--	130	21	1	29
Chlorodibromomethane	15	0	--	--	8	25	NQ	NQ	130	8	1	5
Chloroform	15	0	--	--	8	100	1.3	4.1	130	88	1	61
Dichlorobromomethane	15	0	--	--	8	75	0.2	0.4	130	19	1	5
Ethylbenzene	15	0	--	--	8	13	NQ	NQ	130	21	1	11
Tetrachloroethylene	15	0	--	--	8	100	0.5	7.0	130	82	0	320
1,1,1-Trichloroethane	15	0	--	--	8	100	0.1	0.4	130	57	1	370
Trichloroethylene	15	0	--	--	8	50	0.2	0.5	130	54	1	97
MISCELLANEOUS												
Cyanide	5	80	17	74	279	82	5	370	126	94	2	2,211

NOTE: a Minimum value above detection limit
b Only one value above detection limit

PASSAIC VALLEY WATER SUPPLY COMMISSION - PASSAIC RIVER INTAKE AT LITTLE FALLS

The Passaic River at the Little Falls intake to the Passaic Valley Water Commission (PVWC) Treatment Plant is an example of a surface source with significant upstream discharges of industrial and municipal wastewaters. A recent study by the New Jersey Department of Environmental Studies (1982) estimated that the current quantities of these upstream municipal wastewater discharges were 53 mgd (82.2 cfs). The municipal discharges have received secondary treatment with varying degrees of nitrification. Based on measurements of several parameters in these effluents, the NJDEP calculated the average loadings of ammonia nitrogen as 5,803 lbs/day, TOC as 7,445 lbs/day, and COD as 32,552 lbs/day above the Little Falls intake. Based on these average loadings and a total discharge of 53 mgd, average concentrations of ammonia nitrogen 13 mg/l, TOC of 16.8 mg/l, and COD of 73.6 mg/l were calculated for this study. The current quantity of point source industrial discharges above the Little Falls intake was estimated to be 9 mgd (14 cfs) (NJDEP, 1982). The report stated that these industrial discharges contributed insignificant loadings of ammonia nitrogen, TOC and COD. Loadings of SOCs from these two types of sources were not considered in the NJDEP report.

In estimating expected water quality conditions under low flow conditions, the NJDEP (1982b) used an exceedence flow curve developed for the 1961-1966 drought period. This study used a different approach to calculate expected magnitudes of low flows. Using a program available through the National Water Data Exchange (NAWDEX), low flow duration curves were developed for the Passaic River at Little Falls. The program discretized and categorized the low flows over the period of record according to duration. Log-Pearson Type III statistics were used to predict the magnitude of a given duration of low flow as a function of non-exceedence probability. The results of this analysis for the Passaic River at Little Falls are shown in Table IV-53. For a hypothetical drought of 90 days duration, used for purposes of discussion in this study, the magnitude of flows range from 41 to 588 cfs (26 to 379 mgd). The non-exceedence probability refers to the probability that the flow will not be greater than or equal to the flowrate listed. For example, there is a 50% probability that, in any one year, the flowrate will not be greater than or equal to 218 cfs for 90 days. This combination of flowrate and duration can also be described by the return period, which is simply the reciprocal of the non-exceedence probability. For this example, the return period is two years.

Figures IV-17a, b and c show the variation of TOC, NH_3-N, fecal coliform and fecal streptococci with stream flow for those flows less than 600 cfs. Observed values of TOC, NH_3-N and fecal bacteria for these low flows ranged from 4 to 12 mg/l, for NH_3-N from 0.8 to 9.2 mg/l, and 4 to 1585 colonies/100 ml, respectively. Assuming the simple dilution of TOC and NH_3-N to be conservative, the fraction of wastewater observed at Little Falls ranges from 6 to 71% when compared to the concentrations in wastewater discussed above. These calculations, based on concentrations of TOC and NH_3-N, are affected by biological transformation processes in addition to simple dilution. Comparing the flowrate of treated wastewater to the average monthly flows observed

TABLE IV-53

PREDICTED LOW FLOWS AT USGS STATION 01389500
PASSAIC RIVER AT LITTLE FALLS
(BASED ON PERIOD OF RECORD 1899-1981)

Duration (days)	Non-Exceedence Probability (Recurrence Interval) 0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	140.1 cfs	106.6	54.7	22.7	13.1	7.9	4.2	2.7
3	166.9	131.1	73.1	34.2	21.4	13.9	8.2	5.6
7	196.8	153.8	88.6	45.7	30.9	21.8	14.3	10.6
14	228.9	179.6	105.2	55.9	38.6	27.8	18.7	14.2
30	287.9	224.4	133.4	74.7	53.8	40.5	29.1	23.1
60	442.2	316.9	170.6	93.9	69.4	54.2	41.3	34.6
90	587.8	416.1	218.4	117.0	85.1	65.7	49.4	41.0
120	732.6	527.9	283.0	152.3	110.4	84.7	62.9	51.6
183	1019.5	758.2	428.5	240.7	177.7	138.1	103.8	85.8
365	1695.0	1487.9	1123.1	811.2	671.9	569.5	467.8	407.6

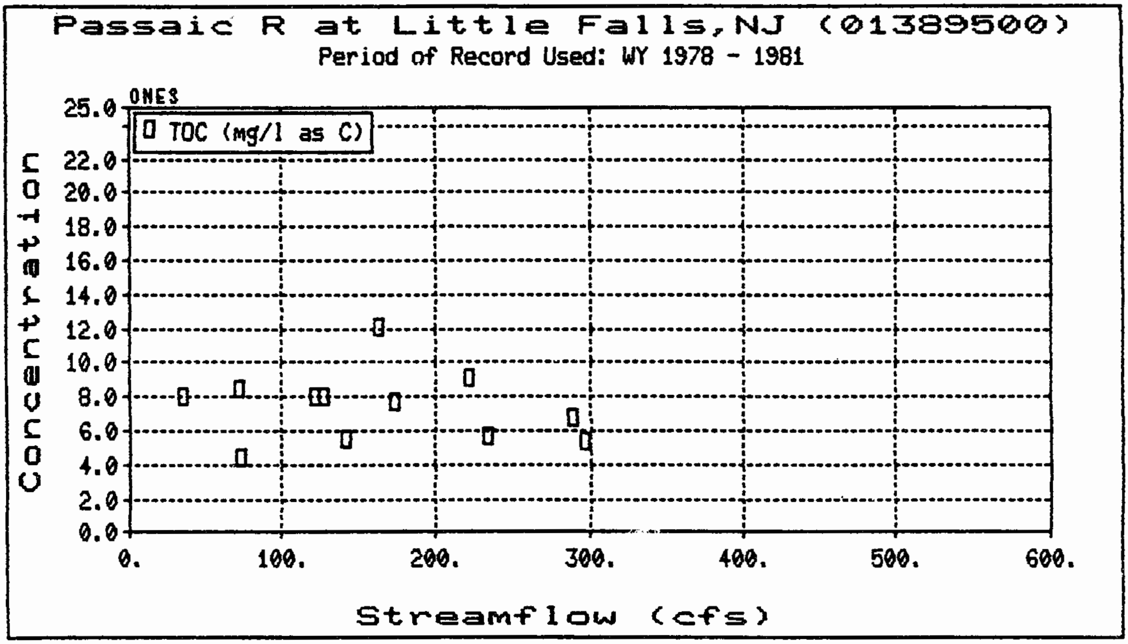

FIGURE IV-17a. VARIATION OF TOC WITH STREAMFLOW FOR PERIODS OF LOW FLOW, PASSAIC RIVER AT LITTLE FALLS, NEW JERSEY

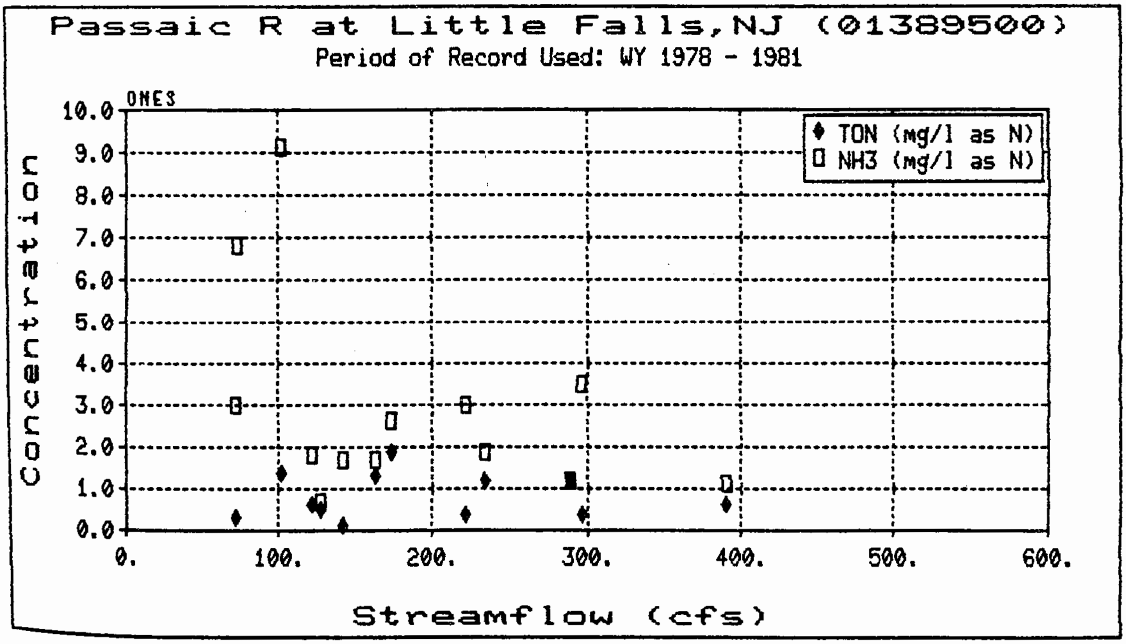

FIGURE IV-17b. VARIATION OF NH_3 AND TON WITH LOW FLOW, PASSAIC RIVER AT LITTLE FALLS, NEW JERSEY

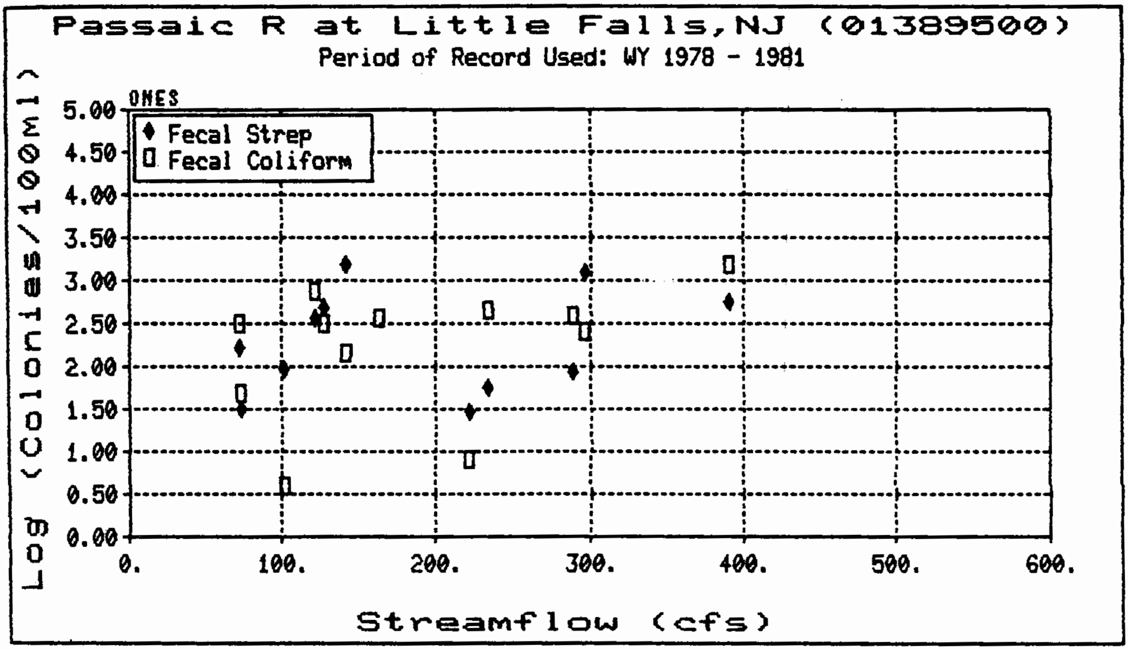

FIGURE IV-17c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH LOW FLOW, PASSAIC RIVER AT LITTLE FALLS, NEW JERSEY during the recent drought from October 1980 through January 1981, the Passaic River at Little Falls would consist of from 42 to 80% wastewater under these conditions.

Based on THM yields previously observed and discussed aboved , THM concentrations at the PVWC Little Falls Plant could range from 80 to 200 ug/l based on the median of the range of TOC values estimated during low flow periods, and assuming a 50% TOC reduction through conventional treatment should free chlorine be used for disinfection. The practice of breakpoint chlorination to reduce the high NH_3-N levels expected during low flow periods will compound the problem of controlling chlorinated organics in the finished water. In addition, the observed range of fecal bacteria in the raw water may limit the use of alternative disinfectants for THM control while maintaining acceptable microbiological quality.

The expected levels of SOCs at the PVWC Little Falls intake under low flow conditions are more uncertain. A worst-case scenario can be constructed from the water quality data presented above. The flowrate for a 90 day drought, with a return period of five years, is predicted to be 117 cfs, as listed in Table IV-53. With a combined upstream wastewater discharge of 83 cfs, the Passaic River at Little Falls consists of, on the average, 71% wastewater under these conditions. Assuming the maximum observed concentrations of benzene and tetrachloroethene in municipal wastewaters listed in Table IV-52, the concentrations of these two compounds at Little ,Falls due to dilution effects only would be 70 ug/l and 227 ug/l, respectively. However, as discussed in previous sections, the concentrations of these volatile compounds would be further reduced due to natural aeration processes in the Passaic River. Hunter and Sabatino (undated) observed an average concentration reduction of 60% for seven volatile halogenated compounds in the Passaic watershed during winter. Such additional losses due to natural volatilization would further reduce the concentrations of benzene and tetrachloroethene to 28 ug/l and 91 ug/l, respectively. Thus, the potential exists for relatively high levels of certain VOCs under drought conditions in this watershed. Available monitoring results, however, suggest that this is not the case.

Note that the discussion above has not considered non-volatile SOCs. Under drought conditions, when flows in the Passaic River may consist of greater than 50% wastewater, the concentrations of refractory, high molecular weight compounds may be present at levels which may pose health risks. Loadings of SOCs, both volatile and non-volatile, due to industrial sources could not be estimated due to lack of monitoring data. More complete monitoring data for these compounds, coupled with health effects data,will help to identify potential problems due to these SOCs during low flow periods.

ELIZABETHTOWN WATER COMPANY RARITAN RIVER INTAKE

In contrast to the Passaic River at Little Falls, the Raritan River at Manville, New Jersey is an example of a less contaminated surface source as measured by the surrogate parameters TOC and NH_3-N. Insufficient detail about the location and flowrates for municipal wastewater discharges above the Elizabethtown Water Company intake were given in the 1982 State Water

Quality Inventory Report (NJDEP, 1982a) to estimate the magnitude of upstream discharges. Therefore, estimates of the concentration range for several water quality parameters are based on observations of these parameters at previous low flowrates.

The predicted low flows at the Raritan River at Manville, NJ are listed in Table IV-54. For the low flow duration of 90 days, the flowrate ranges from 51 to 443 cfs. The concentration variations for five water quality parameters versus stream flow, for flows less than 600 cfs are shown in Figures IV-18a, b and c. For these low flows, the TOC, NH_3-N, and fecal bacteria concentrations range from 1 to 8.5 mg/l, less than 0.5 mg/l, and 3 to 31,623 MPN/100 ml, respectively.

Based on the THM yield values presented above, THM concentrations at the Raritan River intake could range from 20 to 425 ug/l for the range of TOC values estimated during low flow periods should free chlorine be used for disinfection. The low concentration of NH_3-N estimated eliminates the requirement for breakpoint chlorination. Therefore, the range of estimated fecal bacteria concentrations estimated is the primary water quality concern in the use of alternative disinfectants to reduce THM concentrations.

In contrast to estimations in the Passaic River watershed, which had the greatest quantity of organic water quality data of rivers considered in this study, estimates of SOC concentrations expected during low flows were not possible for the Raritan River due to lack of data.

SUMMARY

As discussed in Section IV, MCLs have been established for THMs and pesticides in finished waters. The range of observed concentrations of pesticides and herbicides in untreated surface supplies, based on data reviewed in this section, currently meets the MCLs for finished water. These organic compounds do not currently present a treatment problem.

However, problems from high concentrations of THMs are expected in drinking waters produced from several surface supplies reviewed in this section. Median values of TOC greater than 6 mg/l represent a potential for the formation of THMs at greater than 0.1 mg/l in those water systems using free chlorine for disinfection. This assumes a 50% removal of TOC in a conventional filtration treatment process, and the formation of between 20 and 50 ug of THMs per mg of TOC.

Another issue of concern is the lack of monitoring data for compounds not measured in the volatile fraction using a gas chromatograph. The majority of analytical data summarized in this section are for volatile organic compounds. As Figure IV-19 shows, using the Mississippi River as an example, a large proportion of organic compounds, especially the higher molecular weight compounds, are not measured.

Therefore, to ascertain and define the nature and extent of organics in New Jersey's drinking waters, there is a need for systematic monitoring of water

TABLE IV-54

PREDICTED LOW FLOWS AT USGS STATION 01400500 RARITAN RIVER AT MANVILLE (BASED ON PERIOD OF RECORD 1905-1981)

	Non-Exceedence Probability (Recurrence Interval)							
Duration (days)	0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	174.8 cfs	143.0	91.0	52.7	38.1	28.5	20.1	15.7
3	186.2	153.5	99.7	59.3	43.5	33.1	23.7	18.8
7	204.2	168.0	109.5	66.3	49.5	38.2	28.0	22.6
14	221.8	181.7	118.8	73.3	55.6	43.6	32.8	26.8
30	268.3	215.7	138.0	84.9	64.8	51.5	39.3	32.7
60	350.6	276.2	172.6	105.7	81.2	65.0	50.4	42.4
90	443.2	345.1	211.9	128.4	98.3	78.7	61.0	51.4
100	534.1	414.5	252.2	150.9	114.7	91.1	70.0	58.6
183	723.5	567.3	349.2	209.5	158.7	125.5	95.7	79.6
365	1056.0	945.7	743.8	562.1	477.4	413.5	348.3	308.8

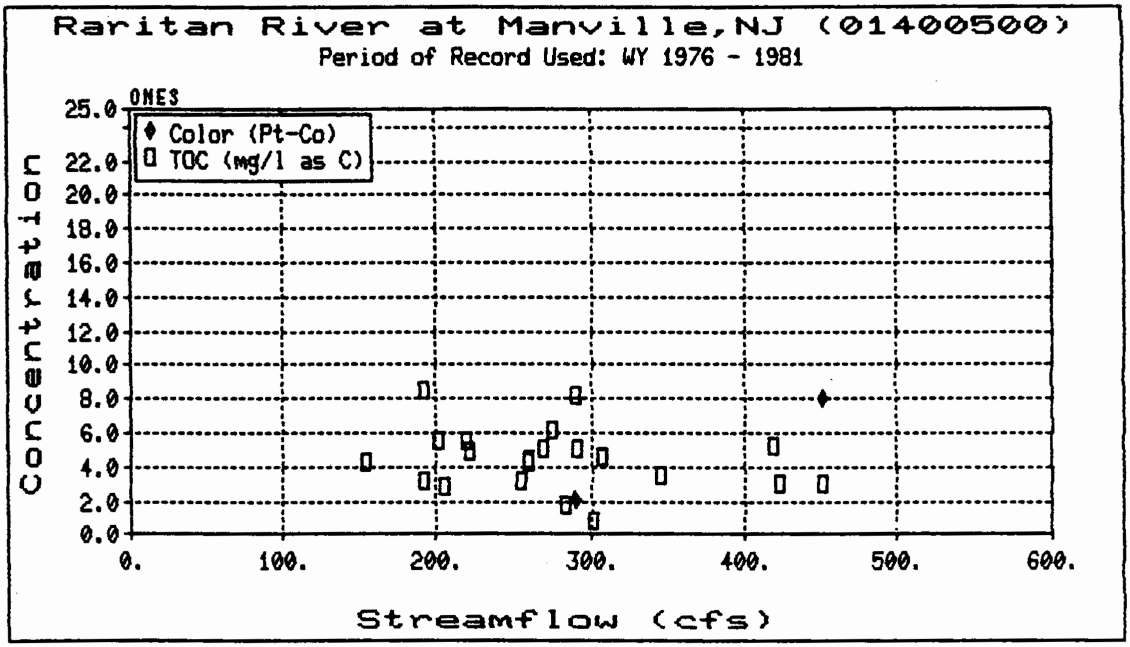

FIGURE IV-18a. VARIATION OF TOC WITH LOW FLOW, RARITAN RIVER AT MANVILLE, NEW JERSEY

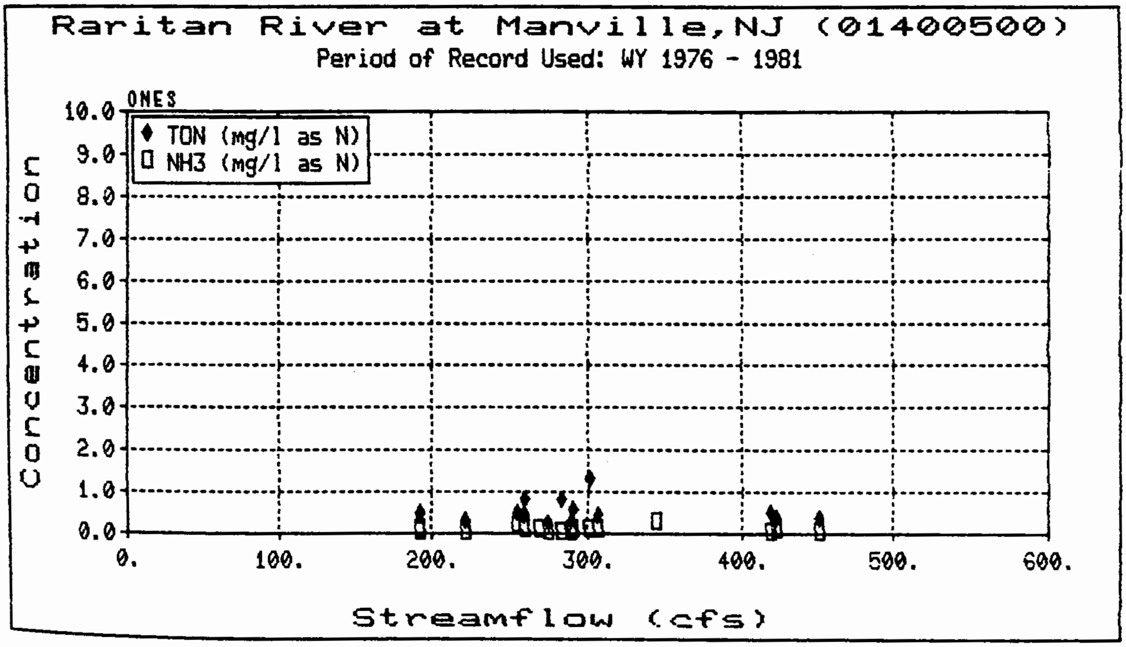

FIGURE IV-18b. VARIATION OF NH_3 AND TON WITH LOW FLOW, RARITAN RIVER AT MANVILLE, NEW JERSEY

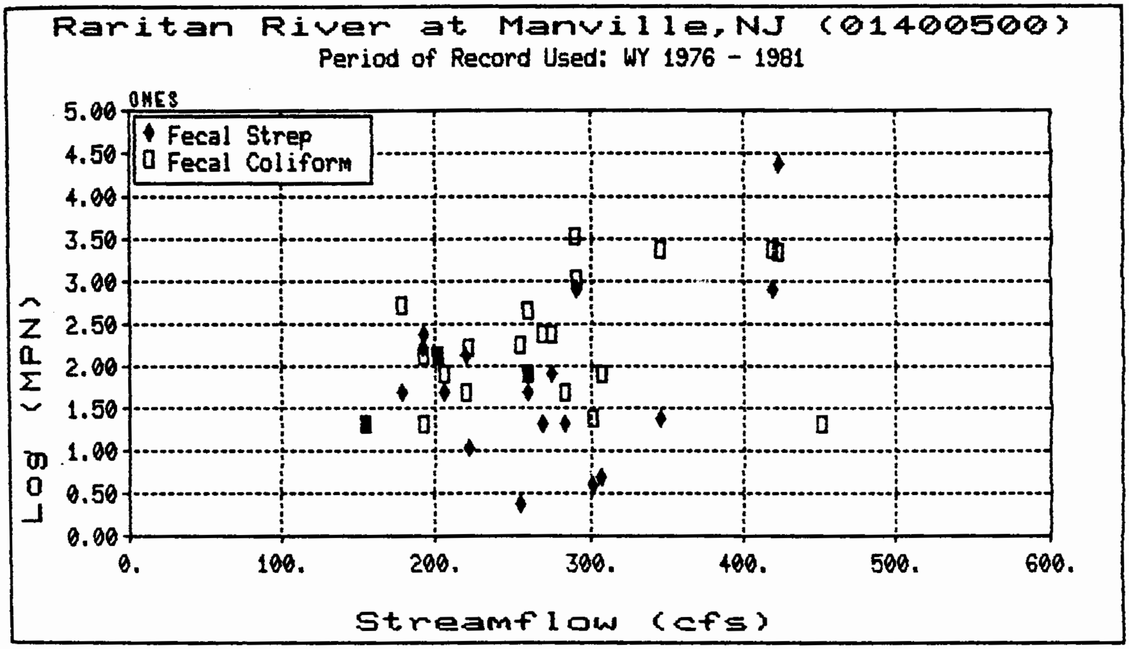

FIGURE IV-18c. VARIATION OF FECAL COLIFORM AND FECAL STREPTOCOCCI WITH LOW FLOW, RARITAN RIVER AT MANVILLE, NEW JERSEY

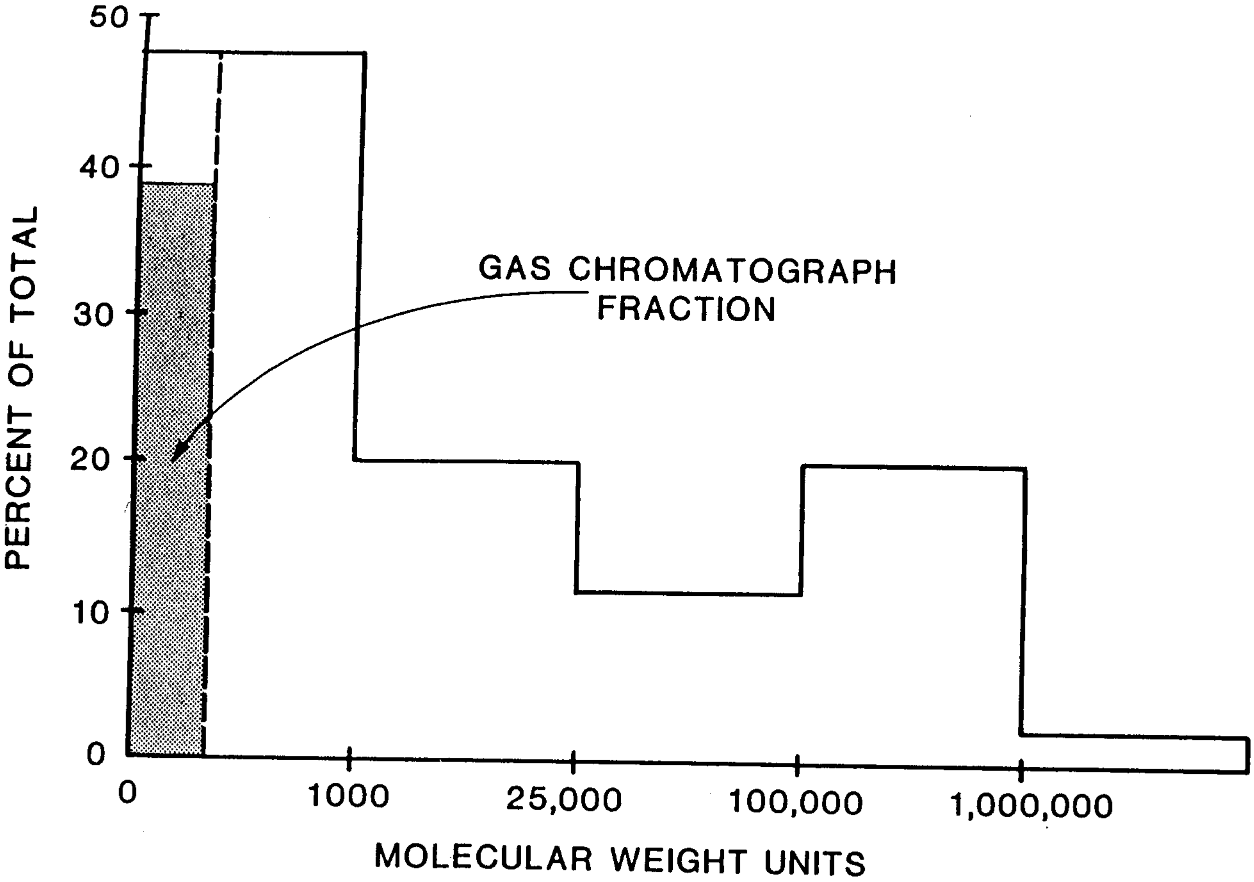

FIGURE IV-19 DISTRIBUTION OF ORGANIC COMPOUNDS IN MISSISSIPPI RIVER WATER
(After Anderson and Maier, 1977)

supplies used for drinking water purposes for several reasons. First, long term monitoring data is needed to assess the risks from compounds which pose health risks at low concentrations. The available water quality data summarized above is not adequately representative of the extent of organic contamination due to infrequent collection of grab samples. As the data presented above shows, concentrations at a given site vary with time. Second, more information is needed on ranges of concentrations of those compounds not measured in the volatile gas chromatograph fraction, for these higher molecular weight compounds may also pose health risk at low concentrations. There is a need to fill this gap in the data base even though these compounds are not now regulated.

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SECTION V

SECTION V

TREATABILITY OF ORGANIC CONTAMINANTS: PROBLEM DESCRIPTION AND PROCESS ALTERNATIVES

This section presents an overview of organics removal processes based on experience gained in the United States and Europe. Because the effectiveness of a given treatment process in organics removal depends upon the physical and chemical characteristics of the organics present, this section begins with a discussion of the classification of these compounds. It is intended to provide a frame of reference for interpretation of the organic water quality data presented in Section IV with respect to treatability. The unit processes discussed in this section include coagulation/flocculation/sedimentation, filtration, powdered activated carbon (PAC) adsorption, aeration processes, granular activated carbon (GAC) adsorption, and oxidation processes. This seciton concludes with a summary of unit process combination selection.

CLASSIFICATION OF ORGANIC COMPOUNDS WITH RESPECT TO TREATABILITY

A striking variety of organic compounds have been identified in the aquatic environment. Figure V-1 illustrates a simplified scheme for the categorization of the organics that are known to exist in drinking water, based on their volatility, molecular weight and polarity (Trussell and Umphres, 1978). Shown in Figure V-2 are representative compounds from each region of the chart in Figure V-1 (Trussell and Umphres, 1978). The size and complexity of the organic molecules increase as a function of molecular weight until the structures become polymeric in nature. The highly polar compounds listed at the top of each column contain a large number of oxygenated functional groups relative to the nonpolar compounds. While a great many structural variations are possible within each chemical class, e.g., substitution by halogen atoms, the general trends depicted by this scheme are valid.

SOURCES AND CONCENTRATION RANGES OF ORGANIC COMPOUNDS IN NATURAL WATERS

There are three major sources of organic compounds in natural waters:

1. Compounds derived from the dissolution of naturally-occurring organic materials.

2. Compounds formed through chemical reactions occurring during disinfection/treatment and transmission of water.

3. Contaminants from the manufacture and use of synthetic organic chemicals (SOCs).

VOLATILITY

		VOLATILE	SEMI-VOLATILE	NON-VOLATILE
POLARITY	POLAR	ALCOHOLS KETONES CARBOXYLIC ACIDS	ALCOHOLS KETONES CARBOXYLIC ACIDS PHENOLS	POLYELECTROLYTES CARBOHYDRATES FULVIC ACIDS
	SEMI-POLAR	ETHERS ESTERS ALDEHYDES	ETHERS ESTERS ALDEHYDES EPOXIDES HETEROCYCLICS	PROTEINS CARBOHYDRATES HUMIC ACIDS
	NON-POLAR	ALIPHATIC HYDROCARBONS AROMATIC HYDROCARBONS	ALIPHATICS AROMATICS ALICYCLICS ARENES	NON-IONIC POLYMERS LIGNINS HYMATOMELANIC ACID
		LOW	MEDIUM	HIGH

MOLECULAR WEIGHT

FIGURE V-1. SCHEMATIC CLASSIFICATION OF ORGANIC COMPOUNDS FOUND IN WATER
(from Trussell and Umphres, 1978)

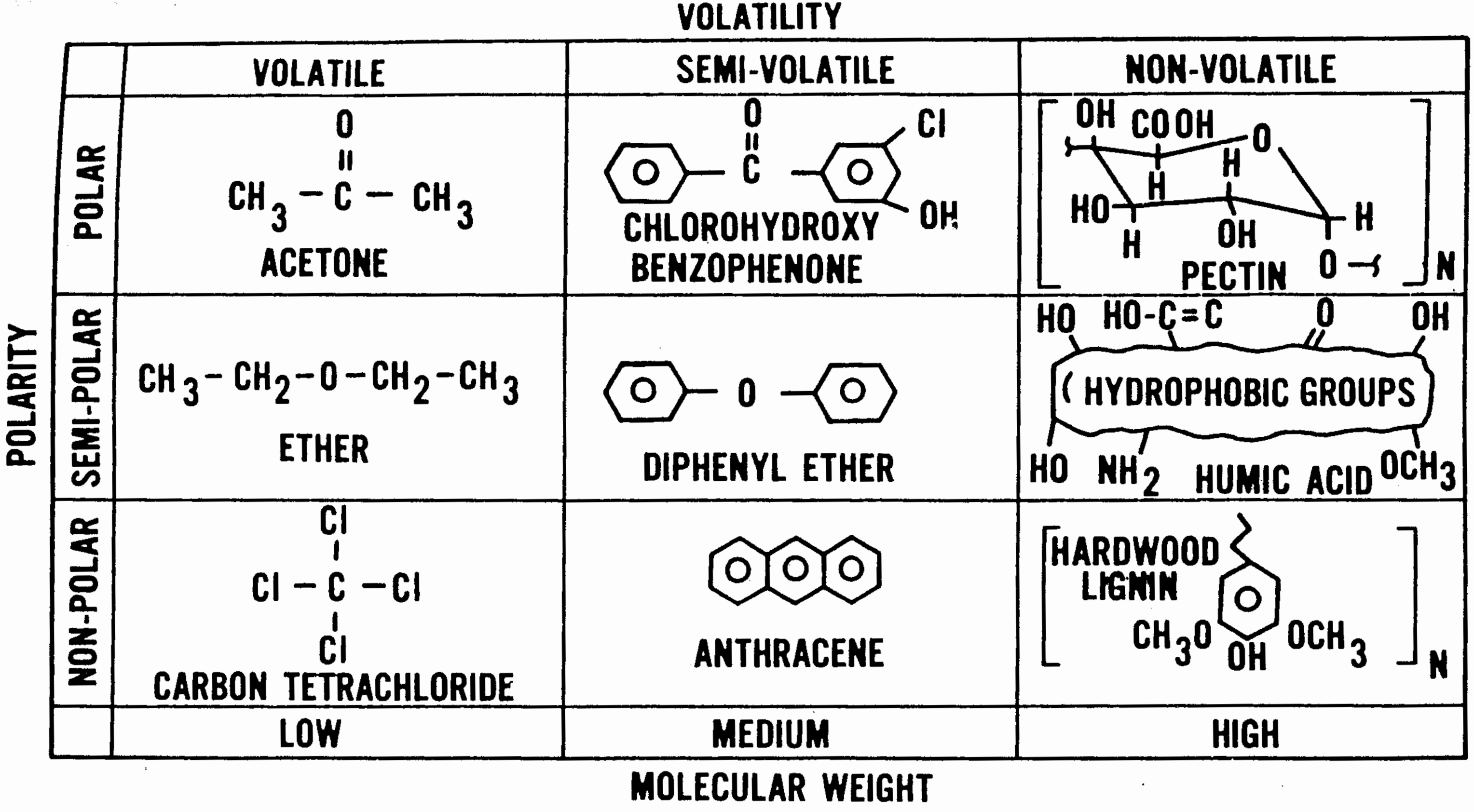


FIGURE V-2. EXAMPLE COMPOUNDS IN CLASSIFICATION SCHEMATIC
(from Trussell and Umphres, 1978)

In general, the attention of the water treatment industry has focused primarily on reducing the input of compounds from the latter two categories of sources. However, substances such as pesticides and chlorinated hydrocarbons which result from man-made sources comprise only a very small fraction of the total mass of organic material present in most water systems. Typically, anthropogenic organic pollutants occur in the aquatic environment at low parts-per-billion (ug/l or ppb) concentrations, whereas, the total organic carbon (TOC) content of water may approach levels of several parts-per-million (mg/l or ppm) (Kavanaugh, 1978). The organic carbon concentrations of ground and surface waters often fall in the ranges of 0.1 to 2 mg/l and 1 to 20 mg/l, respectively. By contrast, the highly colored waters of most swamps may possess considerably higher TOC levels which approach several hundred mg/l.

Naturally Occurring Organics

The vast majority of organic material present in water, as mentioned above, is comprised of naturally-occurring humic material. A general mechanism for the synthesis of these organic substances is the decomposition of carbohydrates and proteins through chemical and microbiological oxidation into smaller chemical units such as dihydroxybenzoic acids and amino acids. In a separate series of reactions, phenolic polymers are formed by intramolecular condensation of lignins and tannins derived from plants. These reactants then combine with the metabolities of living and deceased micro-organisms to yield an amorphous polyheterocondensate product.

Aquatic humic material is composed primarily of two fractions, humic acids and fulvic acids. These two fractions are characterized by differenes in their solubility in acid and alkali, their molecular weight, and their functional group composition. In general, humic acids comprise the higher molecular weight fraction, with molecular weights ranging up to 200,000. The molecular weight of the fulvic acid fraction ranges from 200 to 1,000.

There are two additional sources of naturally-occurring organics in water: microorganisms and petroleum residues. Algae, bacteria and actinomycetes are ubiquitous organisms in surface water supplies. Under conditions in which the populations of these organisms fluorish, as in the case of an algal bloom, their cellular mass can contribute significantly to the total organic carbon content of water. In addition to cellular matter, a variety of plants and microorganisms excrete metabolites into the water. For example, methylisoborneol (MIB) and geosmin impart the characteristic musty odor and taste to aquatic systems that are densely inhabited by blue-green algae and actinomycetes. In contrast to the substances of biological origin, petroleum-based chemicals are seldom encountered in surface waters. Instead, methane and higher molecular weight aliphatic and aromatic hydrocarbon pollutants often contaminate groundwaters in regions where deposits of natural gas and oil come in contact with subterranean aquifers.

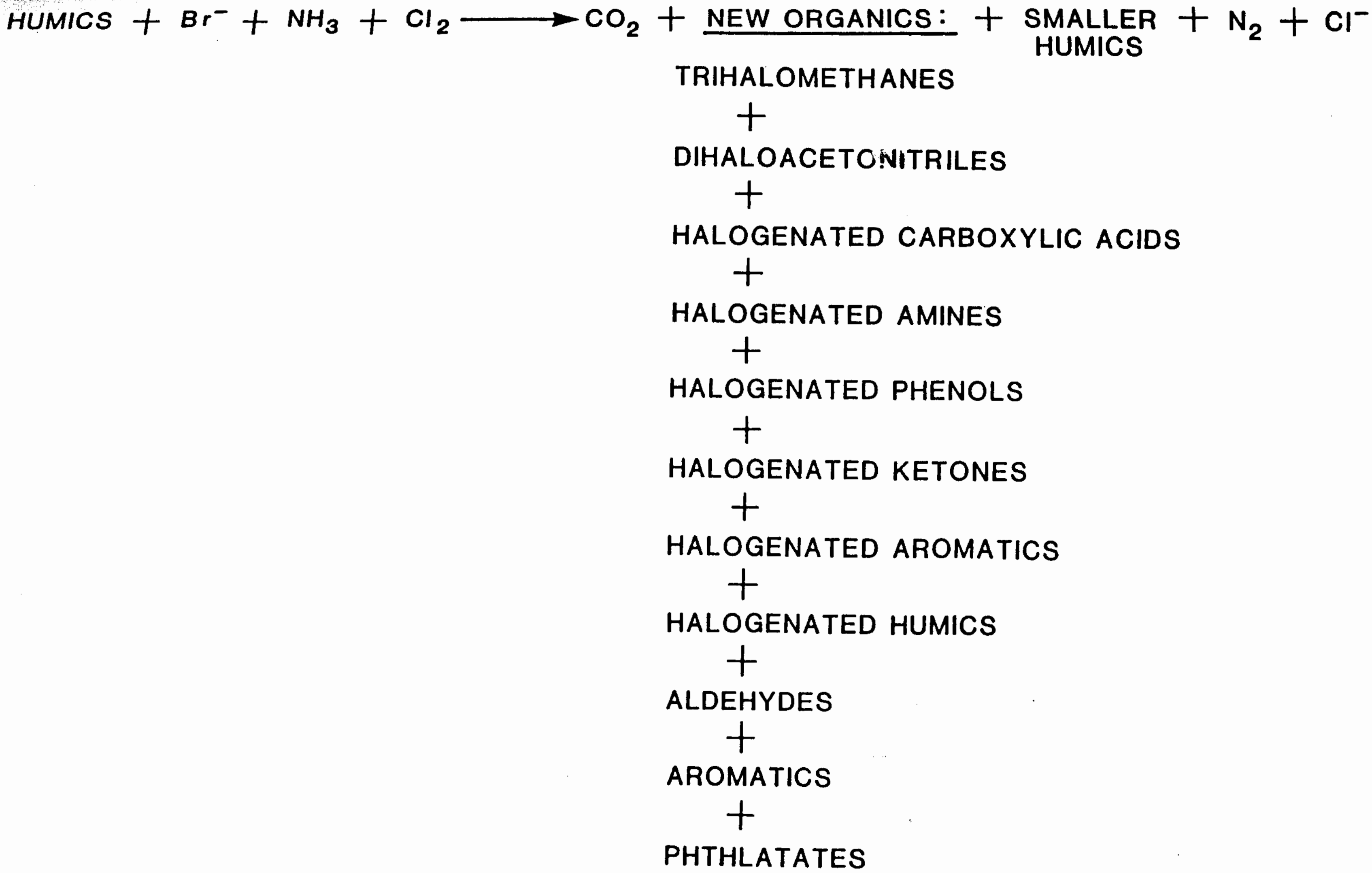
Organic Compounds Formed During Water Disinfection, Treatment and Transmission

The treatment of water for human consumption can produce a variety of organic compounds. Numerous contaminants are formed through chemical transformations of naturally-occurring organic matter that occur during water disinfection. For example, chlorine can efficiently convert humic substances to trihalomethanes and other organohalogen oxidation products under the reaction conditions encountered in water treatment systems (Rook, 1976, 1977; Babcock and Singer, 1979; Trussell and Umphres, 1978; Stevens et al., 1977). Other treatment chemicals may also pass through the purification process.

Chlorine (Cl_2) is the most commonly used chemical for the disinfection of water and wastewaters. The impact of chlorination on the chemical composition of organic matter in aqueous systems has become the subject of intensive study since Rook (1974) initially reported the formation of chloroform in drinking water. Shown in Figure V-3 are some of the "new" compounds that are produced during water chlorination. Under conditions of incomplete reaction, chlorine may also decompose aquatic humus to yield fulvic and humic acids of lower molecular weight.

The composition of the organics formed during water treatment is now known to be far more complex than originally discovered in 1974. In addition to the trihalomethanes, eleven classes of compounds have been detected in drinking water supplies (see Figure V-3). For example, analytical surveys indicate that dihaloacetonitriles are present in a high percentage of treatment plant effluents (Trehy and Bieber, 1981). Other types of organic chemicals such as halogenated carboxylic acids and halogenated amines have been reported to occur in only a limited number of water supplies. However, infrequent detection of these substances may simply reflect the limitations in available analytical methods. The total organic halogen (TOX) content of finished waters is typically three to four times higher than values which can be attributed to trihalomethanes. Future improvements in techniques for trace organics analysis should, therefore, provide more information about the chemical reactions that occur as the result of water disinfection.

The trihalomethanes are the most common by-products of water chlorination that are detected using currently available analytical techniques. These compounds generally occur at elevated concentrations relative to other organohalide contaminants. By definition, trihalomethanes represent structural variations of the methane molecule (CH_4) in which three halogen atoms (F, Cl, Br, or I) are substituted for hydrogen. The THMs which commonly occur in drinking water supplies include chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), bromoform ($CHBr_3$), dichloroiodomethane ($CHCl_2I$), and bromochloroiodomethane ($CHBrClI$). Several of the factors which influence the formation of trihalomethanes include pH, Br concentration and NH_3 concentration. THM production increases in proportion to increases in the pH of the aqueous system. This results from a key step in the pathway of trihalomethane formation which becomes favored under alkaline reaction conditions (Trussell and Umphres, 1978). Second, increases in the concentration of bromide ion (Br^-)



$$\text{HUMICS} + \text{Br}^- + \text{NH}_3 + \text{Cl}_2 \longrightarrow \text{CO}_2 + \underline{\text{NEW ORGANICS:}} + \begin{array}{c}\text{SMALLER}\\ \text{HUMICS}\end{array} + \text{N}_2 + \text{Cl}^-$$

TRIHALOMETHANES

+

DIHALOACETONITRILES

+

HALOGENATED CARBOXYLIC ACIDS

+

HALOGENATED AMINES

+

HALOGENATED PHENOLS

+

HALOGENATED KETONES

+

HALOGENATED AROMATICS

+

HALOGENATED HUMICS

+

ALDEHYDES

+

AROMATICS

+

PHTHLATATES

FIGURE V-3. CHLORINATION BYPRODUCTS
(from JMM)

enhance the yield of trihalomethanes and rate of reaction. Ammonia can be employed to arrest the reactions responsible for THM production. Addition of ammonia readily converts residual free chlorine to chloramines which cannot undergo rapid reaction with humic substances to give trihalomethanes (Stevens et al., 1977).

Use of ozone for water disinfection causes the formation of numerous types of organic compounds, but not trihalomethanes. The products of ozonation of naturally-occurring organic substrates include aldehydes, ketones, carboxylic acids, phthalates, and, of course, carbon dioxide. The gas chromatogram depicted in Figure V-4 shows the volatile organic by-products that resulted from treatment of a sample of water from the Colorado River with ozone. The most notable treatment products were a series of aliphatic aldehydes which contained from four to ten carbon atoms. In this experiment, the ozone was applied at elevated levels (20 mg/l) in order to insure the formation of products at sufficient concentrations (1-10 ppb) for identification by gas chromatography/mass spectrometry. At dosages of ozone typically used for water treatment (3 mg/l), aldehyde concentrations may range from 0.01-1 ppb.

Similar by-products are formed from the reactions of less widely used disinfectants and oxidants such as chlorine dioxide ($Cl0_2$), hydrogen peroxide (H_20_2), and potassium permanganate ($KMn0_4$) with organic substrates dissolved in raw water. It appears that the use of these disinfectants does not lead to the production of halogenated compounds. Formation of THMs may occur through application of chloride dioxide due to the presence of molecular chlorine as an impurity from the manufacture of chlorine dioxide. In the results from the EPA's National Organics Reconnaisance Survey, Symons et al. (1975) reported only trace concentrations of trihalomethanes in municipal drinking water supplies that were treated with ozone as an alternative or supplement to chlorine. Presumably, initial addition of permanganate or ozone acts to oxidize the primary trihalomethane precursors.

Bulk chemicals used in water treatment plants can also contribute to the organic content of finished water supplies. Under certain conditions, organic polymers which are added to improve the efficiency of coagulation and filtration steps, can break through the treatment process. In addition, low concentrations of the monomeric substances that make up the structure of coagulant polymers have also been found in drinking water. Contaminants in treatment chemicals represents another source of pollution that may potentially affect an aquatic system. For example, solvents such as carbon tetrachloride are routinely employed in cleaning cylinders used for storage and delivery of chlorine. Therefore, traces of carbon tetrachloride can be dissolved in water upon disinfection with chlorine.

Synthetic Organic Chemicals

Organic chemicals from industry, agriculture and municipal effluents contribute extensively to the pollution of many water supplies. Surface waters are especially vulnerable to these types of pollution but, as recent experience has shown, groundwater systems are also susceptible.

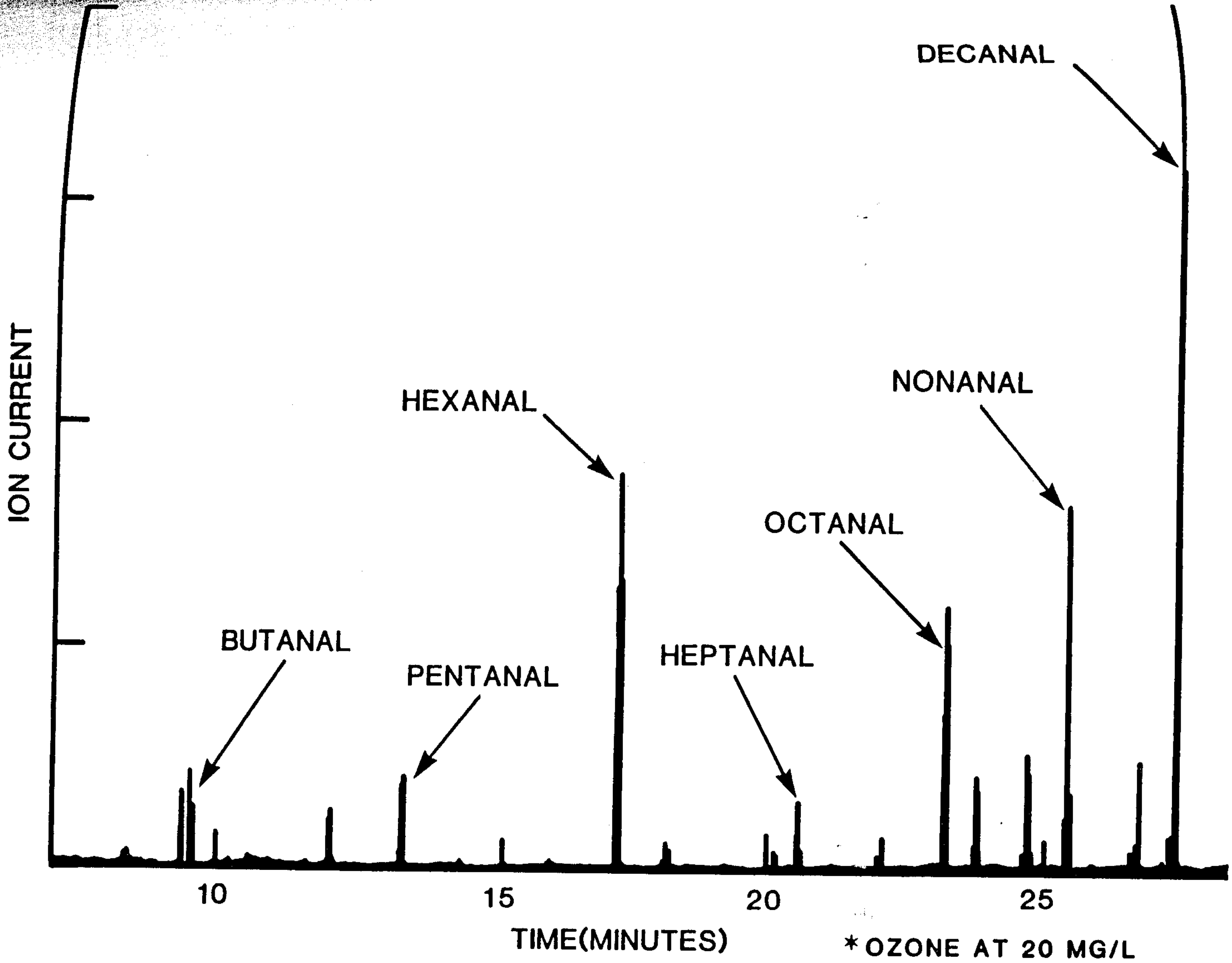


FIGURE V-4. VOLATILE BYPRODUCTS OF THE OZONATION OF COLORADO RIVER WATER
(from JMM)

Industries which utilize large quantities of chemicals in manufacturing processes are major sources of organic pollutants. Commercial facilities are often located in close proximity to major bodies of surface water. Consequently, effluents from these activities can introduce a broad range of chemical contaminants to these river systems depending on the nature of the materials being processed at each facility.

Municipal sewage treatment plants constitute a second major point-source of organic contamination. Listed in Table V-1 are fifty organic chemicals that are most often detected in municipal effluents (Shackleford, 1981). The substances have been ranked in order of decreasing frequency of occurrence. Chlorinated aliphatic and aromatic solvents were among those compounds most frequently found.

Other sources of SOCs are from the use of pesticides, herbicides, and fungicides on agricultural land.

ORGANIC COMPOUNDS FOUND IN NEW JERSEY WATERS

The types and concentration ranges of organic compounds found in New Jersey water supplies were discussed in Section IV. The majority of the studies and monitoring results summarized measured only the volatile organic fraction. Therefore, most of the available data are limited to THMs and VOCs.

For those compounds monitored, there were generally few volatile synthetic organic chemicals found in New Jersey water supplies. Those volatile compounds detected were primarily found in river basins with significant industrial development. The formation of ice cover on these rivers increased the probability of finding volatile compounds. The compounds identified most frequently in treated surface supplies were the trihalomethanes. These compounds are formed by the reaction of naturally occurring organic compounds with free chlorine which is used as a disinfectant in the majority of New Jersey surface water treatment plants. Treatment processes effective in controlling the formation of trihalomethanes are discussed below.

In contrast to surface waters, groundwaters in New Jersey often contained high concentrations of volatile synthetic organic chemicals. Additional treatment techniques useful in controlling these compounds are also discussed below.

TABLE V-1

COMPOUNDS MOST FREQUENTLY REPORTED IN MUNICIPAL EFFLUENTS (Shackleford, 1981)

Reported Frequency Ranking	Compound
1	Tetrachlorethene
2	Dichloromethane
3	Trichloroethene
4	2-(2-Butoxyethoxy)ethanol
5	Benzene
6	Toluene
7	Chloroform
8	Ethylbenzene
9	1,1,1-Trichloroethane
10	Phenol
11	p-Cresol
12	Caffeine
13	m-Cresol
14	Cycloheptatriene
15	Octadecane
16	Phenylacetic Acid
17	Dioctylphthalate
18	1,4-Dimethylbenzene (p-xylene)
19	1-Methylnapththlene
20	m-Xylene
21	Hexadecane (Practical)
22	2-Methylnaphthalene
23	o-Cresol
24	alpha-Terpineol
25	Naphthalene
26	1,1-Dichloroethene
27	o-Ethyltoluene
28	Benzoic Acid
29	2-N-Butoxyethanol
30	Dimethyldisulfide
31	Diethyl d-Phthalate
32	Lauric Acid (N-Dodecanoic Acid)
33	1,8-Dimethyldisulfide
34	2-Propanone (Acetone)
35	Tetraoecanoic Acid
36	Decanoic Acid
37	Methylisobutylketone
38	2,7-Dimethylnaphthalene
39	n-Pentadecane
40	Dibutylphthalate
41	1-Hydroxy-2-phenlybenzene
42	1,2,4-Trimethylbenzene
43	Indole
44	n-Hexane
45	n-Eicosane
46	Dioctylphthalate
47	1,3-Dimethylknaphthalene
48	p-Ethyltoluene
49	2,4-Dimethylphenol
50	1,3,5-Trimethylbenzene

CURRENT TREATMENT REGULATIONS IN NEW JERSEY

Current treatment regulations in New Jersey as specified in the New Jersey Safe Drinking Water Act, are based on the source and microbiological quality of the water supply. Table V-2 summarizes the four classes of water supplies and associated treatment requirements. The current treatment requirements do not require removals of natural organics, as measured by TOC, or SOCs which may be present in the untreated water. They reflect treatment goals set for conventional water quality parameters.

ALTERNATIVE PROCESSES FOR ORGANICS CONTROL AND REMOVAL

COAGULATION/FLOCCULATION/SEDIMENTATION

The goal of coagulation, flocculation and sedimentation is to remove colloidal and suspended particulates from water. This is accomplished by providing sufficient mixing energy to bring particles together and by providing favorable conditions for the particles to adhere to one another and subsequently settle. The unit processes most often used are rapid mix with the addition of coagulants and coagulant aids, coagulation and flocculation, and sedimentation.

In those cases where conventional treatment has already been installed, improved levels of TOC removal can often be achieved by optimizing the process parameters, e.g., mixing conditions, coagulant type and dose, and settling conditions. The advantages of this strategy are:

- Little or no capital investment
- Minimal increase in operations costs
- Well-known technology

Design Parameters

The key design parameters influencing TOC removal in these processes are the selection and dose of coagulants, the use of coagulant aids, and pH. The two most commonly used primary coagulants are ferric and aluminum salts. The doses of these coagulants are usually selected to achieve desireable removals of turbidity in the sedimentation basin. Optimization studies must usually be conducted to determine if the chemical doses can be altered to improve removal of TOC.

Often, the use of coagulant aids, such as synthetic organic polymers, can allow the use of a lower dose of the primary coagulant. A variety of polymers are available for use as coagulation aids. Selection should be based on plant testing and cost analysis.

Typically, coagulation doses for alum range between 20 and 70 mg/l for turbidity removal when treating fairly turbid surface sources. For increased removal of TOC, however, higher doses are required.

TABLE V-2

CLASSIFICATION AND TREATMENT REQUIREMENTS FOR NEW JERSEY WATER SUPPLIES

	Class 1	Class 2	Class 3	Class 4
Source	Groundwater	Groundwater	Groundwater or surface water	Groundwater or surface water
Average monthly Total coliform MPN	50/100 ml	50/100 ml	50 - 5000/100 ml	>5000/100 ml
Required treatment	Disinfection (meets primary & secondary NJ Drinking Water Standard without treatment)	Filtration Straining Aeration Fe Removal (where Fe>0.6 ppm) Mn removal (where Mn>0.1 ppm) Polyphosphate Complexation pH Adjustment Lime Softening	Pretreatment (coagulation, flocculation, & sedimentation) Filtration Disinfection (Plus necessary processes as lsited under Class 2)	Prechlorination Pretreatment Filtration Disinfection (Plus necessary processes as listed under Class 2)

The third parameter commonly used in the control of the coagulation process is pH. Typically, for alum, the minimum dose to achieve a given level of TOC removal occurs at around pH 6. Selection of the optimum pH to minimize chemical costs requires plant scale tests. Care must also be taken, however, to minimize corrosivity of the finished water.

Removal Characteristics For Natural and Synthetic Organics

The effectiveness of coagulation, flocculation and sedimentation has been reported extensively in the technical literature. One summary of reported removals of organic constituents from water is shown in Table V-3. Removals range from a low of 10 to 60% for fulvic acids to a high of 60 to 90% for humic acids. The removals of these types of compounds from water by coagulation have been found to reduce the subsequent formation of THMs by chlorine disinfection. Table V-4 from Babcock and Singer (1977), shows that the yields of chloroform from the chlorination of humic acid and fulvic acid solutions are lower after coagulation.

TABLE V-3

SUMMARY OF REPORTED REMOVALS OF
ORGANIC CONSTITUENTS FROM WATER BY COAGULATION
(from Kavanaugh, 1978)

Water Source and Type of Organic	Test Conditions	Constituent	Percentage Removals
National Organics Reconnaissance Survey (63 plants)	Treatment plant studies coagulation, sedimenta-filtration	NVTOC	30
EPA-Ohio River	Pilot plant studies, coagulation, sedimentation, filtration	TOC	30
Rhine River, alpine lakes	Al(III), pH 7	DOC	25-40
Humic acids	lab tests, Al(III), and Fe(III)	DOC	60-90
Fulvic acids	Lab tests, Al(III), and Fe(III)	DOC	10-60
Effluents from biological treatment	Pilot plant, treatment plant studies, Fe(III)	COD, TOC	60-80, 40-60

TABLE V-4

EVIDENCE FOR SELECTIVE REMOVAL OF THM PRECURSORS BY COAGULATION

(from Babcock and Singer, 1977)

Organics	Yield of $CHCl_3$*
Raw humics	1.5
Residual humics (after coagulation)	0.86
Raw fulvics	0.5
Residual fulvics	0.16

---

* Yield based on 100-hour contact time, pH 6.5, excess Cl_2; yield = moles of $CHCl_3$ produced per mole carbon in precursors.

The use of coagulant aids, such as synthetic organic polymers, can improve the effectiveness of coagulation in removing natural organic compounds from water. This is shown by the results in Table V-5, which report the effectiveness of anionic polymers used in combination with alum for the removal of humic acids from solution. Similar results for the use of cationic polymers, together with alum, have been shown by James and O'Melia (1982).

TABLE V-5

EFFECT OF POLYMER ON REMOVAL OF HUMIC ACIDS IN JAR TESTS

(from Kavanaugh, 1978)

Anionic Polymer Dose mg/l	Percentage Residual Humics	Residual Turbidity-jtu
0.01	30	2
0.1	15	1.2
1	5	0.2
10	5	0.2
100	10	0.5

NOTE: humic acid concentration = 5 mg/l, alum concentration = 50 mg/l, pH 6.

Most often, the processes of coagulation, flocculation and sedimentation have several goals. Until recently, turbidity removal has been the primary objective. However, for those utilities required to meet the 100 ug/l MCL for total trihalomethanes, the removal of THM precursors must now be included as an objective. The optimal operating conditions for turbidity removal have been found to be different from those for maximum TOC removal. For example, both Kavanaugh (1978) and James and O'Melia (1982) reported a lower optimal operating pH to achieve maximum TOC compared to turbidity removal, for a given alum dosage.

In summary, coagulation, flocculation, and sedimentation are most useful for the removal of colloidal and suspended particulate matter from water supplies (AWWA Research Committee on Coagulation, 1979). Thus, these processes are useful for the removal of synthetic organic chemicals (SOCs) if these compounds are adsorbed to the surfaces of natural particulates. To date, little work has been done to evaluate the effectiveness of coagulation in removing SOCs (Trussell and Trussell, 1980). To a first approximation, those compounds which are hydrophobic and thus tend to accumulate on surfaces, would show some degree of removal through coagulation.

FILTRATION

Filtration is typically used as a finishing step in water treatment, preceded by coagulation and sedimentation in conventional treatment or simply by flocculation in direct filtration of low turbidity waters. For removal of naturally occurring organics, filtration serves this same finishing or polishing role. In conventional treatment trains, the coagulation and sedimentation steps accomplish the bulk of the total turbidity and/or organics removal. In direct filtration, the filter is used as the sole removal element for particulates. The filter is used as the sole removal element for particulates. The removal of TOC achieved in either type of treatment train relies heavily on the effectiveness of the coagulation and flocculation steps. Neither conventional nor direct filtration treatment removes significant amounts of volatile organics.

Design Parameters

The major classes of filters are slow sand and rapid sand filters. Slow sand filters operate by gravity flow, and operate at surface loading rates typically on the order of 0.5 gpm/ft^2. Because of large area requirements, no slow sand filters are currently used in United States practice. Such filters are still widely used in European practice, however. Rapid sand filters operate by gravity flow or under a pressure driving force, at rates typically between 2-5 gpm/ft^2. Various types of media designs are used. Specific design criteria and operational modes selected for rapid sand filters depend upon the water quality problem.

Parameters which describe specific filter design include the surface loading rate and media depth. Table V-7 gives typical values for these design parameters. Other design variables which are not as generalized include media size, media type (i.e., conbinations of sand, anthracite, and/or other materials), backwash rates, solids handling and method of flow control.

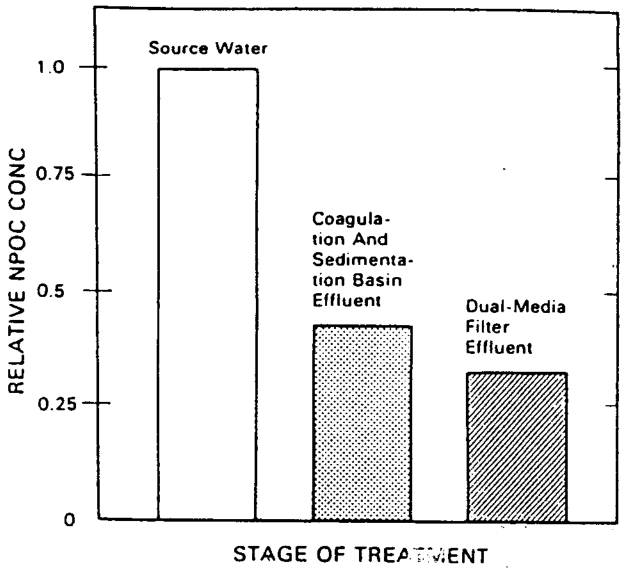


FIGURE V-5. RELATIVE NPOC REMOVAL DURING WATER TREATMENT IN A PILOT PLANT (from Symons, et al, 1981)

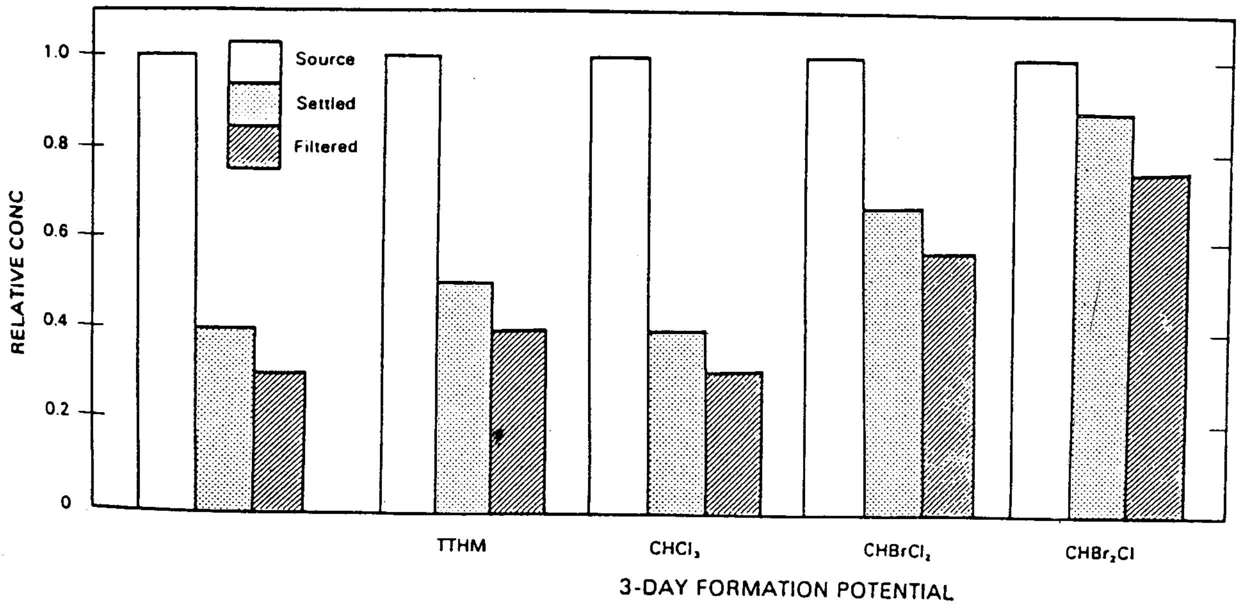


FIGURE V-6. COMPARISON OF THMFP AND NPOC IN CHLORINATED WATER SAMPLES OF VARIOUS QUALITIES (from Symons, et al 1981)

TABLE V-7

GENERALIZED FILTER DESIGN CRITERIA

Filter Type	Surface Loading Rate (gpm/ft²)	Media Depth (inches)
Slow Sand	.03-.06	24-36
Rapid Sand	2-4	24-36
Dual Media	3-10	30-40
Mixed Media	3-10	28-48

Removal Characteristics for Natural and Synthetic Organics

The general range of removal efficiencies for natural organics with filtration is summarized in Table V-8. SOCs which are very soluble in water will not be removed through filtration. However, those compounds adsorbed onto the surface of particulate matter will be removed to the extent that those particles are removed. Examples of these hydrophobic compounds include polynuclear aromatic hydrocarbons and DDT. Table V-8 is based on results from specific bench, pilot, and full scale studies, which are described in the following sections.

TABLE V-8

SUMMARY OF ORGANICS REMOVAL RANGES ACHIEVED BY FILTRATION

	Conventional Treatment		Direct Filtration
Organic Compound	Full Process Train	By Filters Only	Full Process Train
Non-Purgeable Organic Carbon (NPOC)	30-70	10	—
THM Precursor (THMFP)	20-60	10-16	13-54

Organic Carbon and Trihalomethane Precursors. Conventional treatment trains, consisting of coagulation-flocculation-sedimentation-filtration, generally remove between 30 to 70 percent of influent NPOC (non-purgeable organic carbon). Figure V-5 from EPA in-house studies is representative (Symons, 1981). As shown, when the influent NPOC was between 2.2 and 3.9 mg/l, coagulation and sedimentation removed 60 percent of the influent

NPOC while filtration removed an additional 10 percent. In many cases, these results may be matched by similar reductions in trihalomethane formation potential (THMFP) as shown in Figure V-6. However, the variable nature of organic carbon and water quality with respect to trihalomethane formation results in numerous discrepancies. For example, bromide is not significantly affected by coagulation and filtration, yet if present in water to which chlorine is added, reacts more quickly to form THMs than do chlorine and organics. Thus, a TOC measurement for a raw water containing substantial bromide may give a low indication of its trihalomethane formation potential. Also, although both fulvic and humic acids are reflected in TOC measurements, as are other organics, they are removed to different degrees through coagulation (and thus filtration) and show differing capacities to form THMs.

The EPA reported on 28 studies of THM precursor (THMFP) removal via conventional treatment (coagulation, settling, and filtration) and direct filtration. The net removals for filtration in conventional treatment ranged from 10 to 16 percent for a total process train removal between 16 and 51 percent, while the range of removals for the direct filtration process ranged from 13 to 54 percent (excluding the EPA's sample of spiked humic acids mentioned above).

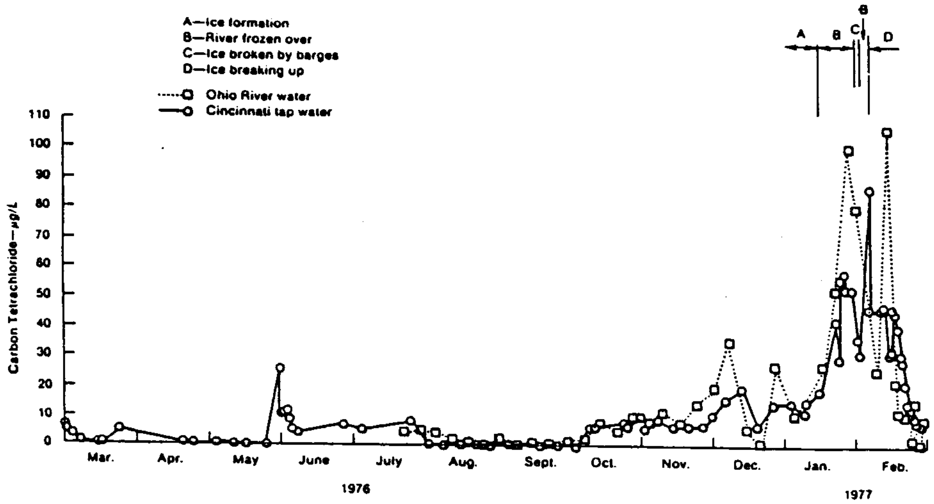
Synthetic Organics. In full-scale water treatment plants, volatile organics such as tetrachloroethylene, cis-1,2-dichloroethylene, 1,2-dichlorethane, and carbon tetrachloride have been found not to be removed by coagulation, sedimentation, and filtration (Love, 1982). The removal of other volatile organics through filtration is unlikely. Figure V-7, which illustrates this point, shows that CCl_4 concentrations do not decrease after conventional treatment at the Cincinnati Water Treatment Plant.

POWDERED ACTIVATED CARBON ADSORPTION

Powdered activated carbon (PAC) is used in a large number of water treatment plants for control of taste and odor. Dosage rates can be easily modified to meet changing influent water qualities. Because of this, PAC is low cost process alternative for taste and odor control. The very high doses which may be required for effective removal of THMs or specific synthetic organics, however, are not usually cost-effective when compared to other feasible processes. On the other hand, if a utility's organics problem is seasonal, then intermittent PAC use may be warranted. Under these circumstances, the annual average PAC use may be low enough to be cost effective. Temporarily high TOC concentrations, corresponding to high THM values, during periods of spring runoff is an example where this alternative may be feasible.

Design Parameters

When used for taste and odor or organics control, PAC systems are designed based upon the type of carbon, dosage, and point of application. Although various indices such as the iodine number and the phenol value may be used to screen carbons for feasibility, bench scale testing to determine relative removal efficiencies and/or adsorptive capacities is usually required. The



Water treatment consisted of powdered activated carbon, coagulation, settling, filtration, and chlorination.

FIGURE V-7. CARBON TETRACHLORIDE IN RAW AND TREATED WATER AT CINCINNATI, OHIO (from Love and Eilers, 1982)

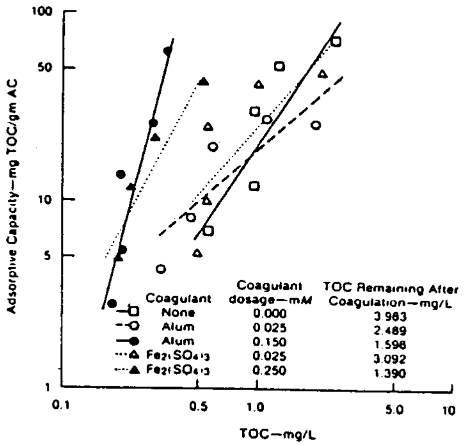


FIGURE V-8. ADSORPTION ISOTHERMS FOR UNTREATED AND PRETREATED GROUNDWATER (from Randtke and Jepson, 1981) results of these tests and previous experience can be used to guide the selection of carbon type and dose for the particular situation.

The point of application of PAC within the treatment plant should be selected to ensure adequate mixing and contact time as well as to avoid interferences from water treatment chemicals and processes. Points of application within existing plants include raw water lines, rapid mix basins, flocculation basins, sedimentation basins, and conduits to the filters. Information on the optimum application point can be determined using jar tests, although plant scale tests are best. Except in high turbidity waters, addition of PAC to the raw water is generally the most effective. Influent lines are typically long enough to provide good mixing and sufficient contact times, and interference from chlorine and other chemicals is minimized. Application to the flocculators or sedimentation basins is generally least effective. Typical doses for taste and odor control range from 0.5 to 5 mg/l PAC with an average of 2.5 mg/l (Sanks, 1978).

Removal Characteristics for Natural and Synthetic Organics

Organic Carbon and Treatment By-Products. PAC has shown a wide range of removal efficiencies for organic compounds in water. Although many natural taste and odor causing compounds, as well as some higher molecular weight synthetic organics, may be satisfactorily removed with PAC, many compounds exhibit low removals because of slow rates of adsorption. Thus, systems having many types of organic compounds in their water may achieve only limited organics control through PAC adsorption. Table V-9 summarizes typical removal efficiencies observed for several types of organic compounds. As shown, high concentrations of PAC are needed to remove even 25 to 50 percent of the particular compound or parameter. Results of bench, pilot, and full-scale studies summarized in Table V-9 are described below.

TABLE V-9

REMOVAL EFFICIENCIES OF ORGANICS USING PAC

Parameter	Carbon Dose (mg/l)	% Removal
TOC	8-40	35*
THMFP	45-80	45-50
THM		
$CHCl_3$	50-197	50
$CHBr_3$	15	50
Halogenated Aliphatics	27	25

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* (65% with 2.5 hour contact time)

Jar tests conducted at the Contra Costa Water District in Concord, California demonstrated a maximum of 20 percent removal of TOC and 15 percent removal of THMFP with PAC doses up to 40 mg/l, as shown in Table V-10.

TABLE V-10

PAC VERSUS PRECURSOR REMOVAL, CCWD[a]

Alum Dose (mg/l)	Carbon Dose (mg/l)	Residual Cl_2 (mg/l)	TOC (ppm)	Total THM (umol/l)
0	0	—	4.95	292
50	0	4.7	2.66	116
50	2	4.7	2.63	121
50	4	4.7	2.49	111
50	10	4.7	2.42	101
50	20	4.7	2.33	103
50	40	4.7	2.16	99

---

[a] From Contra Costa Water District, 1977

Slightly better results were obtained in a full-scale plant test in West Virginia using a PAC which had been specially formulated for organics removal. A 34 percent reduction in TOC from 0.59 to 0.39 mg/l, with a PAC dose of 21.6 mg/l was achieved (Anderson, et al., 1981). In both of these studies the PAC was added to the rapid mix along with alum and/or chlorine. Similar removals, on the order of 35 percent, were observed when the PAC was added at the raw water intake in North Miami Beach, Florida, with a lower dosage of 7.9 mg/l. This application point allowed a 45 minute contact time prior to coagulant addition. With an even longer contact time, 65 percent removal of TOC was measured, as shown in Table V-11 (Singley, 1979).

A series of PAC adsorption isotherm tests was conducted by Randtke, et. al. (1981), in which raw water, consisting of groundwater mixed with humic and fulvic acid solutions, was pretreated using coagulation, sedimentation, and filtration and then dosed with PAC. Adsorption capacity of PAC was shown to be strongly related to coagulant type and dose, as shown in Figure V-8. Because previous tests had shown the initial concentration of TOC to have a minor effect on adsorptive capacity, most of the effect shown in Figure V-8 was attributed to coagulant-organic interactions.

The study in West Virginia showed a 56 percent removal of instantaneous trihalomethanes at the plant effluent, with a 21.6 mg/l PAC dose added to the rapid mix basin. EPA studies with three brands of carbon using Ohio River water which had been coagulated and settled, demonstrated that reduction of terminal trihalomethane (TTHM) by 50 percent (from 1.0 to 0.5 umol/l) would

TABLE V-11

TOTAL ORGANIC CARBON FOR VARIOUS DOSES OF POWDERED ACTIVATED CARBON
(from Singley, 1979)

Dose	Average Raw Water TOC (mg/l)	Average Finished Water TOC (mg/l)	Average Percent Reduction
0	(15.2)	13.0	14.5
7.9	12.3	8.0	35.0
14.3	14.6	10.7	26.7
26.6	13.6	10.0	26.5
7.1*	12.6	4.4	65.1

*Chlorination point at recarbonation unit. (All other chlorination points at raw water.) First chlorination in both cases.

require approximately 45 mg/l of powdered activated carbon, as shown in Figure V-9 (Symons, et al., 1981). In water with high color, TOC, and THMFP in Pembroke Pines, Florida, 150 mg/l of PAC was required to reduce the TTHM by 35 percent as shown in Figure V-10 (JMM, 1980). Note that the scales for TTHM and color in Figure V-10 are not linear. However, 80 percent of the color and 50 percent of the TOC were removed under these same treatment conditions. These results are representative of typical THMFP removal efficiencies, and represent a relatively high, and therefore costly, PAC dose (Symons, et al., 1981).

Chloroform is poorly adsorbed onto PAC, while those THM compounds containing bromine are more strongly adsorbed, as shown in Figure V-11. Similar results were obtained by Dobbs and Cohen, Weil, and Hoehn with different influent water qualities and using different carbons, as shown in Figure V-12 (Symons, et al., 1981). In all of the studies, at least 50 mg/l carbon was required to achieve 50 percent concentration reduction of any of the compounds.

The adverse effect of free chlorine residual on PAC adsorption is shown in Figure V-13. It is hypothesized that the chlorine reacts with the surface of the carbon to reduce adsorption capacity. As will be described subsequently, a similar effect for high ozone doses has also been hypothesized.

Synthetic Organics. The highest percentage removals observed for PAC control of synthetic organics were at the City of North Miami Beach (Singley, 1979). Figure V-14 shows removals obtained for three-day THM, volatile halogenated aliphatics (VHA, i.e., dichloroethenes and chloroethanes), chlorobenzene, and nonvolatile synthetic organics (NVSOC). While nonvolatile compounds, denoted by NVSOC, were removed well, the only volatile organic compound with good removal characteristics was chlorobenzene.

This work and other studies to date have shown that PAC has limited potential for volatile organics removal for several reasons. First, the doses required for removal are large, thus, effectively pricing PAC out of the market. Second, PAC contact times are often too short to permit the removal of a wide variety of organics. A third disadvantage of PAC, particularly in groundwater systems, is the requirement for coagulation and sedimentation facilities, which are not normally used in groundwater treatment schemes.

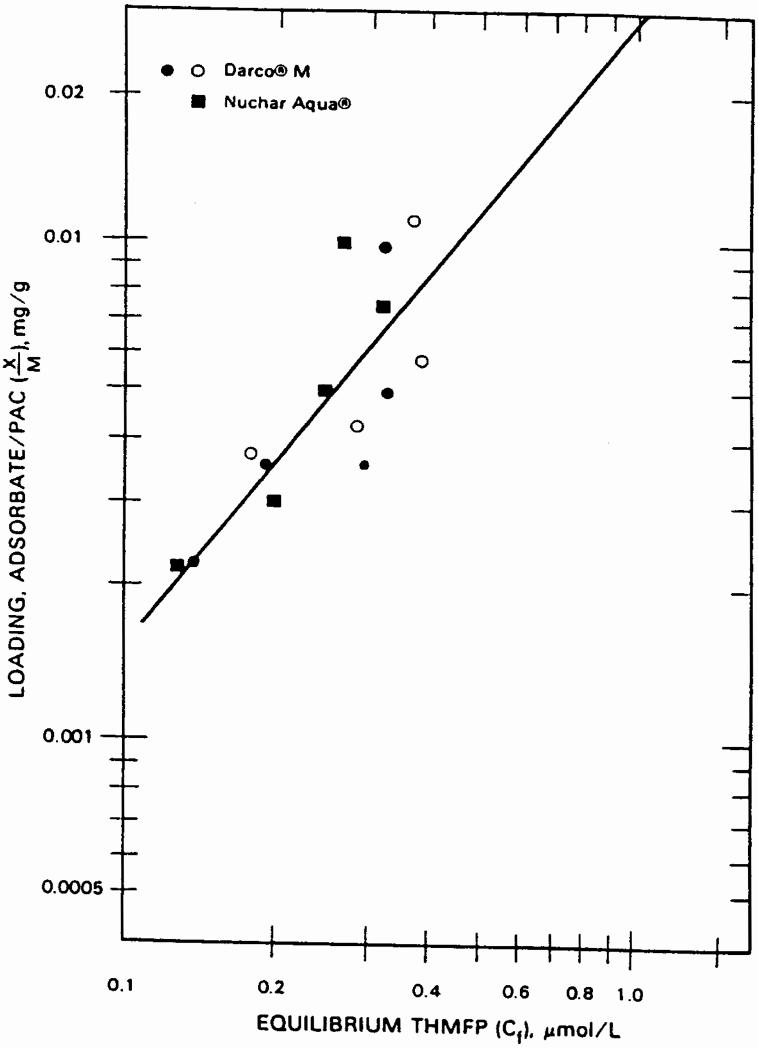


FIGURE V-9. ADSORPTION ISOTHERMS FROM THREE STUDIES USING PAC TO REMOVE TRIHALOMETHANE PRECURSORS FROM COAGULATED AND SETTLED OHIO RIVER WATER
(from Symons, et al, 1981)

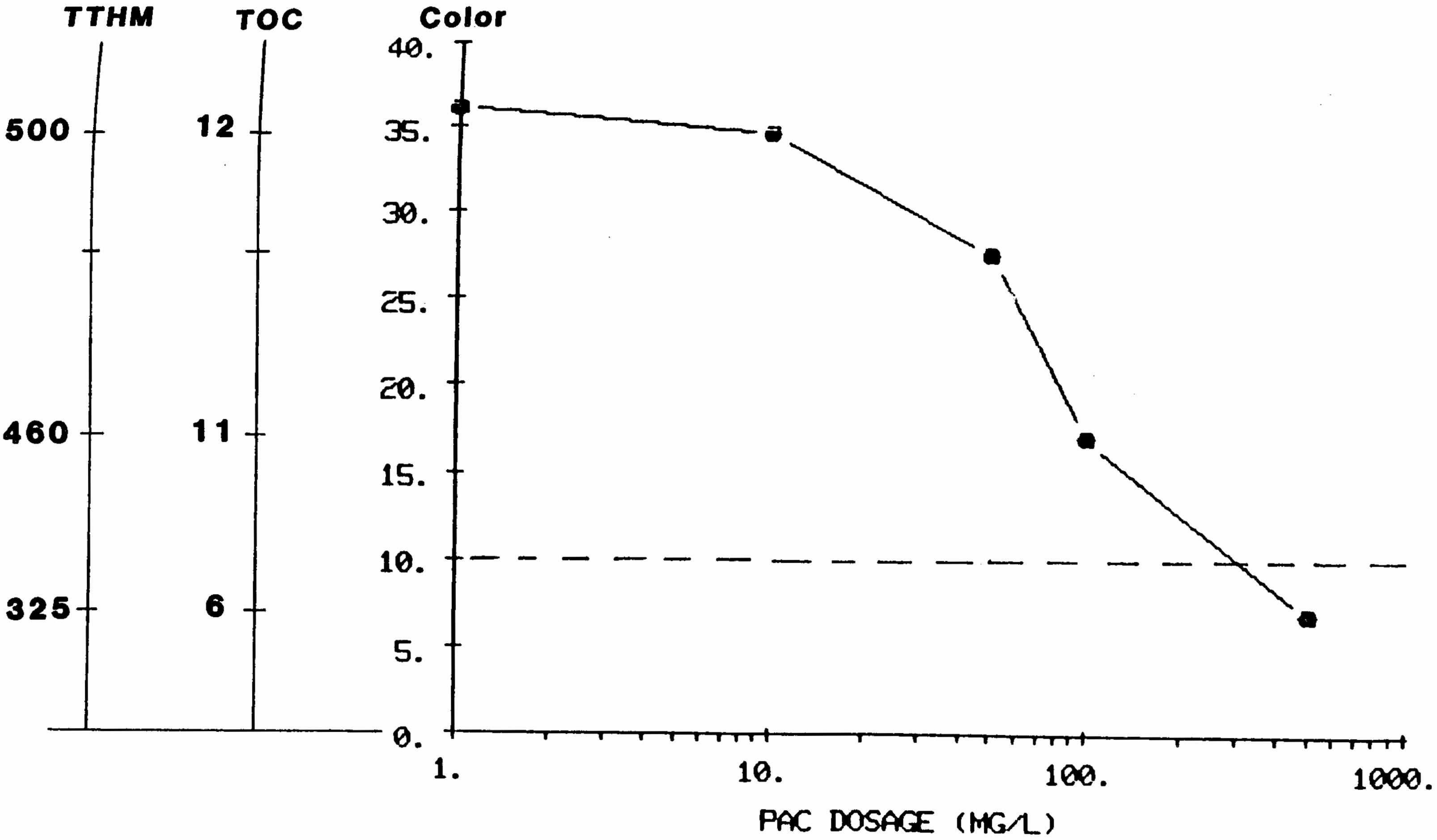


FIGURE V-10. REMOVALS OF TTHM, TOC, AND COLOR AS A FUNCTION OF PAC DOSE
(from JMM, 1980a)

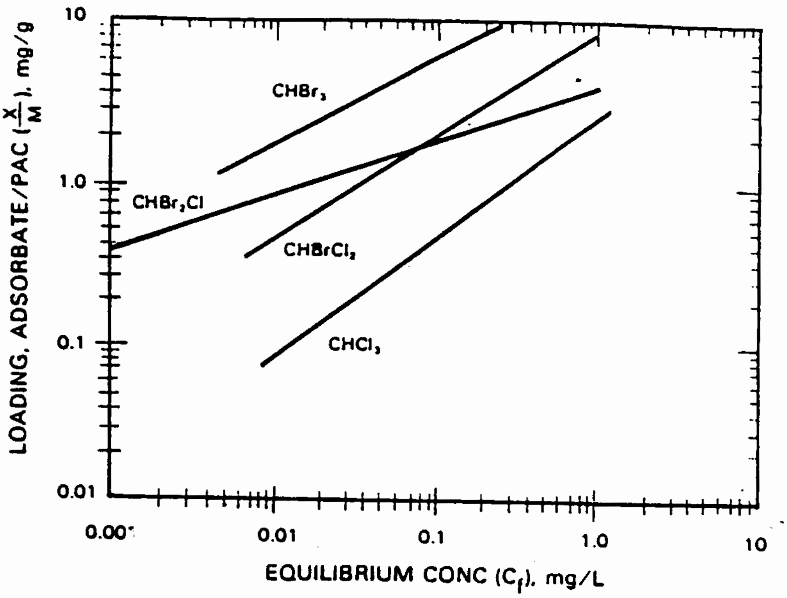


FIGURE V-11. ADSORPTION ISOTHERM FOR FOUR TRIHALOMETHANES
(from Symons, et al, 1981)

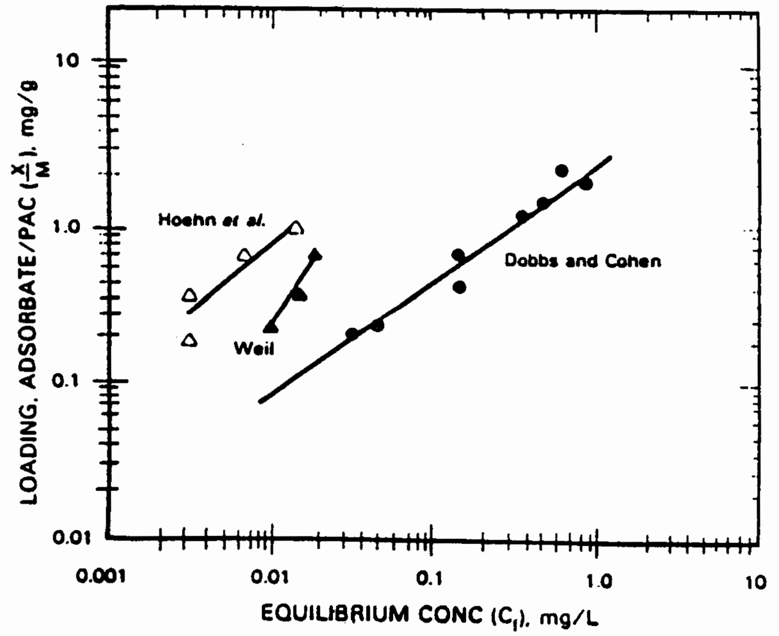


FIGURE V-12. SUMMARY OF THREE STUDIES OF THE ADSORPTION OF CHLOROFORM ON POWDERED ACTIVATED CARBON
(from Symons, et al, 1981)

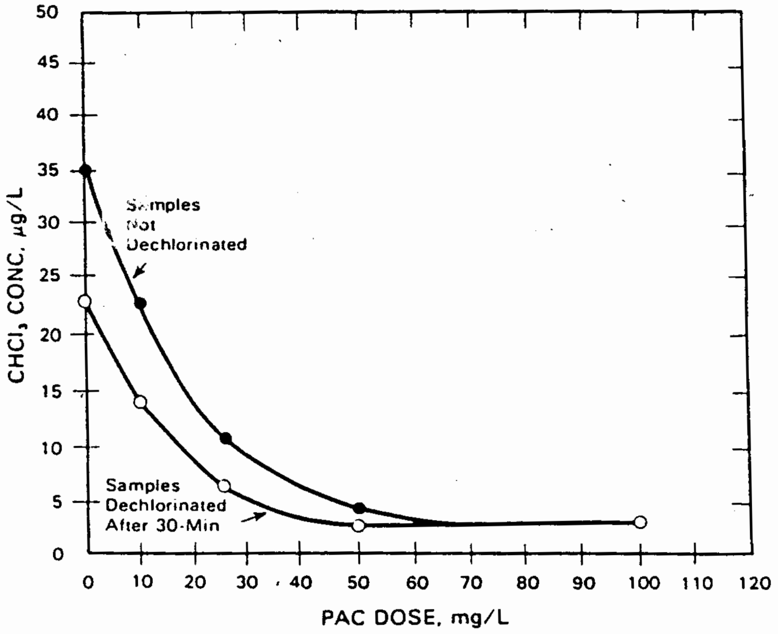


FIGURE V-13. TREATMENT OF SIMULATED LAKE WATER WITH PAC
(from Symons, et al, 1981)

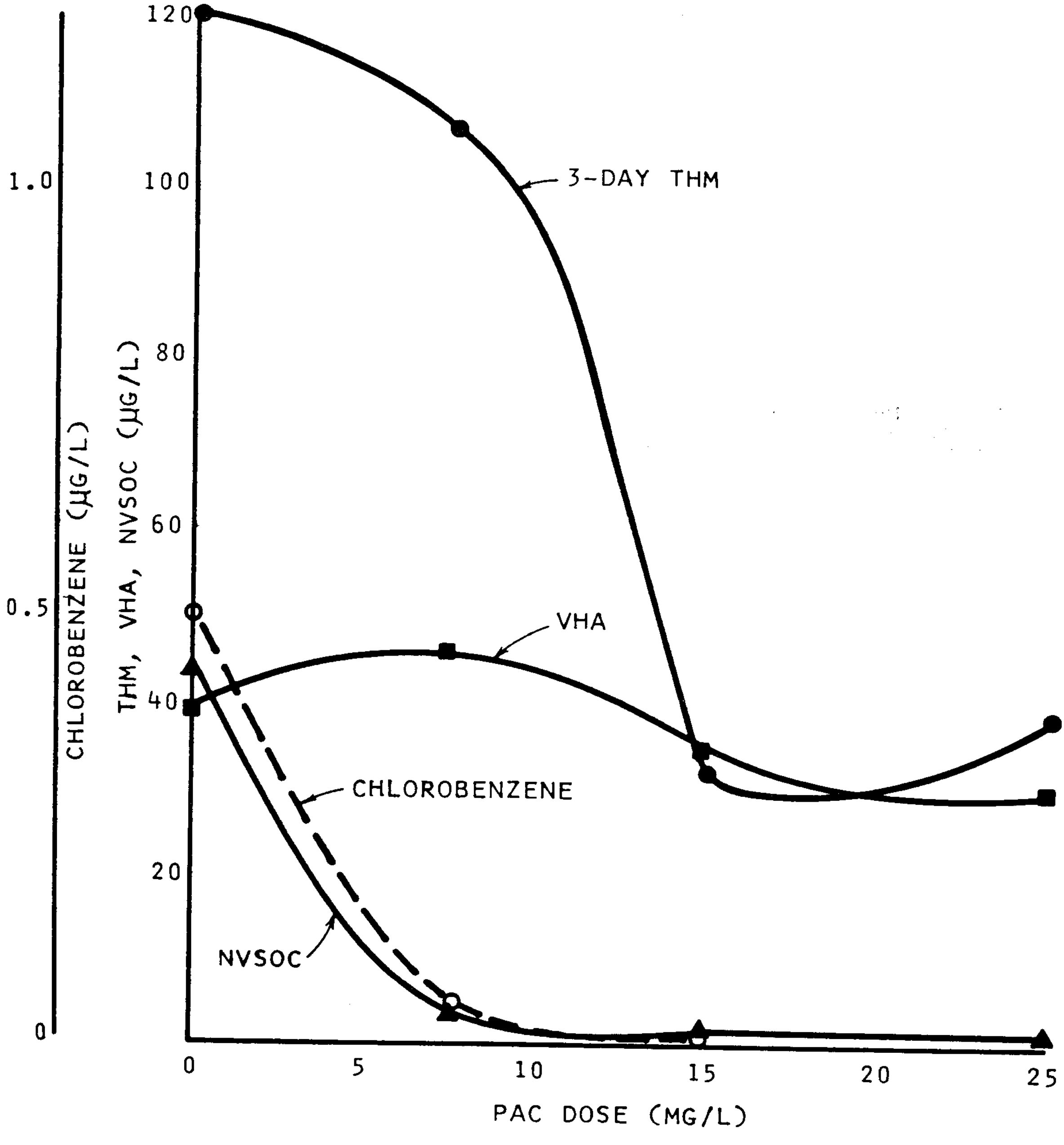


FIGURE V-14. REMOVALS OF THMs, VHA, CHLOROBENZENE, AND NVSOC AS A FUNCTION OF PAC DOSE (from Singley, et al, 1979)

AIR STRIPPING

The process of air stripping has been used for many years within the chemical process industries. During the past decade, however this process has been used in the water and wastewater industries for removal of ammonia from wastewater, and more recently for removal of volatile organics from contaminated groundwater.

The principle of air stripping is based on the fact that volatile compounds partition between the air and water phases until equilibrium concentrations are reached. The rate of movement between phases is a function of the relative concentrations of the molecule in the air and water phases with respect to equilibrium concentrations. The rate of transfer between phases will be greater when the concentrations in each phase are far from equilibrium. The effectiveness of air stripping depends on continuously contacting contaminated water with air containing the compound(s) of interest at a concentration below equilibrium.

The objective of air stripping design is to maximize the rate of transport of the contaminant from the water to air at a reasonable cost. The most effective configuration to achieve this goal is a packed tower providing an upward flow of air contacting a downward flow of water. Other possible design alternatives include diffused aeration and spray aeration. In general, packed towers achieve the highest removals of volatile compounds, and spray aeration the lowest (Kavanaugh and Trussell, 1981). Schematics of a diffused aeration basin and a countercurrent aeration tower are shown in Figure V-15.

Process Design

In diffused aeration, air is bubbled into a contact chamber through a diffuser. Diffused aeration is ideally conducted counterflow, with the untreated water entering at the top, the treated water exiting through the bottom, the fresh air entering at the bottom, and the exhausted air leaving through the top. Gas transfer can be improved by increasing basin depth, producing smaller bubbles, improving contact basin geometry, and using a turbine to reduce bubble size and increase bubble holdup (Kavanaugh, et al., 1980).

In surface aeration, an impeller is used to provide mixing energy to the contact chamber, which is considered as a complete-mix reactor. Mass transfer of volatile organics occurs at the air/water interface of the contact basin. The complete-mix conditions ensure a homogeneous concentration throughout the basin. This process is similar to surface aeration in activated sludge wastewater treatment. Design variables include hydraulic residence time, surface area of contact basin, and mixing energy of the impeller (Roberts, Munz, and Dandliker, 1983; Roberts and Dandliker, 1982; Roberts, et al, undated.)

In countercurrent packed towers, packing materials are used which provide high void volumes together with high surface area. The water flows downward by gravity and air is forced upward. The untreated water is usually distributed on the top of the packing with sprays or distribution trays and the air is forced

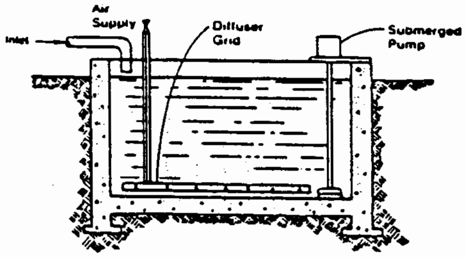


FIGURE V-15a. DIFFUSED AERATION SCHEMATIC (from Kavanaugh and Trussell, 1980)

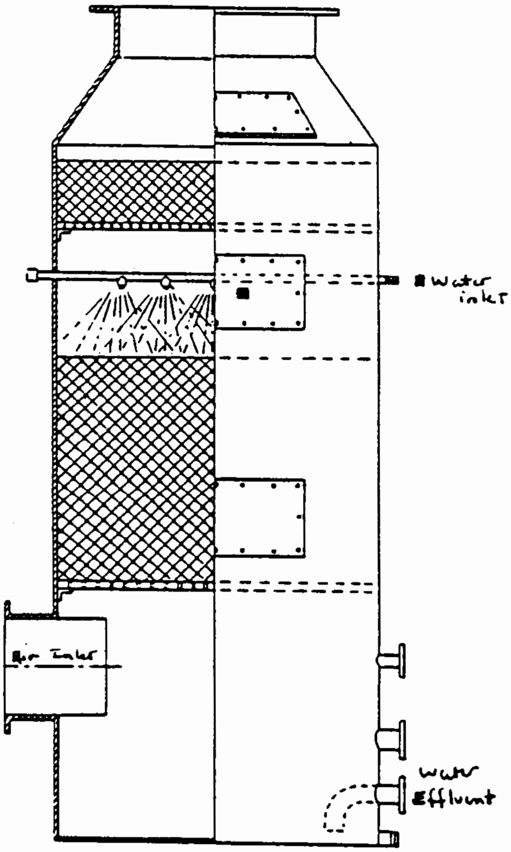


FIGURE V-15b. PACKED TOWER AERATION SCHEMATIC (from JMM, 1980b) through the tower either by blowers or induced draft. This design results in continuous and thorough contact of the liquid with the gas and minimizes the thickness of the water layer on the packing, promoting efficient mass transfer.

Specific design of a stripping tower is rather complex because of the many variables associated with the dynamics of the mass transfer process. The usual starting point for design is the selection of the type of stripping tower and the type of internal packing.

There are many options for packings, which come in a variety of shapes and materials. The packings are available in plastic, metal and ceramic. Plastics are the best material for water treatment because of their high durability and low cost. In addition, they exhibit better flooding and mass transfer characteristics. The other materials are used in special applications requiring inert material.

The type and size of the packing selected determines the maximum air and water loading rates for a given stripping tower, and therefore must be considered in the design. In addition, the type of packing determines the amount of interfacial surface area and hence the rate of removal of the organic.

The most important criteria for design of a stripping facility are the air-to-water ratio, A/W, and the water loading rate (gpm/ft^2 or m/s). The latter parameter determines the tower diameter for a given application, and has a dramatic effect on the pressure drop through the column, and thus, energy costs. Given a water loading rate and a selection of packing material, the A/W ratio determines the height of the stripping tower required to provide a specified removal. There is some freedom in choosing this value, the limitations being the economic tradeoffs between a higher tower, and corresponding higher pumping and blower costs, or larger tower diameters and corresponding greater capital costs.

One of the major constraints to design relates to the flooding point, or the point at which the tower is hydraulically overloaded. The flooding point is approached as either the liquid or gas velocity is increased. The gas velocity selected should generally not exceed 60 percent of the velocity at which flooding occurs. This provides an adequate safety margin for design.

Several methods are available for calculating the optimal stripping tower dimensions. The most convenient is a revision of the graphical method presented by Kavanaugh and Trussell (1980). In essence, the procedure involves:

(1) Select appropriate range of allowable head loss; or, alternately, a range or liquid loading rates (gpm/ft^2 or m/s).

(2) Select an appropriate A/W ratio after several values hae been evaluated to determine the most economical combination.

(3) Calculate the lower height and diameter from a series of graphs relating the A/W ratio to the gas flow rate, G.

(4) Determine the overall optimum design (i.e., the liquid loading rate, L; which, with G, determines the A/W ratio).

Removal Characteristics for Natural and Synthetic Organics

The ideal equilibrium between water and air for a compound is described by Henry's Law, which states that the concentration in air is proportional to the concentration in water at equilibrium. Higher Henry's constants denote low solubilities in water, or good potential for air stripping. As Figure V-16 shows, compounds with higher Henry's constants show greater removal efficiencies with aeration. Figure V-16 also shows the practical operating boundaries for the three most common types of aeration systems as a function of Henry's constant and the percent removal required. Spray towers accomplish limited removals due to poorer mass transfer, but can handle high air-to-water ratios. Diffused aeration is effective for compounds with high Henry's constants. For H values of 1000 atmospheres, or less, spray towers are less costly than diffused aeration because the work required to pressurize large volumes of air becomes more important than the pressure drop through the spray nozzle. Packed towers are effective over a broad range of Henry's constants and required removals, but even these devices fail when H values become low enough so that the gas phase transfer becomes important (Kavanaugh and Trussell, 1980).

Figures V-17 and V-18 show removals relative to ideality (based only on Henry's constants) in aeration applications for chloroform and synthetic organics found by the EPA and others (Love, et al., 1982). As shown for chloroform, the best removals, greater than 90%, are achieved in countercurrent towers even though maximally efficient use of air was not observed. Design improvements are feasible, however, to increase efficiency in air usage. For the diffused air systems, poor total chloroform removals of approximately 50% occurred although again, design improvements to achieve greater removals are technically feasible. Similar conclusions for additional synthetic organic chemicals can be drawn. Details on some relevant bench, pilot, and full-scale operations are given below.

Trihalomethanes. Diffused air batch aeration studies conducted in Louisville, Kentucky, showed good THM removals of 30 to 80 percent for A/W ratios of 2:1 to 20:1 and aeration times of 5 or 10 minutes, as shown in Table V-12 (Symons, et al., 1981). Less effective removals of 13-57 percent were demonstrated at Concord, California for similar A/W ratios of 4:1 to 19:1 but longer aeration times of 30 - 240 minutes, as shown in Table V-12 (Lange, et al., 1978). The difference is attributed to the ratio of Cl/Br for the two sites. In the former case, almost all of the THMs occur as chloroform while in Concord, essentially all are as $CHBr_3$. Since the latter compound has a significantly lower Henry's constant, it is more difficult to remove using air stripping. EPA in-house aeration studies showed similar results to those found at Louisville for water with THMs consisting predominantly of $CHCl_3$ (Symons, et al., 1981).

TABLE V-12

DIFFUSED AERATION EFFICIENCIES FOR THM REMOVAL IN LOUISVILLE, KENTUCKY

Air to Water Ratio (V/V)	Aeration Time (min)	THM Removal[a] (%)
1.25:1	2.5	25
5:1	5	46
5:1	10	47
10:1	5	55
10:1	10	67
15:1	10	80
20:1	10	75

---

[a] Influent THM = 35-52 ug/l

TABLE V-13

DIFFUSED AERATION EFFICIENCIES FOR THM REMOVAL IN CONCORD, CALIFORNIA

Air to Water Ratio (V/V)[b]	Aeration Time (min)	THM Removal[a] (%)
1:1	10	1.5
4:1	30	19
6:1	60	13
6:1	120	19
8:1	60	32
9:1	240	39
15:1	120	39
19:1	120	57

---

[a] Influent THM = 230-290 ug/l

[b] For comparative purposes, an A/W ratio of 1:1 is typical for taste and odor control, 8:1 for activated sludge treatment and 44:1 for purge and trap THM analysis.

Tower aeration, which has better efficiency of removal at the same A/W ratios than diffused aeration, shows better results. Pilot-scale packed tower aeration studies conducted at Concord, California (JMM, 1982) demonstrated $CHCl_3$ removals up to 95 percent, $CHCl_2Br$ of 94 percent, $CHClBr_2$ of 88 percent, and $CHBr_3$ of 75 percent at rates of 4 gpm/ft^2 and an A/W ratio of 100. As Figure V-19 shows, higher loading rates showed lower, but still effective, removals. As expected, the brominated compounds showed consistently lower removals under all conditions. Similar results have been obtained at Valley County Water District in Southern California, and at Pembroke Pines, Florida, two utilities with distinctly different ground water qualities (JMM 1981, 1983). The first utility is characterized by low concentrations of naturally occurring organics (TOC$<$1 mg/l) but substantial concentrations of TCE and PCE due to industrial contamination. Pembroke Pines has high concentrations of naturally occurring humics as indicated by high raw water color and TOC ($>$70 color units, TOC $>$ 14 mg/l). Typical results for the two systems are shown in Tables V-14 and V-15.

TABLE V-14

REMOVAL OF THMS THROUGH AIR STRIPPING AT
VALLEY COUNTY WATER DISTRICT, CALIFORNIA (JMM, 1982)

Packing Depth (feet)	Loading Rate (gpm/ft^2)	Removal Efficiencies (%)[a] $CHCl_3$	$CHBrCl_2$
9.75	4	99	98
9.75	17	96	94
7.75	4	98	96
7.75	17	99	99
5.50	4	96	91
5.50	17	89	84

---

a Influent (spiked) concentrations.
$CHCl_3$: 87-202 ug/l
$CHBrCl_2$: 103-218 ug/l

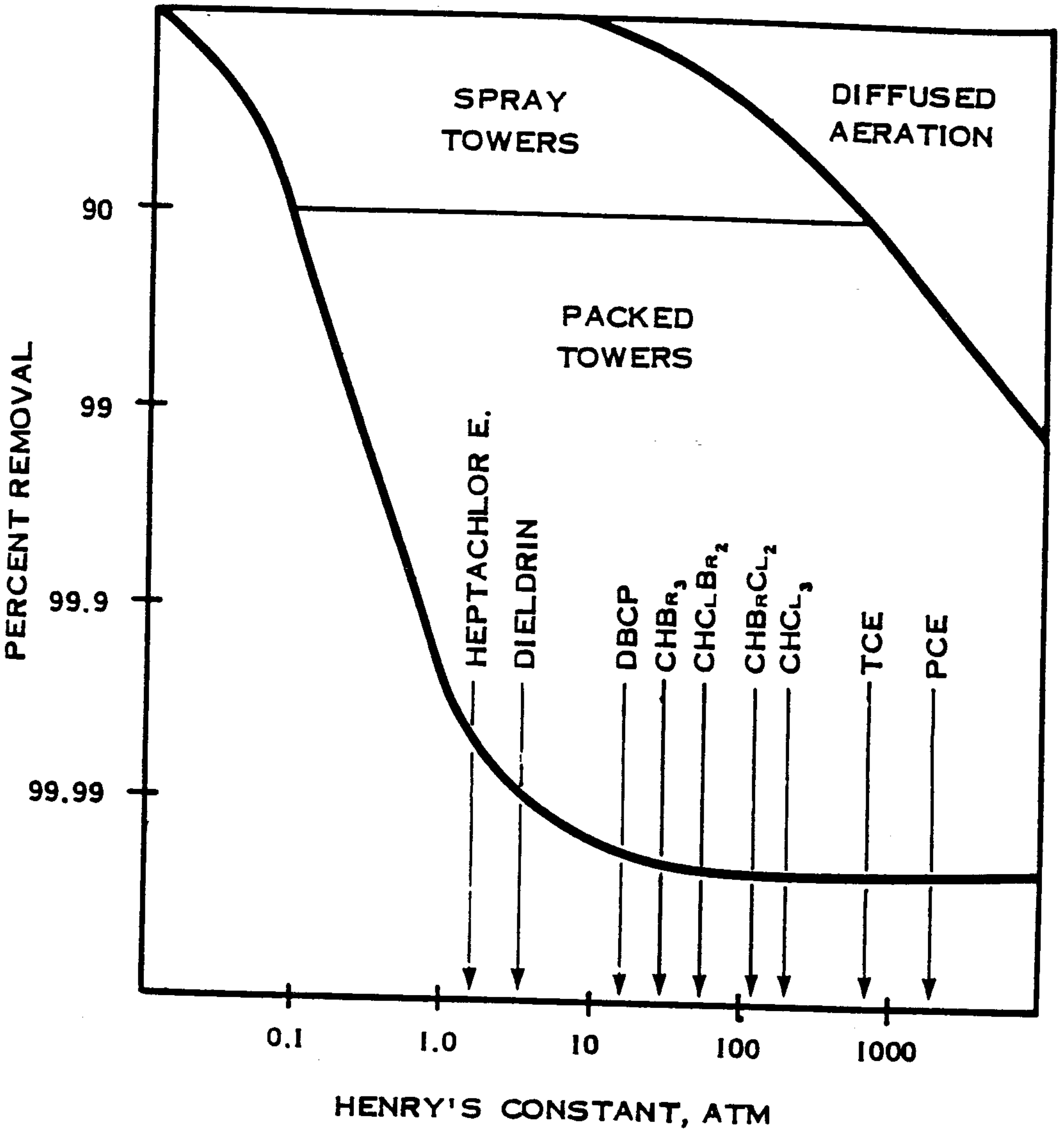


FIGURE V-16. AERATION PROCESS SELECTION DIAGRAM (from Kavanaugh)

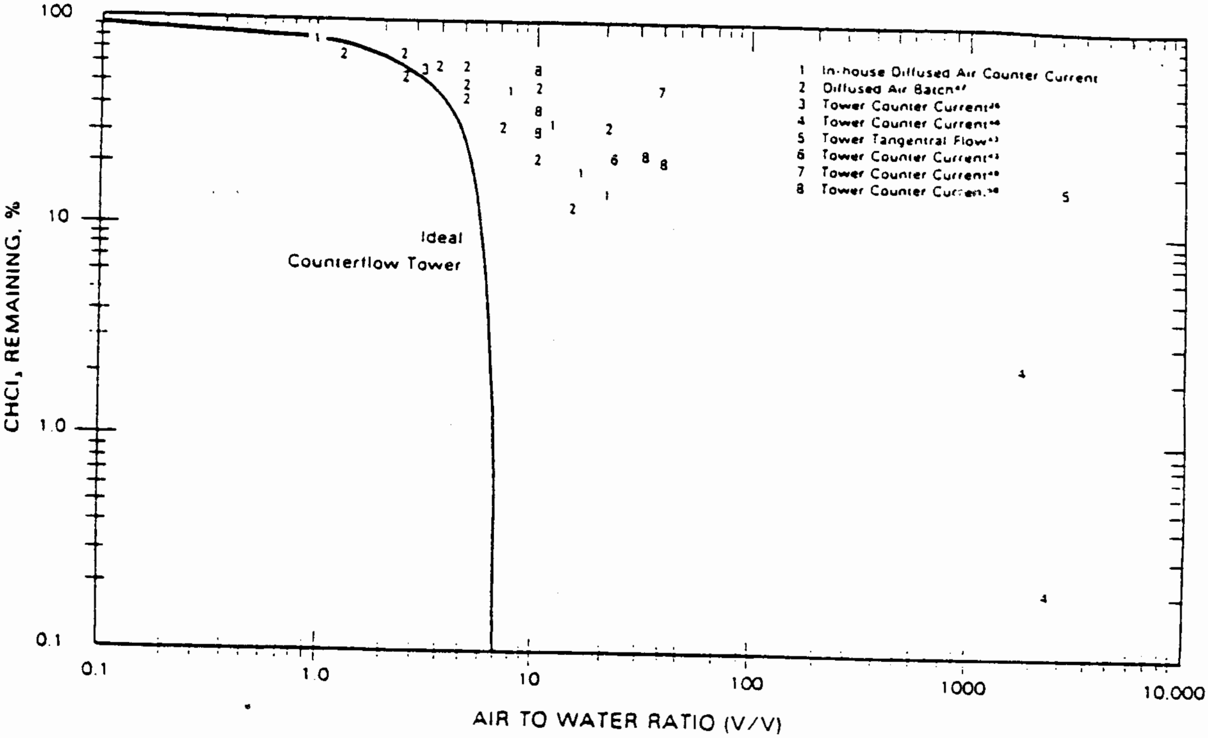


FIGURE V-17. COMPARISON OF CHLOROFORM REMOVAL FOR VARIOUS EXPERIMENTAL SYSTEMS WITH IDEAL TOWER OPERATION
(from Symons, et al, 1981)

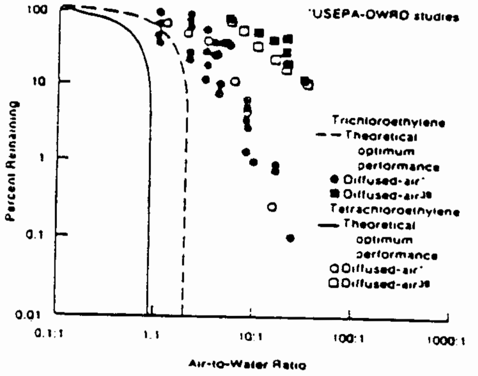


FIGURE V-18a. COMPARISON OF ACTUAL AND THEORETICAL REMOVAL OF TRICHLOROETHYLENE AND TETRACHLOROETHYLENE FROM DRINKING WATER BY AERATION
(from Love and Eilers, 1982)

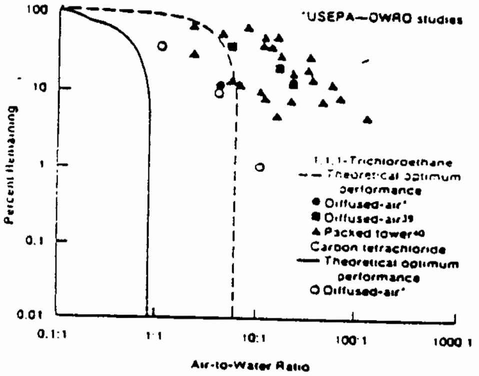


FIGURE V-18b. COMPARISON OF ACTUAL AND THEORETICAL REMOVAL OF 1,1,1-TRICHLOROETHANE AND CARBON TETRACHLORIDE FROM DRINKING WATER BY AERATION
(from Love and Eilers, 1982)

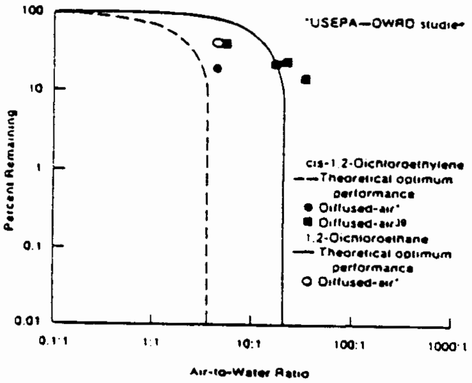


FIGURE V-18c. COMPARISON OF ACTUAL AND THEORETICAL REMOVAL OF CIS-1,2-DICHLOROETHYLENE AND 1,2-DICHLOROETHANE FROM DRINKING WATER BY AERATION
(all from Love and Eilers, 1982)

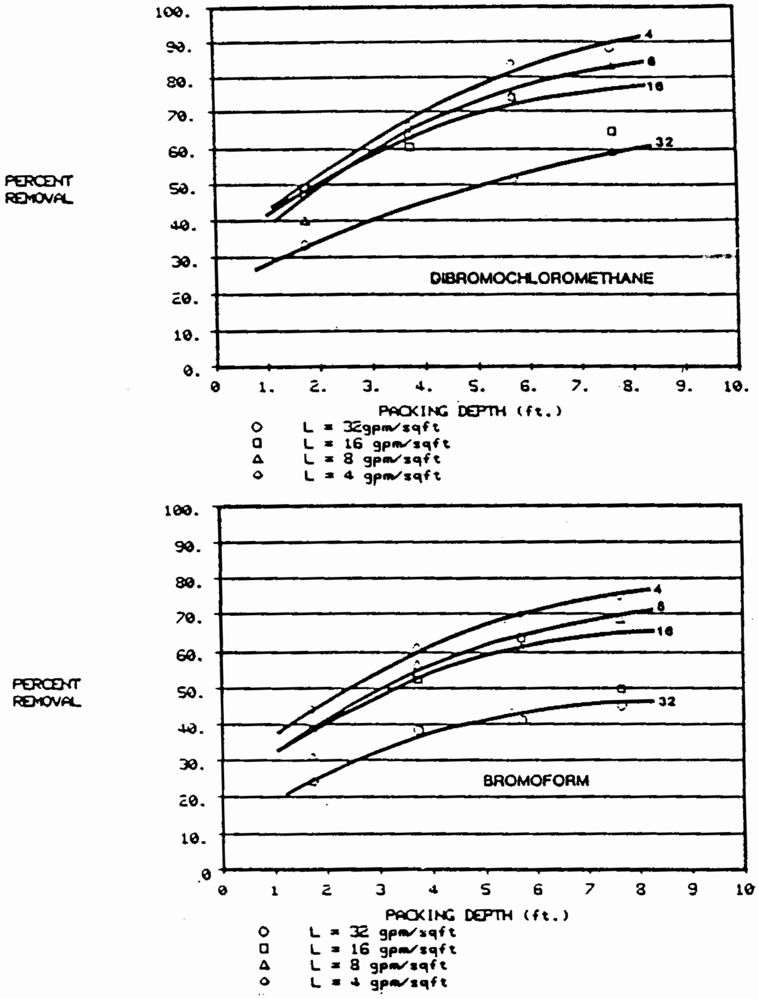
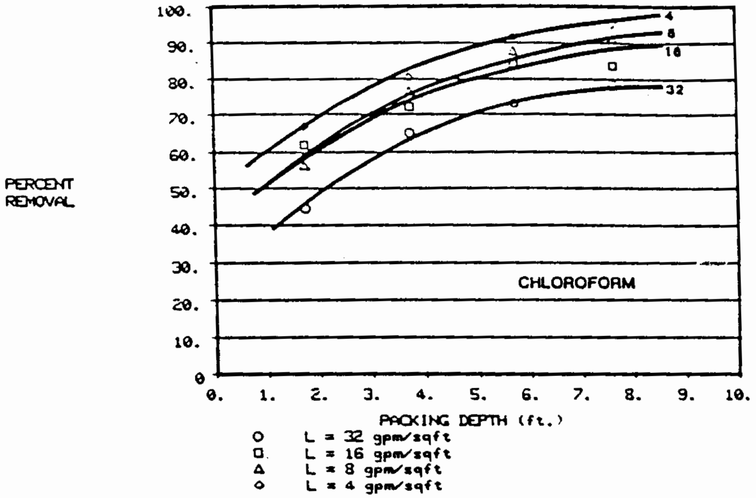
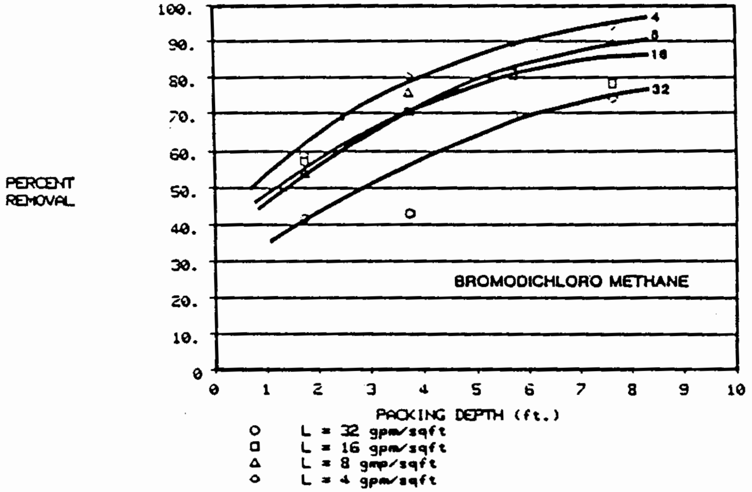


FIGURE V-19. REMOVALS OF THMs BY PACKED TOWER AERATION
(from JMM, 1982)



100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0
PERCENT REMOVAL
CHLOROFORM
4
8
16
32
0.
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
PACKING DEPTH (ft.)
○ L = 32 gpm/sqft
□ L = 16 gpm/sqft
△ L = 8 gpm/sqft
◇ L = 4 gpm/sqft



100.
90.
80.
70.
60.
50.
40.
30.
20.
10.
0
PERCENT REMOVAL
BROMODICHLORO METHANE
4
8
16
32
0
1
2
3
4
5
6
7
8
9
10
PACKING DEPTH (ft.)
○ L = 32 gpm/sqft
□ L = 16 gpm/sqft
△ L = 8 gmp/sqft
◇ L = 4 gpm/sqft

TABLE V-15

REMOVAL OF THMS THROUGH AIR STRIPPING AT THE CITY OF PEMBROKE PINES, FLORIDA (JMM, 1980)

Packing Depth (feet)	Loading Rate (gpm/ft^2)	Removal Efficiencies (%)[a]	
		$CHCl_3$	$CHBrCl_2$
7.75	4	93	96
7.75	16	90	89
3.75	4	87	89
3.75	16	80	82

Synthetic Organics. The EPA operated diffused air studies on industrially contaminated water in New Jersey. As shown in Table V-16 the effectiveness of removal correlated well with the Henry's constant.

TABLE V-16

EFFECTS OF AERATION ON A SOLVENT-CONTAMINATED GROUNDWATER*

(from Love and Eilers, 1982)

Compound	Average Concentration - ug/l		Percent Removal	Henry's Law Constant (atm·m^3/mole)
	Before Aeration	After Aeration**		
1,1-Dichloroethylene	122	4	97	6.3
1,1,1-Trichloroethane	237	23	90	1.2
Tetrachloroethylene	94	9	90	1.1
Trichloroethylene	3	0.4	87	0.5
cis-1,2-Dichloroethylene	0.5	0.1	80	0.31
1,1-Dichloroethane	6	1	83	0.24
1,2-Dichloroethane	1.4	0.8	42	0.05

---

* USEPA-DWRD study in New Jersey

** Diffused-air aeration with a 10-min contact time, air-to-water ratio (vol:vol) of 4:1, and a water depth of 0.8 m

Removals ranged from 42 - 97 percent for compounds with Henry's constants of 0.05 (Dichloroethane) to 6.3 (1,1-Dichloroethylene).

Initial bench-scale studies by Roberts and co-workers (Roberts, Munz, and Dankliker, 1983; Roberts and Dandliker, 1982; Roberts, et al, undated) have shown surface aeration to be more effective in VOC removal than bubble (or diffused) aeration under similar conditions. They attribute this to saturation of the bubbles rising through the water column in diffused aeration. In one study (Roberts, Munz, and Dandliker, 1983), the fractional removals for dichlorodifluoromethane, carbon tetrachloride, tetrachloroethene, trichloroethene, and chloroform were in a narrow band between 84 percent and 86 percent for surface aeration, while removals for bubble aeration were between 35 percent and 86 percent, under similar conditions.

Packed tower pilot studies at Valley County Water District demonstrated removals of up to 99 percent for TCE, PCE, and 1,1,1-Trichloroethane at A/W ratios of 50:1 and a loading rate of 4 gpm/ft^2. Influent levels of TCE ranged from 207-412 ug/l and PCE from 83 - 107 ug/l. At higher loading rates and lower tower heights these removals were reduced, but were still substantial. Table V-17 presents representative results from that study (JMM, 1983).

TABLE V-17

AIR STRIPPING AT VALLEY COUNTY WATER DISTRICT, CALIFORNIA

Packing Depth (feet)	Loading Rate (gpm/ft^2)	A/W Ratio	% Removal TCE	% Removal PCE	% Removal 1,1,1-TCE
9.75	4.3	50	99	99	99
5.75	8.6	50	94	93	90
1.75	8.6	50	66	65	46
1.75	28	40	53	47	24

Tests run in Concord (CCWD) at a higher loading rate (32 gpm/ft^2) and a range of packing depths (tower heights) demonstrated feasible removal, but, as expected at such a high loading rate, removals lower than those observed in Valley County were obtained. At a depth of 7.6 feet and at 32 gpm/ft^2 (A/W = 35) removals of 74 percent of TCE, 45 percent of 1,1,2-trichloroethane, 20 percent of 1,1,2,2-tetrachloroethane and 54 percent of methylene chloride were achieved (JMM, 1982).

GRANULAR ACTIVATED CARBON ADSORPTION

Granular activated carbon (GAC) is used in the drinking water industry for dechlorination, the removal of taste and odors, and the removal of natural and synthetic organic compounds. The use of GAC for taste and odor control in the United States is limited. Approximately 25 percent of utilities in the U.S. used PAC, while only about 65 plants were using GAC (McCreary, 1977). Where utilized, however, GAC typically provides long-term odor control for months to years, even with relatively shallow bed depths of 20 to 30 inches.

Recent interest in the application of GAC for control of a greater variety of natural and synthetic organic compounds has developed because of the affinity of GAC for a broad spectrum of compounds. The adsorptive capacity of GAC for some organics of concern, most notably for trihalomethanes and the lower molecular weight synthetic organics, can be low, with regeneration required within several weeks. However, for a large number of nonvolatile synthetic organics (e.g., pesticides, PCBs, PAHs) and natural humic compounds, GAC has a higher adsorptive capacity with subsequently longer periods between regeneration. Because of the varying costs of GAC adsorption for removal of the range of organic compounds found in water, recent research has focused on increasing the understanding and optimization of this process. Research by the EPA and others has thus been directed towards investigating factors affecting the affinity of GAC for specific organic compounds, studying the effects of competition in multi-solute systems, developing predictive models for estimating the effectiveness of GAC under differing influent water qualities, and optimizing pretreatment for maximum adsorption efficiencies. Another area of GAC research is directed towards minimizing regeneration costs. Other adsorbents, which may have higher capacities for THMs and other organic compounds, are being investigated as alternative or complementary adsorbents to GAC. The effects of biological activity within GAC beds on the removals of natural organics (i.e., humic and fulvic acids) is also being investigated.

Design Parameters

In designing an activated carbon system, the controlling parameters include the carbon contact time and the specific physical characteristics of the carbon to be used. The contact time between the water and GAC granules is characterized by the "empty bed contact time" (EBCT). The EBCT is the ratio of the bed volume and the flowrate, $V/Q = m^3/m^3/min = min$, and is a theoretical measure of the residence time of water in the empty GAC bed or contactor. As long as the kinetics of adsorption are not a limiting factor, as the EBCT increases, more water can be treated before breakthrough occurs because of the lower loading rates on the carbon.

The type of GAC material is selected based on the adsorptive capacity for specific compounds found in the water supply. The adsorption characteristics of different classes of organic compounds (e.g., THMs and humic acids) vary with the type of carbon. To determine which carbon is most suitable for a specific application, bench and pilot scale tests may be conducted. Bench-scale GAC studies can be used to develop adsorption isotherms, which reflect the equilibrium relationship between the adsorbed solute concentration (i.e., mg solute adsorbed gm carbon) and the solute concentration (mg/l). Pilot-scale studies are used to determine breakthrough curves, which are plots of effluent concentrations versus cumulative volume treated. These studies provide information on required regeneration frequencies, the key factor influencing the cost of GAC systems. Pilot-scale studies can also yield information on the competitive effects of adsorption in a multi-solute system.

GAC has been used more extensively in Europe than in the U.S. Design criteria derived from experience with GAC in Germany as reported by Sontheimer (1979) are listed in Table V-18.

TABLE V-18

DESIGN CRITERIA FOR GAC
(Sontheimer, 1979)

Treatment Goal	Filtration Velocity (m/hr)[1]	Bed Depth (m)	EBCT (min)	Throughput Ratio Before Regeneration (m^3/m^3)
Dechlorination	25-35	2	2-4	1,000,000
Taste and Odor Control	20-30	2-3	8-10	100,000
Organics Removal	10-15	2-3	8-15	25,000

---

[1] gpm/ft^2 = 0.4m/hr

The values in Table V-18 are useful for comparing order of magnitude differences in the utility of carbon for these three treatment goals. However, conditions at individual sites can alter the throughput ratios and associated costs significantly. Performance of GAC adsorption used for organics removal in Europe is often measured by surrogate parameters such as TOC, TOX and UV absorption or fluorescence. In the U.S., the EPA may specify MCLs for specific organic compounds, which, in turn will require the monitoring for these specific compounds as opposed to surrogate parameters. This more specific approach presents problems in establishing design criteria which are not based upon pilot plant studies at the specific sites of interest (DiGiano, 1980).

Factors which can significantly affect GAC operation and cost effectiveness which are described below, include compound or compounds being removed, background matrix water quality, type and degree of pretreatment, and GAC contactor configuration.

Factors Affecting GAC Operation

Type of Organics. The most common way of comparing the adsorption potential of compounds is by measuring the equilibrium distribution between the adsorbent (i.e., GAC) water. This equilibrium relationship is described by an adsorption isotherm for the organic compound and GAC of interest.

A summary of adsorption isotherms for many organic compounds is shown in Figure V-20. The types of carbon used to generate each isotherm were not specified. As shown in this figure, some of the halogenated organics such as chloroform, bromodichloromethane, carbon tetrachloride, and trichloroethylene are poorly adsorbed. Others such as hexachlorobutadiene, a synthetic organic derived from rubber manufacture, and 2,4,6-trichlorophenol, which is a compound typical of pesticide derivatives, are relatively well adsorbed.

Other work has verified the great range of adsorptivities exhibited by organics (Dobbs and Cohen, 1980). Table V-19 lists the approximate adsorption capacities of typical GAC 68 suspected chemical carcinogens at an equilibrium solution concentration of 1 mg/l. Such isotherm information is useful as a first step in determining if GAC is a potentially cost effective removal mechanism for the compounds of interest. However, pilot and full-scale adsorption studies show quite different adsorptive capacities for specific organics than these isotherms suggest.

Several factors are responsible for these differences. First, in real treatment applications, the influent concentrations of a compound often vary with time. If the compound being investigated is poorly adsorbed, then a decrease in the influent solution concentration will result in desorption of the compound to re-establish equilibrium. Second, isotherms are often measured at concentrations much greater than those encountered in real waters. If the isotherms are non-linear at low concentrations, extrapolation is difficult.

Another problem which can occur in treatment application is competitive adsorption, whereby compounds which adsorb more strongly than others may "outcompete" less strongly adsorbed compounds for available surface sites on the carbon. This phenomena is often used to explain periods of higher column effluent concentrations compared to influent concentrations for poorly adsorbed organics.

Water Quality and Pretreatment Effects. The presence of inorganic salts such as calcium, magnesium, and sodium have been demonstrated to increase the adsorptive capacity of GAC for organics, particularly the naturally occurring fulvic and humic acids (Randtke and Jepsen, 1982). Figure V-21 shows the relative effects of these salts in improving the adsorptive capacity of GAC for peat fulvic acid. The mechanism for such improved adsorption has been hypothesized to be a change in the distribution of organics due to salt-organic interactions, a change in the chemical characteristics, e.g., solubility, degree of ionization, of the organics, or a reduction of repulsive forces between the GAC surface and the organics (Randtke and Jepsen, 1982).

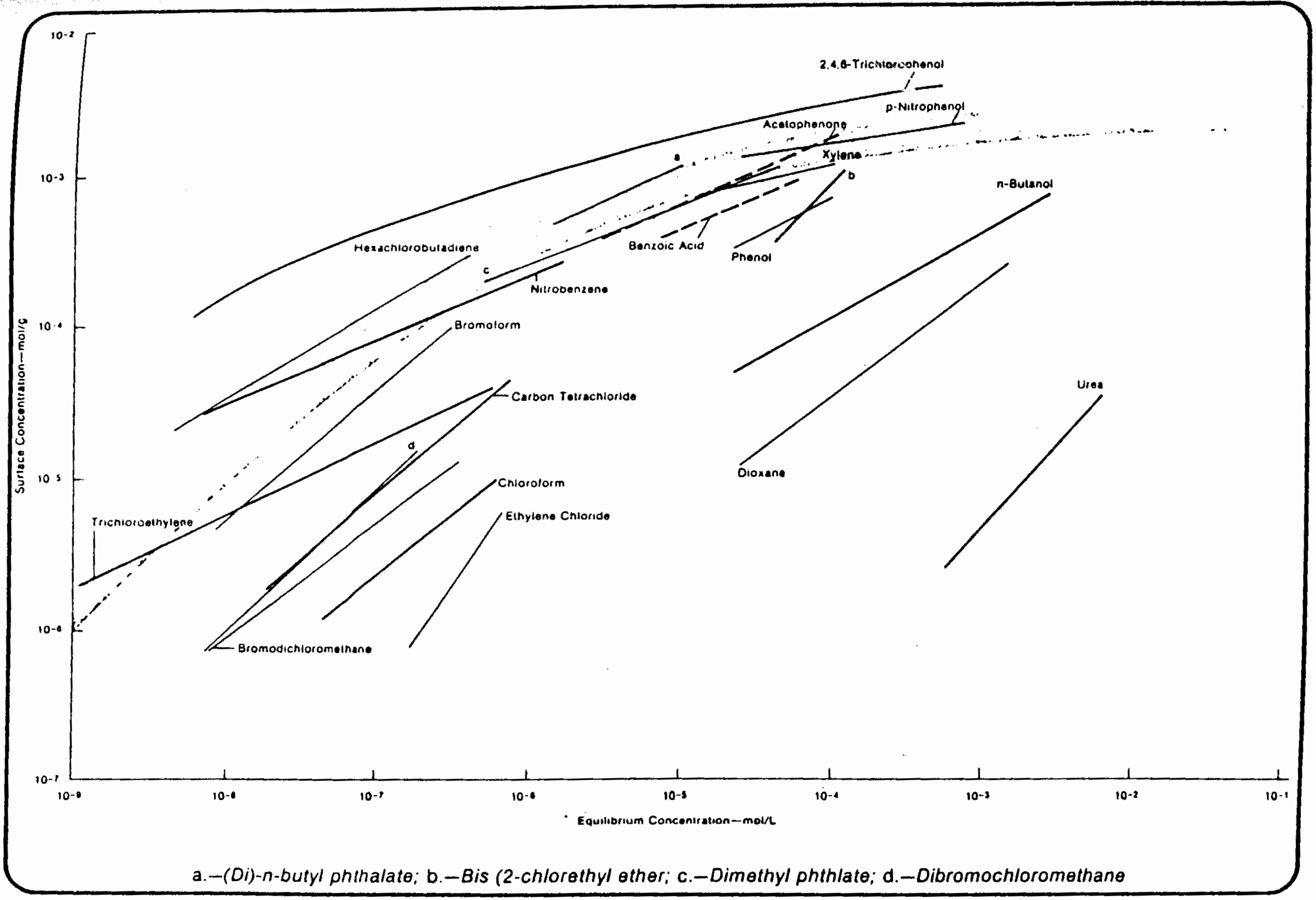
TABLE V-19

SUMMARY OF CARBON ADSORPTION CAPACITIES MEASURED FOR SUSPECTED CHEMICAL CARCINOGENS

(Dobbs and Cohen, 1980)

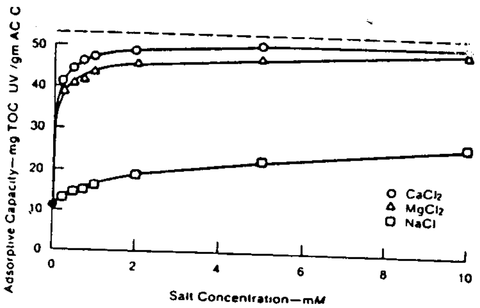
Compound	Adsorption(a) Capacity, mg/g
bis(2-Ethylhexyl) phthalate	11,300
Butylbenzyl phthalate	1,520
Heptachlor	1,220
Heptachlor epoxide	1,038
Endosulfan sulfate	686
Endrin	666
Fluoranthene	664
Aldrin	651
PCB-1232	630
beta-Endosulfan	615
Dieldrin	606
Hexachlorobenzene	450
Anthracene	376
4-Nitrobiphenyl	370
Fluorene	330
DDT	322
2-Acetylaminofluorene	318
alpha-BHC	303
Anethole*	300
3,3-Dichlorobenzidine	300
2-Chloronaphthalene	280
Phenylmercuric Acetate	270
Hexachlorobutadiene	258
gamma-BHC (lindane)	256
p-Nonylphenol	250
4-Dimethylaminoazobenzene	249
Chlordane	245
PCB-1221	242
DDE	232
Acridine yellow*	230
Benzidine dihydrochloride	220
beta-BHC	220
N-Butylphthalate	220
N-Nitrosodiphenylamine	220
Phenanthrene	215
Dimethylphenylcarbinol*	210
4-Aminobiphenyl	200
beta-Naphthol*	200
alpha-Endosulfan	194
Acenaphthene	190
4,4'Methylene-bis-(2-chloroaniline)	190
Benzo(k)fluoranthene	181
Acridine orange*	180
alpha-Naphthol	180
4,6-Dinitro-o-cresol	169
alpha-Naphthylamine	160
2,4-Dichlorophenol	157
1,2,4-Trichlorobenzene	157
2,4,6-Trichlorophenol	155
beta-Naphthylamine	150
Pentachlorophenol	150
2,4-Dinitrotoluene	146
2,6-Dinitrotoluene	145
p-Nitroaniline*	140
1,1-Diphenylhydrazine	135
Naphthalene	132
1-Chloro-2-nitrobenzene	130
1,2-Dichlorobenzene	129
p-Chlorometacresol	124
1,4-Dichlorobenzene	121
Benzothiazole*	120
Diphenylamine	120
Guanine*	120
Styrene	120
1,3-Dichlorobenzene	118
Acenaphthylene	115
4-Chlorophenyl phenyl ether	111
Diethyl phthalate	110

(a) Adsorption capacities when equilibrium fluid phase concentration is 1 mg/ℓ.



a.—*(Di)-n-butyl phthalate;* b.—*Bis (2-chlorethyl ether;* c.—*Dimethyl phthlate;* d.—*Dibromochloromethane*

FIGURE V-20. SPECIFIC ADSORPTION ISOTHERMS (from McGuire and Suffet, 1980)



pH—7.0; Na^+—2.0 mg/L; TOC_0—5.31 mg/L; no buffer; 100 mg/L AC(C)

FIGURE V-21. EFFECTS OF SALTS ON THE ADSORPTION OF GROUNDWATER FULVIC ACID
(from Randtke and Jepsen, 1982)

Pretreatment of the influent to the GAC column is also critical. Coagulation has been demonstrated to be important not only for removal of large, potentially pore blocking humic substances, but also because alum salts appear to react with the organics or the carbon surface to improve adsorption much in the manner described above.

Preozonation can also have important effects on organics adsorption. There is some evidence that ozonation may oxidize some of the larger organics into smaller, more readily adsorbed molecules. In addition, ozonation may render certain organics more biodegradable (Glaze, et al, 1982). Biodegradation within GAC columns has been cited as contributing to removal of organics, and ozonation may enhance this effect. Units specifically designed with preozonation for this purpose are termed "biological activated carbon" (BAC) units (Glaze, 1982).

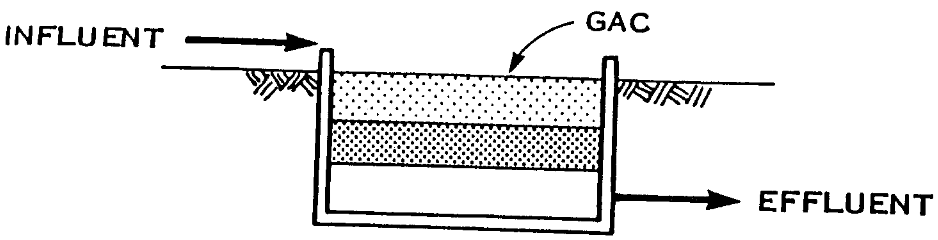
The term BAC is actually a misnomer, since any GAC bed, whether preceded by ozone treatment or not, is inhabited by microorganisms. The biodegradation accomplished by those organisms in conjunction with the adsorption characteristics of the carbon are jointly responsible for organic removal. Due to the wide range of organic characteristics, some are more amenable to removal by adsorption, others by biodegration, and still others by a combination of the two. While European advocates have strongly supported the use of ozone prior to GAC, work in the U.S. suggests that the advantages of ozone extending the service life of GAC are not sufficient to overcome the additional capital and operating costs of ozone.

On the other hand, an excess of ozone may adversely affect the surface of the GAC and decrease its adsorptive capacity. Residual chlorine in the feed water to GAC has been shown to have a similar adverse effect on GAC surfaces.

Process Configuration Effects. The most common manner in which GAC is currently used in water treatment in the US is as a replacement for sand and/or anthracite within an existing filter bed. In this configuration, it tends to serve a dual purpose of filtration and taste and odor removal. However, the EBCT in this application, on the order of 5 min, is typically too short to effectively remove THM precursors, THMs or other synthetic organics. A more effective configuration is a GAC contactor, or series of contactors, added on as separate units after existing treatment processes. Depending on the specific compounds to be removed, this may ultimately be the most cost effective approach. Figure V-22 illustrates these two configurations.

GAC contactors can be designed to remove practically any organic of concern. Certain applications will be straightforward with acceptable costs. In most cases, given the current state of knowledge, pilot plant studies at each potential site are strongly recommended. Experience with pilot and full-scale facilities which illustrates some of the above considerations are described below.

1. FILTER MEDIA REPLACED FIXED BED ADSORBER



2. POST – FILTER FIXED BED ADSORBERS

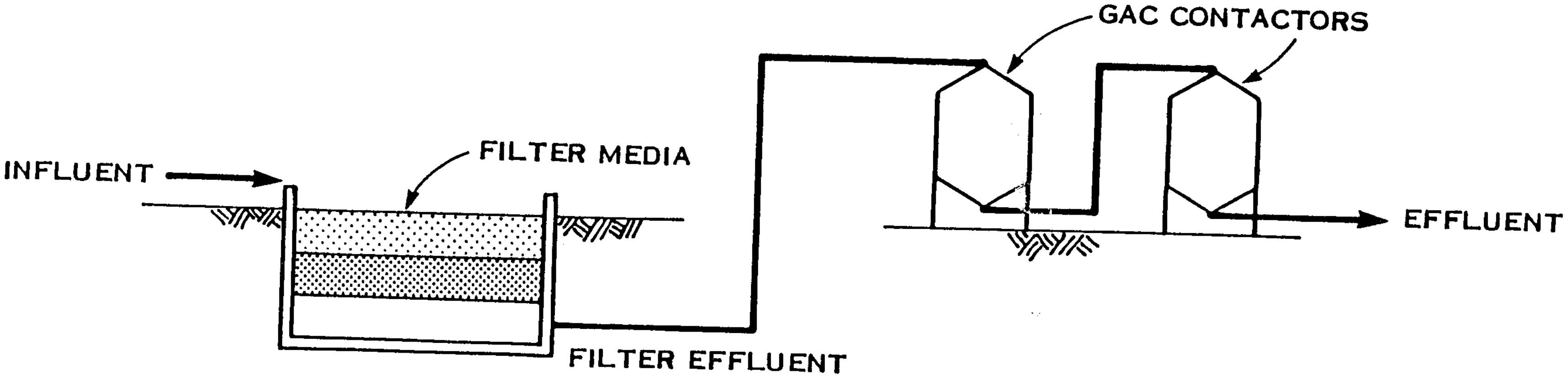


FIGURE V-22. COMMON GAC ADSORBERS FOR WATER TREATMENT
(from JMM, 1980b)

Removal Characteristics For Natural and Synthetic Organics

Table V-20 summarizes observed GAC removal characteristics for various groups of organic compounds. More detailed information for each group of compounds is described below.

TOC Removal Characteristics. In comparing GAC performance for TOC removal from 13 facilities in the US and Europe, a pattern was observed where immediate breakthrough, of 10 to 50 percent, of the applied TOC is followed by a slow increase in effluent TOC to some steady state fraction of the influent (Roberts, et al., 1982)as shown in Figure V-23. Similar results were observed in pilot-scale and full-scale operation at the Cincinnati Water Works (Miller and Hartman, 1982). This final stage of steady state removal is attributed to biodegradation within the GAC bed and/or "slow adsorption" of certain organics. Based upon data compiled from fairly different systems, steady state appears to be reached after approximately 14,000 bed volumes of throughput (volume water treated/volume of GAC contactor) (Roberts, et al., 1982). Thereafter, approximately 25 percent of the influent can be removed somewhat indefinitely. Increased EBCT can increase the length of time to reach steady state. However, as shown in Figure V-24, the relationship is not directly proportional.

Similar "inexhaustible" capacities for TOC on GAC were found in pilot studies in Concord, California. As Figure V-25 shows, effluent TOC levels in virgin GAC effluent, regenerated GAC effluent and BAC effluent all follow this pattern (JMM, 1980) which is more noticeable with increasing EBCT values.

TOX Removal Characteristics. TOX has been cited as a potential surrogate measure of the degree of saturation of activated carbon (Quinn and Snoeyink, 1980). The arguments given are that TOX analysis is less time consuming, less expensive than specific compound analyses. Thus, the TOX profile moves gradually and evenly through a GAC column, as shown in Figure V-26, and provides a gross measure of column saturation. It should be noted, however, that most utilities are concerned with one or more specific compounds which may or may not follow the general pattern of TOX. In order for TOX to be useful under these conditions, a relationship between TOX adsorption profiles and the compounds of concern would need to be established for each particular water supply. This may be useful on a site-specific basis.

Trihalomethanes and THM Precursors. GAC can be used to control trihalomethanes either through adsorption of precursor or through adsorption of particular THM compounds. However, GAC adsorption is not typically the most cost effective option for THM control. The more effective use of GAC is for precursor adsorption, particularly if it is coupled with good pretreatment. In removing THM precursors, the GAC bed often does not reach exhaustion but, rather a steady state is reached and may continue indefinitely. Again, this is attributed to biodegradation on the surface of the GAC media. In removing THMs, on the other hand, GAC adsorbers do reach a definite exhaustion where the effluent concentration equals the influent concentration. This typically

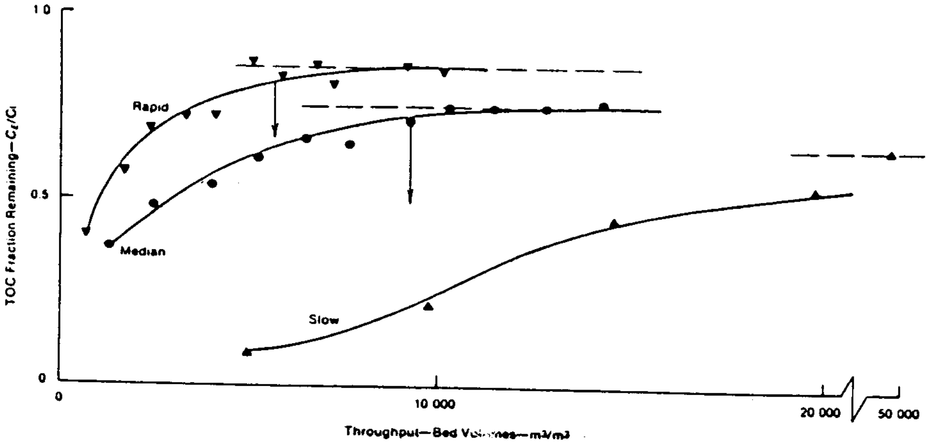


FIGURE V-23. REPRESENTATIVE TOC BREAKTHROUGH CURVES (from Roberts and Summers, 1982)

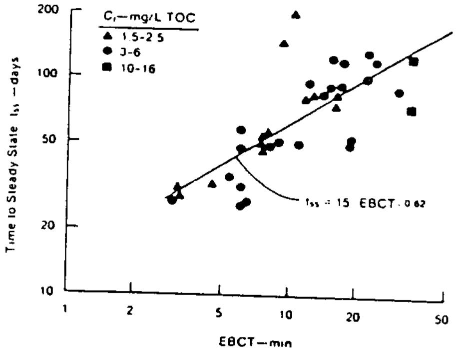


FIGURE V-24. OBSERVED RUN LENGTH AT WHICH STEADY STATE IS REACHED
(from Roberts and Summers, 1982)

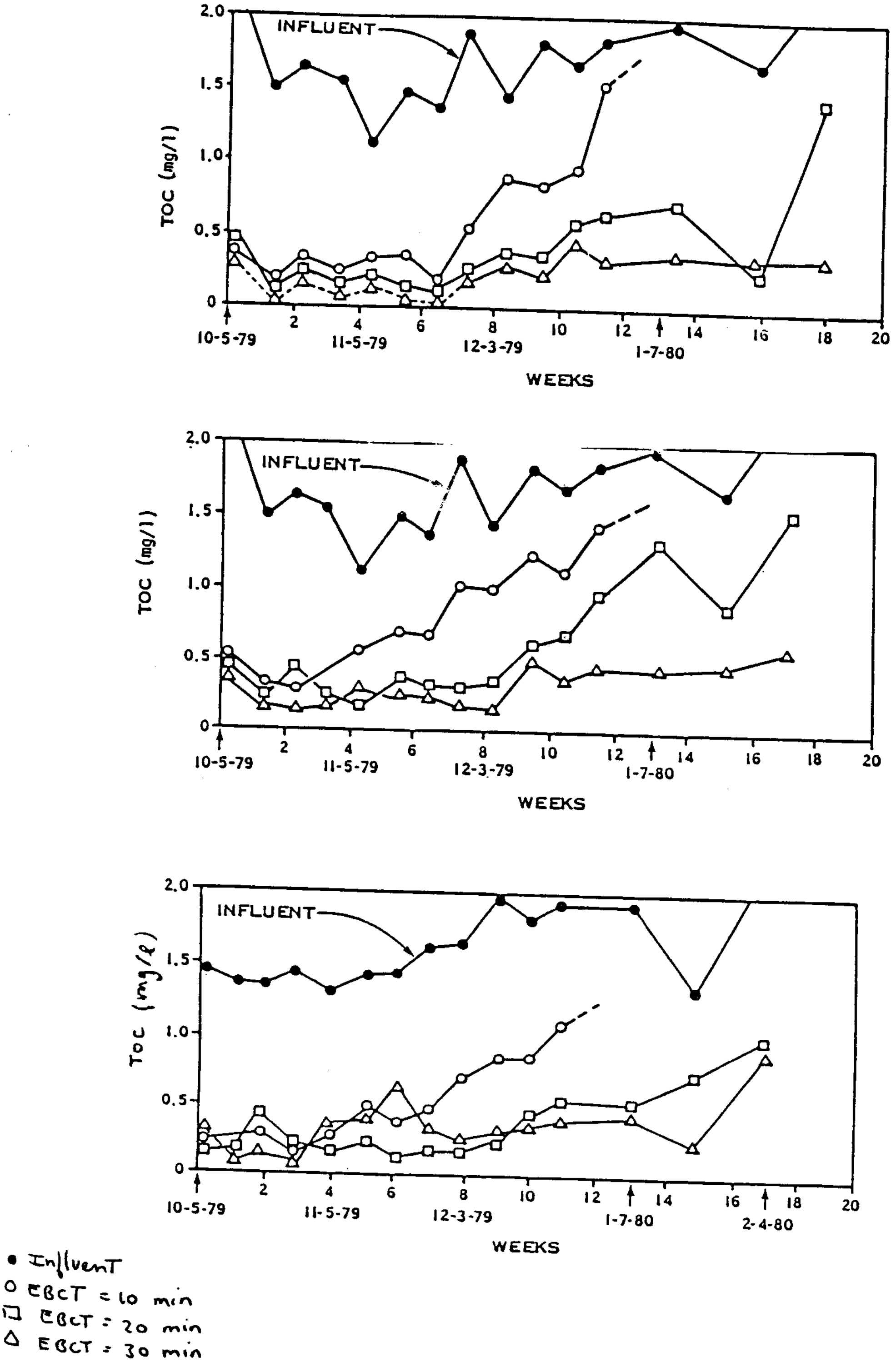


FIGURE V-25. TOC REMOVALS ON VIRGIN GAC, REGENERATED GAC, AND PRE-OZONATED GAC, AT DIFFERING EMPTY BED CONTACT TIMES
(from JMM, 1980b)

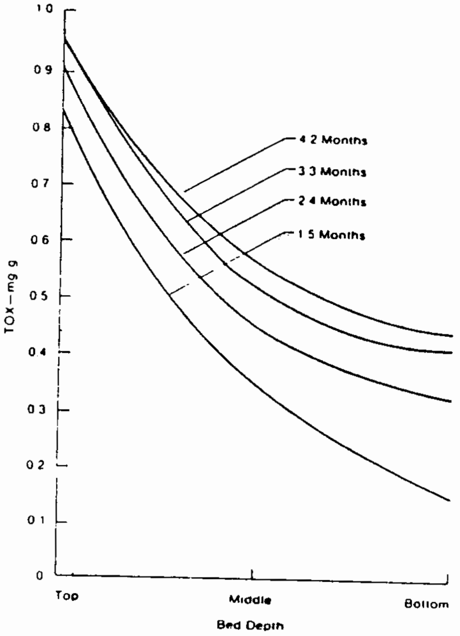


FIGURE V-26. JEFFERSON PARISH ADSORBER TOX PROFILES (from Quinn and Snoeyink, 1980)

TABLE V-20

GAC REMOVAL CHARACTERISTICS - REPRESENTATIVE RESULTS

Organic	EBCT (min)	Time to Steady State or Breakthrough (weeks)	Comments
TOC	3-40	4-14	25% removal occurring at steady state
THMFP	3-45	2-24	0-69% removal occurring at steady state
THM	3-45	3- 26	True breakthrough
Synthetic Organics[a]			
TCE	9	18	True breakthrough
	18	58	True breakthrough
PCE	18	58	True breakthrough
1,1,1-Trichloroethane	7.5	1	True breakthrough
	18	28	True breakthrough
CCl_4	10	14	True breakthrough
1,2, Dichloroethane	20	3	True breakthrough

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[a] Represents data from a limited number of studies, most under controlled conditions. Field results can differ significantly.

occurs within a few weeks after regeneration, depending upon the influent concentration.

Using Ohio River water, the EPA operated pilot-scale GAC columns for 30 weeks prior to THM precursor breakthrough with a 62-inch bed of lignite-based carbon with an 18 minute EBCT. As Figure V-27 shows, a period of nearly complete THM precursor removal is followed by a period of slowly increasing effluent concentrations which approach but do not equal the influent concentration even at 30 weeks. Using a more shallow, coal-based GAC bed, with a 9 minute EBCT, breakthrough of chloroform precursor occurred by the thirteenth week and breakthrough of dibromochloromethane precursor occurred by the fourth week, as shown in Figure V-28.

The EPA also summarized the results from nine studies on GAC performance for precursor removal. The range of values are given below in Table V-21.

TABLE V-21

GAC PERFORMANCE FOR PRECURSOR (THMFP) REMOVAL

Parameter	Range of Values
EBCT	3.2-46.0 min
Approximate Initial THMFP Removed	10-98%
Approximate Time to Steady State	2-24 weeks
THMFP Removal at Steady State	0-69%
Influent THMFP at Steady State	26-365 mg/l

Although the types of GAC and influent water qualities used in these studies varied, the studies demonstrate the general trend of an initial effective removal of THM precursor followed by a relatively short time to steady state or exhaustion.

Typical patterns for THM removal through GAC adsorption demonstrated in pilot studies conducted at Contra Costa Water District in Concord, California (JMM, 1980). Figures V-29, V-30 and V-31 show relationship between TOC and THMs and throughput volume for three columns filled with virgin GAC, regenerated GAC and BAC (preozonated GAC). As shown, while the effluent TOC levels never equalled the influent, THMs demonstrated true breakthrough, where effluent concentrations equalled influent concentrations, after 7 to 13 weeks for an EBCT = 10 minutes. With longer EBCTs, 20 to 30 minutes, breakthrough was not reached even after 17 weeks.

The actual carbon loading or adsorptive capacity (mg/gm of carbon) for a GAC bed can be estimated by the method described by Kornegay (1978). The values provide a reasonable basis of comparison of different GAC systems. Table V-22 compares adsorptive capacities for TOC and THM of the three columns used in the Contra Costa Water District's study to those calculated from an EPA study

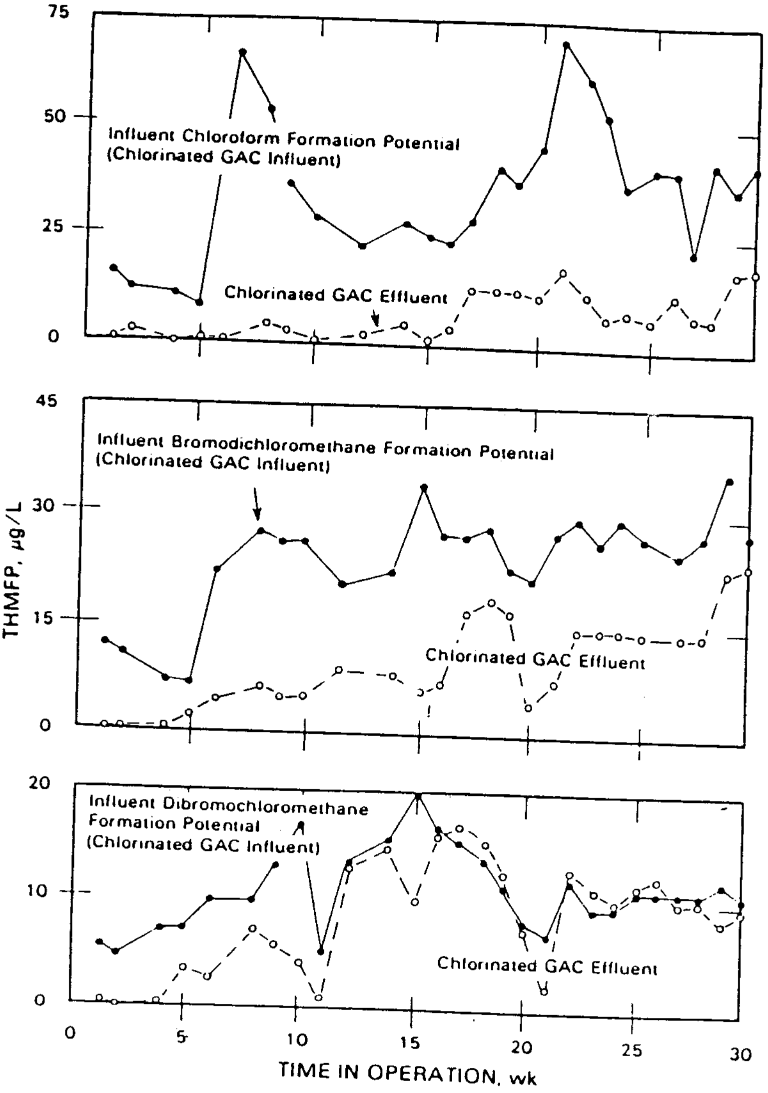

FIGURE V-27. REMOVAL OF THMFP FROM OHIO RIVER WATER BY LIGNITE-BASE GAC
(from Symons, et al, 1981)

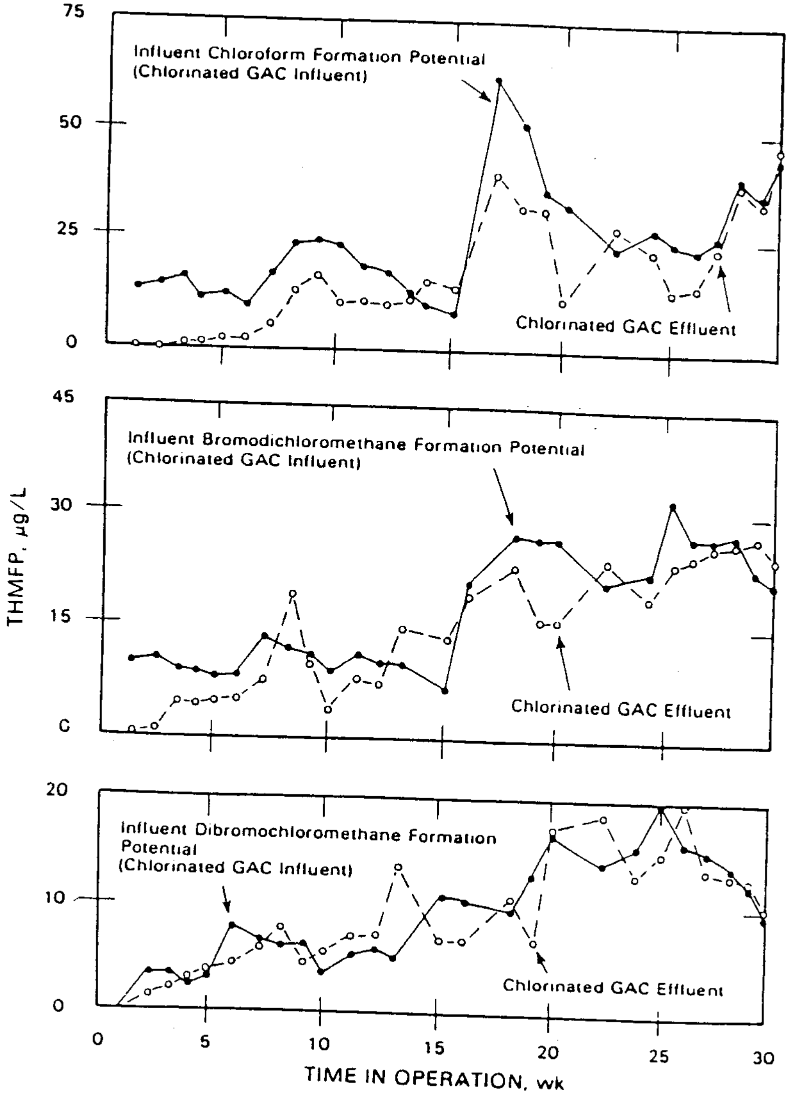

FIGURE V-28. REMOVAL OF TRIHALOMETHANE PRECURSORS FROM OHIO RIVER WATER BY COAL-BASE GAC (from Symons, et al, 1981)

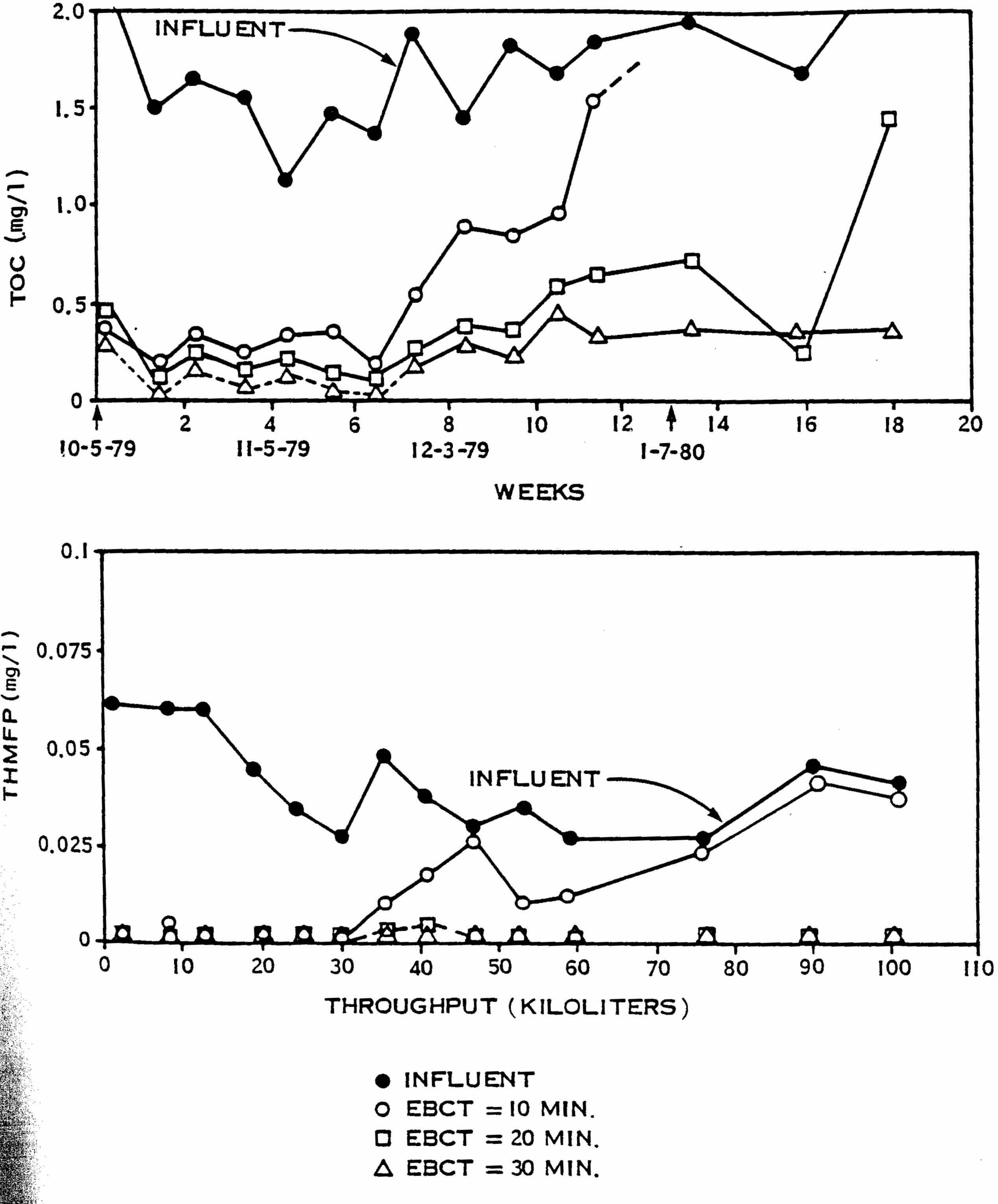

FIGURE V-29. TOC AND THMFP REMOVALS BY VIRGIN GAC ADSORPTION
(from JMM, 1980b)

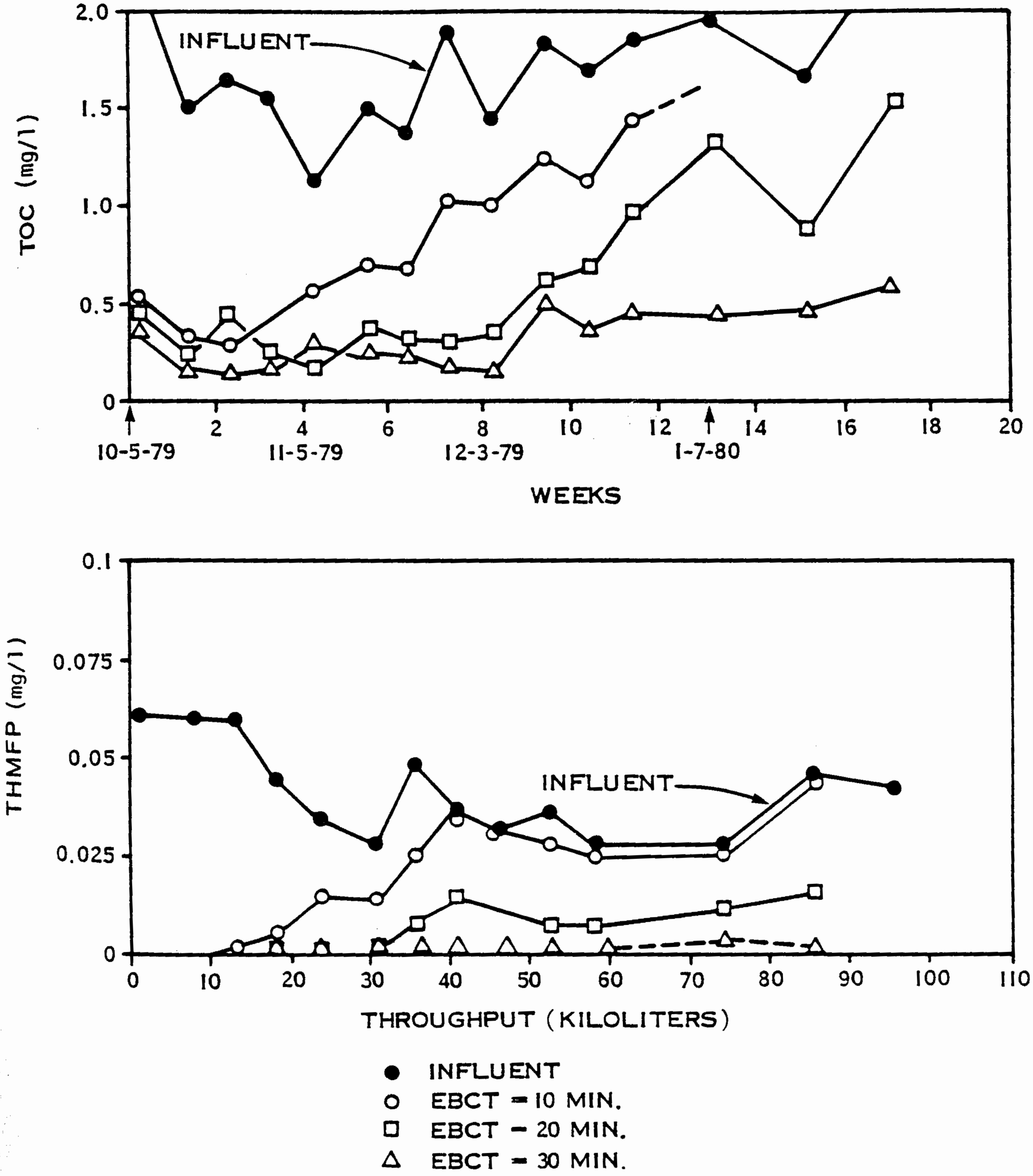

FIGURE V-30. TOC AND THMFP REMOVALS BY REGENERATED GAC ADSORPTION
(from JMM, 1980b)

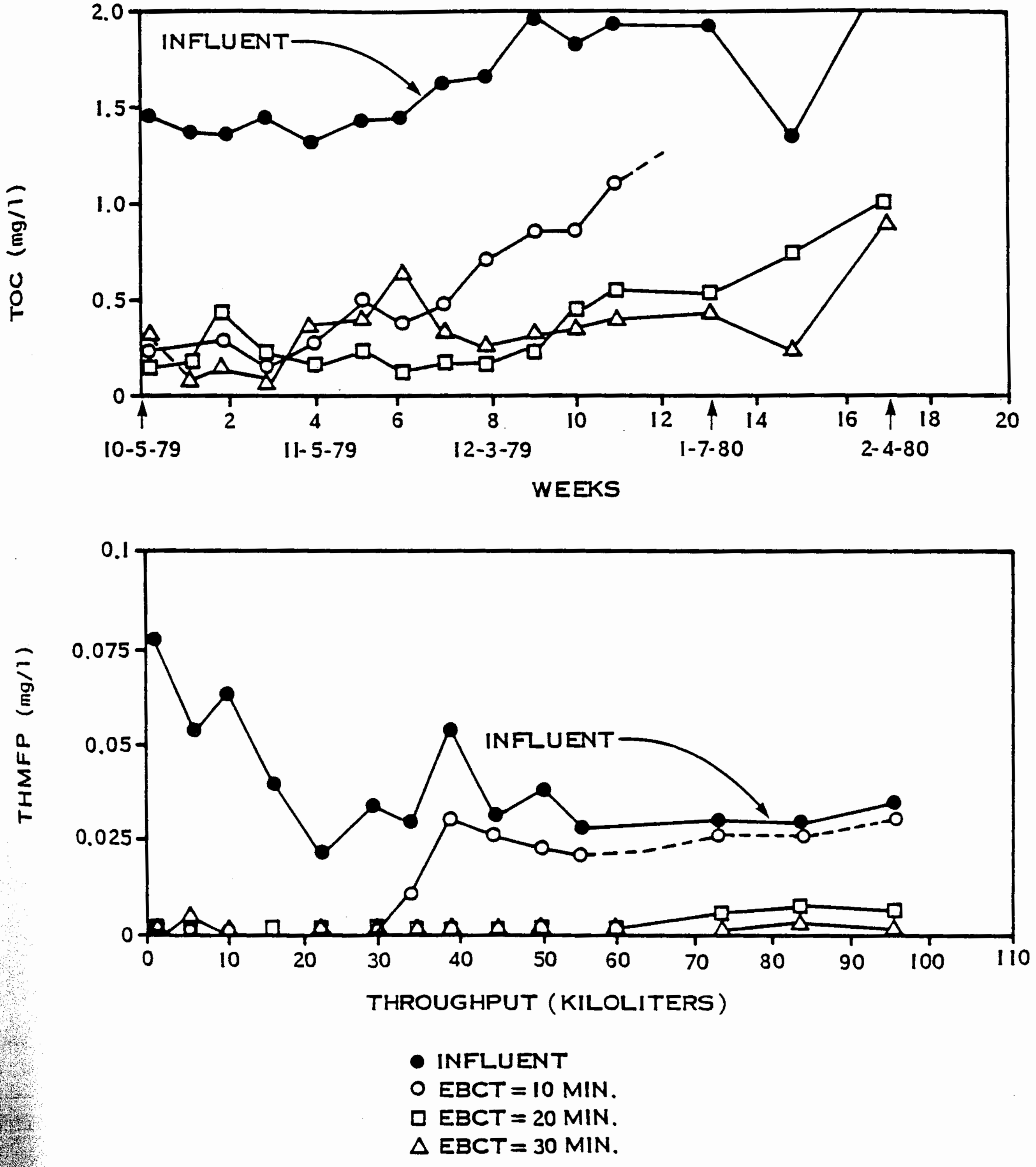

FIGURE V-31. TOC AND THMFP REMOVALS BY BAC (PRE-OZONATED GAC) ADSORPTION
(from JMM, 1980b)

conducted in Southern Florida. The most apparent differences are the higher capacities of carbon in the EPA study. This is principally due to higher influent concentrations in the EPA study. The adsorptive capacities of the District's three columns were essentially the same, except for the TOC capacity of the regenerated GAC, which appears to have been reduced by the regeneration process. This data also concurs with observations that pre-ozonation of GAC influent does not appreciably enhance the capacity of the carbon.

TABLE V-22

GAC ADSORPTIVE CAPACITY ON A VARIETY OF CARBONS AND MEAN INFLUENT CONCENTRATIONS FOR TOC AND THM

	TOC		THM	
	Mean Influent Conc. (mg/l)	Adsorptive Capacity (mg/gm)	Mean Influent Conc. (mg/l)	Adsorptive Capacity (mg/gm)
EPA[a]	6.0	45	0.60	3.0
BAC-Virgin Filtrasorb-400	1.7	28	0.03	0.5
Regenerated Filtrasorb-400	1.7	19	0.04	0.5
Virgin Filtrasorb-400	1.7	25	0.04	0.7

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[a] Data from an EPA sponsored pilot study conducted in Southern Florida.

Data summarized from 14 studies demonstrate a strong relationship between EBCT and THM removal similar to that shown for THM precursor (Symons, et al., 1981). Also important is the mix of THM species denoted by the ratio of Cl/Br, with increasing Cl/Br values corresponding to poorer removals. Table V-23 below, demonstrates the ranges of observed values.

TABLE V-23

GAC PERFORMANCE IN THM REMOVAL

Parameter	Range of Values
EBCT	3.2-46 min
Cl/Br Ratio in Influent	1.8-infinite[1]
Influent THM Concentration	0.7-155 mg/l
Time to Exhaustion	3-26 weeks

---

[1] All $CHCl_3$ with no CHB_3

Synthetic Organics. Pilot studies reported by the EPA and others (Dykson and Hess, 1982; Trussell and Trussell, 1980; Love, 1982; Yohe and Suffett, 1981) show that removal of specific organics differs according to the type of organic and influent water quality. Using the data from several adsorption isotherm studies, Figure V-32 illustrates the adsorption capacity for six organic contaminants found in water, assuming an equilibrium solute concentration of 500 ug/l. The values range from about 2.7 mg/g for 1,2-dichloroethane to about 45 mg/g tetrachloroethylene. Figures V-33 and V-34 summarize the range of values which have been observed for GAC adsorption capacity of organics at lower equilibrium solution concentrations.

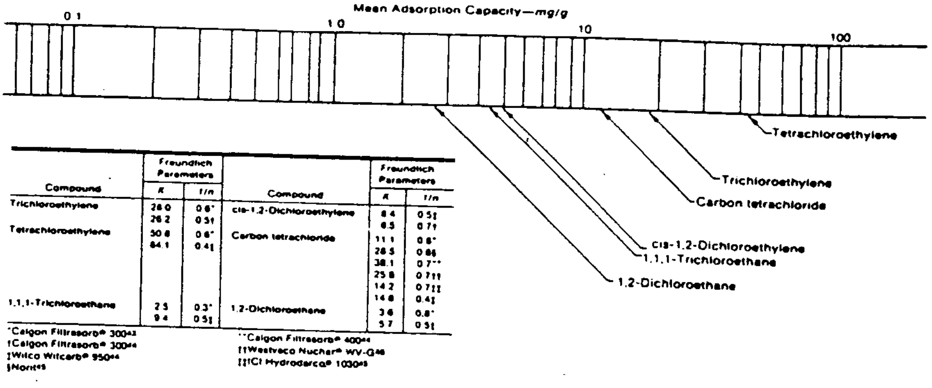
Figure V-35, for example, shows the fluctuations in effluent GAC concentrations of 1,2 bis- (2-chloroethoxy) ethane over a period of weeks (Yohe and Suffett, 1981). The authors concluded that the fluctuations were caused by varying influent concentrations of this compounds. Influent concentrations ranged from 0.01 ug/l to 0.46 ug/l over 15 weeks. As discussed above, such variable influent concentrations for poorly adsorbed compounds result in continuously shifting equilibria within the GAC column and consequent variations in effluent concentrations.

Figure V-36 illustrates the influence of GAC bed depth on the operating capacity of the bed for TOC and cis-1,2-dichloroethene. The data suggest that for a shallow bed contactor, GAC will have a poorer operating capacity for TOC than for cis-1,2-dichloroethene. As the bed depth increases, this difference in operating capacities is reduced (Trussell and Trussell, 1981).

The clear implication of these studies is that use of GAC for treating a contaminated water supply requires a thorough evaluation of the types of organics in the supply, their concentration variations over time, other relevant water quality factors, and a range of design options. Thus, long term pilot studies are needed when GAC is considered to be a potential process for organics control in surface or groundwaters.

OXIDATION

The use of oxidants to break down organics at the head end of treatment plants, or ahead of specific processes such as GAC, has been suggested as an additional process for organics control. Ozone, chlorine dioxide (ClO_2), and permanganate ($KMnO_4$) are all oxidants utilized in water treatment, although not typically for THM precursor or synthetic organics control. Ozone is widely used in Europe, so there is relatively more data on its oxidation and disinfection capabilities compared to the other oxidants. Recent interest in the use of chlorine dioxide as an alternative to chlorine disinfection has generated research in this area, but little information on its oxidative properties with respect to organic compounds is available. Permanganate has long been used for taste and odor control, as well as for manganese and iron oxidation. Again, however, little information on its oxidative properties with respect to organic compounds is available. A major drawback in the use of oxidation processes for the breakdown of organics is the potential for the formation undesirable by-products.



Compound	Freundlich Parameters		Compound	Freundlich Parameters	
	K	1/n		K	1/n
Trichloroethylene	28.0	0.6*	cis-1,2-Dichloroethylene	8.4	0.5‡
	26.2	0.5†		6.5	0.7†
Tetrachloroethylene	50.8	0.6*	Carbon tetrachloride	11.1	0.8*
	84.1	0.4‡		28.5	0.8§
				38.1	0.7**
				25.8	0.7††
				14.2	0.7‡‡
				14.8	0.4‡
1,1,1-Trichloroethane	2.5	0.3*	1,2-Dichloroethane	3.6	0.8*
	9.4	0.5‡		5.7	0.5‡

*Calgon Filtrasorb® 300[43]
†Calgon Filtrasorb® 300[44]
‡Wilco Witcarb® 950[44]
§Norit[45]
**Calgon Filtrasorb® 400[44]
††Westvaco Nuchar® WV-G[46]
‡‡ICI Hydrodarco® 1030[45]

FIGURE V-32. COMPARISON OF ISOTHERM ADSORPTION CAPACITIES ON ACTIVATED CARBON
(from Love and Eilers, 1982)

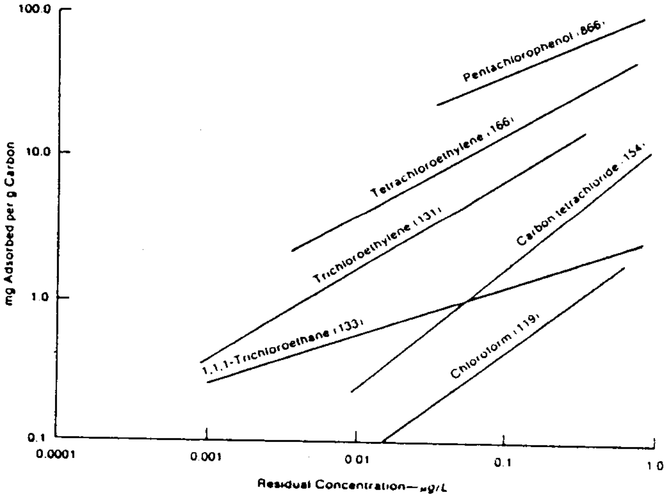


FIGURE V-33. ADSORPTION ISOTHERMS FOR SEVERAL ORGANIC COMPOUNDS FOUND IN GROUND-WATER SUPPLIES
(from Love and Eilers, 1982)

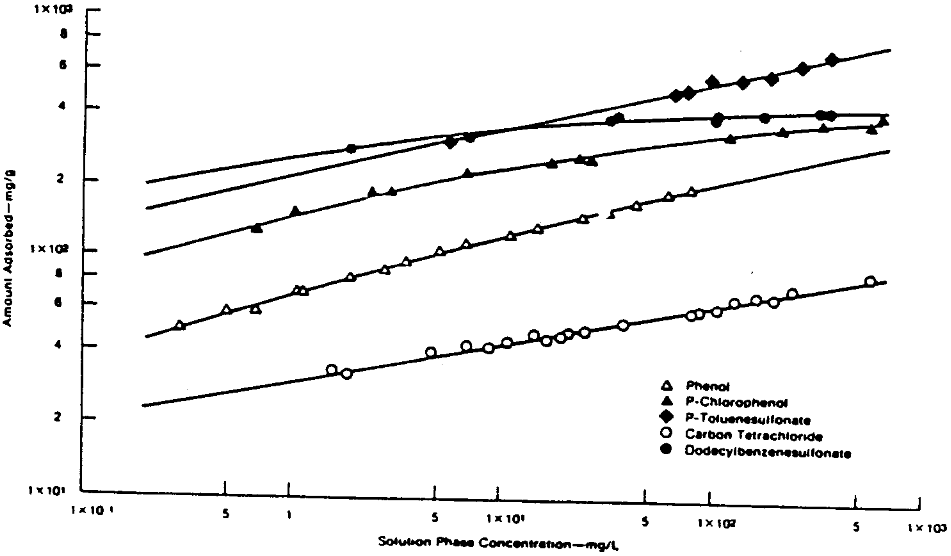


FIGURE V-34. ISOTHERMS FOR VARIOUS COMPOUNDS (CALGON F-400)
(from Weber and VanVliet, 1981)

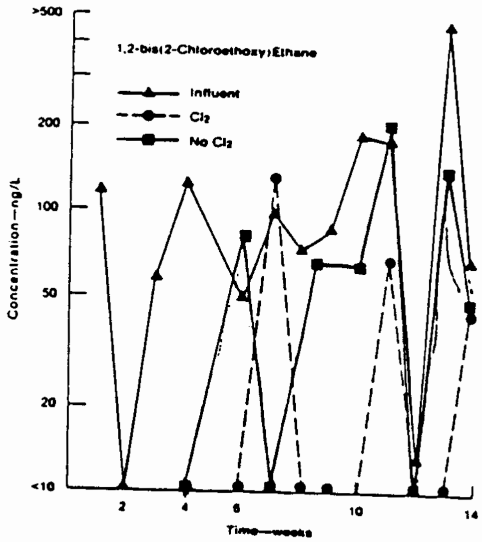


FIGURE V-35. 1,2-BIS(2-CHLOROETHOXY)ETHANE INFLUENT-EFFLUENT CONCENTRATIONS IN A GAC FILTER
(from Yohe, Suffet, and Cairo, 1981)

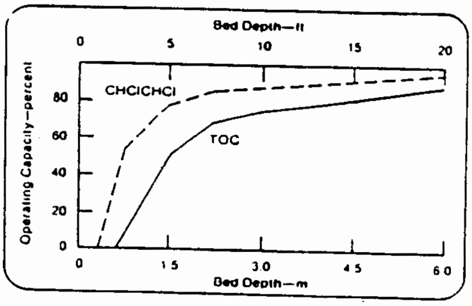


FIGURE V-36. INFLUENCE OF BED DEPTH ON GAC OPERATING CAPACITY
(from Trussell and Trussell, 1980)

Table V-24 summarizes information on the efficacy of these oxidants. The results of studies used to construct this table are described in the following sections.

TABLE V-24

EFFECT OF OXIDANTS ON ORGANICS REDUCTION

	Ozone		$KMnO_4$		ClO_2	
Organic Parameter	Dose (mg/l)	% Removal	Dose (mg/l)	% Removal	Dose (mg/l)	% Removal
TOC	1-2	I[a]	—	—	—	—
THMFP	.5-11	0-78	10	35	2-3	30[b]

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a I = Ineffective
b Batch reactor for 48 hours

Permanganate

An investigation into THM precursor reduction, as measured by THMFP, in Ohio River water showed a maximum removal of 35 percent using 10 mg/l $KMnO_4$, 21 hours of contact time and a pH of 11.5 (Symons, et al., 1981). With lower doses, reaction times and pH values, THMFP removal efficiencies decrease. In particular, at $KMnO_4$ doses commonly used for taste and odor control (e.g., 1-2 mg/l), negligible removal occurs, as shown in Table V-25 (CCWD, 1977).

TABLE V-25

REMOVAL OF THMFP WITH PERMANGANATE

			THMs Formed (ug/L)				
$KMnO_4$	pH Adj.	TOC	$CHCl_3$	$CHCl_2Br$	$CHClBr_2$	$CHBr_3$	Total (ug/l)
0.0 ppm	None	—	5	15	55	75	150
0.5	None	—	5	17	62	80	164
1.0	None	—	5	15	59	82	161
1.0	8.25	2.25	14	22	87	200	323

Similar findings were reported for permanganate treatment of surface supplies in Chapel Hill and Durham, North Carolina (Singer et al., 1980). The authors were able to demonstrate the reduction of $CHCl_3$ formation potential was directly related to permanganate dose, but high doses were required to achieve and significant effect. Subsequent work with humic and fulvic acid solutions demonstrated that of manganese dioxide (MnO_2), a reduction product of $KMnO_4$, absorbed THM precursors in the presence of calcium salts (Colthurst et al., 1982). A 65 percent reduction of seven-day $CHCl_3$ formation potential was observed for Aldrich humic acid in the presence of 40 mg/l Ca^{+2} at a $KMnO_4$ concentration of 25 mg/l as Mn. Removals of fulvic acid were observed under similar conditions.

These modest overall removals described above preclude the use of $KMnO_4$ addition as the sole treatment process for THM control. The intermittent or adjunct use of $KMnO_4$ at specific sites along with other control mechanisms may, however, be useful. The use of $KMnO_4$ at the head end of the plant, as opposed to Cl_2, still allows for taste and odor control, iron and manganese removal, and allows humics to be coagulated.

Ozone

Ozone is ineffective for removal of trihalomethanes. At relatively high doses, however, removal or destruction of THM precursor (THMFP) can be achieved. Figure V-37 is illustrative of a typical pattern of THMFP removal for a batch ozone reactor. As shown, with increasing amounts of ozonation, an initial drop in precursor is followed by a slight increase and a subsequent further decline. However, high doses of ozone (15-20 mg/l) were needed to reduce THMFP by 50 percent; therefore, use of ozone to remove THM precursors may not be cost effective. Figure V-38 shows a similar removal for color with increasing ozone dose (JMM, 1980). Although ozone at 10-12 mg/l achieved the desired color removal, there are other processcombinations which may be more cost effective.

Table V-26 shows the results achieved in a different water system and under differing experimental conditions for ozone doses of 0.5-11.0 mg/l O_3 (Trussell and Umphres, 1978). As shown, a reduction in THM precursor is almost always possible, but the degree of reduction may vary widely.

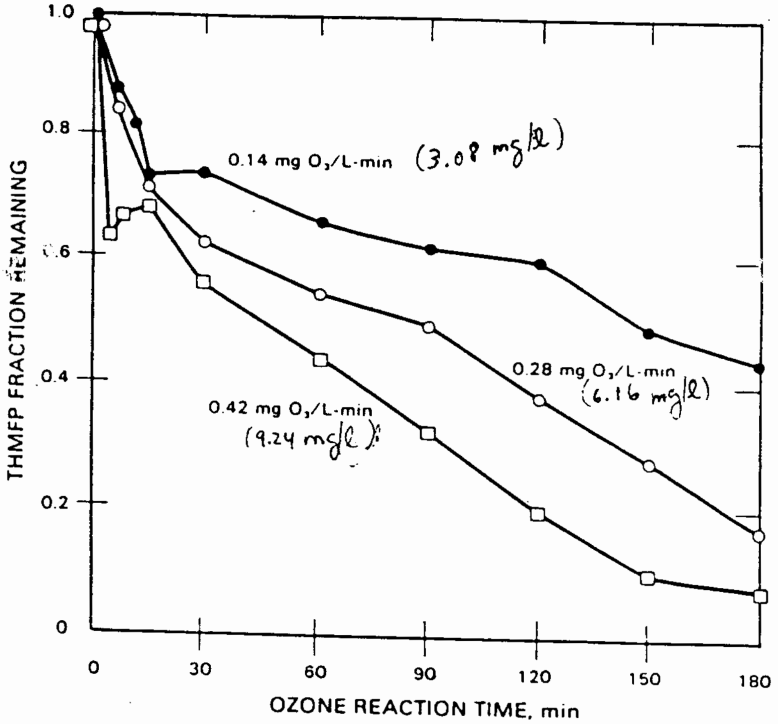

FIGURE V-37. OZONE DESTRUCTION OF TRIHALOMETHANE PRECURSORS IN CADDO LAKE, TEXAS WATER (from Symons, et al, 1981)

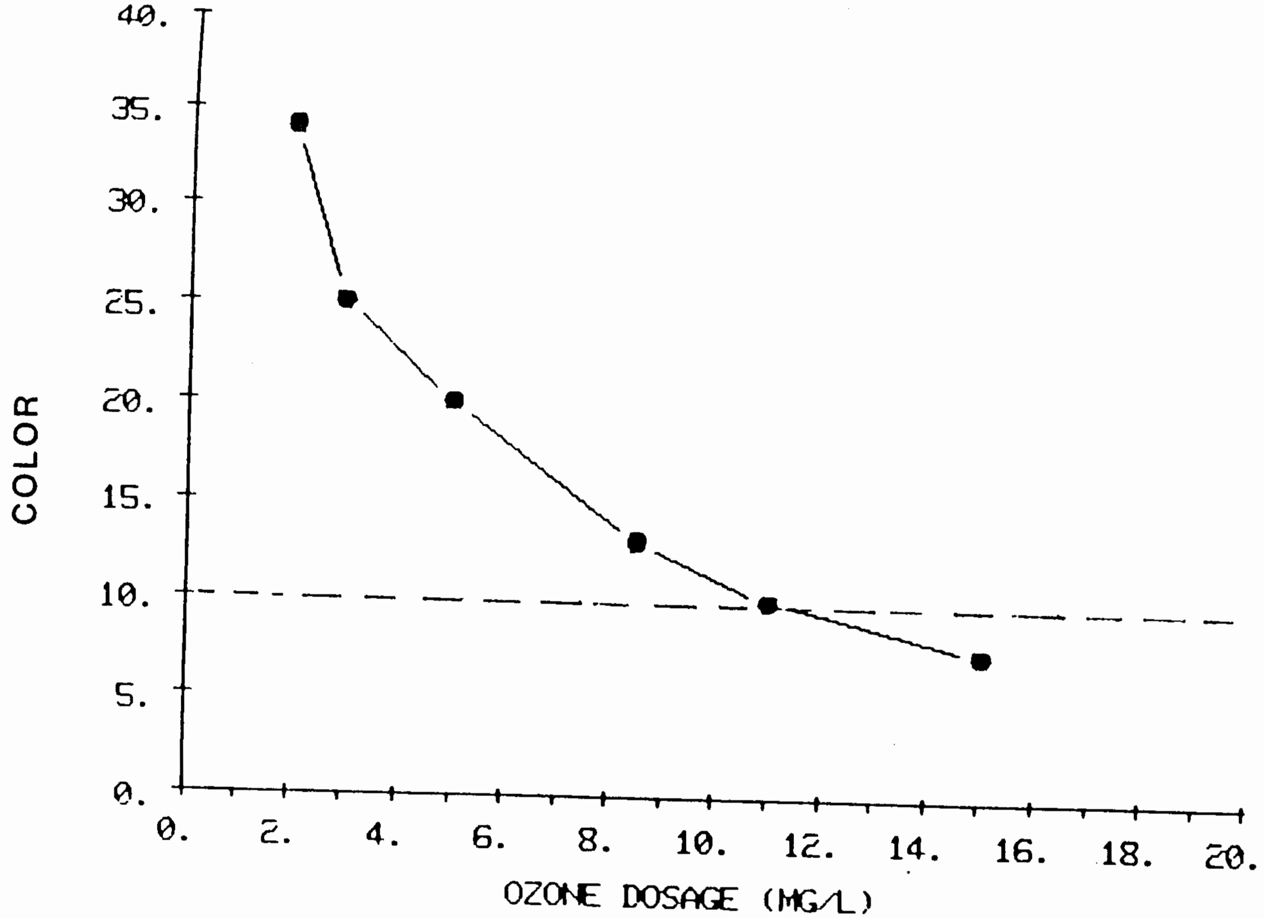

FIGURE V-38. REDUCTION OF COLOR THROUGH OZONE OXIDATION AT PEMBROKE PINES, FL
(from JMM, 1980a)

TABLE V-26

SUMMARY OF DATA ON PRECURSOR REMOVAL WITH OZONE

(Trussel and Umphres, 1978)

Location	Ozone Dose Applied		Water Quality			Maximum TTHM Reduction per cent
	Range mg/l	Optimum mg/l	TOC mg/l	pH	Alkalinity mg/l	
Owens River	1	–	1.3	8.3	116	78‡
Lake Casitas	2	–	3.5	8.1	143	6
Columbia River	0.5–4.0	2.0	2.4	8.0	82	18
Ohio River*	1.0–8.0	6.0	3.0	7.1	45	46
Ohio River†	0.7–227	227	1.5	7.0	45	43‡
Bay Bull's Big Pond	1.0–3.0	3.0	–	5.7	1.0	27
Mokelumne	2.0–6.0	2.0	2.4	9.2	20	62
Middle River	2.6–11.0	5.5	3.5	7.3	71	32
South Bay Aq. (Raw)	0–10	1.0–2.0§	5.5	7.8	80	38
South Bay Aq. (Filtered)	0–12	1.5§	3.5	8.5	80	71
Rotterdam	2–8	2.0	3.6	7.7	–	60
Orange County Well	1.0	–	3.6	8.8	250	33
Synthetic	1.2	–	0.6	7.8	–	38
Synthetic	48	–	0.6	7.8	–	31
Synthetic	1.4	–	0.6	11.3	–	−29
Synthetic	48	–	0.6	11.3	–	54
Lake Ontario	7.3	–	2.1	–	–	40
Private well	1.3	–	0.4	–	–	55
Grand River	3.8	–	5.9	–	–	38
Niagara River	1.3	–	2.27	–	–	6
Humber River	0.2	–	3.7	–	–	46
Peat Bog (Hudson Bay)	17.7	–	–	–	–	42‡
Ohio River*	0–15.6	15.6	1.5	7.0	45	79
Caddo Lake, Tex.	0–23	23	–	–	–	90
Synthetic	0–15.6	15.6	–	–	–	63

*Louisville
†Cincinnati
‡Chloroform only
§Ozone consumed

As described in the GAC section, ozone is frequently used in European plants ahead of GAC to enhance the performance of the contactors. The enhanced adsorption of GAC is attributed to two mechanisms. First, ozone provides a strong dose of dissolved oxygen to the activated carbon, thus maintaining the aerobic conditions required for sufficient biological growth. Second, ozone, an extremely strong oxidant, is believed to oxidize and modify larger biorefractory organics to produce smaller more biodegradable organics such as acetic and oxalic acids. This fragmenting of organics is also believed to facilitate diffusion of larger organics into the smaller pores of the carbon, thus aiding in mass transport.

On the other hand, as pointed out by Benedek (1979), ozonation may, in certain cases, decrease GAC performance. This is of concern especially in those cases where biological growth is relatively poor. Benedek also points out that oxidation of organics generally results in the formation of more polar molecules such as carboxylic acids, ketones, aldehydes, etc., which reduce the equilibrium adsorptive capacity. Furthermore, reactions of ozone with the activated carbon surface may reduce adsorption capacity. Thus, if significant increases in removal are not achieved by ozone assisted biodegradation, the net result of ozone addition may be minor decreases in organic removal because of the decreased adsorptivity. This may be the case when there is preclorination, insufficient nutrient supply, or lack of biodegradeable material (Culp, 1979).

The removal of specific chemicals by ozone treatment is not always feasible. Many organics such as chloroform are neither readily oxidizable by ozone nor are they biodegradable. Removal of such volatile halogenated chemicals has been attributed to the stripping action of the ozone contactor. Still, the EPA is optimistic with respect to the removal of these synthetic organic chemicals using the combination of ozone and GAC.

Chlorine Dioxide

As an oxidant, chlorine dioxide, like ozone, is ineffective for removing trihalomethanes from drinking water (Symons, 1981). Miltner (1976) demonstrated reduction in THM precursor using 2-3 mg/l applied ClO_2 in batch samples stored for 48 hours. Removals were not substantial, ranging from 30-40 percent, and removal of brominated compounds was questionable. The potential effects of higher ClO_2 doses and more realistic application configurations have not been investigated.

Organic by-products formed by chlorine dioxide oxidation of other organics are not yet well understood. Present information indicates that the reaction products would be aldehydes, carboxylic acids, ketones, and quinones. Few chlorinated by-products are known although some are likely. Because of potentially harmful inorganic byproducts, chloriate and chlorate, most European countries limit the level of chlorine dioxide which can be used in water treatment.

SUMMARY OF UNIT PROCESS COMBINATION SELECTION

This section has summarized the control and/or removal characteristics for unit treatment processes for waters containing naturally occurring TOC, THMs, and synthetic organic chemicals (SOCs). Most of the bench-scale, pilot-scale, and full-scale studies summarized in the sections above have focused on the removal of TOC, THMs, trihalomethane formation potential (THMFP), and volatile synthetic organic chemicals (VOCs). There is little information on the removal of other, non-volatile, SOCs.

The studies described in the sections above have demonstrated the feasibility of these unit processes for the removal of the range of organics commonly found to date in drinking water. Selection of a process combination to meet a specific finished water quality goal should not be based on technical feasibility alone. The capital cost and operation and maintenance cost need to be considered as well. These cost issues will be discussed in Section VII.

There are several process alternatives for the removal of TOC from surface waters. Within an existing conventional filtration process, modifications of coagulant dose, pH, and polymer dose have been shown to remove sufficient TOC so that application of free chlorine as a final disinfectant will not form unacceptable levels of THMs. Other alternatives consist of additions to a conventional filtration process. GAC, normally included following filtration, has been shown to achieve a steady-state removal of TOC after several months, most likely due to microbial degredation of natural organics within the GAC bed. The application of ozone ahead of a GAC contactor has been shown to form oxidation products of TOC which are not as readily adsorbed, but which are more biodegradeable.

For the removal of THMs, both GAC and aeration processes have been shown to be feasible alternatives. However, because of the low adsorption capacity of GAC for some of the THM species, frequent regeneration may be required. Depending on the degree of removal required, and the existing treatment facilities, different aeration processes may be feasible. For example, in a water treatment plant with an existing finished water clearwell requiring moderate degrees of removal, bubble aeration or surface aeration may be feasible. Where existing facilities do not include a finished water clearwell and/or high degrees of removal are required, packed tower aeration may be feasible.

The selection of unit processes for the removal of SOCs from ground and surface waters depends upon the physciochemical characteristics of the compounds of interest. For removal of volatile organic chemicals (VOCs), aeration processes, especially packed tower aeration where high levels of removal are required, may be feasible. GAC has been shown to remove a broad spectrum of SOCs found in drinking water. However, the low adsorption capacity of GAC for some compounds (e.g., low molecular weight, polar compounds) requires frequent regeneration.

In some situations with a wide variety or organic contaminants, a combination of GAC preceded by air stripping has been shown to be a feasible solution. That is, air stripping removes the more volatile compounds which breakthrough the GAC bed in a short time, increasing the length of operation of the GAC contactors.

These "add-on" unit processes for the removal of THMs and/or SOCs described above are normally incorporated into an existing groundwater or surface water treatment process immediately preceeding final disinfection. This allows for some degree of removal of THM precursors (as measured by TOC) and hydrophobic SOCs in upstream unit processes (e.g., coagulation/flocculation/sedimentation, PAC adsorption) as discussed in the sections above.

Final determination of feasible unit process combinations needs to be based on results of site-specific studies including bench-scale and/or pilot-scale investigations. In addition, an adequate characterization of untreated water quality is required to assess the design and operations criteria (e.g., regeneration frequency for GAC) for a full-scale facility to meet finished water quality goals.

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SECTION VI

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ALTERNATIVE DISINFECTION PROCESSES FOR WATER TREATMENT APPLICATIONS

The objective of disinfection processes is destruction or inactivation of pathogenic microorganisms, including bacteria, amoebic cysts, algae, spores, and viruses. The goal of this section is to describe commonly used disinfection processes which will maintain the microbiological quality of finished water while minimizing the formation of regulated organic compounds. Disinfectants available to meet these goals are numerous, but can generally be divided into two groups: 1) chemical agents, and 2) non-chemical agents. Chemical agents include an array of compounds with oxidation potential such as chlorine, chlorine dioxide, bromine, iodine, bromine chloride, and ozone. Non-chemical or energy related means of disinfection include ultraviolet (UV) radiation and gamma radiation.

CURRENT PRACTICE IN WATER TREATMENT DISINFECTION

Of the more than 20,000 community water systems in the U.S. which practice water disinfection, the overwhelming number currently use chlorine as the primary disinfectant. Chlorine is often applied for three purposes: 1) as a preoxidant for control of biological growth and/or oxidation of reduced compounds in the water, 2) disinfection of pathogens within the plant, 3) as residual disinfectant added at the end of the treatment process to maintain quality within the distribution system. Generally, chlorine is used as free chlorine as opposed to chlorine combined with ammonia (i.e., chloramines). Due to concern over chlorination by-products, especially THMs, use of chlorine as a pre-oxidant in treatment processes is being reduced. In addition, a number of water utilities with high organic content in their raw water have switched to chloramines for their final disinfectant in order to meet the THM standards. Currently, there are approximately 400 U.S. community water systems using chloramines.

ALTERNATIVES TO CHLORINE DISINFECTION

In the continuing search for alternatives to chlorine, the water treatment profession has evaluated a number of oxidants with a bactericide efficiency equivalent to free chlorine, given a sufficient dose of disinfectant and sufficient contact time. The feasible alternatives include chlorine dioxide, free chlorine followed by ammonia addition to form chloramines, ozone followed by a residual disinfectant such as chlorine dioxide or chloramines, and chloramines alone. Ultra-violet radiation is used in small applications in Europe; however, its application for large scale plants is limited. Selection of an appropriate alternative to chlorine will depend principally upon the raw water quality, overall oxidant demand and required efficiency of the disinfectant. Each of these water quality factors will be discussed in subsequent sections, as well as a description of principal characteristics of each disinfectant.

FACTORS GOVERNING DISINFECTION EFFECTIVENESS

Factors controlling the effectiveness of disinfection include the type and dose of disinfectant, type and concentration of microorganisms, contact time, and water quality characteristics. After selection of the disinfectant, the most common variables used to control the disinfection process in water treatment are contact time, dose, and application technique.

DISINFECTANT CHARACTERISTICS

Selection of proper disinfectant type and dose is a critical step in providing a process to meet water quality objectives. One measure of a disinfectant's ability to oxidize organic material is the standard oxidation potential, simply the negative of the reduction potential. This is an electrochemical characteristic which varies with the type of oxidant, as listed in Table VI-1.

The greater the oxidation potential, the greater the ability to oxidize organic materials. If oxidation was the only mechanism responsible for disinfection, the relative ranking of disinfectants would be ozone > chlorine dioxide > chlorine > bromine > iodine. However, the selection of a disinfectant is more complex because of other factors. For example, for a disinfectant to be effective, it needs to readily diffuse into the cell to achieve inactivation. The rate of diffusion depends upon the cell permeability and the molecular weight, size, and charge of the disinfectant. Within the halogen series, the diffusion order is iodine > bromine > chlorine, just opposite to the oxidation potentials. Thus, in most cases pilot, plant studies and operating experience is required to guide the disinfectant selection process. This is especially true for selection of the disinfectant dose, which is a function of water quality. The dose can only be determined experimentally and must be controlled to respond to fluctuating water quality conditions.

MICROORGANISM CHARACTERISTICS

Pathogens may be divided into four groups, listed in decreasing order of resistance to destruction or inactivation: (1) bacterial spores; (2) protozoan spores; (3) viruses; and (4) vegetative bacteria. Their relative resistance to disinfection can be attributed to differences in cellular structure. The resistance of the spore wall, interior chemical changes (e.g., loss of cations and storage of basic ions) and the partially dehydrated state of the spore protoplasm may be reasons for the increased resistance of spores (Chang, 1971). Similarly, the resistance of the cyst wall is a major factor in determining the cysticidal activity of disinfectants because the diffusion of the disinfectant plays an important part. The high resistance of enteric viruses is associated with their lack of enzymes or other cellular material sensitive to disinfectants. Inactivation of viruses principally involves denaturing of their protein capsid. Destruction of the metabolic systems of vegetative bacteria occurs very rapidly because respiration takes place on the surface of the cell. In addition, highly active systems in these bacteria are present very close to the cell wall.

TABLE VI-1

STANDARD POTENTIALS OF SELECTED CHEMICAL DISINFECTANTS

Compound	Formula	Potential (volts)	Assumed Reactions
Chlorine	Cl_2	1.36	$Cl_2 + 2e^- \rightleftharpoons 2Cl^-$
Bromine	Br_2	1.09	$Br_2 + 2e^- \rightleftharpoons 2Br^-$
Iodine	I_2	0.54	$I_2 + 2e^- \rightleftharpoons 2I^-$
Ozone	O_3	2.07	$O_3 + 2e^- + 2H^+ \rightleftharpoons O_2 + H_2O$
Chlorine Dioxide	ClO_2	1.91[a] 0.95[b]	$ClO_2 + 5e^- + 2H_2O \rightleftharpoons Cl^- + 4OH^-$ $ClO_2 + e^- \rightleftharpoons ClO_2^-$

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[a] Complete reaction, traditionally used to describe chlorine dioxide.
[b] Reaction that often occurs in water.

The relative susceptability of different microorganisms has been determined experimentally under various conditions. Table VI-2 lists the specific lethality coefficient for several disinfectants with respect to several species of bacteria, viruses, and cysts for 99 percent inactivation at or near pH 7.0 and 20°C (NAS, 1980). The values of the specific lethality indicate that the most effective disinfectant is ozone, followed by hypochlorous acid, chlorine dioxide, hypochlorite ion, and the chloramines. This generalization is true for most types of microorganisms. Table VI-2 also points out the enteric bacteria are easier to kill than viruses, and that cysts are particularly resistant.

TABLE VI-2

SPECIFIC LETHALITY COEFFICIENT OF ALTERNATIVE DISINFECTANTS[1]
(Adapted from NAS, 1980)

Disinfectant	E. coli bacteria	Poliovirus 1	Entamoeba histolytica cysts
O_3	2,300	920	3.1
HOCl	120	4.6	0.23
ClO_2	16	2.4	—
OCl^-	5.0	0.44	--
$NHCl_2$	0.84	0.00092	—
NH_2Cl	0.12	0.014	—

---

1 Based on 99% inactivation of microorganisms and conditions closest to pH 7.0 and 20°C. The specific lethality coefficient is represented by the variable "a" in the Chick-Watson disinfection equation (Watson, 1908):

$$\ln \left(\frac{N}{N_o}\right) = -aC^n t$$

where N = number of organisms at time t
N_o = number of oganisms at time zero
C = disinfectant concentration
n =coefficient of dilution

All other terms being equal, a higher coefficient of specific lethality indicates a more powerful disinfectant. Note that this coefficient is organism specific

CONTACT TIME

Disinfection effectiveness depends on microorganism/disinfectant contact time. As with disinfectant dose, required contact time is a function of water quality. However, contact time is less frequently used as a controlling variable, because it is usually determined by facility size and design. For this reason, the aspect of disinfection facility design is quite critical.

Empirical relationships have been developed which predict the percentage destruction of certain organisms as a function of combinations of dose and contact time (Chick, 1908; Watson, 1908; Gard, 1957; Collins and Selleck, 1972). These relationships should be carefully reviewed as part of the initial design of any potable water disinfection facilities.

WATER QUALITY CHARACTERISTICS

Water quality characteristics such as turbidity, concentration of organic compounds, pH,and temperature affect disinfectant efficiency. Turbidity has been shown to interfere with disinfection (Symons and Hoff, 1975; Hoff, 1978; Hijkal, 1979; Foster, et al, 1980; Boyce, et al, 1981; Emerson, et al, 1982), because particulates responsible for turbidity can also surround and shield microorganisms from the action of disinfectants. Organic compounds present can decrease disinfection efficiency by adhering to cell surfaces and hindering attack by the disinfectant, reacting with the disinfectant to form compounds with weaker germicidal properties, or reacting irreversibly with the disinfectant consuming the oxidation potential to produce by-products with no disinfection capabilities. Likewise, compounds such as iron, manganese, hydrogen sulfide, cyanides, and nitrites can decrease disinfection efficiency as they are rapidly oxidized by a disinfectant. This reaction of inorganic compounds with the disinfectant, such as chlorine, creates a demand which must be met before the disinfectant can act on the microorganisms.

The pH of the water can influence microbial destruction by affecting the chemical form of the disinfectant is aqueous solution. For example, the most active chlorine species for disinfection is hypochlorous acid (HOCl), which predominates in water if the pH is less than 7.6. Temperature affects the reaction rate of certain steps in the disinfection process, such as diffusion of the disinfectant through cell walls or the reaction rate with key enzymes, and can thus influence the rate of disinfection.

CHEMISTRY OF DISINFECTANTS

The reaction chemistry of the more common disinfectants used in the United States is discussed below. Of the chemical agents, the disinfectants discussed include chlorine, chloramines, chlorine dioxide, and ozone. A nonchemical disinfectant, ultraviolet radiation, is also included.

CHLORINE

Disinfection capabilities of chlorine are a function of its speciation in solution which in turn is dependent upon pH, temperature, organic content of the water, and other water quality factors. Gaseous chlorine, when added to water, rapidly hydrolyzes to hypochlorous acid (HOCl) and hydrochloric acid (HCl) as shown in equation 1:

$$Cl_2 + H_2O \rightleftharpoons HOCl + H^+ + Cl^- \qquad (1)$$

In dilute solution and at pH levels above 4, the reaction proceeds essentially to completion.

The hypochlorous acid is then subject to additional reactions which include disinfection, reaction with various organic and inorganic compounds, or dissociation to hydrogen and hypochlorite ions (OCl^-) , as below:

$$HOCl \rightleftharpoons H^+ + OCl^- \qquad (2)$$

Hypochlorous acid is weakly acidic and its acid dissociation constant K_a at 20°C is 2.611×10^{-8} moles/liter (Morris, 1966). Thus, the pH of water affects the relative amounts of HOCl and OCl^-. Figure VI-1 is a distribution diagram for the various chlorine species (Cl_2, HOCl, and OCl^-) over a broad pH range. With increasing pH between pH 6 and 9, the relative fraction of HOCl decreases, while the corresponding fraction of OCl^- increases.

The dissociation of hypochlorous acid is also temperature dependent. The effect of temperature is such that at a given pH, the fraction of HOCl will be lower at higher temperatures. A best fit empirical formula, developed by Morris (1966), is shown in equation 3:

$$pK_a = \frac{3000.00}{T} - 10.0686 + 0.0253T \qquad (3)$$

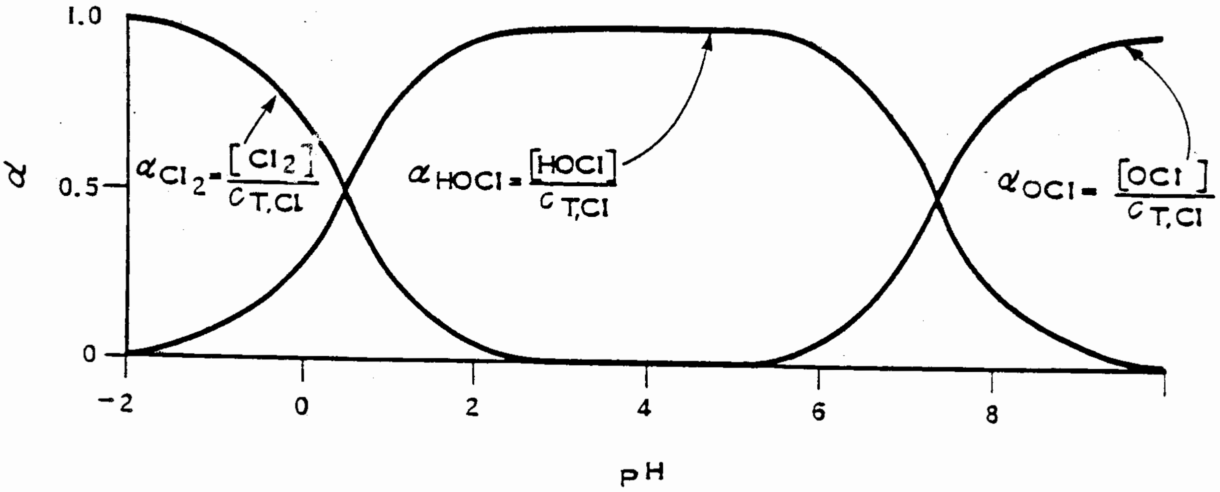
where T = temperature in °K (°C + 273).

Generally, the disinfection capabilities of hypochlorous acid are greater than hypochlorite, especially at short contact times. In Figure VI-2 the log of the bacterial survival ratio is plotted against the product of disinfectant concentration and contact time. The intersection of the two lines in the lower right hand corner of the figure suggests the equivalent efficiency of these free chlorine products at a sufficiently high value of the product of concentration and contact time.

CHLORAMINES

When chlorine (Cl_2) and ammonia (NH_3) are both present in water, they react to form several reaction products collectively known as chloramines. As opposed to the free chlorine described above, the chloramines are referred to as "combined chlorine".

The inorganic chloramines consist of three species: monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine or nitrogen trichloride (NCl_3). The species of chloramines formed as a result of the combination of chlorine and ammonia depend upon the ratio of chlorine to ammonia-nitrogen, chlorine dose, temperature, pH, and alkalinity. As higher chlorine to ammonia-nitrogen ratios



25° C, $[Cl^-] = 10^{-3}$ M, $C_{T,Cl} = [Cl_2] + [HOCl] + [OCl^-]$

FIGURE VI-1. DISTRIBUTION DIAGRAM FOR CHLORINE SPECIES
(from Snoeyink and Jenkins, 1980)

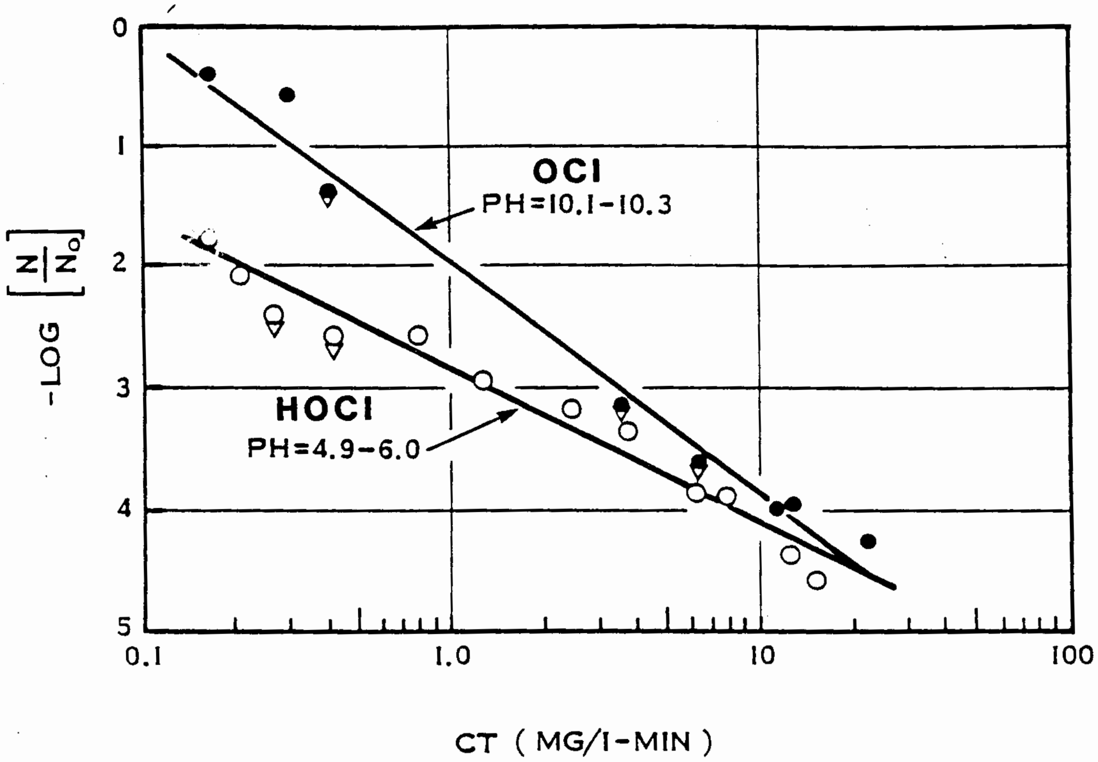


FIGURE VI-2. COMPARISON OF OCl⁻ AND HOCl DISINFECTION OF COLIFORM USING SELLECK MODEL
(From Selleck, et al, 1978)

are reached, the ammonia is eventually oxidized to nitrogen gas (N_2), a small amount of nitrate (NO_3^-), or a variety of nitrogen-containing inorganic oxidation products.

The principal reactions for the successive formation of chloramine species are shown in equations 4-6. The product in equation 4 is monochloramine, followed by dichloramine in equation 5 and trichloramine in equation 6.

$$NH_{3(aq)} + HOCl \rightleftharpoons NH_2Cl + H_2O \tag{4}$$

$$NH_2Cl + HOCl \rightleftharpoons NHCl_2 + H_2O \tag{5}$$

$$NHCl_2 + HOCl \rightleftharpoons NCl_3 + H_2O \tag{6}$$

At low pH, other reactions in the combined region are fairly significant, as shown in equations 7 and 8:

$$NH_2Cl + H^+ \rightleftharpoons NH_3Cl^+ \tag{7}$$

$$NH_3Cl^+ + NH_2Cl \rightleftharpoons NHCl_2 + NH_4^+ \tag{8}$$

At high pH, these reactions for forming dichloramine from monochloramine would not be favored.

In addition to chlorinating the ammonia, as shown above, chlorine reacts to oxidize ammonia to species which are chlorine-free products. The two most common end products of ammonia oxidation by chlorine are nitrogen gas and nitrate, as shown in oxidation-reduction (redox) equations 9 and 10, respectively. Note that the disinfectant concentrations are reduced by these reactions.

$$3Cl_2 + 2NH_3 \rightleftharpoons N_{2(g)} + 6\ HCl \tag{9}$$

$$4Cl_2 + NH_3 + 3H_2O \rightleftharpoons 8Cl^- + NO_3^- + 9H^+ \tag{10}$$

If ammonia is present, either as a natural constituent of the raw water or as an added chemical, a hump-shaped breakpoint curve similar to Figure VI-3, is produced. If inorganic chlorine demand, such as from iron or manganese, is present, the initial chlorine dose produces no residual and the residual versus dose curve would be flat until the demand is satisfied. Figure VI-3 illustrates the breakpoint curve as a function of chlorine to ammonia-nitrogen dose on a weight basis. As the chlorine dose increases (or the chlorine to ammonia-nitrogen ratio increases), the chlorine residual first rises to a maximum and then declines to a minimum.

Up to a chlorine to ammonia weight ratio of five, the predominant product formed is monochloramine. On the declining side of the hump, the monochloramine disappears by forming nitrogen gas or a trace of dichloramine. Prior to the breakpoint, the chlorine residual is a combined residual. After the breakpoint, which occurs at a chlorine to ammonia-nitrogen weight ratio of approximately 7.6, all the ammonia has been oxidized. Therefore, the residual shown in the second rising portion of the curve is free chlorine. There may also

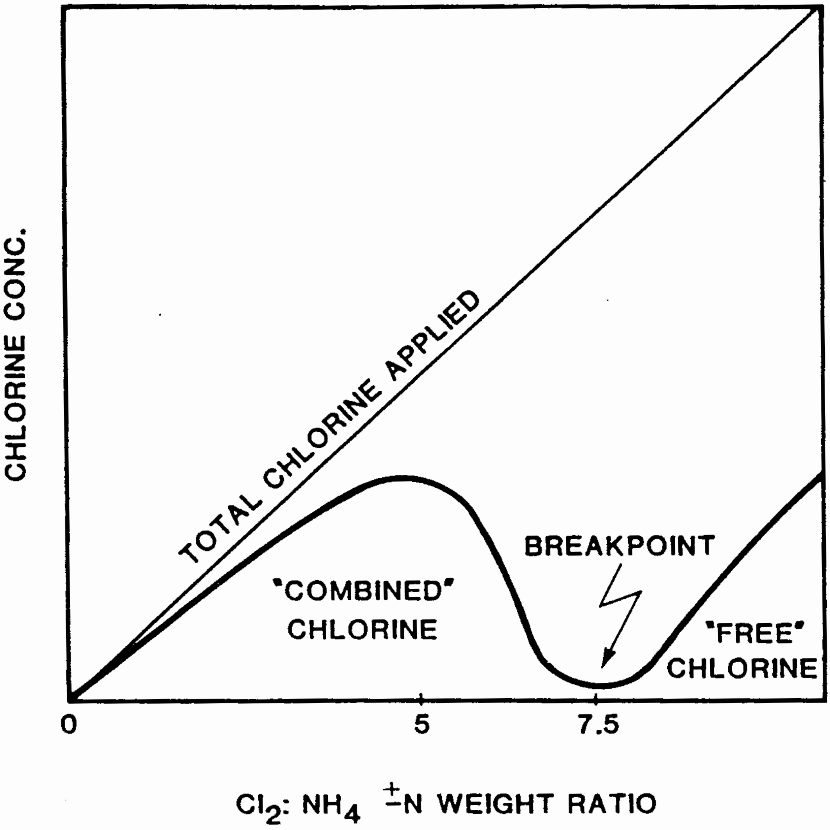


FIGURE VI-3. CHLORINE BREAKPOINT CURVE (from White, 1978) be traces of dichloramine and trichloramine as the equilibrium reactions continue.

Other reaction conditions, such as pH, are also important in determing the final end product of the chlorine reaction. Snoeyink and Jenkins (1980) describe in detail the effect of pH on the formation of monochloramine, since both reactants (ammonia and hypochlorous acid) are affected by pH. The optimum pH for forming monochloramine is around 8.4. In general, monochloramine is formed above pH 7.

The effect of pH on the formation of the various chloramine species is illustrated in Figure VI-4, after Palin (1975). With an initial ammonia-nitrogen concentration of 0.5 mg/l and one-day reaction time, Palin showed that at pH 6, both monochloramine and dichloramine were formed before the breakpoint and that trichloramine and free chlorine existed together after the breakpoint. At pH 7, the principal species before the breakpoint was monochloramine, with only a small amount of dichloramine. Trichloramine continued to exist in combination with free chlorine after the breakpoint. However, at pH 8, only a trace of dichloramine was formed prior to the breakpoint, while the remainder was monochloramine, and trichloramine was not present past the breakpoint.

CHLORINE DIOXIDE

In comparison to Europe, the use of chlorine dioxide for water disinfection in the United States has not been as wide spread. Interest in chlorine dioxide as a disinfectant has increased with evidence indicating that chlorine dioxide does not produce significant amounts of THMs as by-products from reactions with organics (Chow and Roberts, 1981; EPA, 1981).

The chemistry of chlorine dioxide (ClO_2) in water is relatively complex. In acid solution, reduction to chloride predominates:

$$ClO_2 + 5e^- + 4H^+ \rightleftharpoons Cl^- + 2H_2O \qquad (11)$$

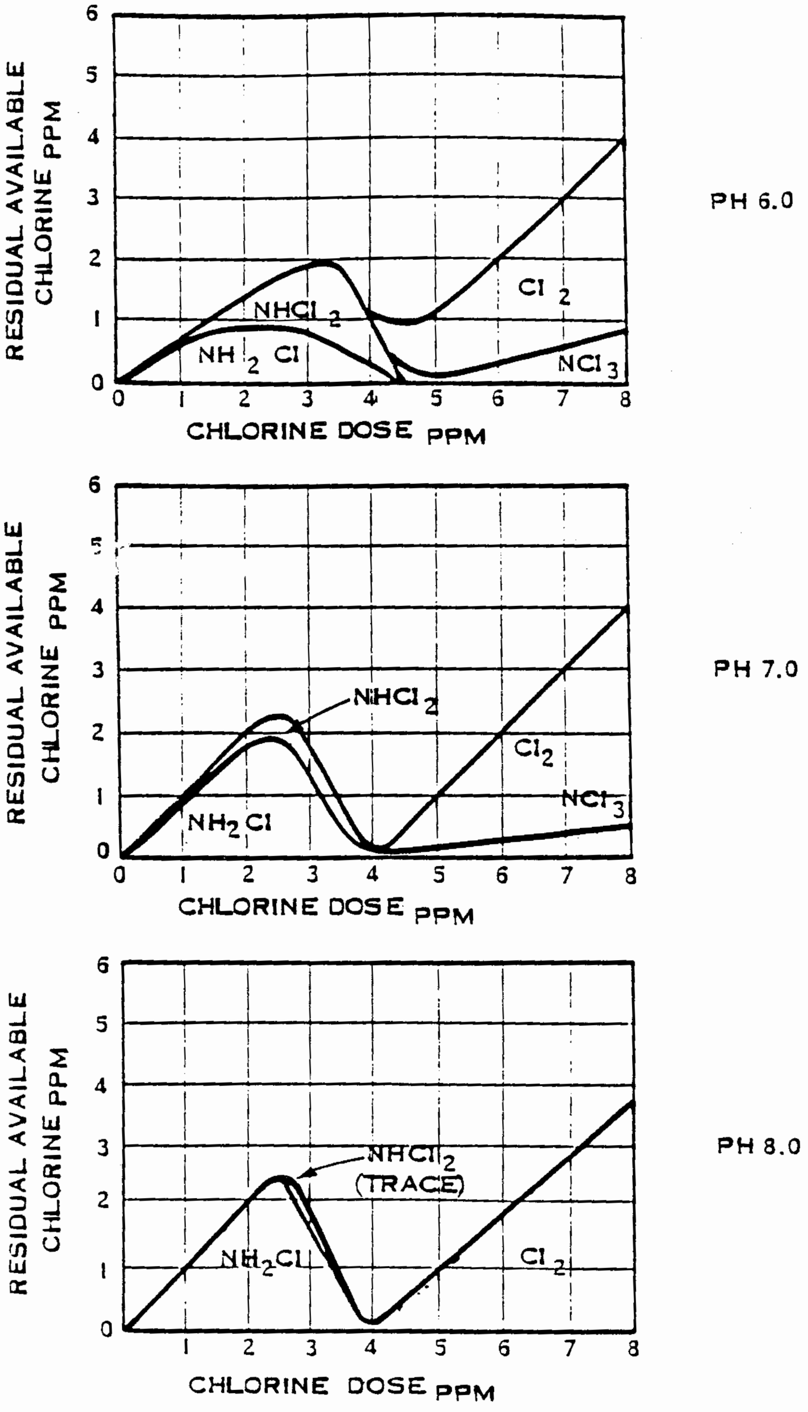
If equation 11 occurred in aqueous solutions, Table VI-1 would indicate that chlorine dioxide has about 1.4 times the oxidizing power of chlorine. However, at the relatively neutral pH found in most natural waters, it is generally accepted that the following reduction to chlorite predominates:

$$ClO_2 + e^- \rightleftharpoons ClO_2^- \qquad (12)$$

With a reduction potential of about 0.95 volts, chlorine dioxide as shown in equation 12, only has about 70 percent of the oxidizing power of chlorine.

Thus, the total oxidizing capacity of chlorine dioxide is not typically used in water treatment practices. Other aqueous reactions of chlorine dioxide and its oxidized forms are discussed by White (1972).

Chlorine dioxide, when used in water treatment applications, is almost always generated on-site directly prior to application. As a gas, chlorine dioxide is explosive at elevated temperatures, on exposure to light, or in the presence of



(AFTER 1 DAY, INITIAL NH_3 — N = 0.5 P.P.M.)

FIGURE VI-4. EFFECT OF pH ON CHLORAMINE SPECIATION (from Palin, 1975) organic substances, so it is usually never shipped in the gaseous state. Therefore, the common method for ClO_2 generation in the United States is the chlorine-chlorite ($NaClO_2$) process:

$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + NaCl \qquad (13)$$

The major drawback of this process is that the ClO_2 gas is only 60 to 70 percent pure and contains a considerable amount of chlorine. This free chlorine is then available to produce the undesirable by-products that selection of chlorine dioxide process was orginally trying to avoid.

Other processes have been developed to produce chlorine dioxide (White, 1978). A recent European system (CIFEC, France) is able to produce 95 to 98 percent pure chlorine dioxide solution through the use of an enrichment loop for the chlorine utilized (No author, 1976).

Several factors are important in the chemistry of chlorine dioxide. In contrast to chlorine, chlorine dioxide remains in molecular form as ClO_2 in the pH range typically found in natural waters, does not react with ammonia or nitrogenous compounds, and does not react with precursors to form chloroform (Roberts, et al, 1980). However, chlorine dioxide produces inorganic breakdown products in water, chlorite (ClO_2^-) and chlorate (ClO_3^-), for which the health effects are not well understood.

OZONE

Ozone is one of the most powerful oxidizing agents that has practical applications for water and wastewater treatment, as shown in Table VI-1. Ozone (O_3), an allotrope of oxygen (O_2) , is a highly reactive gas which is formed by electrical discharges in the presence of oxygen as follows:

$$3O_2 + \text{energy} \rightleftharpoons 2O_3 \qquad (14)$$

Substantial amounts of energy are required to split the stable oxygen-oxygen covalent bond to form ozone.

Ozone's high level of chemical energy is also the driving force for its decomposition. The ozone molecule readily reverts to elemental oxygen during the oxidation-reduction reaction. Hoigne and Bader (1975a, 1975b, 1976) demonstrated that the rate of O_3 decomposition is a complex function of temperature, pH, and concentration of organic solutes and inorganic constituents.

Figure VI-5 shows reaction pathways of ozone as they have been described by these authors. Once ozone enters solution, it follows two basic modes of reaction: direct oxidation which is extremely selective and often times rather slow, and auto-decomposition to the hydroxyl radical. Auto decomposition to the hydroxyl radical (OH·) is catalyzed by the presence of other hydroxyl radicals, by organic radicals, or by high concentrations of hydroxide ion. The hydroxyl radical is extremely fast and non-selective in its oxidation of organic compounds. But at the same time, the hydroxyl radical is scavenged by

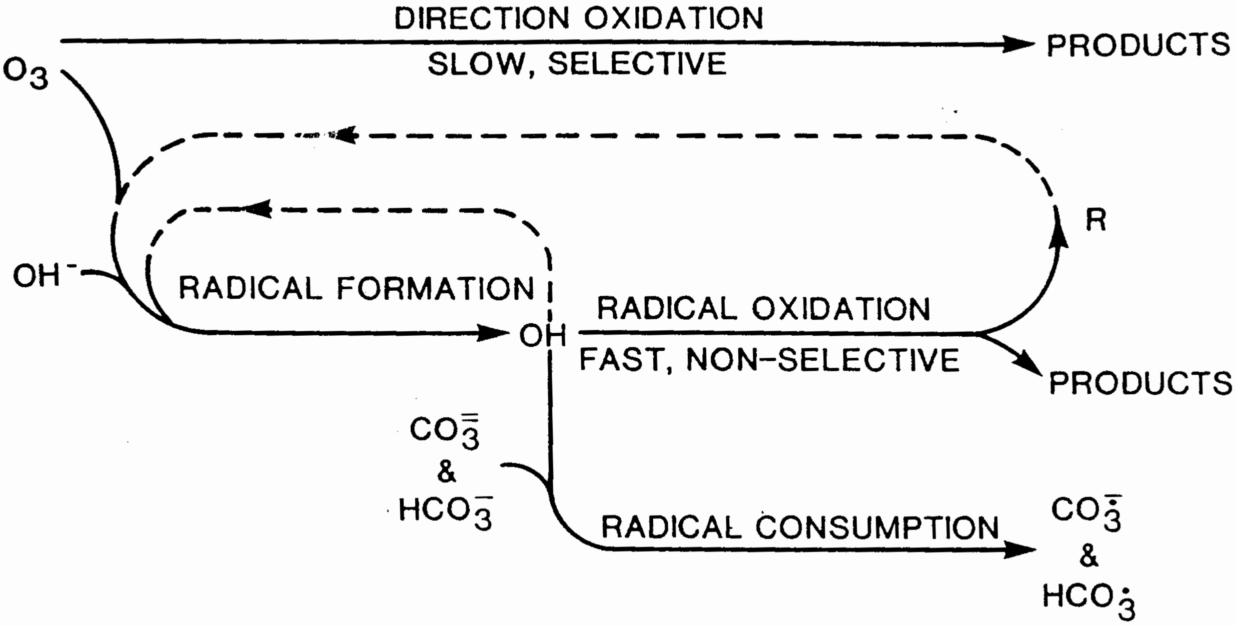


FIGURE VI-5. REACTION PATHWAYS OF OZONE
(from Hoigne and Bader, 1976)

carbonate and bicarbonate ions to form carbonate ($CO_3\cdot$) and bicarbonate ($HCO_3\cdot$) radicals. These radicals are of no consequence in organic reactions. Further, the hydroxyl radicals and organic radicals produced by the auto-decomposition become chain carriers and enter back into the auto-decomposition reaction to accelerate it. Thus, conditions of low pH favor the slow direct oxidation reactions involving O_3, and high pH conditions or high concentrations of organic matter favor the auto decomposition route. In general, better disinfection would be expected at lower pH values.

ULTRAVIOLET RADIATION

Destruction of microorganisms by ultraviolet (UV) radiation occurs when the UV energy is absorbed by the genetic material of the cells. Maximum destructive activity is assumed to occur at 265 nm which corresponds with the maximum absorption of nucleic acids (Stanier, et al, 1963). When the genetic material in the cells absorbs the UV energy, pyrimidine dimers are formed. These dimers, by causing distortions in the DNA, prevent the proper replication of the DNA strands. Under certain conditions, however, the genetic damage may be reversed. When the injured organism is exposed to visible light energy (310-500 nm), photoreactivation occurs, wherein the dimerization is reversed (Harm, 1976; Witkin, 1976; Sheible and Bassell, 1981).

Although all microorganisms are susceptible to ultraviolet radiation, the sensitivity of the organisms varies, depending on their resistance to penetration of ultraviolet energy. The chemical composition of the cell wall and its thickness determines the relative resistance of an organism. An organism's resistance is measured by the time needed to kill a certain percentage of organisms by a specific UV dose (Scheible and Bassell, 1981).

HEALTH EFFECTS OF ALTERNATIVE DISINFECTANTS

Currently, there is considerable interest in potential toxicological risks associated with disinfectants. In the search for alternatives to chlorine, efforts have focused on finding disinfectants that provide equivalent protection for approximately the same cost while reducing the quantity of by-products to an acceptable level of toxicological risk. A recent article by Bull (1982) addresses the latest information on toxicological problems associated with alternative disinfectants.

MONOCHLORAMINE (NH_2Cl)

In comparison to free chlorine- the use of chloramines as a disinfectant do not promote the formation of THMs or show an increase in TOX. This has been the main reason for the increased us of this alternative. Work on toxicological effects of other potential by-products or of monochloramine has been relatively limited. However, there is some concern over the possibility of hemolitic anemia being caused by high levels of chloramines. Monochlorine has also been shown to be mutagenic in the Ames test. Whole animal tests are currently being conducted on chloramine with the results expected in early 1985. Studies investigating the subchronic and chronic effects of chloramine on human adult males prompted the NAS to set a 7-day SNARL for chloramine of 0.125 mg/l

(NAS, 1982). However, the EPA does not consider this to be sufficient basis for regulation.

CHLORINE DIOXIDE

Chlorine dioxide is widely used as a residual disinfectant. The principal concerns with chlorine dioxide are the toxicological effects of chlorine dioxide itself and its two inorganic by-products, chlorite and chlorate.

Chlorite (ClO_2^-) has been shown to cause methemoglobinemia in some patients. The inorganic by-products of chlorine dioxide have also been shown to have anti-thyroid effects. With respect to organic by-products, chlorine dioxide has been shown not to produce trihalomethanes. The levels of total organic halogen (TOX) increase, however, following the addition of chlorine dioxide. The generation of ClO_2 often involves addition of excess Cl_2, which then reacts with organics present. Little work has been done yet on these by-products. As a consequence of the concern over the levels of inorganic by-products with the use of chlorine dioxide, EPA has recommended a total limit in the finished water of 1 mg/l chlorine dioxide, including all inorganic by-products. German practice imposes a 0.1 mg/l limit on chlorine dioxide in the finished water. Based on investigations of the subchronic and chronic effects of chlorine dioxide, and two of its by-products, chlorate and chlorite, the NAS has recommended a 7-day SNARL of 0.125 mg/l for these three compounds. (NAS, 1982). However, the EPA does not consider this study to be sufficient basis for regulation, and debate continues on the allowable levels of chlorine dioxide to be used for disinfection.

OZONE

The potential toxicological hazards associated with the use of ozone have not been extensively tested. Ozone itself has a relatively short half-life in most waters and thus is not considered a hazard. However, ozone does form some organic by-products through reaction between hydroxyradicals and the natural organic compounds present in water. Such by-products include epoxides and aldehydes. Toxicological risks associated with these compounds are unknown at this time.

In summary, research work to date indicates that all oxidants used as disinfectants have some potential toxicological hazards associated with their use. All compounds produce organic by-products, which in most cases have unknown health effects. Current data indicate that future regulations will limit the maximum allowable levels of the alternative disinfectants in water. Depending upon the raw water quality these allowable levels will determine the feasibility of the alternative disinfectants compared to chlorine. It is likely, however, that some combination of chlorine with the alternative disinfectants will provide both sufficient germicidal results. as well as minimizing the formation of undesirable by-products.

SUMMARY OF DISINFECTANT CHARACTERISTICS

Table VI-3 summarizes significant characteristics of the five disinfectants discussed. As mentioned in the section on general concepts, the selection of an appropriate disinfectant requires the weighted consideration of many factors such as germicidal efficiency, process and design characteristics, cost and health effects of disinfection by-products. According to Bull (1982), additional toxicological data are needed before specific limitations can be set on allowable concentrations of disinfectants for water treatment applications.

SELECTION OF AN ALTERNATIVE DISINFECTANT

As discussed above, the major drawback to the use of free chlorine as a drinking water disinfectant is its interaction with natural organics to form THMs in the finished water. Use of alternative disinfectants has been the preferred approach for THM control because of lower costs when compared to the two other treatment alternatives (i.e., removal of THM precursors and removal of THMs after they have been formed).

The following discussion highlights the factors which must be considered when evaluating the feasibility of alternative disinfectants for primary disinfection and residual maintenance. The ultimate treatment goal is to provide a finished water low in disinfectant by-products (e.g., THMs) while maintaining acceptable microbiological quality. Although the following paragraphs focus on the use of chloramines as an alternative disinfectant, many of the points discussed are applicable to other alternatives as well. The most important point is that a thorough understanding of current water quality conditions, with respect to both chemical and microbiological parameters, are required to evaluate the effects of alternative disinfectants.

PRIMARY DISINFECTION

As discussed above, the effectiveness of a given disinfectant depends upon the product of residual concentration and time. Given sufficient concentration-time products, chloramines can accomplsh reductions in <u>bacterial</u> populations comparable to those achievable by free chlorine. Where viruses and parasites are concerned, chloramines are less effective. However, these latter organisms are generally present at much lower concentrations and a certain amount of removal occurs in the various physiochemical processes employed in water treatment.

It is clear that chloramines can be used in some cases. For example, chloramines are clearly adequate as a primary disinfectant when the raw water supply is well protected, is treated by filtration, has total coliform level in the raw water with a median value of less than 2.2 MPN/100 ml and a 90th percentile value of less than 10/100 ml. Chloramines might even be considered for such a supply without filtration, if the turbidity were to meet drinking water standards, depending on the system's size and other factors.

TABLE VI-3

SUMMARY OF DISINFECTANT CHARACTERISTICS

Characteristics	Free Chlorine	Chloramines	Chlorine Dioxide	Ozone	Ultraviolet Radiation
DISINFECTION					
Bacteria	Excellent (as HOCl)	Moderate	Excellent	Excellent	Good
Viruses	Excellent (as HOCl)	Low (Good at long contact times)	Excellent	Excellent	Good
pH INFLUENCE	Efficiency decreases with increase in pH	Dichloramine predominates pH 5 and below; monochloramine predominates pH 7 and above. Overall relatively independent of pH.	Slightly more efficient at higher pHs	Residuals last longer at low pH	Insensitive
RESIDUAL IN DISTRIBUTION SYSTEM	yes	yes	yes	no	no
BYPRODUCTS					
THM Formation	yes	unlikely	unlikely	unlikely	unlikely
Other	Uncharacterized chlorinated and oxidized intermediates; chloramines; chlorophenols	Unknown	Chlorinated aromatic compounds; chlorate chlorite	Aldehydes; aromatic carboxylic acids; phthalates	Unknown
EXPERIENCE	Widespread use in the U.S.	Widespread use in the U.S.	Widespread in Europe; limited use in the U.S.	Widespread use in Europe and Canada; limited in the U.S.	Use limited to small systems
TYPICAL APPLIED DOSE (mg/l)	2-20	0.5-3.0	h	1-5	h
\$/lb[a]	0.07	0.16[g]	1.44[e]	0.48[c]	--
POUND EQUIVALENT WEIGHT[b]	35.5	25.8[f]	13.4[d]	24	--
COST PER POUND EQUIVALENT WEIGHT (\$/lb)	2.49	4.13	19.3	11.5	—

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[a] Effective January 1982. Does not include shipping.

[b] Weight of compound per 1 electron change in oxidation-reduction reaction, based on equations in Table 1.

[c] Assumes 12 kw-hr per lb O_3; energy cost = \$0.04 per kw-hr

[d] Assumes complete reaction: $ClO_2 + 5e^- + 2H_2O \rightarrow Cl^- + 4OH^-$

[e] Assumes 0.5 lb Cl_2 + 1.4 lb $NaClO_2 \rightarrow$ 1 lb ClO_2 + NaCl

[f] Assumes $NH_2Cl + 2e^- + H_2O \rightarrow NH_3 + Cl^- + OH^-$

[g] Assumes 1.4 lb Cl_2 + .46 lb $NH_3 \rightarrow$ 1 lb NH_2Cl

[h] Insufficient operating knowledge

Sources: Drinking Water and Health, Vol. 2 (1980), EPA (1981), Lawrence, et. al. (1980)

At the other extreme, it is probably not prudent to attempt primary disinfection with chloramines alone on a contaminated water supply having a median total coliform greater than 1,000 MPN/100 ml and a 90th percentile greater than 10,000 MPN/100 ml, even if complete treatment is provided. For such supplies, primary disinfection whould be accomplished by free chlorine, chlorine dioxide, or ozone.

For the many water suplies which fall somewhere between these extremes, no simple statements can be made about when chloramines are or are not appropriate for primary disinfection. In each of these cases, an informed judgment must be made after careful study of such factors as: raw water quality, the exposure of the supply to contamination, treatment processes provided and their performance, and an evaluation of the utility of alternative disinfectants.

The following are illustrative of the sort of information which should be gathered and evaluated in making such a decision and in an effort to develop data for before and after comparison.

1. At least one year of raw water quality monitoring data should be available. As a minimum, data should include at least 50 measurements of coliforms and turbidity. Substantial data on standard plate count, pH, and temperature are also highly desirable.

2. If an existng treatment plant is available, a study should be conducted to establish the performance of the existing process train in removing coliform and standard plate count (SPC) organisms without the aid of disinfection. Coliphage removal should be evaluated if coliform levels in the raw water are high enough to make such a measurement useful.

3. At least one year of data should be gathered on the disinfectant residuals, coliform levels, and SPC levels in the distribution system before a change in disinfectant occurs. Coliform should be monitored with the more sensitive, high volume coliform test now is use by EPA. This is more information than is required in the EPA regulation, but experince has shown that a full year of data is necessary for developing a useful comparison.

4. A sanitary survey of the water supply should be made to assess the risk of contamination from such sources as septic systems, sewage transmission lines, recreational use, and future development.

5. Simple bench-scale experiments should be conducted during each season of the year to determine the demand the water exerts for each of the alternative disinfectants that might be considered (i.e., chlorine, chlorine dioxide, ozone, and chloramines). THM formation potential should also be evaluated for each disinfectant.

6. An analysis of the overall treatment process should be conducted to determine the sort of facility that might be required for each of the major alternatives (e.g., the contact concentration-time product required to ensure adequate protection).

7. This analysis should include such issues as the size and sophistication of the utility, the age and condition of the treatment facility, and the aptitude and interest of the utility's management.

8. Consideration of the impact of blending the treated water with wate from other sources used in the system.

Only after careful consideration of all these factors can an informed judgment be made on the feasibility of chloramines or other alternatives for primary disinfection. If information gathering activities as described above do not fit into a utility's schedule for THM control implementation, a conservative approach should be taken on the use of alternative disinfectants.

RESIDUAL MAINTENANCE

Residual maintenance is the practice of maintaining a disinfectant residual in the distribution system. It is effective in protecting the finished water against aesthetic degradation in the distribution system by reducing the level of biological activity. It is also important in preventing the development of slime layers that may cause unnecessary headloss and/or corrosion problems. It is also helpful in minimizing quality degradation at dead-ends.

Residual maintenance is often cited as a means of protecting the consumer against microbiological contamination due to cross connections or other forms of contamination. It should be recognized that the degree of protection offered in these instances is minimal. Any significant level of cross contamination will consume the disinfectant residual, leaving no protection. The most positive means of preventing contamination due to cross connections is to maintain a strong positive water pressure in the distribution system at all times, to maintain an aggressive, effective cross connection control program, and to require that physical barriers such as double check valves and air gaps be provided between the distribution system and any uncontrolled situation.

Cloramine residuals are stable and long lasting and they have proven effective in controlling bacterial growth. Considering these properties and the requirements outlined above, chloramines would appear to be an entirely satisfactory alternative for maintaining a disinfectant residual in most distribution systems.

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SECTION VII

SECTION VII

PROCESS CONFIGURATIONS AND ASSOCIATED COSTS FOR THE CONTROL AND REMOVAL OF ORGANIC COMPOUNDS

Feasible process configurations to achieve desired removals of organic compounds are discussed in this section. Costs for these processes have been calculated to provide a rough comparison among the different process configurations. As discussed in Section III, MCLs have been set only for THMs, pesticides and herbicides, and several microbiological parameters in finished waters. The process configurations investigated in this section were chosen to meet current or proposed standards for organic contaminants as well as to provide adequate microbiological protection in the finished water.

Background material helpful to the understanding of process configurations discussed below were presented in Sections V and VI. The performance of individual unit processes in removing TOC, and therefore, reducing THM formation potential, and in removing synthetic organic chemicals (SOCs) were discussed in Section V. Experience gained through studies and use of these processes in both the United States and Europe was reviewed. The variety of alternative disinfectants available in the treatment of drinking water were reviewed in Section VI. Use of these alternative disinfectants where feasible is helpful in reducing the formation of THMs as compared to the use of free chlorine.

In this section, the following approach was used in preparing cost estimates for comparison of treatment alternatives. First, cost estimates were calculated using a water treatment process model developed by the EPA (1979). Average values of design criteria were used. Second, estimates were tabulated of the costs of alternative treatment processes for THM control and removal, SOC removal, and disinfection processes for ground and surface water treatment. The range of uncertainty for these estimates is on the order of ±25%. Third, three scenarios were developed to reflect a range of organic contamination problems and cost estimates were developed for several alternative treatment schemes to meet water quality goals. These costs are presented for relative comparison purposes only. More refined cost estimates can be obtained only through consideration of site specific factors.

DEVELOPMENT OF COST DATA AND DESIGN CRITERIA

A computer model developed by the EPA (1979) was used to determine costs for treatment processes applicable to groundwaters and surface waters. Relevant cost factors used as input to the model are listed in Table VII-1.

TABLE VII-1

FACTORS USED IN THE CALCULATION OF TREATMENT PROCESS COSTS

CAPITAL COST FACTORS

Engineering[1]	=	8.00%
Sitework, interface piping[1]	=	5.00%
Subsurface considerations[1]	=	1.00%
Standby power[1]	=	1.00%
Interest rate	=	12.00
Number of years	=	20.00
Land area, acres (i.e., land costs not included)	=	0.00
Land cost, $/acre	=	1.00

UNIT COST FACTORS

Electricity, $/kwh	=	0.06
Labor, $/hr	=	12.00
Diesel fuel, $/gal	=	1.180
Natural gas, $/cu ft	=	0.0710
Building energy use, kwh/sq ft/yr	=	102.6

COST INDICES (as of January 1983)

Excavation (ENR skilled labor)	=	302.8
Manufactured equipment (BLS #114)	=	306.0
Concrete (BLS #132)	=	311.7
Steel (BLS #101.3)	=	336.2
Labor (ENR Skilled Labor)	=	302.8
Pipes and valves (BLS #114.901)	=	322.7
Electical and instr (BLS #117)	=	233.0
Housing (ENR Building Cost)	=	328.7
Producer price index	=	284.2

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[1] Expressed as a percentage of construction cost

SURFACE WATER TREATMENT PROCESSES

Table VII-2 lists the unit processes included in the conventional process scheme together with pertinent design and operating criteria for the treatment of surface sources. Where applicable, design criteria specified in the New Jersey Safe Drinking Water Act were used. Design capacities considered were 1, 10 and 100 mgd. All plants were assumed to operate at 70% of the hydraulic capacity. Chemical feed systems were designed to have a capacity of twice the operating capacity. Thus, the design criteria listed in Table VII-2 represent conservative estimates.

Design criteria for additional surface water treatment processes useful for the control and removal of organic compounds are listed in Table VII-3. Pretreatment options listed include the addition of chlorine, ozone, and/or potassium permanganate. The GAC treatment option includes design criteria for influent pumping, backwash pumping and a post-GAC clearwell. Note that the configuration of GAC contactors varies among the different sized systems. To obtain a range of costs for GAC adsorption, a minimum regeneration frequency of 28 days and a maximum regeneration frequency of 168 days was assumed in order to bracket possible regeneration frequencies for TOC and/or SOC removal. For those systems producing spent carbon at a rate greater than 2,000 lbs/day, on-site regeneration using a multiple-hearth furnace was included. Aeration processes listed in Table VII-3 include diffused air and packed tower aeration. The packed tower aeration option includes influent pumping. The disinfection options listed in Table VII-3 include disinfection by chlorine, chloramines, chlorine dioxide and ozone.

GROUNDWATER TREATMENT PROCESSES

The unit processes considered for the treatment of groundwater for control and removal of organic compounds and for disinfection of the finished water were GAC adsorption, packed tower air stripping and chlorine disinfection. The design parameters for these three processes are listed in Table VII-3. Design hydraulic capacities of 0.5, 1 and 10 mgd were considered for groundwater systems.

TABLE VII-2

DESIGN CRITERIA FOR BASIC FILTRATION PLANT - 1, 10, 100 MGD DESIGN CAPACITY

1. Low Lift Pumping
   Flowrate = Q mgd (i.e., 1, 10 or 100 mgd)
   TDH = 35 ft
2. Alum Feed
   Dose = 40 mg/l
3. Lime Feed
   Dose = 20 mg/l
4. Polymer Feed
   Dose = 0.5 mg/l
5. Rapid Mix
   $G = 300 s^{-1}$
   $\bar{t} = 2$ min
6. Three-Stage Flocculation
   $G = 80/50/20 s^{-1}$
   $\bar{t} = 8/8/8$ min
7. Sedimentation Basin
   Overflow Rate = 500 gpd/ft^2
8. Sludge Pumping
9. Sludge Dewatering Lagoons
10. Dewatered Sludge Hauling
    Once/yr, 50 mile radius
11. Dual-Media Gravity Filtration
    Loading Rate = 3 gpm/ft^2
12. Hydraulic Surface Wash
    1.5 gpm for 3 min
13. Filter Backwash
    20 gpm for 10 min
14. Backwash Storage
    Sized to store backwash from 2 filters and 2 GAC contactors, where applicable
15. Washwater Return Pumping
    TDH = 20 ft
16. Post-Filter Clearwell
    $\bar{t} = 30$ min
17. Administration, Lab, and Maintenance Building

TABLE VII-3

DESIGN CRITERIA FOR ADDITIONAL SURFACE AND GROUNDWATER TREATMENT PROCESSES - 0.5, 1, 10, 100 MGD DESIGN CAPACITY

1. Pre-Chlorination
    - Dose = 5 mg/l
2. Pre-Ozonation
    - Dose = 2 mg/l
    - Contact Chamber Detention Time = 10 min
3. Potassium Permanganate Feed
    - Dose = 1 mg/l
4. GAC
    - Pumping
        - Flow = Q mgd (i.e., 0.5, 1, 10 or 100 mgd)
        - TDH = 35 ft
    - Contactors
        - EBCT = 15 min
        - Surface Loading = 5 gpm/ft^2
        - Configuration
            - Package carbon columns for 0.5 mgd system, gravity concrete contactor for 1.0 mgd system, gravity steel contactors with diameter = 30 ft for 10 and 100 mgd systems
    - Initial Carbon Charge
        - Carbon Density = 31 lb/ft^3. Purchase of two charges.
    - Backwash
        - Q = 12 gpm for 15 min
    - Regeneration Frequency
        - Minimum = 28d
        - Maximum = 168 d
    - Makeup Carbon
        - 10% loss per regeneration
    - Regeneration
        - 0.5 and 1.0 mgd systems: use a carbon service (i.e., removal and hauling of spent carbon, replacement with virgin carbon)
        - 10 and 100 mgd systems: on-site regeneration using a multiple hearth furnace. Loading rate used was 44 lb/day/ft^2 hearth area
    - Post-GAC Clearwell
        - $\bar{t}$ = 60 min
5. Diffused Air Aeration
    - $\bar{t}$ = 30 min
    - Air:water ratio = 10:1 to 20:1

TABLE VII-3 (Continued)

DESIGN CRITERIA FOR ADDITIONAL SURFACE AND GROUNDWATER TREATMENT PROCESSES - 0.5, 1, 10, 100 MGD DESIGN CAPACITY

6. Packed Tower Aeration
   - Pumping
     - Flow = Q mgd
     - TDH = 35 ft
   - Configuration
     - Height = 10 ft
     - Surface Loading = 20 gpm/ft^2
     - Air:water ratio = 30:1 to 50:1
   - Post-Aeration Clearwell
     - $\bar{t}$ = 60 min
7. Chlorine Disinfection
   - Dose = 3 mg/l
8. Chloramine Disinfection
   - Cl_2 Dose = 3 mg/l
   - NH_3 Dose = 0.5 mg/l
9. Chlorine Dioxide Disinfection
   - Dose = 1 mg/l
10. Ozone Disinfection
    - Dose = 1 mg/l
    - Contact Chamber Detention Time = 20 min

MULHEIM SURFACE WATER TREATMENT PROCESS

For comparison to surface water treatment as practiced at one location in West Germany, costs of treatment at the Mulheim Water Works were calculated using unit processes available in the EPA model. The original treatment process at Mulheim used breakpoint chlorination for high levels of ammonia found in water from the Ruhr River. The high doses of chlorine required, and subsequent formation of chlorinated organics, lead to development of the treatment process described by Sontheimer (1978) and Heilker (1979). Unit processes included in this new treatment scheme are listed in Table VII-4 together with design criteria used in calculating the cost estimates. Pre-chlorination in the original treatment process has been replaced by pre-ozonation and intermediate ozonation. Very low doses of chlorine are used as a final disinfectant. Several processes used at the Mulheim Water Works were not able to be included in the cost estimates discussed below. The Mulheim process uses a unique dual-media filter and GAC contactor configuration not available in the EPA model. Also, the coagulant used in Mulheim is polyaluminum chloride, an inorganic polymer not available in the United States. Oxygen is also fed ahead of the dual-media filter and GAC contactor to promote nitrification in the GAC contactor. Following GAC adsorption, finished water is percolated through an aquifer, which acts as a slow-sand filter, and is pumped from wells prior to chlorination and distribution. This process was also not able to be included in the cost estimates.

TABLE VII-4

DESIGN CRITERIA FOR SURFACE WATER TREATMENT AS USED AT THE MULHEIM WATERWORKS, WEST GERMANY

1. Low Lift Pumping
    Flowrate = Q mgd (i.e., 1, 10 and 100 mgd)
    TDH = 35 ft
2. Alum Feed
    Dose = 40 mg/l
3. Lime Feed
    Dose = 10 mg/l
4. Rapid Mix
    $G = 30 s^{-1}$
    $\bar{t} = 0.5$ min
5. Flocculation
    $G = 50 s^{-1}$
    $\bar{t} = 1.5$ hr
6. Sedimentation Basin
    Overflow Rate = 500 gpd/ft^2
7. Sludge Pumping
8. Sludge Dewatering Lagoons
9. Dewatered Sludge Hauling
    Once/yr, 50 mile radius
10. Intermediate Ozonation
    Dose = 3 mg/l
    Contact chamber detention time = 5 min
11. Dual-Media Gravity Filtration
    Loading Rate = 4.4 gpm/ft^2
12. Hydraulic Surface Wash
    1.5 gpm for 3 min
13. Filter Backwash
    20 gpm for 10 min
14. Backwash Storage
    Sized to store backwash from 2 filters and 2 GAC contactors
15. Washwater Return Pumping
    TDH = 20 ft
16. Post-Filter Clearwell
    $\bar{t} = 30$ min
17. GAC
    - Pumping
        Flow = Q
        TDH = 35 ft
    - Contactors
        EBCT = 15 min
        Surface loading = 6.5 gpm/ft^2
    - All other parameters as in Table VII-3

TABLE VII-4 (Continued)

DESIGN CRITERIA FOR SURFACE WATER TREATMENT AS USED AT THE MULHEIM WATERWORKS, WEST GERMANY

18. Post-GAC Clearwell
    $\bar{t}$ = 60 min
19. Chlorine Disinfection
    Dose = 0.3 mg/l
20. Administration, Lab, and Maintenance Building

FEASIBLE PROCESS COMBINATIONS FOR THE CONTROL AND REMOVAL OF THMs AND SOCs

Treatment schemes for the control and removal of THMs and SOCs are discussed below, together with their associated costs as estimated by the EPA computer model. Process schemes considered are based on existing treatment of surface and groundwaters. That is, treatment alternatives consist of modifications to existing treatment processes and/or addition of new unit processes to existing facilities. Cost estimates are presented in a manner which allows the construction of a treatment process by choosing among several feasible unit processes achieving the same goals (e.g., volatile organics removal, microbiological inactivation).

CONTROL AND REMOVAL OF THMs

The EPA has recently classified the strategies for the control and removal of THMs into several categories (EPA, 1982). The treatment strategies identified as the "best generally available" treatment methods for reducing total THMs include:

- Use of chloramines as an alternate or supplemental disinfectant or oxidant.

- Use of chlorine dioxide as an alternate or supplemental disinfectant or oxidant.

- Improved existing clarification for THM precursor reduction.

- Moving the point of chlorination to reduce total THM formation, and where necessary, substituting for the use of chlorine as a preoxidant chloramines, chloride dioxide, hydrogen peroxide, or potassium permanganate.

- Use of powdered activated carbon for THM precursor or total THM reduction, seasonally or intermittently, at dosages not to exceed 10 mg/l on an annual average basis.

Those processes categorized as "additional treatment methods" for reducing total THMs include:

- Off-line water storage for THM precursor reduction.
- Aeration for total THM reduction where geographically and environmentally appropriate.
- Introduction of clarification where not currently practiced.
- Consideration of alternative sources of raw water.
- Use of ozone as an alternate or supplemental disinfectant or oxidant.

Additional processes considered by EPA were GAC and BAC.

Because different cost factors and design assumptions were used in this study in comparison to those used in cost estimates for THM control in two EPA studies (1981, 1982b), absolute comparisons of costs among these different studies are not valid.

Modifications to existing treatment processes, such as optimizing coagulation for THM precursor removal and changing the point of chlorination, were not calculated in this study. In cases where these options are a feasible alternative, as determined by bench-scale or pilot-scale investigations, they would represent the least cost alternatives. Cost curves presented in the treatment techniques manual (EPA, 1981) show the variation in total treatment cost for a 10 mgd and 100 mgd plant over a range of doses from 2 to 60 mg/l to be less than 5¢/1,000 gal. Thus, increasing alum doses in order to achieve greater THM precursor removal would result in small cost increases. Note that this does not include any additional mechanical equipment necessary for increased quantities of sludge produced with this option. Costs presented in the EPA report (1982b) show an increase of less than 1¢/1,000 gal for modifying the point of chlorination and/or substitution of an alternative oxidant for pre-chlorination.

Additional unit processes effective in the control and removal of THMs, for which costs were calculated in this study, include GAC, ozonation, chlorine dioxide disinfection, aeration and chloramine disinfection as discussed in Sections V and VI. Costs calculated using the EPA computer model are shown in Table VII-5. The capital cost for each process is listed, together with the annual operation and maintenace cost in ¢/1,000 gal, and total cost, also in ¢/1,000 gal. Total costs are comprised of annual O&M costs and amortized capital costs using cost factors shown in Table VII-1.

The costs of a basic filtration treatment process (i.e., coagulation, flocculation, sedimentation and filtration) are also included in Table VII-5 to illustrate the relative incremental costs of alternative THM control processes. As shown in the table, alternative disinfection processes are the most cost effective, but their operational effectiveness in providing required microbiological protection needs to be evaluated on an individual case basis as discussed in Section VI. Cost estimates prepared in the two EPA reports (1981, 1982b) show a greater difference between the total costs of chloramine and chlorine dioxide disinfection than is shown in Table VII-5. In these two EPA reports, chloramines were shown to be more cost effective throughout the entire range of design capacities considered.

SOC CONTROL

The contamination of natural waters by synthetic organic chemicals (SOCs) has been observed in both surface and groundwaters. Treatment alternatives effective in the removal of SOCs consist of additions to existing treatment processes. The alternatives investigated in this study include:

- Packed tower aeration
- Diffused air aeration
- GAC adsorption

The aeration processes are most effective for the removal of volatile organic compounds. Thus, these treatment processes are most useful in the treatment of groundwaters, where volatile compounds are often found in high concentrations. Aeration processes are not as effective in the removal of non-volatile SOCs or of volatile SOCs from surface waters, because the highest concentrations of volatile SOCs in surface waters are most often found during winter months when low water and air temperatures occur. As discussed in Section V, GAC has an affinity for a broad group of organic compounds, ranging from volatile organics to higher molecular weight organic fractions. Thus, GAC adsorption is useful for the treatment of both groundwaters and surface waters.

The costs for these alternative SOC removal processes for the treatment of surface waters are presented in Table VII-5. The costs for these SOC removal processes for the treatment of groundwater are presented in Table VII-6. Note that the costs for SOC removal are more uncertain than the costs for THM control, because of the uncertainty with respect to the specific compound(s) for removal. As discussed in Section V, the type and concentration of SOCs present determine the required GAC regeneration frequency, which represents a major portion of the operation and maintenance cost. The costs shown in these two tables are accurate to ±25%. To obtain a better estimate of SOC removal treatment costs, pilot-scale testing needs to be conducted at a specific site to determine optimal design and operating criteria. Systematic water quality testing and statistical analysis of the data will also lead to estimates of SOC concentrations to be expected. This information combined with desired treatment goals, will lead to more accurate cost estimates.

TABLE VII-5

COSTS FOR SURFACE WATER TREATMENT PROCESSES

	1 mgd Design Capacity			10 mgd Design Capacity			100 mgd Design Capacity		
	Capital Cost[1]	O&M Cost[2]	Total Cost[2]	Capital Cost[1]	O&M Cost[2]	Total Cost[2]	Capital Cost[1]	O&M Cost[2]	Total Cost[2]
Basic Filtration Process	$1,784	49	142	$6,570	17	52	$39,118	13	33
Pre-Chlorine	30	2	3	94	0.6	1	439	0.5	0.7
Pre-Ozone	180	5	15	923	2	7	3,748	1	3
Potassium Permanganate	19	2	3	22	1	1	34	0.8	0.8
GAC Minimum	662	15	50	3,813	38	58	26,179	30	44
GAC Maximum	662	31	66	5,345	172	200	30,296	160	175
Diffused Aeration	264	21	34	1,574	13	21	9,416	12	17
Packed Tower Aeration	195	5	15	655	2	5	4,386	1	4
Chlorine Disinfection	27	2	3	66	0.4	0.7	344	0.3	0.5
Chloramine Disinfection	38	4	6	94	1	1	428	0.4	0.6
Chlorine Dioxide Disinfection	55	4	7	90	0.6	1	388	0.3	0.5
Ozone Disinfection	160	5	13	727	1	5	3,825	1	3

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[1] In thousands of dollars.

[2] In ¢/1,000 gals.

TABLE VII-6

COSTS FOR GROUNDWATER TREATMENT PROCESSES

	0.5 mgd Design Capacity			1.0 mgd Design Capacity			10 mgd Design Capacity		
	Capital Cost[1]	O&M Cost[2]	Total Cost[2]	Capital Cost[1]	O&M Cost[2]	Total Cost[2]	Capital Cost[1]	O&M Cost[2]	Total Cost[2]
GAC Minimum	$ 238	16	41	$ 549	16	45	$3,468	40	58
GAC Maximum	238	32	57	549	32	61	4,975	174	200
Packed Tower Aeration	78	3	11	93	6	10	241	2	3
Chlorine Disinfection	8	2	3	26	2	3	64	0.4	0.8

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[1] In thousands of dollars.
[2] In ¢/1,000 gals.

MULHEIM PROCESS

Ranges of costs for the Mulheim treatment process are shown in Table VII-7. These estimates are conservative, because several processes used in West German practice were not available in the EPA model, as discussed above. Ranges of costs are presented for the three design capacities considered due to the uncertainty in regeneration frequency for GAC adsorption. Again, there is a ±25% uncertainty assocaited with these minimum and maximum values.

TABLE VII-7

COSTS FOR MULHEIM WATERWORKS TREATMENT PROCESS

		Capital Cost[1]	O&M Cost[2]	Total Cost[2]
1 mgd Design Capacity	min	$ 2,672	66	206
	max	2,672	82	222
10 mgd Design Capacity	min	11,437	58	118
	max	12,078	63	253
100 mgd Design Capacity	min	66,153	43	78
	max	70,288	173	210

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[1] In thousands of dollars.
[2] In ¢/1,000 gallons.

EXAMPLES OF TREATMENT COST COMPARISON

Three water quality scenarios are discussed below, and the costs of feasible process schemes to meet desired water quality goals are presented.

SURFACE WATER SOURCES

Scenario 1 - High TOC

Four alternatives for the control of THM formation are listed below. The first three alternatives consider the addition of unit processes to an existing filtration process.

Alternative 1 - Chloramine Disinfection. Addition of chlorine and ammonia feeding facilities to the basic filtration costs shown in Table VII-5.

Alternative 2 - Ozone Disinfection Followed by Chloramine Addition.

Alternative 3 - GAC Adsorption and Chlorine Disinfection. For the removal of TOC, the less frequent regeneration frequency was assumed.

Alternative 4 - Mulheim Treatment Process.

Scenario 2 - Non-Volatile SOCs

For treatment of surface waters with high concentrations of non-volatile SOCs, GAC adsorption is the most effective alternative. For this application of GAC adsorption, the minimum and maximum costs presented in Table VII-5 were used.

Table VII-8 shows the range of treatment costs for design capacities of 10 and 100 mgd for these five surface water treatment alternatives. The costs shown represent the construction of an entire new treatment facility. The corresponding daily per capita cost for those alternatives shown in Table VII-8 can be found by dividing the total costs (in ¢/1000 gal) by 6.67, which assumes an average daily per capita consumption of 150 gal. As an example, for the scenario of contamination with non-volatile SOCs assuming the maximum costs (i.e., minimum regeneration frequency), the daily per capita total costs range from 28.5¢ to 47.4¢.

To illustrate costs applicable to the addition of these processes to existing filtration plants, Figures VII-1 through VII-4 show plots of the incremental capital and total costs relative to the costs of the basic filtration treatment process. The range of treatment costs, equal to ±25% of the costs listed in Table VII-5, are shown for the four alternatives described above. Costs for 10 mgd capacity are plotted in Figures VII-1 and VII-2, and costs for 100 mgd capacity are plotted in Figures VII-3 and VII-4. The figures show that the first two alternatives do not represent a substantial capital investment or increase in total costs for the removal of TOC. However, the addition of GAC roughly doubles the capital and total costs relative to the basic filtration process. As expected, economies of scale are exhibited for all four alternatives at the higher design capacity.

GROUNDWATER SOURCES

Scenario 1 - Volatile SOCs

Three alternatives were considered for the removal of volatile SOCs from groundwater.

Alternative 1 - Packed Tower Aeration and Chlorine Disinfection.

Alternative 2 - GAC Adsorption and Chlorine Disinfection.

Alternative 3 - Packed Tower Aeration, GAC Adsorption, and Chlorine Disinfection.

The ranges of costs for these three groundwater treatment alternatives are presented in Table VII-9 for design capacities of 0.5 and 1 mgd. For those

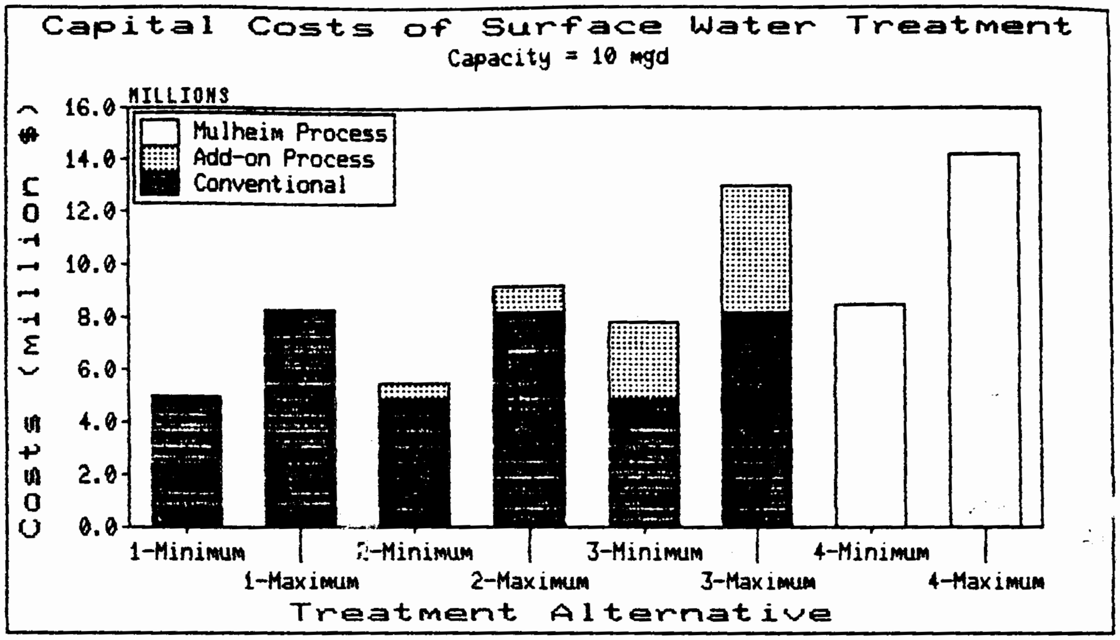

FIGURE VII-1. CAPITAL COSTS OF ALTERNATIVE SURFACE WATER TREATMENT PROCESSES FOR TOC REMOVAL AT A 10 MGD DESIGN CAPACITY

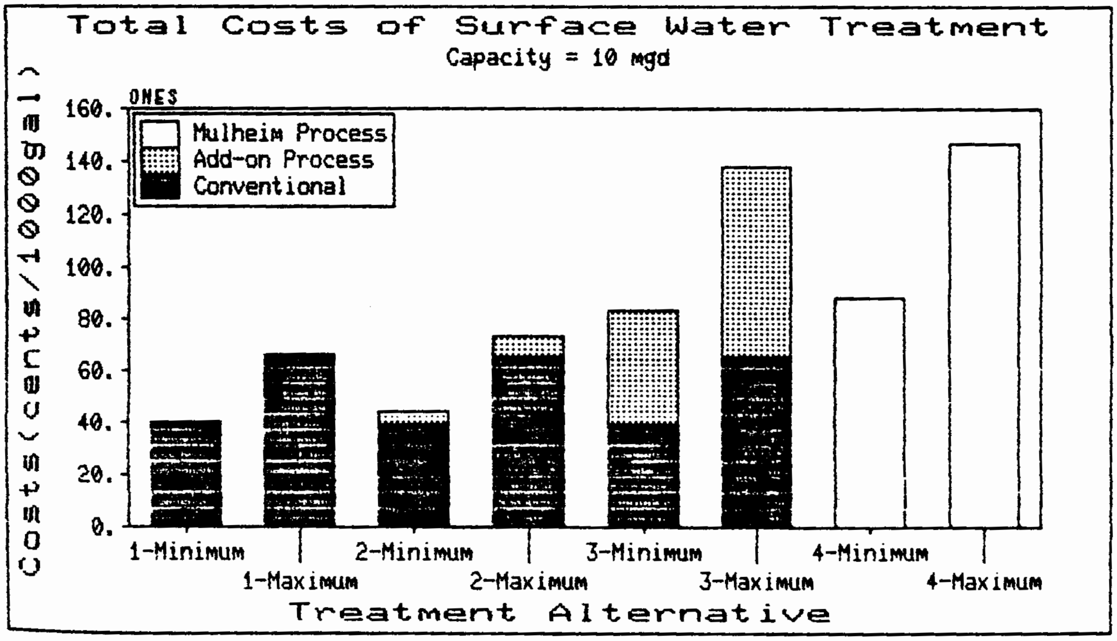

FIGURE VII-2. TOTAL COSTS OF ALTERNATIVE SURFACE WATER TREATMENT PROCESSES FOR TOC REMOVAL AT A 10 MGD DESIGN CAPACITY

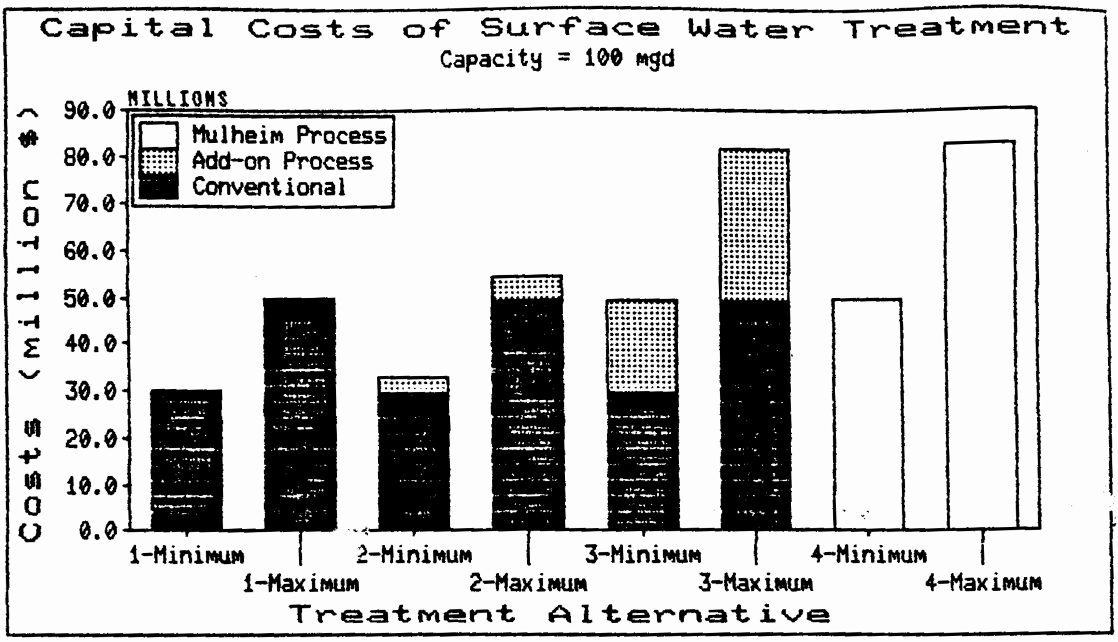

FIGURE VII-3. CAPITAL COSTS OF ALTERNATIVE SURFACE WATER TREATMENT PROCESSES FOR TOC REMOVAL AT A 100 MGD DESIGN CAPACITY

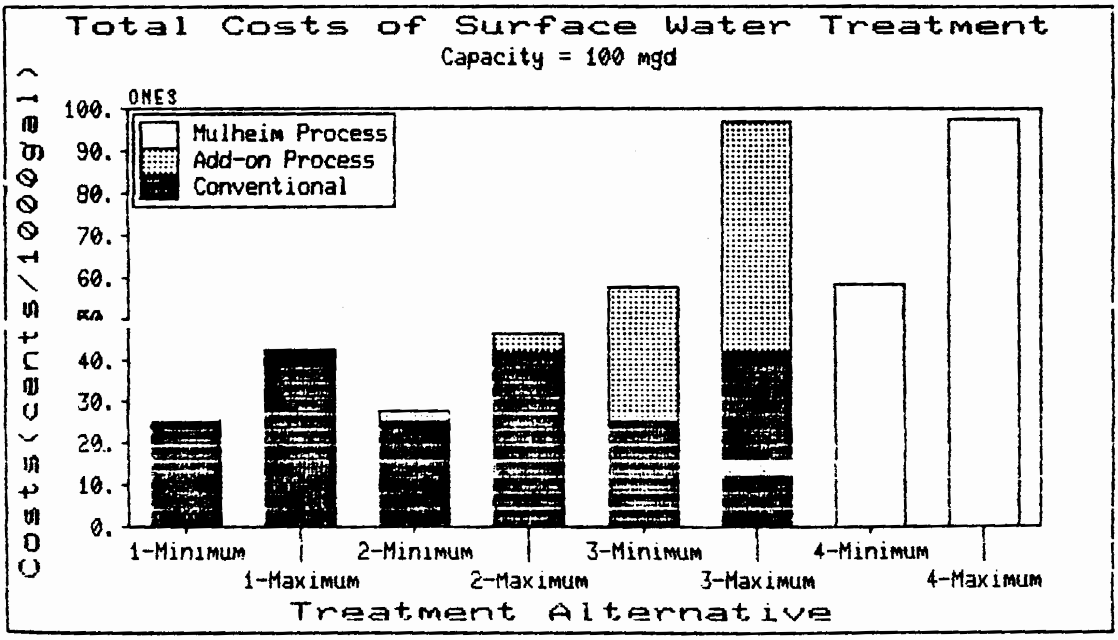

FIGURE VII-4. TOTAL COSTS OF ALTERNATIVE SURFACE WATER TREATMENT PROCESSES FOR TOC REMOVAL AT A 100 MGD DESIGN CAPACITY alternatives which include GAC adsorption, the minimum and maximum cost ranges are used.

SUMMARY OF TREATMENT COSTS

Based on current and proposed treatment goals, combinations of unit processes were selected and costs calculated using an EPA cost estimation model. The costs presented in this section are useful for relative comparisons of costs among several technically feasible treatment processes to meet the same finished water goal. More refined cost estimates to meet a given treatment goal need to be based on site-specific factors.

Three scenarios were presented in this section which reflect the possible quality of raw water from ground and surface water sources in New Jersey. The two surface water scenarios consisted of the presence of high levels of natural TOC (i.e., high THM precursor levels) and contamination with non-volatile SOCs. The groundwater scenario consisted of contamination with volatile SOCs. The ranges of capital costs and annual operation and maintenance costs reflect the uncertainty in raw water quality and design and operation parameters for this level of cost estimation. These two types of costs were combined and amortized over the life of the project to arrive at a total cost expressed in ¢/1,000 gal.

Among the three feasible alternatives for removal of high levels of TOC from surface waters and/or control of THM formation, the capital costs for the installation of GAC were shown to be the greatest. This treatment option nearly doubled the capital cost relative to a conventional filtration process. The installation of GAC for the removal of SOCs would exhibit similar capital costs.

Assuming an average daily per capita water consumption of 150 gal, per capita total costs can be calculated. The per capita total cost for the conventional filtration process for surface waters ranges from 5.9¢/day to 9.8¢/day for a 10 mgd plant. The per capita incremental total costs for unit processes to avoid formation of THMs due to high TOC levels and provide microbiological protection range from negligible, for chloramine disinfection, to between 6.6¢/day and 10.8¢/day for GAC and chlorine disinfection in a 10 mgd plant. Costs for the Mulheim treatment process are slightly higher than costs for conventional filtration plus GAC and chlorine. The per capita incremental total costs for unit processes to remove non-volatile SOCs and provide microbiological protection range from between 6.6¢/day and 10.8¢/day to between 22.7¢/day and 37.5¢/day for GAC and chlorine disinfection in a 10 mgd plant. The large range of costs are due to the uncertainty in GAC regeneration frequency, which has a strong effect on operation and maintenance costs. Corresponding costs for a 100 mgd plant, which range from between approximately 60 percent to 90 percent of the costs for a 10 mgd plant, exhibit economies of scale.

The per capita total costs for unit processes to remove volatile SOCs from groundwater and provide microbiological protection range from between 1.5¢/day and 2.4¢/day, for packed tower aeration and chlorine disinfection, to between 8.4¢/day and 14.0¢/day, for packed tower aeration, GAC, and chlorine disinfection with the more frequent regeneration frequency, for a 1 mgd plant.

TABLE VII-8

RANGE OF COSTS FOR ALTERNATIVE SURFACE WATER TREATMENT PROCESSES IN TWO SCENARIOS

	10 mgd Design Capacity			100 mgd Design Capacity		
	Capital Cost[1]	O&M Cost[2]	Total Cost[2]	Capital Cost[1]	O&M Cost[2]	Total Cost[2]
SCENARIO 1 - HIGH TOC						
Alternative 1						
Chloramine disinfection[3]	4998-8330	14-23	39-66	29660-49433	10-17	34-42
Alternative 2						
Ozone and chloramine disinfection[3]	5543-9239	14-24	44-73	32528-52214	11-18	27-46
Alternative 3						
GAC and chlorine disinfection[3,4]	7837-13061	42-69	83-138	65634-82043	32-54	58-97
Alternative 4						
Mulheim process[4]	8578-14296	44-73	89-148	49615-82691	32-54	59-98
SCENARIO 2 - NON-VOLATILE SOCs						
Alternative 1						
GAC and chlorine disinfection[3]						
Minimum	7837-13061	42-69	83-138	65634-82043	32-54	58-97
Maximum	8986-14976	142-237	190-316	52319-87198	130-216	156-261

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[1] In thousands of dollars.

[2] In ¢/1,000 gallons.

[3] Includes costs of basic filtration treatment process (i.e., coagulation, flocculation, sedimentation, and filtration).

[4] The lower estimate of GAC regeneration frequency was used for TOC removal.

TABLE VII-9

RANGE OF COSTS FOR ALTERNATIVE GROUNDWATER TREATMENT PROCESSES IN ONE SCENARIO

	0.5 mgd Design Capacity			1.0 mgd Design Capacity		
	Capital Cost[1]	O&M Cost[2]	Total Cost[2]	Capital Cost[1]	O&M Cost[2]	Total Cost[2]
SCENARIO 1 - VOLATILE SOCs						
Alternative 1						
Packed tower aeration Cl_2 disinfection	65-108	4-6	11-18	89-149	6-10	10-16
Alternative 2						
GAC and Cl_2 disinfection						
Minimum	185-308	14-23	33-55	431-719	14-23	36-60
Maximum	185-308	26-43	45-75	431-719	26-43	48-80
Alternative 3						
Packed tower aeration, GAC, and Cl_2 disinfection						
Minimum	243-405	16-26	41-69	501-835	18-30	44-73
Maximum	243-405	28-46	53-89	501-835	30-50	56-93

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[1] In thousands of dollars.
[2] In ¢/1,000 gallons.

As discussed above, a large range of costs is associated with options which include GAC due to the uncertainty in regeneration frequency. Because of economies of scale, corresponding costs for a 0.1 mgd plant will be higher.

In summary, based on the cost estimates discussed in the sections above, the total incremental costs for the control and/or removal of organics in surface and groundwaters and the provision of microbiological proction are generally less than total costs for treatment of surface waters with a conventional filtration process. Higher costs for options which include GAC will arise when frequent regeneration of GAC is required due to breakthrough of specific compounds. Site-specific studies are necessary to determine these cases and to provide a more refined cost estimate.

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APPENDIX A

TABLE A-1
PREDICTED LOW FLOWS AT USGS STATION 01377000 HACKENSACK RIVER AT RIVERVALE BASED ON PERIOD OF RECORD 1943-1981

Duration (days)	Non-Exceedence Probability (Recurrence Interval)							
	0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	24.3 cfs	20.3	14.1	9.7	7.9	6.7	5.5	4.8
3	25.0	20.9	14.6	10.0	8.2	6.9	5.7	5.0
7	27.7	22.8	15.7	10.8	8.9	7.5	6.3	5.6
14	31.5	25.9	17.8	12.2	10.0	8.5	7.1	6.3
30	41.3	33.5	22.2	14.5	11.6	9.6	7.7	6.6
60	56.7	47.1	31.4	19.6	14.9	11.7	8.7	7.1
90	64.2	53.9	37.2	24.3	19.1	15.4	12.0	10.0
120	69.8	59.9	43.0	29.3	23.4	19.2	15.2	12.9
183	83.7	72.7	54.5	37.2	30.1	24.9	19.9	17.0
365	123.3	110.3	87.8	68.5	59.7	53.0	46.1	41.9

TABLE A-2
PREDICTED LOW FLOWS AT USGS STATION 01379500
PASSAIC RIVER NEAR CHATHAM
BASED ON PERIOD OF RECORD 1904-1981

Duration (days)	Non-Exceedence Probability (Recurrence Interval) 0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	19.9 cfs	14.8	8.2	4.4	3.1	2.3	1.6	1.3
3	21.2	15.8	8.7	4.6	3.2	2.4	1.7	1.3
7	23.4	17.5	9.7	5.1	3.6	2.7	1.9	1.5
14	26.7	20.0	11.2	5.9	4.2	3.1	2.2	1.8
30	36.8	27.0	14.9	8.1	5.9	4.5	3.3	2.7
60	62.1	44.2	23.5	12.8	9.5	7.4	5.6	4.7
90	90.4	62.7	31.8	16.6	11.9	9.2	6.8	5.6
120	115.1	80.8	41.4	21.5	15.4	11.6	8.5	6.9
183	172.6	128.0	68.8	34.6	23.5	16.9	11.4	8.7
365	248.5	217.7	165.5	122.2	103.1	89.0	74.9	66.5

TABLE A-3
PREDICTED LOW FLOWS AT USGS STATION 01391500
SADDLE RIVER AT LODI
BASED ON PERIOD OF RECORD 1925-1981

Duration (days)	Non-Exceedence Probability (Recurrence Interval)							
	0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	31.6 cfs	27.2	19.4	12.9	10.1	8.2	6.3	5.3
3	33.2	28.2	20.3	14.2	11.6	9.8	8.0	7.0
7	35.7	30.1	21.7	15.6	13.0	11.3	9.5	8.5
14	40.2	33.7	24.0	17.0	14.3	12.3	10.4	9.3
30	47.9	39.9	28.2	19.8	16.4	14.1	11.8	10.5
60	60.9	50.2	34.5	23.6	19.3	16.3	13.5	11.9
90	70.7	58.0	39.9	27.7	22.9	19.7	16.5	14.8
120	79.1	65.2	45.2	31.5	26.2	22.5	18.9	16.9
183	100.1	82.4	57.0	39.6	32.8	28.0	23.5	21.0
365	134.8	120.1	95.9	76.1	67.2	60.6	53.8	49.7

TABLE A-4
PREDICTED LOW FLOWS AT USGS STATION 01394500 RAHWAY RIVER NEAR SPRINGFIELD BASED ON PERIOD OF RECORD 1940-1981

Duration (days)	Non-Exceedence Probability (Recurrence Interval)							
	0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	4.0 cfs	3.2	2.0	1.1	0.8	0.6	0.4	0.3
3	4.2	3.4	2.2	1.3	0.9	0.7	0.5	0.4
7	4.6	3.8	2.4	1.5	1.1	0.9	0.7	0.5
14	5.5	4.5	3.0	1.9	1.5	1.2	0.9	0.8
30	8.2	6.7	4.5	2.9	2.3	1.9	1.4	1.2
60	12.7	10.1	6.5	4.2	3.3	2.7	2.2	1.9
90	17.4	13.3	8.4	5.6	4.6	4.0	3.4	3.1
120	21.0	16.7	10.8	7.0	5.5	4.6	3.7	3.2
183	29.2	23.3	15.0	9.7	7.7	6.3	5.1	4.4
365	42.3	36.4	26.9	19.5	16.4	14.2	12.0	10.7

TABLE A-5
PREDICTED LOW FLOWS AT USGS STATION 01395000
RAHWAY RIVER AT RAHWAY
BASED ON PERIOD OF RECORD 1923-1981

Duration (days)	Non-Exceedence Probability (Recurrence Interval) 0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	7.7 cfs	4.5	1.4	0.4	0.2	0.1	0.04	0.03
3	8.8	5.4	1.9	0.6	0.3	0.2	0.08	0.05
7	10.3	6.7	2.3	0.5	0.2	0.1	0.04	0.02
14	11.5	8.2	3.5	1.1	0.5	0.3	0.1	0.1
30	15.4	12.6	6.9	2.6	1.3	0.7	0.3	0.2
60	21.9	18.5	11.4	5.3	3.1	1.9	1.0	0.6
90	29.3	22.9	13.8	7.9	5.8	4.4	3.2	2.6
100	34.9	28.0	17.5	10.2	7.5	5.8	4.2	3.4
183	48.9	38.5	23.9	14.5	11.0	8.8	6.7	5.6
365	69.2	60.3	45.2	32.6	27.1	23.1	19.1	16.8

TABLE A-6
PREDICTED LOW FLOWS AT USGS STATION 01407705
SHARK RIVER NEAR NEPTUNE CITY
BASED ON PERIOD OF RECORD 1968-1981

Duration (days)	Non-Exceedence Probability (Recurrence Interval)							
	0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	2.7 cfs	2.4	1.8	1.2	1.0	0.8	0.6	0.5
3	2.9	2.6	2.0	1.5	1.2	1.1	0.9	0.8
7	3.6	3.2	2.5	2.0	1.8	1.6	1.4	1.3
14	4.4	3.8	3.0	2.3	2.0	1.9	1.7	1.5
30	5.9	4.7	3.5	2.9	2.7	2.6	2.6	2.6
60	9.1	7.1	4.9	3.8	3.4	3.2	3.1	3.0
90	11.7	9.3	6.4	4.7	4.2	3.8	3.5	3.3
120	13.2	10.5	7.4	5.7	5.1	4.8	4.5	4.3
183	15.7	12.8	9.1	6.9	6.0	5.5	5.0	4.7
365	20.6	18.3	14.6	11.6	10.2	9.2	8.2	7.5

TABLE A-7
PREDICTED LOW FLOWS AT USGS STATION 01463500 DELAWARE RIVER AT TRENTON, NEW JERSEY BASED ON PERIOD OF RECORD 1914-1982

Duration (days)	Non-Exceedence Probability (Recurrence Interval)							
	0.90 (1.11 yr)	0.80 (1.25)	0.50 (2.0)	0.20 (5)	0.10 (10)	0.05 (20)	0.02 (50)	0.01 (100)
1	3517 cfs	2985	2204	1648	1423	1264	1109	1019
3	3755	3177	2332	1736	1495	1325	1161	1064
7	4000	3384	2482	1841	1583	1400	1222	1118
14	4326	3625	2624	1936	1664	1474	1291	1185
30	4868	4060	2910	2126	1817	1602	1397	1277
60	5966	4843	3352	2413	2063	1826	1605	1479
90	6894	5593	3833	2701	2274	1984	1712	1556
100	8047	6517	4421	3058	2542	2190	1860	1673
183	10188	8481	5920	4086	3350	2837	2346	2064
365	15421	14093	11563	9158	7988	7079	6125	5533