New Jersey Department of Environmental Protection
Division of Water Resources

FINAL REPORT

New Jersey Special Water Treatment Study
Phase II

May 1988

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Edison, New Jersey

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September 25, 1989

Mr. Steve Nieswand
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Subject: Special Water Treatment Study - Phase II
Revised Final Report

Dear Mr. Nieswand:

We are pleased to submit the attached camera-ready copy of the revised Final Report for the above referenced project. Your new version of appendix B and other minor adjustments have been inserted and correction of typographical errors have been made to the version submitted May 1, 1988. This report, together with the other task reports delivered to you (listed in Appendix G), fulfills the contractual requirements of Contract S85117 between Camp Dresser & McKee Inc. and the New Jersey Department of Environmental Protection dated June 18, 1985.

The state has taken bold steps to ensure safe drinking water is provided to New Jersey residents. The commissioning of this study is, in part, evidence of the State's commitment to move ahead in its quest to develop the necessary technical information and guidance to make informed decisions regarding the evolution of the regulation of chemicals in drinking water. This effort has helped put the State in a position of national leadership for the control of contaminants in drinking water.

The report was prepared under my direction by Gary R. Kroll, P.E. Project Manager, and Bruce R. Roberts, Project Engineer.

Thank you again for this opportunity to serve you. We look forward to the opportunity to work with you and your staff again.

Very truly yours,

CAMP DRESSER & McKEE INC.

Steve Medlar

Steven J. Medlar, P.E.
Senior Vice President
Project Director

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The preparation of the Special Water Treatment Study - Phase II was performed by Camp Dresser & McKee Inc. under the direction of Mr. Steven J. Medlar, P.E., Project Director with the assistance of Mr. Gary R. Kroll, P.E., Project Manager and Mr. Bruce R. Roberts, Project Engineer.

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Executive Summary

EXECUTIVE SUMMARY

SPECIAL WATER TREATMENT STUDY - PHASE II

The presence of low levels of suspected cancer-causing chemicals in some drinking water supplies has been recognized since the 1970's. Many of these substances -- organic chemicals of manmade origin -- are widely used throughout the nation. This widespread use, complicated by sometimes inappropriate handling and disposal, has resulted in contamination of many drinking water supplies.

The federal government and many states have now begun to define the extent of the contamination, to regulate use of these chemicals, and to define the technologies needed to remediate the contamination. The State of New Jersey is at the forefront of this effort. This study -- the Special Water Treatment Study - Phase II -- represents a major step in assuring clean drinking water supplies for all New Jersey residents. This study provides technical guidance needed to evaluate, test, and treat water supplies contaminated with organic chemicals.

> **<u>Chapter 1: Introduction</u>. Chapter 1 reviews the background of recent water supply planning in the state, with particular emphasis on the genesis of this study. The findings of past work described in the Special Water Treatment Study - Phase I are reviewed in light of the Phase II study. The State and federal laws and regulations pertaining to the control of volatile organics in drinking water supplies are summarized. New Jersey Assembly Bill A-280 amends the New Jersey Safe Drinking Water Act and sets forth initiatives to sample and set standards for organic and carcinogenic compounds.**

New Jersey is among the first states to attempt to deal with contaminants in water supplies on a wide-scale basis, anticipating even federal initiatives in this area. The framework for the current study is New Jersey Assembly Bill A-280 (A-280), which amends portions of the New Jersey Safe Drinking Water Act (NJSDWA) and sets forth initiatives to evaluate the occurrence of 22 organic compounds (A-280 compounds) in drinking water and to establish maximum contaminant levels (MCL) for these compounds.

This study is intended to assist the New Jersey Department of Environmental Protection (NJDEP) in addressing this legislative mandate. The study provides information which NJDEP can use to consider the technological feasibility of treatment to remove the A-280 compounds, and in providing technical assistance, when necessary, to protect the purity of the state's drinking water.

The Special Water Treatment Study - Phase I reviewed in-stream and treatment plant water quality data from 25 of the largest water purveyors in the state. The study reviewed the technologies available for removal of organic contaminants from drinking water supplies, and the regulations in effect as of 1983 applying to organic contaminants.

The overall goal of the Phase II study is to enhance the New Jersey water industry's understanding of the nature of volatile organics in drinking water. The study's objectives are to:

Establish the extent of volatile organics in New Jersey's potable water supplies

Review the regulatory framework

Assess leading treatment technology

Review alternative treatment technologies

Develop planning level costs

Examine the feasibility of using surrogate parameters to lower the cost of monitoring

Provide guidance on water treatment plant sampling programs

Assess the fate of volatile A-280 organics in traditional water treatment plants by conducting plant sampling programs

Design additional water treatment plant sampling programs

Identify a nonpublic water supply strategy

Perform a literature review of biological monitoring techniques

Provide technical guidance

Chapter 2: Nature and Occurrence of Organic Contaminants. A review of the relative occurrence of A-280 organics in both surface and ground water supplies introduces this chapter. The nature of these contaminants from health, physical-chemical, and relative treatability perspectives is summarized. Low-level occurrence of A-280 compounds in water supplies is a relatively common occurrence in New Jersey in both surface and ground waters. Almost all of the drinking water supplies are at some degree of risk of contamination from volatile or synthetic organics.

A great deal of data on New Jersey water quality has been collected and organized into a comprehensive database as part of this study. Review of the database helped to identify data gaps and deficiencies and to make recommendations to address them (see Chapter 8: Future Needs).

Several special studies related to water quality were also reviewed to assess whether they contained useful organic analysis results. The result of these extensive data searches was a comprehensive water quality database consisting of five volumes of computer printouts totaling over 1,500 pages.

Occurrence of Organics. Volatile and synthetic organics in drinking water supplies are of particular concern in New Jersey, where high population densities and high levels of industrial and commercial activity have historically provided greater opportunity for these compounds to enter the water supply.

Contamination is evident in New Jersey in both public and nonpublic water systems. There are approximately 630 public water systems in the state. An overwhelming majority of New Jersey's inhabitants are served by public water systems.

Incidence of Organics. As a result of the A-280 law, the State of New Jersey initiated a comprehensive testing program to ascertain the occurrence of certain volatile organic compounds in finished water supplies. The database developed as part of this study contains information pertaining to all of the A-280 samples plus many additional volatile organics samples taken at water supply facilities throughout the state.

This database and the sampling work performed at selected water treatment facilities in connection with this study appears to confirm the relative pervasiveness of A-280 type compounds in New Jersey water supplies.

Types of Organics. Volatile organics, as the contaminants of concern are generally called, are a group of compounds of generally low molecular weight, carbon-based, and of synthetic (man-made) origin. They are referred to as "volatile" because of the relative ease with which they evaporate when found in pure form.

The volatile organic compounds on the A-280 list include:

Trichloroethylene
Tetrachloroethylene
Carbon tetrachloride
1,1,1-Trichloroethane
1,2-Dichloroethane
Vinyl chloride
Methylene chloride
Benzene
Dichlorobenzenes
1,1-Dichloroethylene
trans-1,2-dichloroethylene
cis-1,2-Dichloroethylene
n-Hexane
Methyl ethyl ketone
Chlorobenzene
Trichlorobenzene
Formaldehyde

Contaminants that are listed in the A-280 law, but are not considered volatile, include:

Polychlorinated biphenyls (PCB)
Chlordane
Ethylene glycol

In addition, kerosene is listed in the A-280 law, but is not a pure compound. It is a mixture of compounds, some volatile and some not volatile.

Health Effects. Concerns about the health effects of A-280 contaminants focus on their potential as carcinogens. The A-280 law defines a drinking water source to be safe if the risk of contracting cancer is less than 1 in

1,000,000 over a 70-year lifetime, assuming a consumption of 2 liters of water per day. NJDEP has classified the A-280 compounds into three general health categories:

Group A - Known or probable human carcinogens
Group B - Possible human carcinogens
Group C - Insufficient or negative data available on human carcinogenicity

Treatment Technology Application. Some contaminants are more easily removed from water than others, even when the same process is used. In addition, the relative treatability of a contaminant is a function of the treatment objective, i.e., the maximum concentration that is allowed by regulation. All other factors being equal, the lower the treatment objective, the more difficult the compound is to treat. Given the very low allowable concentrations contemplated for some of the A-280 organics, and the relative pervasiveness of these compounds, the extent of treatment that could be required throughout the state may be substantial.

Based on the water quality data base compiled as part of this study, it is evident that low-level occurrence of A-280 compounds in water supplies is a relatively common occurrence in New Jersey in both ground and surface waters. Almost all of the drinking water supplies of the state are at some risk of contamination from synthetic and/or volatile organics.

Chapter 3: Fate of Volatile A-280 Organics in Traditional Water Treatment Plants: Sampling Methodology and Results. A more thorough understanding of the fate of A-280 organics in typical water treatment processes has resulted from the sampling programs carried out under the Phase II study. This sampling work also provides some insight into the generation and removal of trihalomethanes in the treatment process. Volatile organics are not remved uniformly in conventional plants with ground or surface water supplies. Precursors for THM's are removed consistently in surface water plants. Chlorination generates measurable levels of THM's in the conventional treatment plant.

This chapter summarizes the results of sampling at five New Jersey water treatment plants, and describes a sampling methodology that will be helpful to water purveyors in meeting future requirements for removal of A-280 organics. Because water purveyors will also have to meet future, more stringent regulation of trihalomethanes (THM), this chapter is also provides information on formation and removal in water treatment plants.

Sampling Programs. Sampling programs were designed for a total of eleven water treatment plants, but sampling was actually performed at only five plants -- two surface water treatment plants and three ground water treatment plants. The plants at which sampling programs were carried out did not undertake any modifications or make special provisions for the removal of volatile or synthetic organics. Consequently, any removal of volatile or synthetic organics from, or generation within, the treatment process would be incidental to the treatment process.

The data generated under the sampling program was reviewed for confirmation of expected removals of volatile organics. At the surface water plants sampled, the following volatile compounds were observed at concentrations above detectable levels in the raw water:

Dichlorodifluoromethane
1,1,1-Trichloroethane
Trichloroethylene
trans-1,2-Dichloroethylene
Trichlorofluoromethane

In addition, there is evidence of methylene chloride and trihalomethanes in the raw water.

The volatile compounds found at the ground water purveyors sampled include:

1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
Methylene chloride
Tetrachloroethylene
trans-1,2-Dichloroethylene
Trichloroethylene
Chlorobenzene
Chloroform
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Nitrobenzene

Of these contaminants, trichloroethylene occurred most often and at the highest concentrations.

The most notable aspect of volatile organic generation and removal at surface water treatment plants is the effect chlorination has on the generation of chlorination by-products, particularly trihalomethanes. In addition, some incidental removal of the synthetic volatile organics was evident through the treatment process.

Trihalomethanes were generally not detected in the treatment process train, except following chlorination. The sampling data confirmed the general approach to THM control that has been taken by many water purveyors: relocating the point of predisinfection from the plant intake to the point immediately following sedimentation, and then adding post-disinfection chlorine at a point of lowered trihalomethane formation potential.

Detailed and specific analytical results of the sampling program are not included in this report. Analytical results are summarized at the end of chapter 3. Laboratory results are included in the task reports on file at NJDEP. Based on the sampling data generated by this study, the following observations can be made:

- All plants sampled, regardless of time of year or weather conditions, showed evidence of volatile A-280 compounds.
- The raw water concentrations of volatile A-280 compounds in surface water supplies is relatively variable and is dependent on the time of the day and the season.
- The raw water concentrations of A-280 compounds in ground water are not as variable -- seasonally or based on time of day -- as in surface water.
- Without deliberate application of an aeration process, it appears that high removals of volatile organics cannot be achieved.
- Trihalomethanes and their precursors were lowest in the winter, moderate during the summer, and highest following a fall storm.
- Trihalomethane precursors were found to be reduced in concentration by nearly all unit processes.

- The most significant reductions in trihalomethane precursors were generally found earlier in the treatment system where the major removal of organic solids and other dissolved and suspended materials occurred.

Sampling Methodology. It is crucial to schedule the taking of samples so that all samples are taken from the same slug of water as it enters and exits each treatment process. This method of sampling minimizes the effects of variable water quality on the measured performance of the unit processes.

To determine detention times, complete mixing and plug flow through a particular process was assumed. For processes that deviate from plug flow, the use of composite samples at the inlet and/or outlet of the unit process was considered. (It may also be appropriate with such processes to use a detention time longer than the theoretical plug flow detention time.) The longer the detention time, the more advisable the use of composite sampling. A typical composite sampling scenario would be to take three samples at 15-minute intervals for a total of one-half hour. For most analytical parameters, composite samples can be made up in the field.

Before samples are taken, a detailed sampling schedule should be prepared. The schedules should identify all the chemical parameters to be analyzed for the selected sampling points within the plant, and the type of sample to be taken (grab sample, field composite sample, or lab composite sample).

A major concern during sampling is the safety of individuals. Special care should be taken when working near potentially hazardous mechanical equipment such as pumps and treatment chemicals such as chlorine. All sampling personnel should be properly warned and trained.

Selection of Sampling Points. Optimum sampling points for evaluating process effectiveness in removing organic contaminants, and for identifying locations where organics are generated, are as follows:

- Raw water sampling prior to fine screening by traveling screens, to establish what is coming into the plant

- Raw water sampling following the traveling screens, to determine how much of the volatile organics are removed by the traveling screens

- Treated water sampling after addition and mixing of pretreatment chemicals, to determine changes in chemical quality of the raw water, particularly formation of THMs due to prechlorination

- Settled water sampling after flocculation/sedimentation, to detect any removal of organic precursors (which generate THMs due to chlorination) and organic compounds associated with the flocs and colloidal substances

- Filtered water sampling at the filter effluent line, to measure removal of organic compounds that may be attached or adsorbed to the suspended solids removed by the filter media

- Post-chlorinated water sampling after addition and mixing of chlorine with treated water and after sufficient detention to allow formation of THMs (when dissolved organics react with chlorine), to measure THM formation

- Aerated water sampling following the aerators, to determine removal of any portion of the volatile organic compounds present in the water

- Water sampling following granular activated carbon (GAC) filtration, to determine removal of organic compounds and reduction of contaminant peaks

- Adsorbed water sampling following addition of powdered activated carbon (PAC) and after the removal of the PAC containing organic contaminants, either by settling or by filtration, to measure reduction of organic compounds

Sampling at the above locations in a treatment plant will generally provide sufficient entry and exit data for each process to evaluate a treatment plant's effectiveness. Not all plants have all the processes identified above, however. Before a sampling program is undertaken, a schematic of the plant's process flow should be prepared to determine the suitable locations for sampling.

Chapter 4: Application of Leading Treatment Technologies to Removal of A-280 Compounds. This is a thorough review of the application of packed tower air stripping and granular activated carbon adsorption to potable water treatment. Methods for sizing these facilities and for estimating their costs are discussed along with operational and maintenance considerations. The reader is provided with a methodology for performing conceptual

sizings and cost estimates for each of these technologies. Also, pretreatment must be considered on a site specific basis. Vapor phase treatment of stripper off-gases and disposal of GAC from contactors must be addressed early in the design process.

This chapter is intended to serve as a brief "design manual" for use by water purveyors, engineering consultants, and State officials. The overall goal is to give the user enough information to make planning decisions on the applicability of air stripping and carbon adsorption to specific treatment needs.

A generalized approach is provided for selecting an appropriate process for a given contamination scenario, and for sizing and estimating the cost of an appropriate treatment system.

A comprehensive technology assessment was conducted to evaluate the appropriateness and feasibility of air stripping and carbon adsorption for removal of volatile organics to meet the maximum contaminant levels allowable under New Jersey law A-280. The technology assessment consisted of a thorough review of published and unpublished research, vendor information, and process and operational data from available sources.

Site visits to six full-scale, operating air stripping and/or carbon adsorption facilities were also conducted to gain additional information about actual operation of such facilities and to assure that the recommendations of this study reflect actual, real-world operating experience in New Jersey.

The technology assessment demonstrated that, in most cases, it is feasible to remove volatile organic contaminants by air stripping, carbon adsorption, or a combination of the two processes. Both processes also have wide applicability to removal of many other natural and synthetic organic compounds.

The assessment also revealed that conventional constituents in raw water -- such as iron, manganese, pH and hardness -- can cause problems in the air stripping and carbon adsorption processes. Pretreatment to remove or reduce these conventional constituents should be considered for use prior to the air stripping or activated carbon processes, in order to achieve maximum treatment efficiency and cost-effectiveness.

Based on this assessment, the following A-280 compounds are highly amenable to removal by air stripping:

Carbon tetrachloride
Vinyl chloride
1,1-Dichloroethylene

The following A-280 compounds are highly amenable to removal by activated carbon adsorption:

Chlordane
Polychlorinated biphenyls

The remaining compounds now regulated under A-280 are all removable (but less readily so than the above compounds) by either air stripping or carbon adsorption. By analyzing each particular case, using the approach suggested in this chapter, the reader will be able to identify an appropriate treatment scheme.

Some A-280 compounds not currently regulated show resistance to removal by both air stripping and activated carbon filtration. These include methyl ethyl ketone (MEK), formaldehyde and some components of kerosene. MEK will represent a difficult treatment problem when it becomes regulated.

> **Chapter 5: Alternative Treatment Techniques. This chapter reviews the use of ozonation and reverse osmosis to remediate A-280 contaminants. While the use of air stripping or carbon adsorption is generally more common, some circumstances warrant serious consideration of these processes as alternatives.**

In addition to air stripping and carbon adsorption, ozonation and reverse osmosis were selected for further assessment because they have shown some limited applicability to the destruction and/or removal of synthetic and naturally occurring organics.

Ozonation. Ozone has been used continuously in Europe for more than 80 years as a disinfectant in water treatment, principally for municipal water supplies. For the past few years evidence has been accumulating to strongly indicate that ozone and granular activated carbon perform mutually supportive and complementary functions in the treatment of water supplies for the removal of organic matter.

Because of the enhanced effectiveness of this combination of treatment steps, most new or redesigned large water treatment plants in western Europe that use major rivers or other similarly polluted waters as their sources employ both ozonation and GAC filtration as treatment steps. Use of this combination of processes usually provides for greater overall removal of organic matter than can be attained practically by extension or intensification of either one of the individual processes.

To compare the cost of ozonation to other disinfectants or oxidants solely on a process-versus-process basis is not entirely reasonable. On this basis, ozone usually proves not to be cost-effective. However, the properties of ozone are such that reduced chemical feed of coagulants and coagulant aids, and increased activated carbon life can result. The estimated cost savings from these advantages should be weighed against capital cost.

Reverse Osmosis. Reverse osmosis (RO) is a membrane process in which the semipermeable (molecular selective) characteristics of a membrane are used to separate contaminants from feed water under high pressure.

The molecular weights of typical volatile organics and THMs may be too low for removal by RO. RO should be evaluated on a case-by-case basis for appropriateness to removal of volatile organics. Typically, 95 percent of all organic materials with molecular weights higher than 400 cannot pass through an RO membrane.

Reverse osmosis represents a relatively expensive treatment process. For small installations, construction costs in excess of $1.0 million for each million gallons per day of capacity are not uncommon.

Both ozonation and reverse osmosis have limited applicability to the removal of synthetic volatile organics from drinking water. These processes should be applied with the recognition of their limitations in regard to the removal of A-280 contaminants.

> **<u>Chapter 6: Nonpublic Water Supplies</u>. A sizable number of water consumers in New Jersey rely on private wells for water supply. The unique institutional, financial and technical issues applying to these water users are discussed in this chapter. Point of use treatmnet and use of bottled water is recommended only as an interim solution for most organic contamination problems. The local health department, existing water authorities or newly created water districts should address the testing, funding ownership, monitoring and maintenance issues of point of use devices. Alternative sources of water supply and centralized treatment are preferred corrective measures for high levels of organic contamination.**

The need exists to establish a comprehensive testing program for organic contamination in nonpublic single-user wells. Although the total number of nonpublic wells statewide, and the cost of organic testing, may prohibit the sampling of all wells at once, a phased sampling program is recommended. To effectively manage the large number of test results and coordinate the implementation of a statewide management program, a centralized reporting and data management system may be necessary.

As cases of organic contamination are identified, affected homeowners and local agencies should be advised by the regulatory authority of the recommended action to be taken. In cases where alternative sources of water supply or treatment must be provided, a review of alternatives and treatment technologies must be performed. It is recommended that NJDEP provide guidance in the evaluation of alternatives. However, the actual review and evaluation would be performed and administered by a local entity. The local entity could be a water authority, water quality district, or local health department.

Alternative sources of water supply and centralized water treatment are the preferred corrective measures in cases of high levels of organic contaminants of health concern. In general, point-of-use treatment and use of bottled water are only recommended as an interim solution or for cases of low levels of organic contamination.

Point-of-use (POU) treatment to reduce contaminants of health concern poses specific problems with respect to unit selection and testing, ownership, monitoring and maintenance, and funding. A local entity should be established to address these specific concerns associated with POU treatment. The local entities identified previously, including existing water authorities, local health departments, or newly created water quality districts, could be used in this capacity.

Because the availability and resources of existing water authorities and county or local health departments will vary throughout the state, no single type of local entity has been identified to exclusively perform this role. Instead, it is recommended that sufficient flexibility be provided to permit local water authorities and health agencies to assume this role where they have sufficient resources.

In the absence of these agencies, flexibility should be provided for the formation of new water quality districts. New legislation, however, may be needed to allow the formation of new water quality districts to manage POU devices for nonpublic wells. The formation of water quality districts and their operations should be regulated and reviewed by either NJDEP or the State Department of Health.

> **Chapter 7: Alternative Monitoring Techniques. The use of generally accepted analytical techniques for A-280 organic detection can be time-consuming and expensive. Possible alternative analytical or monitoring techniques are reviewed in this chapter. However neither surrogate tests nor biomonitoring are presently acceptable as substitutes for quantitative regulatory monitoring requirements. Both surrogates and biomonitoring can be useful, operation tools when used on a site specific basis. GC should be considered for ordinary and routine operations monitoring in most water treatment plant laboratories.**

Laboratory analysis for synthetic organic compounds can be costly, particularly when large numbers of analyses must be performed. Alternatives that could reduce these costs would be of obvious benefit. This section explores the use of (1) substitute, or surrogate, parameters that would provide reliable information equivalent to that provided from more costly analyses and (2) biological monitoring systems.

Surrogate Tests. In the monitoring of water quality, a surrogate parameter is used to replace another parameter whose measurement usually requires a more specific and time-consuming chemical test. Ideally, tests for surrogate parameters can be performed relatively quickly and inexpensively. The potential for reducing time and cost by using collective or nonspecific analyses -- such as a surrogate test to replace a more complex analysis of individual organic compounds by gas chromatography (GC) and mass spectroscopy (MS) -- is the primary reason for attempts to apply surrogate tests in routine monitoring.

However, investigations have indicated that surrogate tests can probably not be used to meet specific monitoring requirements for individual organic compounds. Until other techniques are refined, GC/MS is probably the best analytical procedure for quantifying individual organic compounds.

Biological Monitoring Systems. An extensive literature search was undertaken to assess the applicability and usefulness of biological early warning systems for the purpose of monitoring raw drinking water. In addition to the literature research itself, information regarding recent technical developments was obtained.

Sixteen response variables and sensors that either have been used or considered for use in an early warning system were identified. Most of these systems have not been specifically examined as to their applicability with the A-280 compounds. Each field-tested system was evaluated on the basis of reliability, sensitivity to toxicants, degree of skill required for use, degree of maintenance required, and approximate cost. The results of these evaluations indicated that fish ventilatory/activity monitors hold the most promise as a biological early warning system for assessing raw drinking water.

Based on the conclusions from the literature search and information survey, several recommendations were made with respect to future research and testing.

> **Chapter 8: Future Needs. Recommendations are provided regarding the need for future work in New Jersey to better define the extent of synthetic organic contaminants in raw water sources, and to improve understanding of the problem of trihalomethane formation and control.**

This chapter summarizes the needs for future work that have been identified as part of this study. Major needs for new data include the following:

- Collection, analysis and presentation of data regarding the quality of water resources throughout the state
- Evaluation of the technologies available for the prevention and removal of chlorination by-products in drinking water
- Field studies of air stripping and activated carbon treatment, specifically for removal of contaminants regulated, or to be regulated, by New Jersey Assembly Bill A-280
- Field or literature studies of advanced oxidation/disinfection and reverse osmosis treatment processes

(3)

Section 1

1.0 INTRODUCTION

The presence of low levels of suspected cancer-causing chemicals in drinking water supplies has been recognized since the 1970's. Many of these substances -- organic chemicals of manmade origin -- are widely used throughout the nation, typically as solvents, fuels, pesticides, fertilizers, and raw chemicals for a variety of industrial and commercial purposes. This widespread use, complicated by sometimes inappropriate handling and disposal, has resulted in contamination of many drinking water supplies.

The federal government and many states have now begun to define the extent of the contamination, to regulate use of these chemicals, and to define the technologies needed to remediate the contamination. The State of New Jersey is at the forefront of this effort. This study -- the Special Water Treatment Study - Phase II -- represents a major step in assuring clean drinking water supplies for all New Jersey residents. This study is intended to provide technical guidance needed to evaluate, test, and treat water supplies contaminated with organic chemicals.

In New Jersey, where use of such chemicals has been widespread, an intensive State-directed program to address their presence in drinking water supplies is currently under way. This study is intended to provide technical guidance for evaluating, testing, and treating water supplies contaminated with these organic chemicals. This guidance will form the basis for increased understanding throughout New Jersey's water supply industry of the facilities and procedures needed to meet regulations to be implemented by both the State and federal governments to control these chemicals in drinking water. Though water purveyors of all sizes will benefit from a review of this report, the midsize ground water purveyor producing a supply in the range of about one million gallons a day will find this study particularly informative.

1.1 BACKGROUND

After drought conditions in the 1960's focused attention on New Jersey's water supply problems, the State began a series of planning efforts, culminating in publication of the Statewide Water Supply Master Plan and the passage of the Water Supply Bond Act in 1981. A specific recommendation of the Master Plan was the implementation of a major effort to ascertain the extent of water supply contamination by hydrocarbons, toxics, and carcinogens, and the technology necessary to remediate the contamination. The Special Water Treatment Study was undertaken in response to the Master Plan recommendation, and was funded by the proceeds of the Water Supply bond act.

1.1.1 NEW JERSEY SAFE DRINKING WATER ACT AMENDMENTS OF 1984

New Jersey is among the first states to attempt to deal with organic contaminants in water supplies on a wide-scale basis, anticipating even federal initiatives in this area. The framework for the current study is New Jersey Assembly Bill No. A-280 (A-280 law), signed by Governor Thomas Kean on January 9, 1984. The A-280 law amends portions of the New Jersey Safe Drinking Water Act (NJSDWA) and sets forth initiatives to evaluate the occurrence of 22 organic compounds in drinking water and to establish maximum contaminant levels (MCL) for these compounds. The contaminants listed in table 1-1 were designated for monitoring and regulation.

There is a significant likelihood that New Jersey will promulgate lower MCLs than the federal government, particularly for carcinogens. Thus, for some contaminants, New Jersey regulations may be more stringent than federal regulations.

MCLs to be promulgated under A-280 include the eight volatile organics regulated by the U.S. Environmental Protection Agency (EPA) and 11 other organic chemicals. In the special case of carcinogens, the A-280 law requires the New Jersey Department of Environmental Protection (NJDEP) to:

TABLE 1-1

DRINKING WATER CONTAMINANTS INITIALLY LISTED UNDER NEW JERSEY LAW A-280 FOR MONITORING AND REGULATION

- Trichloroethylene
- Tetrachloroethylene
- Carbon tetrachloride
- 1,1,1-Trichloroethane
- 1,2-Dichloroethane
- Vinyl chloride
- Methylene chloride
- Benzene
- Chlorobenzene
- Dichlorobenzene
- Trichlorobenzene
- 1,1-Dichloroethylene
- *cis*-1,2-Dichloroethylene
- *trans*-1,2-Dichloroethylene
- Polychlorinated biphenyls
- Xylenes
- Ethylene glycol
- Chlordane
- Kerosene
- Formaldehyde
- *n*-Hexane
- Methyl ethyl ketone

> ...establish, within the limits of medical, scientific, and technological feasibility, maximum contaminant levels...which, with respect to carcinogens, permit cancer in no more than one in one million persons ingesting that chemical for a lifetime...

This statement has been interpreted to mean the following: on the basis of ingesting two liters of drinking water per adult per day over a 70-year lifetime, the MCLs established for carcinogens must not increase the relative risk of cancer by more than one in one million cases.

In the case of noncarcinogens and "those carcinogens resulting from compounds with public health benefits," the A-280 law requires that MCLs be set at levels that can eliminate all adverse physiological effects resulting from ingestion, within the limits of practicability and feasibility. The interpretation of this requirement has been that the one-in-one-million cancer risk must be met unless it is technologically unfeasible.

The Special Water Treatment Study - Phase II is intended to assist NJDEP in addressing this legislative mandate to consider the technological feasibility of treating to remove the A-280 compounds, and in providing technical assistance, when necessary, to protect the purity of the state's drinking water.

All purveyors must conduct periodic testing of their water supplies in accordance with a schedule prescribed in the A-280 law. Prior to the publication and promulgation of final MCLs, NJDEP has developed Interim Action Levels as a means to respond to initial A-280 testing data and to set forth response actions based on the levels found during the testing of purveyor supplies. Of the 22 chemicals cited in the A-280 law, purveyors have monitored for 16. The frequency of testing is specified under the enabling regulations promulgated under A-280 (NJAC 7:10-14.1 et seq.). All public community water systems completed their initial testing during early 1985.

NJDEP has established four Interim Action Levels. Depending on the concentrations of the specified contaminants found in drinking water samples (table 1-2), four levels of responses to be taken by NJDEP, municipalities,

TABLE 1–2

INTERIM ACTION LEVELS AND RECOMMENDED RESPONSES FOR SELECTED ORGANICS IN DRINKING WATER

(January 1986)

Contaminant	Level I (mcg/l)	Level II (mcg/l)	Level III (mcg/l)	Level IV (mcg/l)
Benzene	0-0.68	>0.68≤6.8	>6.8≤68	>68
Carbon tetrachloride	0-0.27	>0.27≤2.7	>2.7≤27	>27
Chlordane	0-0.8	>0.8≤32	>32≤63	>63
Dichlorobenzene(s)	0-94	>94≤425	>425≤750	>750
1,2-Dichloroethane	0-0.7	>0.7≤7	>7≤70	>100
1,1-Dichloroethylene	0-7	>7≤53	>53≤100	>100
trans-1,2-Dichloroethylene	0-27	>27≤148	>148≤270	>270
Methylene chloride	0-4.8	>4.8≤47	>47≤479	>479
Polychlorinated biphenyls	0-0.007	>0.007≤0.07	>0.07≤0.7	>0.7
Tetrachloroethylene	0-0.67	>0.67≤6.6	>6.6≤66	>66
1,1,1-Trichloroethane	0-20	>20≤110	>110≤200	>200
Trichloroethylene	0-3.1	>3.1≤30	>30≤309	>309
Vinyl chloride	0-0.015	>0.015≤0.15	>0.15≤1.5	>1.5
Xylene(s)	0-100	>100≤550	>550≤1200	>1200

water purveyors, and local health officers have been established. The four levels of response established are described below:

Level I - No recommended action. Random spot checking is required.

Level II - Confirmation of sampling results and periodic monitoring is required. Alternative water sources and/or appropriate treatment techniques should be recommended.

Level III - Confirmation of sampling results and monthly monitoring is required. Within one year alternative water supplies and/or treatment techniques for public community water systems must be developed, and appropriate remedial actions are recommended. Quarterly progress reports are required from water systems.

Level IV - Confirmation of sampling results and immediate remedial action is required.

The New Jersey Drinking Water Quality Institute (NJDWQI), a 15-member board whose appointees represent water purveyors, academia, public health officials, and State officials, is charged under A-280 with the development of recommendations for MCLs in drinking water. On March 26, 1987, NJDWQI formally reported its recommendation for MCLs to the Commissioner of Environmental Protection. The responsibility for actual promulgation of MCLs lies with the Commissioner. Acting upon these recommendations, on October 1, 1987, the Commissioner of NJDEP formally issued proposed maximum contaminant levels for 19 of the A-280 compounds. (A list of the compounds and proposed MCLs appears in table 1-3.)

1.1.2 FEDERAL SAFE DRINKING WATER ACT AMENDMENTS OF 1986

In June of 1986, Congress passed and the President signed into law the Safe Drinking Water Act Amendments (1986 SDWA). The 1986 SDWA recognizes 83 contaminants for which MCLs must be developed. EPA initially listed these contaminants for regulation in two advance notices of proposed rulemaking (ANPRM) published in the Federal Register on March 4, 1982 and October 5,

TABLE 1–3

MAXIMUM CONTAMINANT LEVELS FOR A-280 COMPOUNDS PROPOSED BY NJDEP

Contaminant	MCL (mcg/l)
Benzene	1
Carbon tetrachloride	2
Chlordane	0.5
Chlorobenzene	4
o-Dichlorobenzene	600
m-Dichlorobenzene	600
p-Dichlorobenzene	6
1,2-Dichloroethane	2
1,1-Dichloroethylene	2
cis-1,2-Dichloroethylene	10
trans-1,2-Dichloroethylene	10
Methylene chloride	2
PCBs	0.5
Tetrachloroethylene	1
Trichlorobenzenes	8
1,1,1-Trichloroethane	26
Trichloroethylene	1
Vinyl chloride	2
Xylenes	44

1983. EPA may substitute up to seven of the listed contaminants with alternative contaminants.

The 1986 SDWA establishes a very strict time schedule for the promulgation of new standards. Within 12 months of the date of enactment (June 19, 1986) EPA had to promulgate MCLs for no fewer than nine of the contaminants in the ANPRM. In fact, EPA promulgated MCLs for eight of these contaminants in July 1987. These compounds are synthetic or volatile organics (see table 1-4 for a summary of volatile organic compounds regulated by the EPA as of August 1987). EPA also originally intended to regulate tetrachloroethylene, but, because of conflicting data on the health effects of this compound, it has postponed action on this compound. Therefore, the ninth compound to be regulated is undetermined at this time. An additional 40 of the listed contaminants must be regulated within 2 years of enactment (by June 1988). The remainder of the contaminants must be regulated within 3 years of enactment (June 1989).

The process of MCL promulgation has been made more rigorous by Congress through enactment of the 1986 SDWA. Simultaneous with the promulgation of MCLs for each contaminant, EPA must also promulgate a maximum contaminant level goal (MCLG) that in concept replaces the prior terminology of recommended maximum contaminant level (RMCL). EPA must set the MCLG with an adequate margin of safety, at the level at which no known or anticipated health effects occur. Each MCL must be set as close as feasible to the MCLG. The word feasible, as defined in the law, means "...feasible with the use of the best technology (and) treatment techniques..."

The SDWA specifically mentions that any treatment technique proposed for synthetic organics removal must be at least as effective as granular activated carbon. In the event that it is not economically or technologically feasible to ascertain the level(s) of a regulated contaminant, EPA must require the use of a treatment technique that would prevent known or anticipated health effects.

TABLE 1-4

USEPA STANDARDS FOR VOLATILE ORGANIC CHEMICALS IN DRINKING WATER

Chemical	MCLG (mcg/l)	MCL (mcg/l)
Trichloroethylene	0	5
Carbon tetrachloride	0	5
Vinyl chloride	0	2
1,2-Dichloroethane	0	5
Benzene	0	5
1,1-Dichloroethylene	7	7
1,1,1-Trichloroethane	200	200
p-Dichlorobenzene	75	75

MCLG = Maximum contaminant level goal
MCL = Maximum contaminant level

One significant difference between the federal legislative mandate and the mandate under New Jersey law A-280 concerns carcinogens. Under A-280 technological feasibility is given less emphasis than under the federal approach. Another significant difference between the state and federal approach is that the federal regulation-setting process allows for economic considerations in setting the MCLs for carcinogens.

1.1.3 SPECIAL WATER TREATMENT STUDY - PHASE I

The Special Water Treatment Study - Phase I reviewed in-stream and treatment plant water quality data from 25 of the largest water purveyors in the state. The study reviewed the technologies available for removal of organic contaminants from drinking water supplies, and the regulations applying to organic contaminants in effect as of 1983. The Phase I study resulted in several important findings:

- Monitoring of organic contaminants in surface sources in New Jersey did not provide adequate data to determine the full extent of organic contamination. Additional monitoring of unprotected surface sources near water intakes subjected to high levels of municipal and industrial discharges was recommended. Monitoring should be of sufficient frequency and of sufficient breadth to measure a wide spectrum of organic fractions, in addition to volatile organic compounds (VOC).

- Much higher levels of VOCs were found in ground waters than in surface waters within the state.

- Organic contamination in ground water could become more serious in the future. A broader spectrum of organic compounds may threaten ground water resources than indicated by current water quality data. These other compounds may be detected years after the first signs of contamination have appeared.

- A coordinated approach to data collection, statistical evaluation, and reporting on the organic contamination problems in New Jersey waters is needed. Several agencies collect data on organic contamination in raw ground and surface water, and in finished drinking waters. This data is, for the most part, difficult to obtain and evaluate.

- Air stripping using packed columns and carbon adsorption were the recommended processes for removal of VOCs found in ground water. The secondary effects of air stripping (such as air pollution impacts) and the range of applicability of this process for less-volatile compounds were identified for further investigation.

- Activated carbon was the primary process identified for the treatment of surface water contaminated with nonvolatile synthetic organic compounds.

- The need for refined cost estimates for the designated unit treatment systems was identified.

An additional output of the Phase I study was the scope of work for the Phase II study. This scope evolved to address the issues discussed in the present study.

1.2 OBJECTIVES OF SPECIAL WATER TREATMENT STUDY - PHASE II

The overall goal of the Phase II study is to enhance the New Jersey water industry's understanding of the impacts of volatile organics in drinking water. Study objectives are outlined in the following paragraphs.

Establish Extent of Volatile Organics in New Jersey's Potable Water Supplies. The Phase I study identified the presence and concentrations of the contaminants of concern at 25 of the largest water treatment facilities in the state, based on existing information. The Phase II study updates the assessment of the extent of organic contamination and levels of contamination present on a statewide level, particularly in ground water, based on available data. To accomplish this task, all available water quality data relating to potable water supplies was assembled into a single comprehensive data base.

Review Regulatory Framework. Regulation is an important means of interaction between government and the water utilities industry. A summary and explanation of the regulatory experience of other jurisdictions, particularly other states and the federal government, was prepared in order to provide insight into and guidance on New Jersey's regulatory approach.

Assess Leading Treatment Technology Applications. The assessment of treatment technologies focused on two particular unit processes: air stripping and activated carbon adsorption.

Review Alternative Treatment Technologies. Two additional technologies that show some applicability to the destruction and/or removal of volatile organics were also reviewed: reverse osmosis and ozonation.

The effectiveness of each process in removing volatile organics from drinking water supplies was reviewed on the basis of current literature, site visits to treatment facilities, and historical experience. The ability of each treatment technology to remove contaminants to the anticipated maximum contaminant levels was emphasized.

Develop Planning Level Costs. In conjunction with the treatment technology assessment, technical guidance on the costs of implementing treatment is provided. Cost curves were generated to enable purveyors and others to determine approximate costs for the installation of various treatment alternatives.

Examine Feasibility of Using Surrogate Parameters to Lower the Cost of Monitoring. To reduce the potential high cost of laboratory analysis that may be required, use of surrogate parameters was examined. Specific parameters are monitored in the water treatment industry to evaluate the characteristic qualities of water. The analyses required often are either costly or time-consuming to perform. The monitoring of a surrogate parameter (more appropriately termed nonspecific parameters) as a substitute is supposed to indicate the magnitude of the specific parameter of concern. The potential for reducing analytical time and cost by using a nonspecific analysis as a surrogate test for a more complex organic analysis is the reason for attempting to apply surrogates in routine monitoring. However, given the limitations of currently available nonspecific analytical techniques, these methods should not generally be used for regulatory compliance.

Conduct Water Treatment Plant Sampling Programs. To ascertain the fate of volatile organics in traditional water treatment plants, sampling programs were conducted at three ground water and two surface water plants around the state. As part of this program, surrogates, particularly surrogates for trihalomethanes, were tested and observations made of the formation of trihalomethanes in the treatment process.

Design Additional Water Treatment Plant Sampling Programs. In accordance with the scope of services, sampling programs were designed but not carried out at six additional water treatment plants. These unexecuted sampling programs can be used by the purveyors or NJDEP to assist in process evaluation for volatile organics removal.

Identify Nonpublic Water Supply Strategy. Nonpublic water supplies are subject to contamination. Throughout New Jersey, individuals have been faced with contamination problems that require substantial financial and technical resources to resolve them. Local governing bodies may be able to provide assistance. The supporting documentation for implementation of a statewide policy on this problem was prepared.

Literature Review for Biological Monitoring. The feasibility of using living organisms as sensors for detecting spills or other unexpected increases of contaminants in raw water intakes was assessed.

Provide Technical Guidance. In meeting the aforementioned objectives of the study, all information has been presented in a style and format suitable for technology transfer to New Jersey's water industry.

1.3 ORGANIZATION OF THE FINAL REPORT

This final report for the Special Water Treatment Study - Phase II summarizes the information provided in the task reports, and provides additional information and results completed after submission of the individual task reports.

Appendix G lists the titles of the interim reports produced as part of this study. These reports generally cover one topic in detail. They are labeled interim because they present material that, at the time, had not been reviewed by the State. Any revisions to the information in the interim reports have been incorporated only into this final report.

The final report is organized into eight chapters. Each chapter discusses a separate set of issues related to synthetic and volatile organics in drinking water supplies, particularly the A-280 organics:

Chapter 1:	Introduction
Chapter 2:	Nature and Occurrence of Organic Chemicals
Chapter 3:	Fate of Volatile A-280 Organics in Traditional Water Treatment Plants: Sampling Methodology and Results
Chapter 4:	Application of Leading Treatment Technologies to Removal of A-280 Compounds
Chapter 5:	Alternative Treatment Technologies
Chapter 6:	Nonpublic Water Supplies
Chapter 7:	Alternative Monitoring Techniques
Chapter 8:	Future Needs

To assist the reader, summaries for each of these chapters are provided below. For specific page numbers, consult the table of contents.

Chapter 1: Introduction. This chapter reviews the background of recent water supply planning in the state, with particular emphasis on the genesis of this study. The findings of the Special Water Treatment Study - Phase I are reviewed in light of the Phase II study. The State and federal laws and regulations pertaining to the control of volatile organics in drinking water supplies are summarized.

Chapter 2: Nature and Occurrence of Organic Chemicals. The relative occurrence of A-280 organics in both surface and ground water supplies is reviewed. The nature of these contaminants from health, physical-chemical, and relative treatability perspectives is summarized.

Chapter 3: Fate of Volatile (A-280) Organics in Traditional Water Treatment Plants: Sampling Methodology and Results. A more thorough understanding of the fate of A-280 organics in typical water treatment processes has been gained as a result of the sampling programs carried out under the

Phase II study. This sampling work also provides some insight into the generation and removal of trihalomethanes in the treatment process. A methodology for implementing sampling programs is also presented.

Chapter 4: Application of Leading Treatment Technologies to Removal of A-280 Compounds. This is a thorough review of the application of air stripping and carbon adsorption to potable water treatment. Methods for sizing these facilities and for estimating their costs are discussed along with operational and maintenance considerations. A methodology for performing conceptual sizings and cost estimates for each of these technologies is provided for the reader's use.

Chapter 5: Alternative Treatment Technologies. This chapter reviews the use of ozonation and reverse osmosis to remediate A-280 contaminants. While the use of air stripping or carbon adsorption is generally more widespread, some circumstances warrant serious consideration of these processes as alternatives.

Chapter 6: Nonpublic Water Supplies. A sizable number of water consumers in New Jersey rely on private wells for water supply. The unique institutional and technical issues applying to these water users are discussed.

Chapter 7: Alternative Monitoring Techniques. The use of generally accepted analytical techniques for detection of A-280 organic compounds can be time- consuming and expensive. Possible alternative analytical or monitoring techniques are reviewed in this chapter.

Chapter 8: Future Needs. Recommendations are provided regarding the need for future work within New Jersey to better define the extent of synthetic organic contaminants in raw water sources, to improve understanding of the problem of trihalomethane formation and control and to gain a better understanding of several treatment technologies.

(3)

Section 2

2.0 NATURE AND OCCURRENCE OF ORGANIC CHEMICALS

SUMMARY OF FINDINGS

One of the goals of the Special Water Treatment Study - Phase II is to assist in the implementation of treatment technologies on a widespread basis in New Jersey. To do this it is necessary to understand the nature of organic contaminants in state water supplies as well as the extent of their presence.

Several questions need to be answered in order to achieve a confident understanding of the treatment problems facing New Jersey water purveyors. In regard to the nature of organic contaminants present:

> What organic chemicals are present?
>
> What are their concentrations?
>
> What are their health effects?

In regard to their occurrence:

> Where are these organics found: in ground water or surface water?
>
> Are organic contamination problems more or less prevalent in certain regions of the state?

Some of these questions have been answered by this study. A comprehensive water quality database was created as a result of extensive data searches. No other single database has consolidated the data available on contamination of drinking water supplies in New Jersey to this extent.

This database and the sampling performed for this study appear to confirm the relative pervasiveness of A-280 type contaminants in New Jersey water supplies. It is evident that low-level organic contamination of water supplies is relatively common in both ground and surface waters. Almost all of the purveyors of the state are at some risk of contamination from synthetic and/or volatile organics.

In terms of order of magnitude, the level of concentration of A-280 organics in raw water supplies is usually in the micrograms per liter (mcg/l) or parts per billion (ppb) range. The most common contaminants are the degreasers used by both industrial and commercial cleaners and the petroleum-based aromatic compounds. Examples of the first type are trichloroethylene, trichloroethane, and tetrachloroethylene; examples of the second type are benzene and toluene.

However, this study also has revealed that considerable research and investigation remains to be performed before a complete understanding of the nature and occurrence of synthetic organic contaminants in New Jersey water supplies can be obtained.

Review of the database assisted in identifying data gaps and deficiencies and in making recommendations to address them. It is of significance that information on in-stream water quality in surface waters is not readily available for characterization of watersheds in New Jersey. The framework of a program to address this and other data deficiencies is outlined in Chapter 8.

2.1 OCCURRENCE OF ORGANICS

Volatile and synthetic organics in drinking water supplies are of particular concern in New Jersey, where high population densities and high levels of industrial and commercial activity have historically provided greater opportunity for these compounds to enter the water supply.

Organics may enter a water supply through numerous routes. These routes of entry include inadvertent industrial spills, leachate from sanitary landfills, disposal practices of small industries, uncontrolled hazardous waste sites, and exfiltration from sanitary sewers. It is frequently difficult to determine the source of a contamination problem. To do so may require installation of a number of monitoring wells, taking of numerous analytical samples and, in some cases, the development of a sophisticated computer model to predict the movement of the contaminants through the ground water. Even if the source of the contamination is found and remediated, a substantial period may lapse before concentrations in the water supply decline to acceptable levels. Therefore, in many instances of contamination it is more reasonable and cost-effective to provide treatment to protect public health while investigations proceed to locate and eliminate the source of the contamination.

Contamination is evident in New Jersey in both public and nonpublic water systems. The fundamental difference between these two types of supplies is the number of people served. The legal definitions used in New Jersey are as follows:

- A public water system serves at least 15 service connections used by year-round residents, or regularly serves at least 25 people.
- A nonpublic water system is any water system that is not defined as a public water system, including single user wells.

There are approximately 630 public water systems in the state. An overwhelming majority of New Jersey's inhabitants are served by public water systems.

2.1.1 WATER QUALITY DATABASE

As part of the Phase II study effort, a water quality database was created. This computerized data management system is a comprehensive compilation of chemical data on New Jersey water supplies. No other single database has consolidated the data available on contamination of drinking water supplies in New Jersey to the extent performed for this study.

Most of the data was obtained from the New Jersey Department of Environmental Protection's (NJDEP) existing central files. (Data sources also included A-280 analyses reported to NJDEP through the end of 1985.) The objective of using existing files was to create a single, computerized database of all data available from NJDEP. In developing this database, a number of reports and other data sources were also consulted for results of volatile and other organic contaminant testing performed on New Jersey's drinking water supplies. Review of the database assisted in identifying data gaps and deficiencies and in making recommendations to address them (see Chapter 8: Future Needs).

Several special studies related to water quality were also reviewed to assess whether they contained useful organic analysis results. The documents reviewed included the following:

Manasquan River Reservoir - Sampling Survey by B. Cann and P. Morton

Boonton Reservoir Study by A. Wicklund and I.H. Suffet

Delaware and Raritan Canal Conduit Special Study by The Mercer County Water Quality Planning Program.

Sources of Halogenated Hydrocarbons in an Urban Water Supply by J.V. Hunter and T. Sabatino

New Jersey 1982 State Water Quality Inventory Report by Keith Robinson (principal author)

Wastewater in Receiving Waters at Water Supply Abstraction Points, Municipal Environmental Research Laboratory, Cincinnati, Ohio

Although the studies did contain some data on organics, in many cases the data was outdated (i.e., from before 1979). Data in the Water Quality Inventory Report took the form of rankings or ratings of percent of organic contaminants in water supplies; this was not in a usable format for the Special Water Treatment Study. Some usable data on organics was found in the documents relating to the Boonton Reservoir and the Manasquan River.

The result of these extensive data searches was a comprehensive water quality database consisting of five volumes of computer printouts (over 1,500 pages). It is of significance that information on in-stream water quality in surface waters is not readily available for characterization of watersheds in New Jersey. The framework of a program to address this data deficiency is outlined in Chapter 8.

2.1.2 INCIDENCE OF ORGANICS

As a result of the A-280 law, the State of New Jersey initiated a comprehensive testing program to ascertain the occurrence of certain volatile organic compounds in finished water supplies. Of the 22 compounds listed in the A-280 law, extensive testing of 16 of them has been performed by water purveyors and the results of these tests forwarded to NJDEP (see table 2-1).

The database developed as part of this study contains information pertaining to all of the A-280 samples plus many additional volatile organics samples taken at water supply facilities throughout the state. On the basis of this database, a number of observations can be made regarding the incidence of organics in drinking water supplies in New Jersey.

For the period 1980 through 1985, it was found that 193 (30 percent) of the 630 purveyors in the State had shown evidence of volatile organics, whether from A-280 reporting or other reporting to NJDEP. As of May 1985, 566 purveyors out of the total of 630 had reported at least some A-280 testing results to NJDEP. On the basis of these A-280 test results, 101 water systems, or 18 percent, reported the detection of one or more A-280 chemicals. Multiple A-280 chemicals were identified in the finished water of 30 purveyors (5 percent).

Using the database, flow-proportioned data was derived to characterize the extent of A-280 chemicals. In New Jersey, public water supplies produce about 1.24 billion gallons a day of potable water. Of this total, 695 million gallons a day (mgd), or 56 percent, is derived from surface water sources. The remaining 545 mgd is derived from ground water sources. Using A-280 data only, 296 mgd of surface water supplies and 139 mgd of ground water supplies have shown the presence at least one A-280 chemical.

TABLE 2–1

A–280 CONTAMINANT LIST

Compounds for which monitoring is now required

- Benzene
- Carbon tetrachloride
- Chlordane
- Chlorobenzene
- Dichlorobenzene(s)
- 1,2-Dichloroethane
- 1,1-Dichloroethylene
- *trans*-1,2-Dichloroethylene
- Methylene chloride
- Polychlorinated biphenyls
- Tetrachloroethylene
- Trichlorobenzene(s)
- 1,1,1-Trichloroethane
- Trichloroethylene
- Vinyl chloride
- Xylene(s)

Compounds for which monitoring is not now required [a]

- *cis*-1,2-Dichloroethylene
- Ethylene glycol
- Formaldehyde
- *n*-Hexane
- Kerosene
- Methyl ethyl ketone

[a] Monitoring is not required because acceptable methods for analysis have not been recommended.

Therefore, 43 percent of surface water and 25 percent of ground water supplies have exhibited at least minimal levels of A-280 chemicals under the A-280 testing program. Taking the entire database into account, including samples taken for reasons other than A-280 monitoring, 507 mgd, or 73 percent, of surface water supplies and 305 mgd, or 56 percent, of ground water supplies have shown some evidence of A-280 chemicals. This data is summarized in table 2-2.

This summary of the incidence of A-280 chemicals does not indicate anything about the acceptability of the quality of drinking water in New Jersey; it only indicates the geographical extent to which these synthetic compounds were detected at levels equal to or greater than the minimum, analytical detection levels. Detection of a chemical during lab analysis does not necessarily indicate contamination of water. Confirmational sampling and analysis must be performed to verify the analytical results. Table 2-3 provides a breakdown of water supplies based on production on a county basis.

The sampling work performed at selected water treatment facilities in connection with the Special Water Treatment Study - Phase II appears to confirm the relative pervasiveness of A-280 chemicals. Analytical results indicated the presence of A-280 organics at every plant sampled and during every sampling event. However, the plants selected for sampling were selected because A-280 compounds were previously evident. Regardless, the recurrent detection of these compounds provides an indicator of the pervasiveness and persistence of these compounds.

2.2 TYPES OF ORGANICS

Volatile organics, as the contaminants of concern are generally referred to, are a group of synthetic compounds of generally low molecular weight (less than 200 atomic units), carbon-based, and of man-made origin. They are referred to as "volatile" because of the relative ease with which they evaporate when found in pure form.

TABLE 2-2

SUMMARY OF INCIDENCE OF A-280 COMPOUNDS ACCORDING TO PHASE II STUDY

Water supply type	Statewide capacity (mgd)	At least one A-280 contaminant detected [a] (mgd)	Percentage of production by supply type	Percentage of total production
Surface water	695	276	56	23
Ground water	545	139	44	11
Total flow	1,240			

[a] For the purpose of this summary, detection of A-280 contaminants at or above the minimum analytical detection level does not signify acceptability or unacceptability of water, it only helps to assess the geographical extent of these synthetic organic compounds.

TABLE 2–3

NATURE OF SOURCES OF WATER IN NEW JERSEY [a]

County	Water source	Production (mgd)	Total production (mgd)
Atlantic	Surface water	12.5	21.4
	Ground water	8.9	
Bergen	Surface water	88.1	121.1
	Ground water	33.0	
Burlington	Surface water	1.5	36.4
	Ground water	34.9	
Camden	Surface water	0	71.4
	Ground water	71.4	
Cape May	Surface water	0	12.1
	Ground water	12.1	
Cumberland	Surface water	0	15.8
	Ground water	15.8	
Essex	Surface water	141.4	186.5
	Ground water	45.1	
Gloucester	Surface water	0	19.8
	Ground water	19.8	
Hudson	Surface water	52.1	143.3
	Ground water	3.5	
Hunterdon	Surface water	33.2	39.7
	Ground water	6.5	
Mercer	Surface water	33.2	39.7
	Ground water	6.5	
Middlesex	Surface water	14.0	77.8
	Ground water	63.8	
Monmouth	Surface water	94.2	120.5
	Ground water	26.3	
Morris	Surface water	10.1	43.6
	Ground water	33.5	
Ocean	Surface water	0	35.2
	Ground water	35.2	
Passaic	Surface water	131.1	146.2
	Ground water	15.2	
Salem	Surface water	1.3	5.5
	Ground water	4.1	
Somerset	Surface water	0	2.8
	Ground water	2.8	
Sussex	Surface water	2.1	6.0
	Ground water	4.0	
Union	Surface water	110.3	123.7
	Ground water	13.4	
Warren	Surface water	2.5	7.2
	Ground water	4.7	

[a] Does not take into account interconnections or the county where the source is located.

The volatile organic compounds on the A-280 list are the following:

Trichloroethylene
Tetrachloroethylene
Carbon tetrachloride
1,1,1-Trichloroethane
1,2-Dichloroethane
Vinyl chloride
Methylene chloride
Benzene
Dichlorobenzenes
1,1-Dichloroethylene
trans-1,2-dichloroethylene
*_cis_-1,2-Dichloroethylene
*n-Hexane
*Methyl ethyl ketone
*Chlorobenzene
*Trichlorobenzene

The compounds marked by an * do not have approved analytical test methods approved by the U.S. Environmental Protection Agency (EPA). Contaminants that are listed in the A-280 law, but are not considered volatile, are the following:

Polychlorinated biphenyls (PCB)
Chlordane
*Ethylene glycol
*Kerosene
*Formaldehyde

In actuality, the most widely accepted classification methods for these compounds are not based strictly on the characteristics of the compounds themselves, but on the EPA-accepted analytical test methods used to quantify them at commercial laboratories. On this basis, the compounds break down into the following categories:

Volatile compounds

- Acid compounds
- Base/neutral compounds
- Pesticides/PCBs

There is a tendency in the water industry to refer to the compounds that fall into the above four categories collectively as volatile organics, which is a misnomer. There is also a tendency to refer to the A-280 compounds in their entirety as volatile organic compounds when, in reality, they are a collection of volatile and nonvolatile organic compounds.

2.2.1 HEALTH EFFECTS

Health effects concerns for A-280 contaminants focus on the carcinogenicity of these compounds. Generally, when a compound is a carcinogen, the lowest concentration at which there is a risk of adverse health effects is defined by the one-in-one-million health risk. However, other health effects are also relevant; they include central nervous system disturbances, metabolic effects, and reproductive effects, among others.

In regard to carcinogens, the A-280 law defines a drinking water source to be safe if the risk of contracting cancer is less than 1 in 1,000,000 over a 70-year lifetime, assuming a consumption of 2 liters of water per day. NJDEP has classified the A-280 compounds into three general health categories:

Group A - Known or probable human carcinogens

Group B - Possible human carcinogens

Group C - Insufficient or negative data available on human carcinogenicity

These classifications are based on existing health-based standards developed by the federal government. Each of the A-280 compounds has been assigned by a carcinogenicity evaluation to Group A, B or C. Each group represents an NJDEP categorization based upon the weight of evidence of carcinogenicity for each contaminant.

2.2.2 TREATMENT TECHNOLOGY APPLICATION

The treatability of any contaminant is a combination of its treatment objective and its amenability to treatment. While a complete discussion of treatability can be found in chapter 4, a few basic treatment/risk-related issues should be reviewed here.

Some contaminants are more easily removed from water than others, even when the same process is used. This is largely because of the scientific principle that no two compounds can exhibit exactly the same chemical behavior. Since most treatment techniques for A-280 chemicals are physical and/or chemical techniques, the efficiency of a technique is dependent on the properties of the chemical of interest in water.

In addition, the relative treatability of a chemical is a function of its treatment objective, i.e., the maximum concentration that is allowed by regulation. All other factors being equal, the lower the treatment objective, the more difficult the compound is to treat. Given the very low concentrations contemplated for some of the A-280 organics, and the relative pervasiveness of these compounds, the extent of treatment that could be required throughout the state may be substantial.

2.3 FINDINGS

In terms of order of magnitude, the level of concentration of A-280 organics in raw water supplies is usually in the micrograms per liter (mcg/l) or parts per billion (ppb) range. Rarely does the concentration of these compounds in raw water exceed 1,000 mcg/l or the 1.0 mg/l concentration in drinking water supplies. In fact, chemical levels in raw water are typically below 200 mcg/l.

The most common chemicals are the degreasers used by both industrial and commercial cleaners and the petroleum-based aromatic compounds. Examples of the first type are trichloroethylene, trichloroethane, and tetrachloroethylene; examples of the second type are benzene and toluene.

Based on the water quality data base compiled under the Special Water Treatment Study - Phase II, it is evident that low-level concentrations of A-280 chemicals in water supplies is a relatively common occurrence in New Jersey in both ground and surface waters. In many cases the source of the contamination is difficult to identify. Yet the high level of development found in New Jersey creates a situation where the use of A-280 type chemicals is more widespread than in other parts of the country. Essentially, almost all of the purveyors of the state are at some risk of contamination from synthetic and/or volatile organics.

(4)

Section 3

3.0 FATE OF VOLATILE A-280 ORGANICS IN WATER TREATMENT PLANTS: SAMPLING METHODOLOGY AND RESULTS

SUMMARY OF FINDINGS

This chapter summarizes the results of sampling at five New Jersey water treatment plants, and describes a sampling methodology that will be helpful to water purveyors in meeting future requirements for removal of A-280 organics. Because water purveyors will also have to meet future changes in regulation of trihalomethanes (THM), attention is also given to THM formation and removal in water treatment plants.

The data from the sampling program was reviewed for confirmation of expected removals or generation of volatile organics. The most notable aspect of volatile organic generation and removal at surface water treatment plants is the effect chlorination has on the generation of chlorination by-products, particularly trihalomethanes. In addition, some incidental removal of the synthetic volatile organics was evident in the raw water.

Trihalomethanes were generally not detected in the treatment process train, except following chlorination. The sampling data confirmed the general approach to THM control that has been taken by many water purveyors. Essentially, this approach consists of relocating the point of predisinfection from the intake to the plant to the point immediately following sedimentation, and then adding chlorine at a point of lowered trihalomethane formation potential.

Detailed and specific analytical results of the sampling program are not included in this report. Analytical results are summarized at the end of this chapter. Laboratory results are included in task reports on file at NJDEP. However, based on the sampling data generated by this study, the following observations can be made:

- All plants sampled, regardless of time of year or weather conditions, showed evidence of volatile A-280 compounds. In some cases, the concentrations of the A-280 compounds were low enough that the traditional processes removed these organics to below detectable limits in the finished water.

- The raw water concentrations of volatile A-280 compounds in surface water supplies is relatively variable. A-280 compounds that were evident at very low concentrations during the morning sampling period were not evident in the afternoon sampling on the same day. In addition, further variability in raw water quality from season to season is evident.
- The raw water concentrations of A-280 compounds in ground water are not as variable -- seasonally or based on time of day -- as in surface water.
- Without deliberate application of a specifically designed aeration process, it appears that high removals of volatile organics cannot be achieved. However, reductions of volatile organics in the range of 20 to 40 percent can be achieved without use of special aeration processes.
- Trihalomethanes and their precursors were lowest in the winter, moderate during the summer, and highest following a fall storm, as expected.
- Trihalomethane precursors were found to be reduced in concentration by nearly all unit processes.
- The most significant reductions in trihalomethane precursors were generally found earlier in the treatment system where the major removal of organic solids and other dissolved and suspended materials occurred. Typically, this reduction occurs at the influent screens or during the passage of water through the flocculation/sedimentation basins.

3.1 SAMPLING PROGRAMS

Water treatment processes can remove or change organics that are present in raw water. These processes, in some cases, also can create new organic compounds. A major goal of this study was to gain a more precise understanding of the fate of the organics regulated, or expected to be regulated, by New Jersey Assembly Bill A-280 (listed in table 3-1). As used here, "fate" refers to the removal or destruction, and to the creation, of organic compounds by water treatment processes.

TABLE 3–1

VOLATILE A-280 ORGANIC COMPOUNDS

Benzene
Carbon tetrachloride
Chlorobenzene
Dichlorobenzene
1,2-Dichloroethane
1,1-Dichloroethylene
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
Ethylene glycol
Formaldehyde
Methyl ethyl ketone
Methylene chloride
n-Hexane
Tetrachloroethylene
Trichlorobenzene
1,1,1-Trichloroethane
Trichloroethylene
Vinyl chloride
Xylenes

Another major goal of the study was to develop a methodology that can be used by water purveyors to develop and implement sampling programs needed to comply with the A-280 law requirements. Descriptions of the sampling methodology and its application are provided in this chapter. This information will serve as a useful guide to readers in developing and implementing their own programs.

Sampling programs were designed and conducted at five public water treatment plants in the state to assess the following:

1. The nature and extent of organics entering and created in the plants, to the extent that this can be done with standard analytical testing.
2. The removal of volatile A-280 organics by conventional, existing unit treatment processes.
3. Whether regulated organics are being created in treatment processes used in New Jersey.
4. The formation of trihalomethanes within treatment facilities in New Jersey.

The fate of an A-280 organic in a treatment facility is influenced by the level of natural organics in the raw water as well as use of chlorination and addition of other chemicals. Each of these factors can influence the concentration(s) of volatile organics at any point in the treatment process. Although it may be possible to predict the fate of volatile organics in a treatment process based on experience and technical understanding, there is no adequate substitute for the concrete, site-specific information provided by a sampling program.

3.1.1 TRIHALOMETHANE FORMATION

Because this report is concerned with man-made organic contaminants artificially introduced into water -- specifically the A-280 organics -- a decision was made to include another group of man-made organic chemicals, trihalomethanes (THM), in the monitoring programs. Like many of the A-280 organics, THMs are suspected carcinogens. It is expected that THMs will also be regulated more stringently in the future under A-280. While THM formation is dealt with more fully in a separate study and report completed under the Special Water Treatment Study - Phase II contract, the following background material on THMs is useful in understanding the findings of the site-specific monitoring programs.

The majority of organic material present in water is composed of naturally occurring humic materials. These humic materials are very large molecular weight organics that result from natural chemical and biological reactions. Naturally occurring humic substances are very pervasive in surface waters.

Typically generated in the treatment process, trihalomethanes are common by-products of water chlorination. THMs form when free chlorine reacts with the naturally occurring humic organics found in most surface water supplies. Some of the A-280 organics can also play a role in THM formation. Naturally occurring organics that are specifically identified as playing a role in the formation of THMs are referred to as THM precursors, organic precursors, or simply precursors.

Trihalomethanes derive their name from their chemical structure. A trihalomethane molecule consists of a carbon atom bound to four other atoms. Of these four atoms, one is hydrogen and the other three are halogens. The halogens that can form THMs are chlorine (Cl), bromine (Br) and iodine (I). (Organohalides are the general set of carbon-based halogen compounds of which the THMs are a subset.) THMs generally occur at perhaps 10 percent of the total concentration of the organohalide contaminants that may also be generated.

The THMs commonly occurring in drinking water supplies that are regulated by both the State and federal government include chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), chlorodibromomethane ($CHBr_2Cl$), and bromoform ($CHBr_3$). Other, iodine-based THMs exist, but they are relatively uncommon and are not regulated. The chemical pathway to the formation of fluorine-based THMs is not a factor in the natural formation of THMs.

3.1.2 PROCESSES USED IN WATER TREATMENT PLANTS

Design and proper implementation of a sampling program requires a thorough understanding of the unit processes used in water treatment, and of their effects on volatile organics and THM precursors in the water.

Water treatment plants use many types of unit operations, processes, and equipment to produce safe, palatable drinking water. The unit operations and processes selected for a particular water are determined by a variety of factors including raw water quality, treatment requirements, treatment plant hydraulics, the plant designer's experience and preferences, availability of materials and equipment, site restrictions, and capital and operation costs.

Unit Processes

Unit processes, equipment and facilities commonly used in treatment plants include the following:

- Bar screens (coarse screens)*
- Traveling screens (fine screens)*
- Low-lift pumps
- Predisinfection
- Preoxidation
- Presedimentation/prestorage
- Aeration or Air Stripping
- Chemical Mixing/coagulation
- Flocculation basins*
- Sedimentation/flotation basins
- Filters
- Carbon adsorption
- Post-disinfection
- Filtered water storage
- High-lift pumps

*Typically found only in surface water plants

Descriptions of these unit processes and a brief assessment of the effect of each process on removal of volatile and precursor organics is provided below.

Raw Water Intake and Bar Screens. Intakes are used to draw water from rivers, lakes, and reservoirs to surface water plants. The raw water intake may be located at the shoreline or at some distance from the shore, and at different water depths. The function of the intake is to allow withdrawal of water from the river or reservoir over a preset range of water levels, and to protect the raw water conduit from damage or clogging by ice, trash, waves, currents or other conditions. Either open channels or pressure conduits may be used to bring the raw water supply from the intake to the plant.

Bar screens (also known as coarse screens) are used to prevent debris and large objects from entering the plant and damaging equipment, particularly raw water pumps. Bar screens with bars spaced from 2 to 4 inches on center are placed at the intake to the entrance. In water treatment plants, hand-cleaned bar screens are usually used. Mechanically cleaned bar screens are used where the amount of debris is excessive and could cause rapid clogging of the screens. Bar screens are sometimes placed in the intake channel or conduit.

Since raw water intakes are not designed to remove dissolved contaminants, reduction of volatile organics at this stage of the treatment process is not expected unless aeration results from the intake turbulence.

Traveling Screens. Traveling screens are mechanically driven, fine-screening devices with openings of about 1/8 inch to 1 inch. They rotate through the water as endless bands made of perforated, noncorroding metal plates or screens. The screens are cleaned by jets of water, brushes, or air blasts. Traveling screens are used to removed smaller debris not removed by bar screens.

Screening facilities can incidentally remove a very low level of volatile organics owing to turbulence or natural aeration.

Low-Lift Pumps. Low-head, vertical, turbine-type pumps are used to raise raw water from the surface water supply to an elevation that will enable gravity flow through the treatment plant. One or more pumps with a standby unit are used for pumping raw water. In some plants, these pumps are installed at the raw water intake.

Low-lift pumping will result in negligible removal of volatile organics. Only in those instances where the turbulence of pumping results in some aeration of the water can removal of organic contaminants be expected. The increase in discharge pressure can maintain volatile organics in solution.

Predisinfection/Preoxidation. Chlorine, chlorine dioxide, potassium permanganate, ozone and chloramines have been used for predisinfection and preoxidation. Many plants have changed disinfectant practices to minimize the formation of trihalomethanes. Ozone and chlorine dioxide, which do not form THMs, are rapidly emerging as the most popular predisinfectants.

Both ozone and chlorine dioxide can generate oxidation by-products. Ozone by-products have not been measured routinely, nor have their health effects been extensively evaluated, as have those of the chlorinated organics, but they are thought to be relatively innocuous. Chlorine dioxide can produce chlorites, which can have toxic effects. (Chlorites are formed during the chlorine dioxide generation reaction.) Because chlorine dioxide use is limited by most states to 1 milligram per liter (mg/l), which limits the concentration of chlorites, its oxidation by-products are not considered a to be a problem. If the USEPA promulgates stricter standards for disinfectant by-products, then this subject must be revisited.

The effect of chlorine, ozone, chlorine dioxide, potassium permanganate and chloramines on volatile A-280 organics should be negligible at the disinfectant concentrations normally encountered in water treatment practice. While chlorine dioxide, ozone and chloramines do not form THMs, the oxidation effect of each of these disinfectants on precursors can increase or decrease the potential to form trihalomethanes.

Predisinfection and preoxidation will not affect the formation or removal of volatile A-280 organics in New Jersey treatment plants. However, predisinfection and preoxidation will affect the potential for THM formation. Additionally, prechlorination can adversely affect the ability of activated carbon treatment processes to remove organics by reducing the carbon adsorption capacity over time.

<u>Presedimentation/Prestorage</u>. At larger surface water treatment plants water is sometimes diverted from the source for storage prior to treatment. The duration of storage may last from a few hours to a few days. Some minor volatilization of synthetic organics may be expected during prestorage but not to a significant level. If raw water is chlorinated for algae control prior to prestorage, trihalomethanes can form. Chlorine dioxide is replacing chlorine as a preferred predisinfectant for prestorage.

<u>Aeration or Air Stripping</u>. Aeration is widely used in water treatment plants for the removal of dissolved gases such as hydrogen sulfide and carbon dioxide, for removal of volatile organic substances and/or inorganic substances such as iron and manganese, for addition of oxygen to water, or for reduction of volatile taste and odor. Aeration processes bring water and air into close contact. This may be accomplished either under atmospheric pressure or under higher pressures. Aeration under atmospheric pressure can be carried out by (a) spraying through nozzles, (b) natural cascading over a series of tray aerators or trickle plates, (c) gravity flow in induced-draft, multiple-slat tower aerators, (d) gravity flow in natural-draft, coke-tray aerators, (e) aspirator-type aerators and (f) flow through a random packing. Pressure aeration is generally carried out by diffusion or bubble aerators using compressed air.

Air stripping is one of the preferred processes for the removal of volatile organics. It can achieve very high levels of removal, depending on the configuration of the aeration system.

Aeration or air stripping will reduce volatile contaminants such as hydrogen sulfide, carbon dioxide, and many volatile A-280 organics, including trichloroethylene, tetrachloroethylene, benzene, 1,1,1-trichloroethane and vinyl chloride. The trihalomethanes are moderately volatile and can be removed by air stripping. However, the trihalomethane formation reaction is slow, and maximum levels of THMs are usually reached at the extremities of a water system. Removal at the source may not be an effective control if the formation reaction is not complete. Organic precursors that can react with chlorine to form THMs are not naturally volatile and, therefore, not amenable to removal with air stripping.

Chemical Mixing. Chemical mixers are devices used to blend treatment chemicals with the plant flow prior to flocculation. Mixers used in water treatment plants include mechanical flash mixers, in-line propeller mixers and blenders, and in-line static mixers. Mixing of treatment chemicals with raw water changes the physical and chemical characteristics of the water.

Low-level removal of volatile A-280 organics can be expected from mixing as a result of aeration caused by turbulence. Organic THM precursors can be coagulated in chemical mixing, for subsequent reduction by sedimentation and filtration.

Flocculation Basins. Flocculation is a pretreatment process used extensively in water treatment. In the coagulation process, chemicals such as aluminum sulfate, sodium aluminate, ferric chloride, lime, and caustic soda are added to the raw water either alone or in combination. The purpose of this chemical addition is to create electrostatically neutral particles (coagulation) that can subsequently be agglomerated by gentle mixing (flocculation). Coagulation takes place as an instantaneous process when chemicals are mixed with water.

Flocculation follows chemical coagulation. Flocculation causes collisions between particles and increases the size of flocs formed after coagulation.

This is accomplished by gently stirring the treated water, bringing the flocs and colloids into contact. Sometimes polyelectrolytes (polymers) and/or activated silica are added during chemical mixing to assist the flocculation process.

Flocculation basins can achieve incidental removal of synthetic organics. Organic THM precursors will be coagulated and flocculated for subsequent precipitation and filtration. However, the A-280 volatile organics will not be significantly reduced by flocculation, except for the minor volatilization that occurs at the liquid/air interface of the mixing tank.

Sedimentation/Flotation. Sedimentation basins are used to remove, by settling, suspended particles or flocs produced by the coagulation-flocculation processes. The simplest form of sedimentation basin is a rectangular or circular tank. Tube or plate settlers are sometimes used to enhance settling.

Dissolved air flotation tanks are gaining popularity in the United States since flotation systems can be designed for high overflow rates and short detention times. The minute air bubbles that create a "float" on the tank surface can cause some stripping of volatile organics.

Volatile A-280 organics will not be significantly removed by sedimentation. However, significant removals may be expected in flotation systems. While sedimentation and flotation will not reduce trihalomethanes, they will significantly reduce coagulated organic THM precursors.

Filtration. Filtration is used to remove small, suspended particles remaining in water after clarification. Common filtration systems include slow sand filters, rapid sand filters, single-media deep bed filters, dual-media filters (anthracite over sand), and multimedia filters. Other types of filters such as microstrainers and pre-coat filters are also used in water treatment. Gravity filters are typically used for surface water treatment, while pressure filters are used for treatment of ground water.

Floc particles too small to settle or float are removed in surface water plants by filtration. Organics entrapped by the floc that were not previously settled will be removed. No significant removal of volatile organics by filtration can be expected.

Carbon Adsorption. Activated carbon has been used for many years in water treatment as an adsorbent for the removal of tastes and odors. Powdered activated carbon (PAC) has been most widely used for removal of naturally occurring taste and odor. Granular activated carbon (GAC) has also been used for removal of phenol and other taste-producing compounds. In recent years, with increasing contamination of water supplies from industrial chemicals, GAC has gained wide popularity.

PAC is used in slurry form and is added prior to the coagulation process or immediately before filtration. Depending on the extent of the taste and odor problem, the PAC feed rate may vary from about 2 to 20 mg/l.

Granular activated carbon can be applied after filtration or can be used in place of filtration after sedimentation. In either case, the adsorption efficiency depends on the contact time between the carbon and water. Adsorption with activated carbon is probably the most efficient treatment technique for adsorbing nonvolatile synthetic organics. It can also be used to reduce volatile organics to very low levels. Although GAC is only moderately effective in removing trihalomethanes, it is very effective in removing naturally occurring THM precursors.

Carbon is highly effective for the removal of volatile and synthetic organics. However, it is much more effective in the form of GAC than as PAC because a given volume of GAC has much more adsorptive capacity than an equivalent dosage of PAC.

Post-disinfection. Post disinfection practice will not affect A-280 volatile organics at the concentrations of disinfectants normally used to treat water. However, if chlorine is added, it can react with remaining precursors to form trihalomethanes.

Filtered Water Storage. In most water treatment plants there is a clearwell or storage tank for storing filtered water. Disinfectants (usually chlorine) are added before the water enters these clearwells to ensure that adequate contact time is attained. A small amount of chlorine is also used to prevent biological growth. Chemicals such as lime or sodium hydroxide are sometimes added to the filtered water to adjust the pH for corrosion control.

High-Lift Pumps. High-lift pumps are used to deliver treated water from the treatment plant to elevated storage tank(s) or to the distribution system. Generally, high-lift pumps draw water from the filtered water storage tank. As with low-lift pumping, negligible removal of organic contaminants can be expected.

3.2 SAMPLING PROGRAM IMPLEMENTATION

3.2.1 PLANT DESCRIPTIONS

Sampling programs were designed for eleven water treatment plants and sampling was performed at five plants in accordance with the scope of services. The five plants at which sampling programs were carried out did not undertake any major modifications specifically for the removal of volatile or synthetic organics. Consequently, any removal of volatile or synthetic organics from, or generation in, the treatment process would be due to the conventional treatment process.

The plants and dates of sampling are listed below:

- Passaic Valley Water Commission, Little Falls Water Treatment Plant

  February 2, 1986
  August 27, 1986
  December 3, 1986

- Rahway, Westfield Avenue Water Treatment Plant

  February 9, 1986
  September 4, 1986
  November 21, 1986

- Hawthorne, Wagaraw Road Water Treatment Plant

  January 28, 1986
  September 9, 1986

- Camden, Parkside Water Treatment Plant

  January 21, 1986
  September 16, 1986

- Merchantville-Pennsauken Water Commission, Park Avenue Water Treatment Plant

  January 21, 1986

Plants for which sampling programs were designed, but not executed, included:

- Newark Water Department, Charlotteburg Water Treatment Plant
- North Jersey District Water Supply Commission, Wanaque Water Treatment Plant
- Jersey City, Boonton Reservoir Water Treatment Plant
- Elizabethtown Water Company, Raritan-Millstone Water Treatment Plant
- Monmouth Consolidated Water Company, Swimming River Water Treatment Plant
- Trenton Water Treatment Plant

Brief descriptions of the treatment processes used at each of the five plants at which sampling was done are presented below. Process flow schematics for the plants are shown in figures 3-1 through 3-5.

Rahway, Westfield Avenue Water Treatment Plant. The Westfield Avenue Water Treatment Plant receives its supply from the Rahway River. Because the watershed of the Rahway River is highly urbanized and industrialized, the Rahway Water Department has instituted a regular drainage area sampling and monitoring program to protect the quality of the raw water.

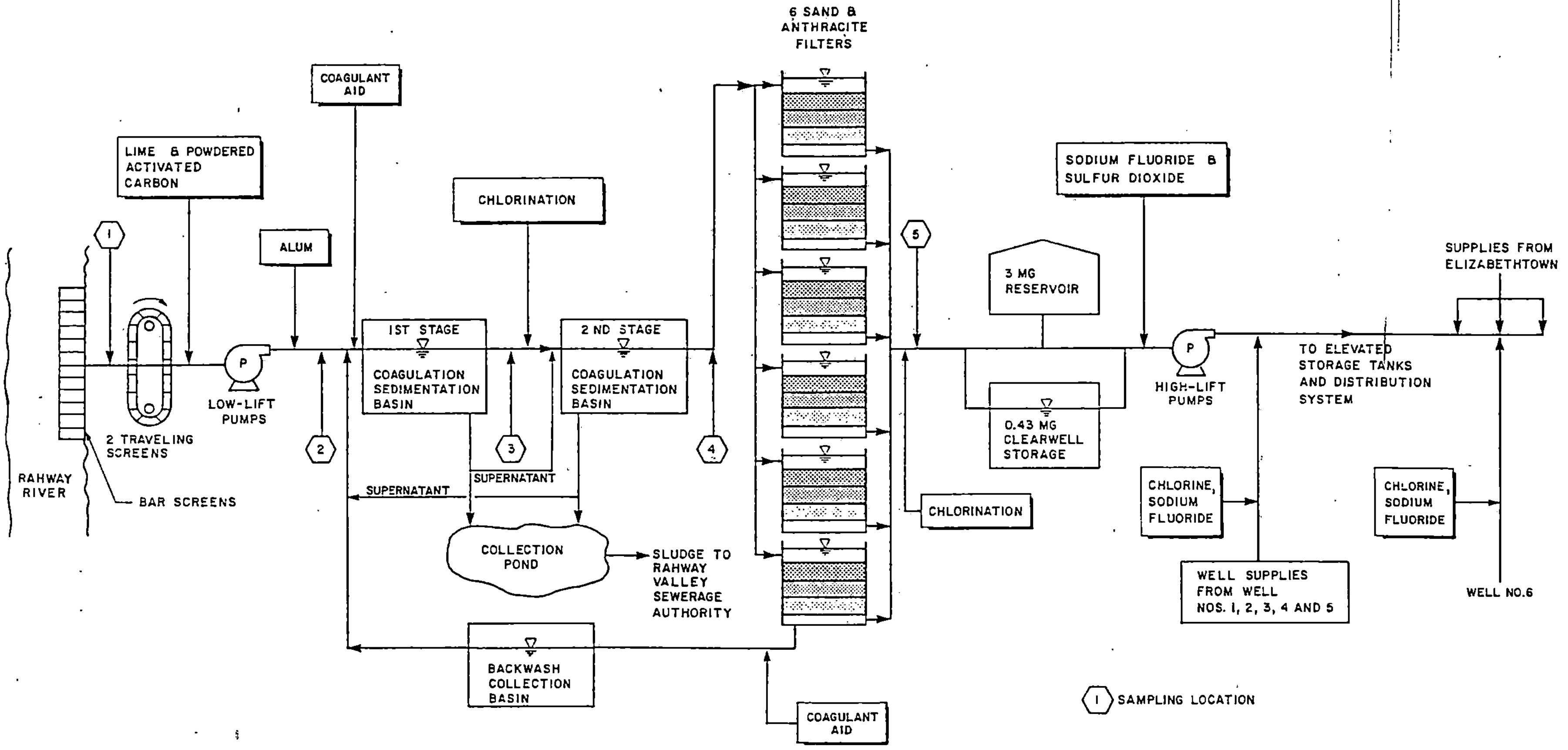

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Figure 3-1

Process Flow Schematic
Rahway's Westfield Avenue WTP
Special Water Treatment Study - Phase II

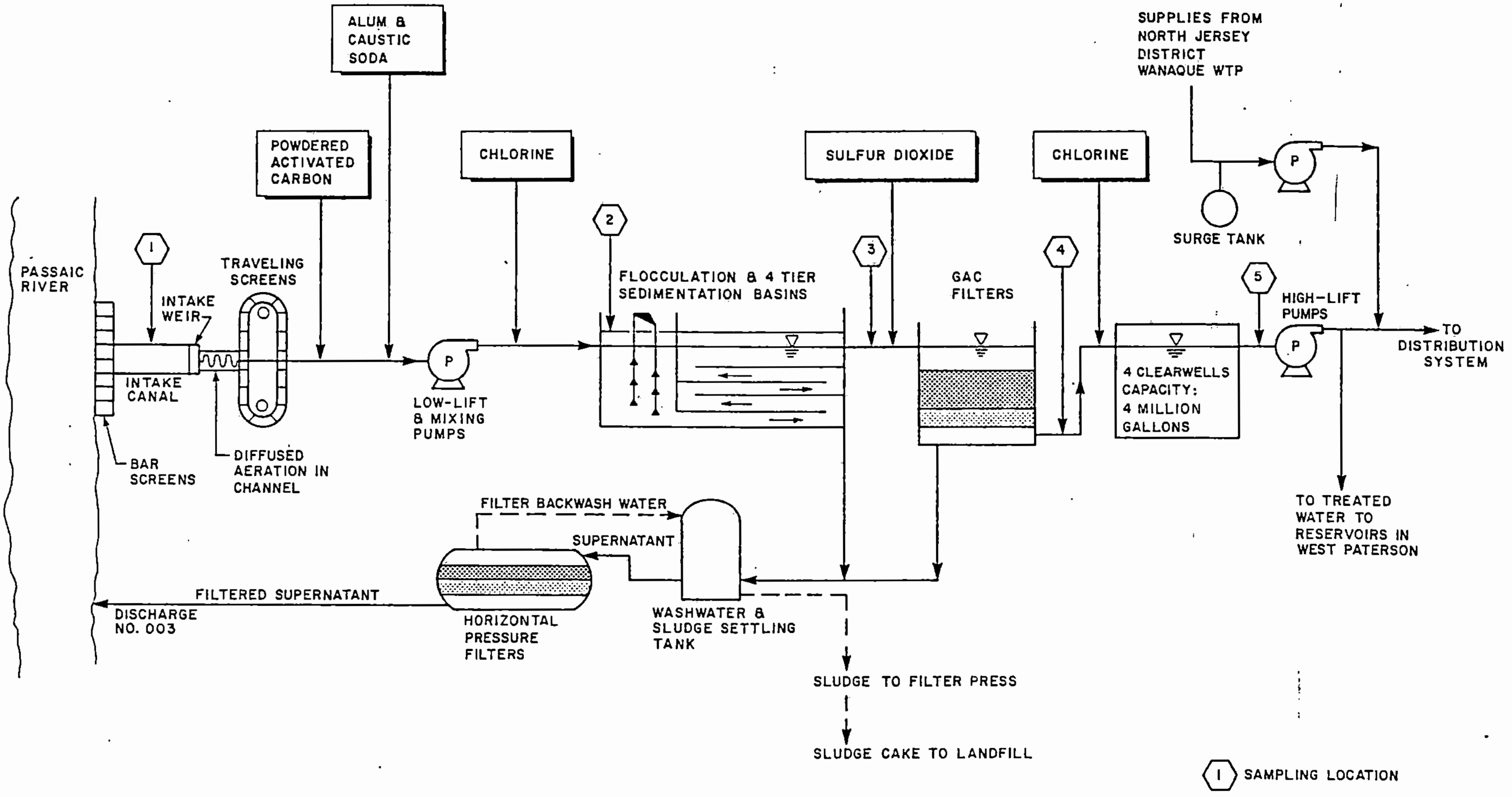

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Figure 3-2

Process Flow Schematic
Passaic Valley Water Commission's Little Falls WTP

Special Water Treatment Study - Phase II

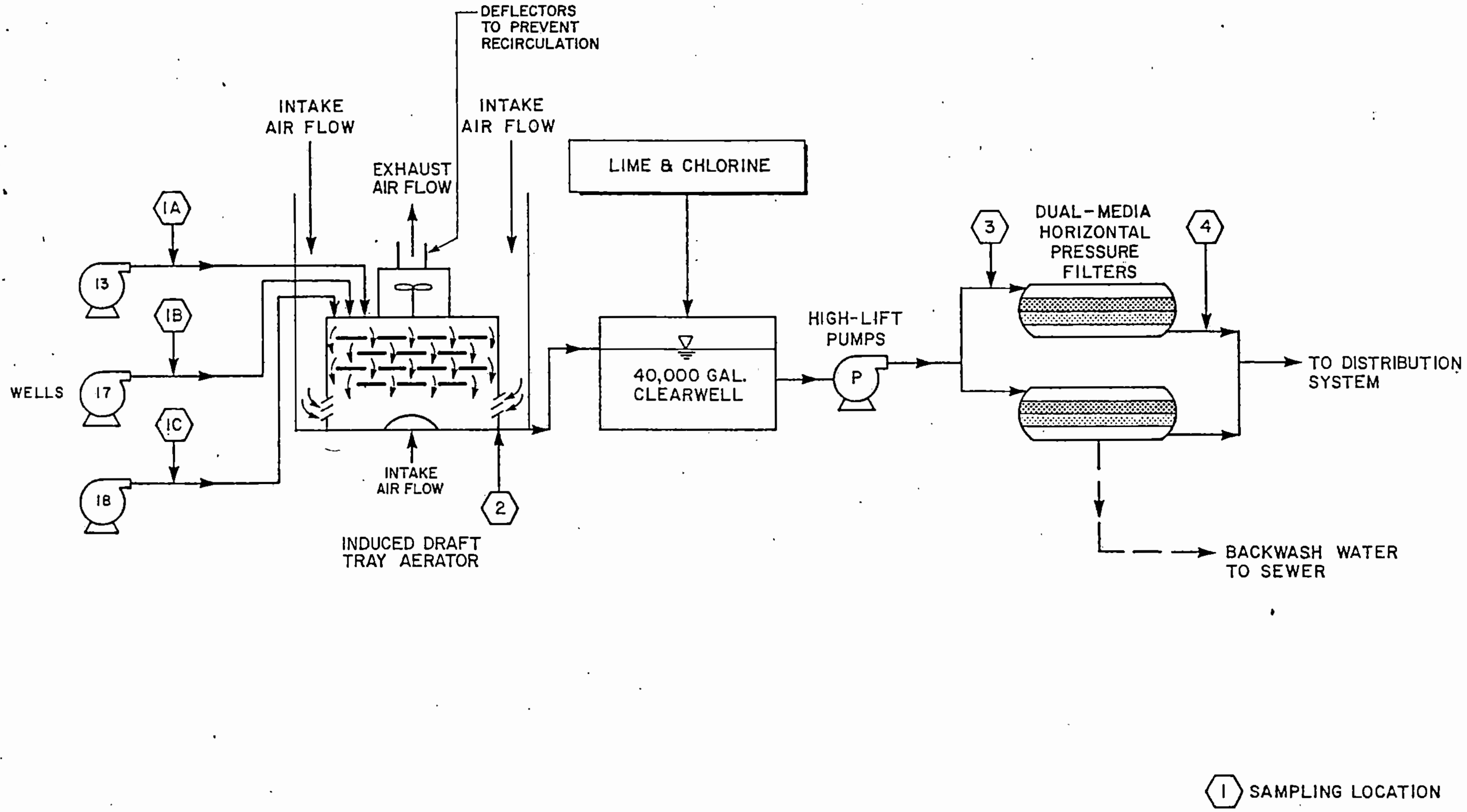

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Figure 3-3

Process Flow Schematic
Camden's Parkside WTP

Special Water Treatment Study - Phase II

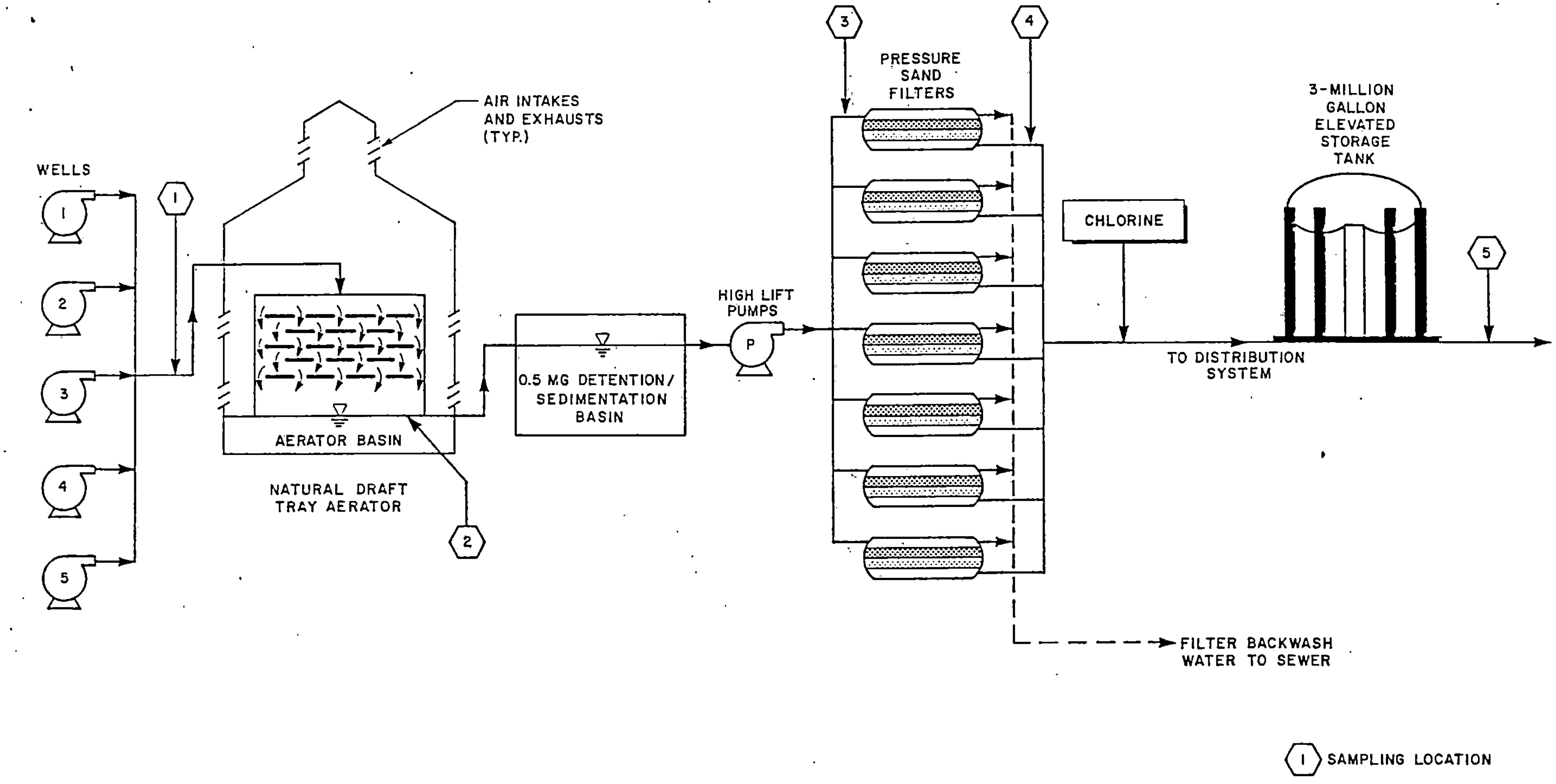

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Figure 3-4
Process Flow Schematic
Merchantville-Pennsauken's Park Avenue WTP

Special Water Treatment Study - Phase II

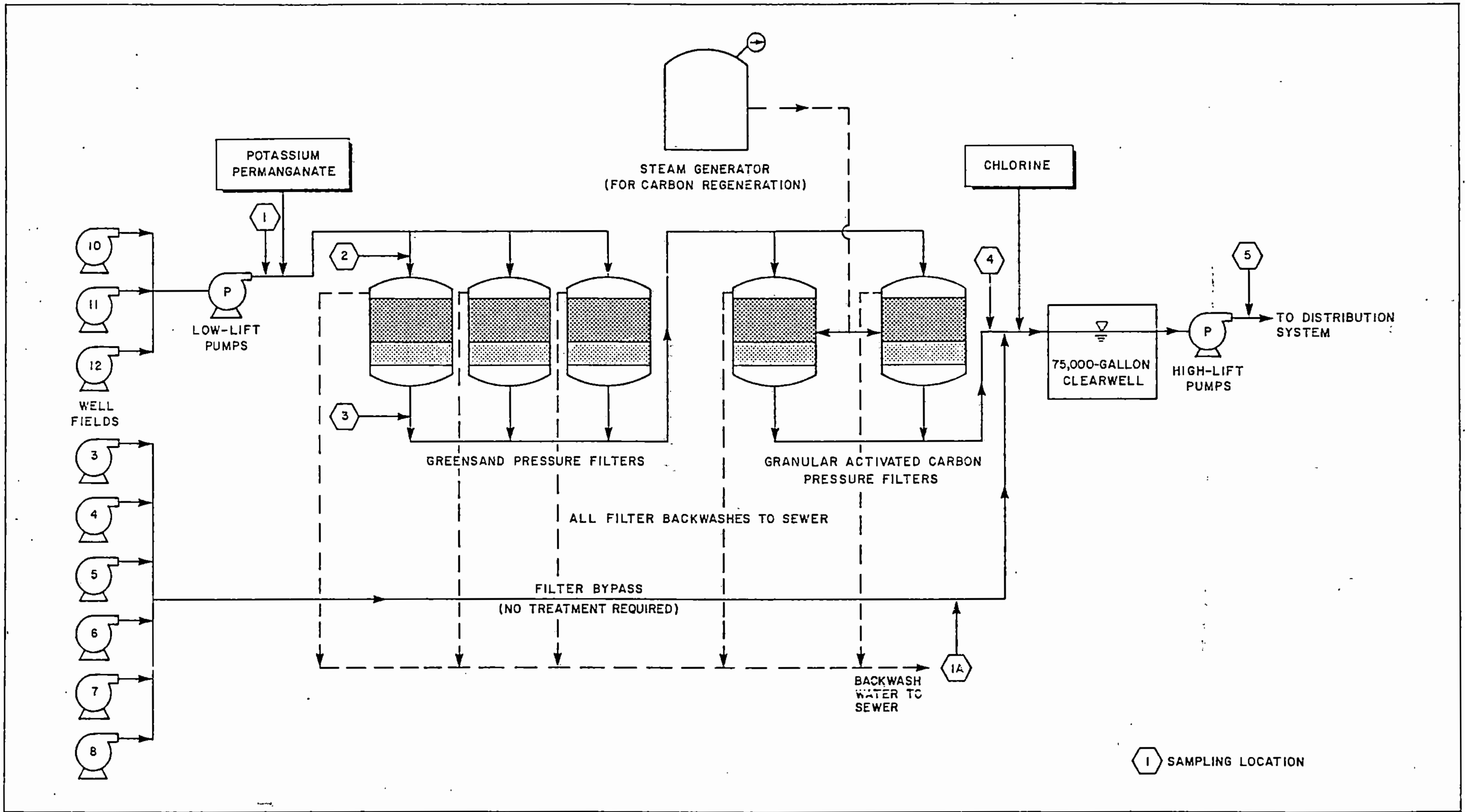

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Figure 3-5
Process Flow Schematic
Hawthorne's Wagaraw WTP

Special Water Treatment Study - Phase II

The Rahway plant is currently operated at 6-mgd average flow, though it is rated at 10 mgd. At the pump intake, raw water is pretreated with PAC and lime slurry. There is also the provision to feed chlorine at the intake, but this is not practiced in the interest of reducing trihalomethane formation. The plant has two coagulation-sedimentation basins operated in series, followed by anthracite-sand, dual-media filters. The effluent from the first basin is chlorinated before entering the second coagulation-sedimentation basin. There is provision for chlorinating the filtered water, but this is not used since chlorine is added prior to the second coagulation-sedimentation basin.

Passaic Valley Water Commission, Little Falls Water Treatment Plant. The Little Falls Water Treatment Plant is located in southern Passaic County on the north bank of the Passaic River, from which it draws raw water for treatment. (Water from the Wanaque Reservoir is sometimes blended with the Passaic River water.) The original plant was completed in 1902. A second phase expansion of the plant was constructed in 1966. An ongoing reconstruction and expansion program, almost completed, will increase the plant's capacity from 65 to 100 mgd.

Water is drawn through sluice gates into the intake conduit of the plant, where PAC can be added to the raw water. The water then passes through the chemical feed building where alum, cationic polymer and, when necessary, caustic soda, are added to the water. The water is then chlorinated to breakpoint, the point where ammonia in the raw water has been completely oxidized by chlorine. Sampling water in the enclosed space where breakpoint chlorination by-products air concentrations are high, poses certain risks to the personnel performing the sampling.

After flocculation and sedimentation, the water is dechlorinated with sulfur dioxide as it flows from the sedimentation basins to the filters. At the time of this study, two different types of filters were in use at the Little Falls plant, granular activated carbon and dual-media sand and anthracite filters. In executing the Phase II study's sampling program, only the GAC filters were sampled. Subsequent to this sampling, the GAC treatment system was removed as part of the plant renewal and expansion.

Caustic soda and chlorine are added to the water as it flows from the filters to the high-lift pumping station.

Camden, Parkside Water Treatment Plant. The Parkside Water Treatment Plant draws water from three wells in the upper Potomac-Raritan-Magothy (PRM) aquifer. Each well's discharge line feeds separately to the top of a 15-foot-square by 12-foot-high induced draft aerator, which was originally designed for the removal of carbon dioxide and iron. The water cascades down through the redwood trays of the aerator to the bottom tray, and from the bottom tray into a wet well. Inadvertent recycling of air from the tower masked removal but was later minimized by improved separation of the exhaust and intake air ducts. Both lime slurry and chlorine are fed directly into the wet well. Settled water is drawn from the wet well and pumped through two multi-cell pressure filters.

Merchantville-Pennsauken Water Commission, Park Avenue Water Treatment Plant. The Merchantville-Pennsauken water treatment plant draws from five wells drilled into the upper PRM aquifer. The water is then pumped to the top of a natural draft aerator. The aerator is approximately 20 feet high and 25 feet square. Two drop shafts allow the aerated water to flow from the aerator basin to a half-million-gallon reaction/detention basin. The water is then pumped into seven horizontal pressure filters. Chlorine is added to the filtered water to form a residual of about 0.1 mg/l. Design of a packed aeration tower was initiated subsequent to the sampling.

Hawthorne, Wagaraw Road Water Treatment Plant. The Hawthorne Water Treatment Plant draws its water from three wells that contain varying levels of synthetic organic compounds. These wells also contain iron and iron oxidizing bacteria. The raw water has iron and manganese concentrations between 1 and 2 mg/l. Potassium permanganate ($KMnO_4$) is used to oxidize the iron and manganese present in the raw water. After addition of potassium permanganate, the water passes through three 10-foot-diameter manganese greensand vertical pressure filters. The potassium permanganate feed also serves to regenerate the filter beds. The filtered water then flows to two 9-foot-diameter GAC vertical pressure contactors. These filters are intended for removal of taste-inducing phenols. Steam cleaning of the carbon is periodically performed to regenerate the carbon's absorption capacity for phenols. Following the carbon contactors, the water is mixed with the raw water from a second well field. The combined water is then chlorinated and flows into a clearwell. From the clearwell, the water is pumped to the distribution system.

After the period of water sampling at this plant, a series of process modifications was begun. Packed aeration towers are being added to remove volatile organics from the raw water, and vapor-phase GAC is being installed to control the VOC emissions in the air exhaust.

3.2.2 SELECTION OF SAMPLING POINTS

Optimum sampling points for evaluating process effectiveness in removing organic contaminants, and for identifying locations where organics are generated, are as follows:

- Raw water sampling prior to fine screening by traveling screens, to establish what is coming into the plant
- Raw water sampling following the traveling screens, to determine how much of the volatile organics are removed by the traveling screens
- Treated water sampling after addition and mixing of pretreatment chemicals, to determine changes in chemical quality of the raw water, particularly formation of THMs due to prechlorination
- Settled water sampling after flocculation/sedimentation, to detect any removal of organic precursors (which generate THMs due to chlorination) and organic compounds associated with the flocs and colloidal substances
- Filtered water sampling at the filter effluent line, to measure removal of organic compounds that may be attached or adsorbed to the suspended solids removed by the filter media
- Post-chlorinated water sampling after addition and mixing of chlorine with treated water and after sufficient detention to allow formation of THMs (when dissolved organics react with chlorine), to measure THM formation
- Aerated water sampling following the aerators, to determine removal of any portion of the volatile organic compounds present in the water

- Adsorbed water sampling following GAC filtration, to determine removal of organic compounds and reduction of contaminant peaks

- Adsorbed water sampling following addition of PAC and after the removal of the PAC containing organic contaminants, either by settling or by filtration, to measure reduction of organic compounds

Sampling at the above locations in a treatment plant will generally provide sufficient entry and exit data for each process to evaluate a treatment plant's effectiveness. Not all plants have all the processes identified above, however. Before a sampling program is undertaken, a schematic of the plant's process flow should be prepared to determine the suitable locations for sampling. For the five plants sampled for this study, selected sampling points are indicated on the process schematics (figures 3-1 through 3-5).

3.2.3 SAMPLING PROCEDURE AND METHODOLOGY

It is crucial to time the taking of samples so that all samples are taken from the same slug of water as it enters and exits each treatment process. This method of sampling minimizes the effects of variable water quality on the performance of the unit processes. The methods used to approximate detention time in each unit process are described below.

To determine detention times, complete mixing and plug flow through a particular process was assumed. For processes that deviate from plug flow, the use of composite samples at the inlet and/or outlet of the unit process was considered. (It may also be appropriate with such processes to use a detention time longer than the theoretical plug flow detention time.) Examples of processes that may require composite samples are filters, coagulation/flocculation basins, and sedimentation basins. Generally, the detention times of typical unit processes range from a few minutes to several hours. The longer the detention time, the more advisable the use of composite sampling. A typical composite sampling scenario would be to take three samples at 15-minute intervals for a total of one-half hour.

For most analytical parameters, composite samples can be made up in the field. For volatile parameters, such as the volatile organics and purgeable organic halides (POX), it is necessary to take grab samples in the field and have the samples composited in the laboratory by methods that eliminate the risk of volatilization of the parameter from the sample prior to analysis.

An attempt was made to ascertain the effect of seasonal variations on the fate of A-280 contaminants. Sampling events were conducted at the surface water plants in the winter, late summer, and late fall during a storm. Two of the three ground water treatment plants were sampled in both the winter and later summer. In particular, in the late fall when the leaves are on the ground, it was expected that the THM precursors would be unusually high. Sampling after a storm event can yield data showing extreme variations in chemical concentrations.

The winter surface water sampling event was to coincide with a period when ice covered the water bodies. Prior studies had suggested that any volatile organics present in the water would be prevented from dissipating into the air by the ice cover. Hence, higher-than-usual levels of VOCs might be detected in the samples. However, owing to difficulties with coordination of sampling teams and laboratories, winter sampling was performed while the surface waters were only partially ice covered.

Before samples are taken, a detailed sampling schedule should be prepared. Tables 3-2 and 3-3 show the sampling schedules prepared for four of the plants sampled for this study. The schedules identify all the chemical parameters to be analyzed for, the selected sampling points within the plant, and the type of sample to be taken (grab sample, field composite sample, or lab composite sample).

A major concern during sampling is the safety of individuals. Special care should be taken when working near potentially hazardous mechanical equipment such as pumps and treatment chemicals such as chlorine. All sampling personnel should be properly warned and trained.

Table 3-2

Surface Water Treatment Plant Sampling Schedule

Parameter Schedule

	Treatment Plants and Sampling Locations									
	Plant B					Plant A				
Parameter List	Raw water sample #1	Treated water sample #2	Settled water sample #3	Post-filtration sample #4	Post-chlorination sample #5	Raw water sample #1	Treated water sample #2	Pre-chlorinated water sample #3	Settled water sample #4	Filtered water sample #5
Purgeable organics - Method 624	◊	◊	CL	CL	◊	◊	CL	CL	CL	◊
Base/neutrals - Method 625	◊	-	CF	CF	-	-	-	CF	CF	-
Acid extractables - Method 625	◊	-	CF	CF	-	-	-	CF	CF	-
Pesticides/PCBs - Method 608	◊	-	CF	CF	-	-	-	CF	CF	-
Total organic halides	◊	◊	CF	CF	◊	◊	◊	◊	CF	CF
Purgeable organic halides	◊	◊	CL	CL	◊	◊	◊	◊	CL	CL
Total organic carbon	◊	◊	CF	CF	◊	◊	◊	◊	CF	CF
Chlorides	◊	◊	CF	CF	◊	◊	◊	◊	CF	CF
Iron	◊	-	-	-	◊	-	-	-	-	◊
Manganese	◊	-	-	◊	-	-	-	-	-	◊
Turbidity	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
True Color	◊	◊	◊	-	◊	◊	-	-	-	◊
Coliform	◊	-	-	-	◊	◊	-	-	-	◊
Chlorophyll [a]	◊	-	-	-	◊	◊	-	-	-	◊
Free chlorine	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Total chlorine	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Temperature	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Dissolved oxygen	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
pH	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Alkalinity	◊	-	-	-	◊	◊	◊	-	-	◊
Hardness	-	-	-	-	-	-	-	-	-	◊

Notes:
1. CL means three grab samples to be composited in the lab.
2. CF means field composite sample.
3. ◊ means grab sample.

Table 3-3

Ground Water Treatment Plant Sampling Schedule

Parameter Schedule

Parameter List	Treatment Plants and Sampling Locations											
	Plant C						Plant D					
	Well supply sample 1A, 1B, 1C			Post-aeration sample #2	Pre-filtration sample #3	Post-filtration sample #4	Well supply sample #1	Well supply sample #1A	Pre-filteration sample #2	Post-filteration sample #3	Post-GAC sample #4	Post-chlorination sample #5
Purgeable organics - Method 624	CL	CL	CL	CL	◊	◊	◊	◊	◊	CL	CL	◊
Base/neutrals - Method 625	-	-	-	-	-	◊	-	-	-	CF	CF	-
Acid extractables - Method 625	-	-	-	-	-	◊	-	-	-	CF	CF	-
Pesticides/PCBs - Method 608	-	-	-	-	-	◊	-	-	-	CF	CF	-
Total organic halides	CF	CF	CF	CF	◊	◊	◊	◊	◊	CF	CF	◊
Purgeable organic halides	CL	CL	CL	CL	◊	◊	◊	◊	◊	CL	CL	◊
Total organic carbon	CF	CF	CF	CF	◊	◊	◊	◊	◊	CF	CF	◊
Chlorides	CF	CF	CF	CF	◊	◊	◊	◊	◊	CF	CF	◊
Iron	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Manganese	◊	◊	◊	◊	◊	◊	◊	-	◊	◊	-	◊
Turbidity	◊	◊	◊	-	-	◊	◊	◊	◊	◊	-	◊
True Color	-	-	-	-	-	◊	-	-	-	-	-	◊
Coliform	-	-	-	-	-	◊	-	-	-	-	-	◊
Total Dissolved Solids	-	-	-	◊	-	◊	-	-	-	-	-	◊
Free chlorine	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Total chlorine	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Temperature	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Dissolved oxygen	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
pH	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Alkalinity	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
Hardness	-	-	-	◊	-	◊	-	-	◊	-	◊	-

Notes:
1. CL means three grab samples to be composited in the lab.
2. CF means field composite sample.
3. ◊ means grab sample.

Trihalomethane Formation Potential Test Procedure

An analytical test for the determination of total or terminal trihalomethane formation potential (TTHMFP) was developed in connection with this study. The uniqueness of this test in comparison to other TTHMFP test procedures is its ability to assess the terminal concentration of total THM precursors. It should be noted that the terminal THM concentrations are greater than any THM concentrations seen in the distribution system because of the high levels of chlorine, long contact times and higher temperatures employed in the test procedure.

These TTHMFP samples were spiked with sodium hypochlorite at the time of sample collection. The equivalent free chlorine residual was approximately 90 mg/l. The objective of this very high overdose of chlorine was to insure that there was sufficient free chlorine in the sample for complete termination of all formation of THMs, based on the precursors as the limit of the trihalomethane formation reaction. The pH of the samples was adjusted to 7.5 and the samples were maintained at 20 °C for 5 days, then quenched with sodium thiosulfate and iced, prior to submission to NJDEP's Bureau of Environmental Laboratories for GC/MS analysis.

QA/QC Procedures

The quality of data generated under a sampling program is only as good as the sampling procedures used. Sampling procedures should be thoroughly reviewed prior to implementation to ensure that the proper protocols are implemented to prevent unintended contamination of the sample or loss of the parameter of interest. These sampling procedures allow maintenance of the original sample composition and integrity.

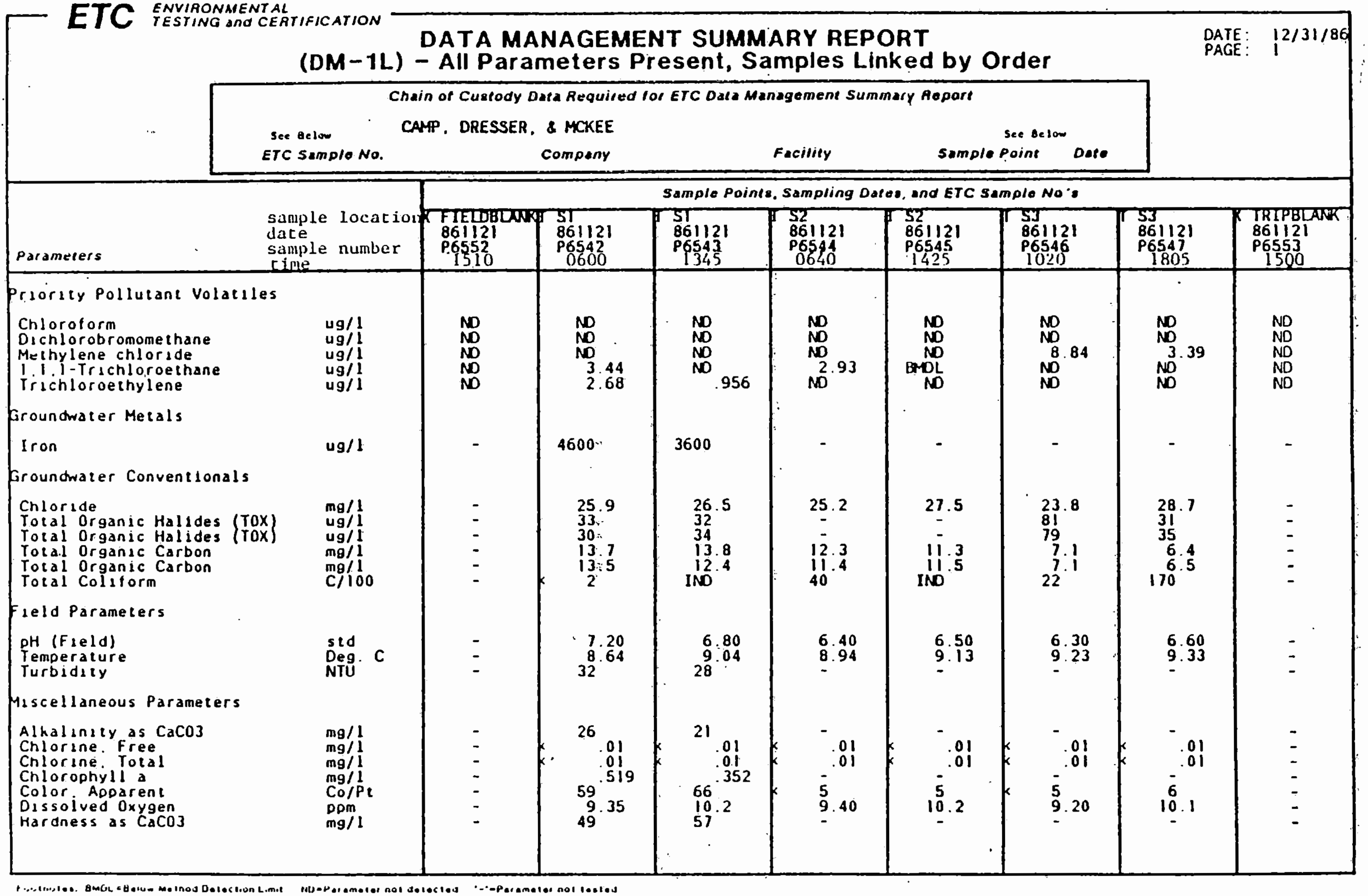
3.2.4 HOW TO INTERPRET ANALYTICAL REPORTS

In practice, interpreting the information conveyed by a commercial laboratory analytical report can be difficult. The sample sheets included in this chapter provide examples of anomalies that may warrant additional interpretation. Users of laboratory analytical data should become familiar with the sampling, analytical and reporting process as well as conditions at the treatment plant and in the watershed. It is difficult to draw appropriate conclusions from the data without this knowledge.

An example of a laboratory's summary analytical report for sampling performed at one of the treatment plants is shown in figure 3-6. In this report, both the trip blank and field blank show no evidence of priority pollutants. This indicates that the samples were probably taken and handled in an appropriate manner. However, this does not insure that all the samples were taken, handled, or analyzed in an appropriate manner. The engineer's responsibility remains to review each data point for analytical and process validity.

In the example data summary, the sampling points through the treatment process are arranged sequentially (e.g., S1, S2, S3, ...). For each sample, the date of the sampling, the laboratory identification number, and the time of the sampling are indicated. In addition to indicating the actual concentration of contaminants, this report also indicates ND for "not detected" and BMDL for "below method detection limit." These two terms are not synonymous. "Not detected" means that, according to the stated analytical technique, no evidence of the contaminant was found. An indication of "not detected" means that the overwhelming probability is that the contaminant is not present. However, its presence cannot be totally ruled out. "Below method detection level" means that the presence of the contaminant is indicated by a very small peak on the chromatograph, but at a concentration too low to quantify with any certainty.

Users of laboratory analytical data should be aware that many laboratory computerized data management systems report significant figures beyond the analytical capability of the laboratory instruments and equipment used. As a general recommendation, the engineer should round the data reported to the nearest whole unit. For example, if the contaminant is reported in mcg/l, then the data should be interpreted only to the nearest whole unit of mcg/l. The first decimal place after the whole unit can be used to



ETC ENVIRONMENTAL TESTING and CERTIFICATION

DATA MANAGEMENT SUMMARY REPORT
(DM-1L) - All Parameters Present, Samples Linked by Order

DATE: 12/31/86
PAGE: 1

Chain of Custody Data Required for ETC Data Management Summary Report

See Below	CAMP, DRESSER, & MCKEE		See Below	
ETC Sample No.	*Company*	*Facility*	*Sample Point*	*Date*

Sample Points, Sampling Dates, and ETC Sample No's

Parameters	sample location date sample number time	FIELDBLANK 861121 P6552 1510	S1 861121 P6542 0600	S1 861121 P6543 1345	S2 861121 P6544 0640	S2 861121 P6545 1425	S3 861121 P6546 1020	S3 861121 P6547 1805	TRIPBLANK 861121 P6553 1500
Priority Pollutant Volatiles									
Chloroform	ug/l	ND	ND	ND	ND	ND	ND	ND	ND
Dichlorobromomethane	ug/l	ND	ND	ND	ND	ND	ND	ND	ND
Methylene chloride	ug/l	ND	ND	ND	ND	ND	8.84	3.39	ND
1,1,1-Trichloroethane	ug/l	ND	3.44	ND	2.93	BMDL	ND	ND	ND
Trichloroethylene	ug/l	ND	2.68	.956	ND	ND	ND	ND	ND
Groundwater Metals									
Iron	ug/l	-	4600	3600	-	-	-	-	-
Groundwater Conventionals									
Chloride	mg/l	-	25.9	26.5	25.2	27.5	23.8	28.7	-
Total Organic Halides (TOX)	ug/l	-	33	32	-	-	81	31	-
Total Organic Halides (TOX)	ug/l	-	30	34	-	-	79	35	-
Total Organic Carbon	mg/l	-	13.7	13.8	12.3	11.3	7.1	6.4	-
Total Organic Carbon	mg/l	-	13.5	12.4	11.4	11.5	7.1	6.5	-
Total Coliform	C/100	-	k 2	IND	40	IND	22	170	-
Field Parameters									
pH (Field)	std	-	7.20	6.80	6.40	6.50	6.30	6.60	-
Temperature	Deg. C	-	8.64	9.04	8.94	9.13	9.23	9.33	-
Turbidity	NTU	-	32	28	-	-	-	-	-
Miscellaneous Parameters									
Alkalinity as CaCO3	mg/l	-	26	21	-	-	-	-	-
Chlorine, Free	mg/l	-	k .01	k .01	k .01	k .01	k .01	k .01	-
Chlorine, Total	mg/l	-	k .01	k .01	k .01	k .01	k .01	k .01	-
Chlorophyll a	mg/l	-	.519	.352	-	-	-	-	-
Color, Apparent	Co/Pt	-	59	66	k 5	5	k 5	6	-
Dissolved Oxygen	ppm	-	9.35	10.2	9.40	10.2	9.20	10.1	-
Hardness as CaCO3	mg/l	-	49	57	-	-	-	-	-

Footnotes: BMDL=Below Method Detection Limit   ND=Parameter not detected   '-'=Parameter not tested

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Figure 3-6

Example Laboratory Analytical Report

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differentiate between two measurements that round off to the same whole value. The second decimal place should generally be disregarded. For example, when reviewing the fate of 1,1,1-trichloroethane in figure 3-6, sample S1 at 6:00 a.m. and sample S2 at 6:40 a.m. indicate that 3.44 mcg/l and 2.93 mcg/l were found at the respective sampling points. After rounding these figures to the first decimal place and observing that the difference between 3.4 mcg/l and 2.9 mcg/l is 0.5 mcg/l, a tentative conclusion can be made that some low-level removal of 1,1,1-trichloroethane is occurring between these two sampling points.

A puzzling aspect of the data within the report in figure 3-6 is the indication of methylene chloride in both the 10:20 a.m. and 6:05 p.m. samples at sample point S3. Methylene chloride, as discussed earlier, is a compound used widely by laboratories and its presence is often a result of accidental contamination of samples. Therefore, unless a pattern of methylene chloride occurrence is found in the water samples, it can usually be presumed that the methylene chloride's origin is the laboratory. This highlights the need to obtain and review laboratory quality control work done on that batch of samples. In this particular case, there was no evidence of methylene chloride in the field blank, trip blank or other samples. In addition, the methylene chloride was detected at the same sampling point at different times of the day. This represents a situation that at the least requires further investigation of the laboratory and treatment plant operation, and may not be fully amenable to a complete and thorough explanation. If a conclusive statement on the existence of methylene chloride is needed, resampling may be necessary.

Tentatively Identified Compounds

As part of the GC/MS work, many laboratories will also perform a computerized library search routine designed to provide additional qualitative and quantitative information on nonpriority pollutant compounds that are present in the chromatograms of samples analyzed by GC/MS. This computerized algorithm typically uses the National Bureau of Standards, National Institute of Health, and Environmental Protection Agency mass spectral data bases, which contain approximately 42,000 unique entries.

At the conclusion of the data search, the computer algorithm attempts to match the unknown spectra with those in its data base. The best library matches are typically printed in the sample report along with the actual sample spectrum and a bar graph of the difference between the two spectra. The program estimates the probability of having selected the correct compound (in percent). The program also calculates a semiquantitative value for the concentration of the identified compound. Further description of the GC/MS equipment is provided in chapter 4.0.

It is crucial to note that, for a definitive determination of the existence of a nonpriority pollutant compound in a sample, a properly trained chemical analyst must review the spectral information. Currently, a computer is less accurate in identifying nontarget compounds than is a chemist.

As part of this study, nonpriority pollutant mass spectral data was generated from all the treatment plants sampled. At this writing, none of this data has been reviewed in a formal manner by a trained analytical chemist. In order to more fully understand the types of organics found and generated at water treatment plants, we recommend that this task be performed.

3.3 INTERPRETATION OF ANALYTICAL RESULTS

After receipt of results from a commercial laboratory, a water supplier must face the task of interpreting the analytical results. There are two aspects to this interpretation. First the supplier must be able to confirm the validity of the data. Second, he must be able to correctly interpret the data and understand its regulatory and technical implications.

3.3.1 DATA VALIDITY

An important part of any data validation program is the proper interpretation of blank sample data generated in conjunction with a sampling program.

A blank is a special type of sample used for quality control. It is made from carefully prepared, distilled water that is free from any detectable levels of contaminants (analyte free). There are three types of blanks generally used: field blanks, trip blanks, and lab blanks.

A field blank sample is prepared at the sampling location. Analyte-free water is brought to the field where it is repackaged in sample vials under conditions very similar to those under which the actual samples are taken. The purpose of the field blank is to determine if any contamination was introduced into the samples in the collection process. The sources of this contamination may include sampling equipment and atmospheric sources. The field blank should be exposed to the same field conditions as the actual sample.

The trip blank is prepared at the laboratory with analyte-free water in sample vials. It is carried to and from the sampling location with the other samples and remains unopened. The trip blank is used to determine if contamination may have been introduced in transit to and from the laboratory or as a result of site conditions. One potential source of contamination is exposure to the atmosphere.

The lab blank is produced by the laboratory from analyte-free water at the time of sample analysis. This blank never leaves the environment of the laboratory. The purpose of the lab blank is to monitor the levels of contaminants in the laboratory atmosphere and equipment. Many commercial laboratories subtract lab blank concentrations from the sample concentrations prior to reporting the analytical results.

Generally, as a criterion for data acceptance, any blank may contain up to five times the required Method Detection Limits (MDL) of any particular parameter. However, a concern should arise if the level of any parameter in any blank exceeds three times the MDL. The contaminants most likely to appear in the blanks are methylene chloride, acetone, and toluene because of their pervasive use in laboratories. Because methylene chloride is regulated under A-280, any data that indicates evidence of methylene chloride should be carefully reviewed.

3.3.2 INTERPRETATION OF THE DATA

The findings based on three executed sampling programs focus on three major sets of issues:

1. Extent of volatile organics in raw water from surface and ground water supplies
2. Confirmation of expected removals in the water treatment process
3. Generation and removal of trihalomethanes and chlorination by-products

Raw Water Concentrations

The selection of the water treatment facilities to be sampled was based on the expectation that there may be volatile organics in the raw water. For surface water facilities, the level of urbanization/industrialization upstream from the water intake was considered because higher levels of development would more likely result in detectable levels of volatile organics in the raw water. The concern was that there be sufficient concentrations of contaminants to assess their removal through the various treatment processes.

In general, ground water quality will not vary with time. However, at one ground water facility sampled, raw water VOC concentrations did appear to vary slightly from the morning to the afternoon. This unexpected finding remains unexplained because contamination in ground water tends to be persistent and to attenuate slowly. At surface water intakes, there appears to be more variability in the type of contamination over time and on a seasonal basis. However, observed concentration levels of individual chemicals tend to be below 5 mcg/l.

Surface Waters. The types of organic contaminants observed in raw surface waters fall into two general categories:

1. Relatively uncommon contaminants that are also nonvolatile, and therefore tend to be resistant to removal by the natural aeration of the surface water body. These contaminants tend to be found in the base-neutral fraction of the priority pollutant list.
2. Volatile contaminants that appear in ground water and have been placed on the A-280 list. They have been found in surface waters at less than 10 mcg/l. These compounds tend to be found in the volatile portion of the priority pollutant list.

Contaminants from the second category were observed with much greater frequency than those from the first category. In fact, except for the occurrence of napthalene, no base neutral compounds were evident above stated detectable levels. The following volatile compounds were observed at concentrations above detectable levels in the raw water:

Dichlorodifluoromethane
1,1,1-Trichloroethane
Trichloroethylene
trans-1,2-Dichloroethylene
Trichlorofluoromethane

In addition, there is evidence of methylene chloride and trihalomethanes in the raw water. Lab results indicating methylene chloride in water samples are usually considered erroneous and disregarded, particularly if there is evidence of this compound in the field blank or trip blank, because use of methylene chloride in the laboratory is so pervasive that contamination of samples by this compound is common. Evidence of trihalomethanes in the raw water may indicate that the water has been previously chlorinated. However, the low levels found in the raw water are negligible compared to the levels generated by the use of chlorine in the treatment process.

Ground Waters. The organics found at ground water treatment facilities tend to be of higher concentrations and more persistent than those found at surface water facilities. Because ground water tends to move slowly with little exposure to the atmosphere, organic contaminants tend to attenuate at a very slow rate. Therefore, incidental removal of contaminants in ground water systems by aeration is minimal. The predominate mechanism for reduction of contaminant concentrations in ground water is by attenuation. Concentrations of synthetic organics found in ground water systems tend to be higher than in surface water systems, and a greater variety of synthetic organics is observed in ground water. The variability of concentration from one sampling event to another also tends to be less in ground water.

The contaminants found at the ground water purveyors sampled include:

1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
Methylene chloride
Tetrachloroethylene
<u>trans</u>-1,2-Dichloroethylene
Trichloroethylene
Chlorobenzene
Chloroform
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Nitrobenzene

Of these contaminants, trichloroethylene occurred most often and at the highest concentrations. Raw water concentrations of trichloroethylene ranged from a low of 8 mcg/l to a high of 65 mcg/l. However, some of these concentrations were measured in water blended from a number of wells prior to treatment.

"Blending" is the terminology used to describe the process of using the output of a number of wells of various contaminant concentrations in a composite manner. For example, if two wells of equal flow capacity are available, and well A contains a measurable amount of trichloroethylene while well B does not, the concentration of trichloroethylene in the raw water will depend on whether well A or B, or a combination of flow from the two wells, is used (and in what respective proportional flowrates).

Observed Removals of Contaminants

Each plant exhibited different contaminant removals depending on flow rate, type of contaminant and type of unit process. The first round of sampling was conducted at all five plants in the winter of 1987 to observe cold weather performance. Because each plant is unique with respect to process, age, operation, chemicals used, and design, observations are made here relative to specific contaminants.

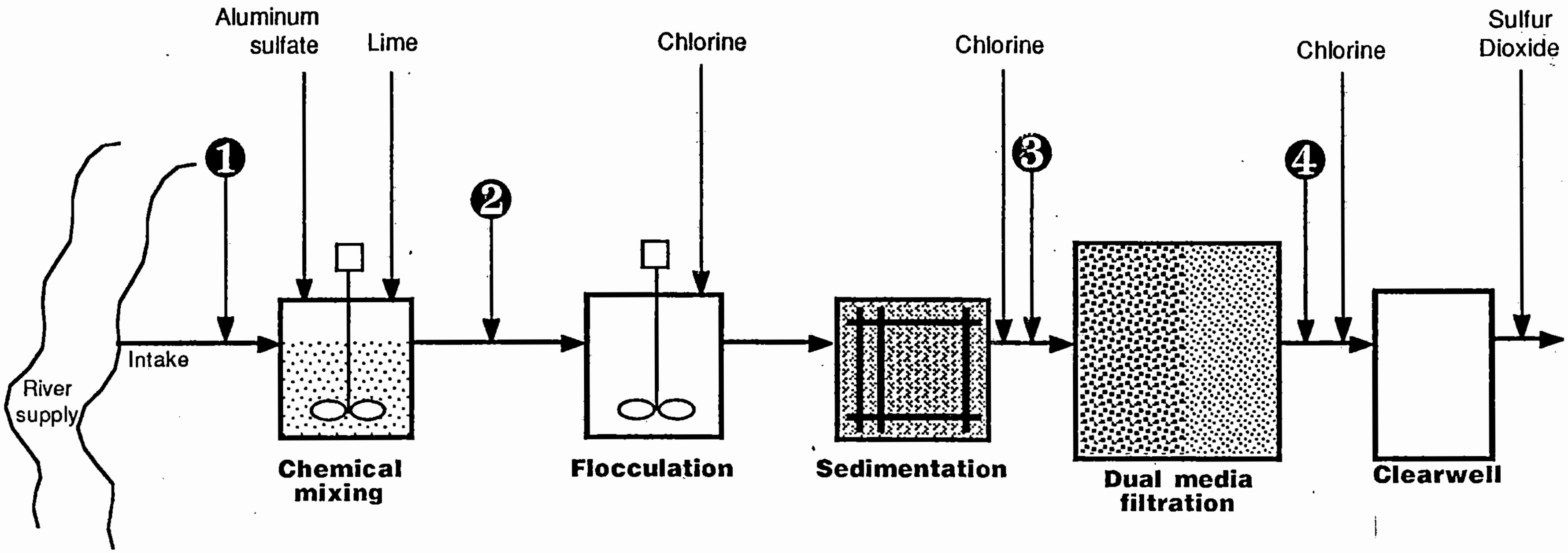
Summaries of water quality sampling results have been given without identifying specific plant locations. Simplified plant schematic flow diagrams for five plants sampled are shown in figures 3-7 through 3-11. Sample location numbers presented on these schematics correspond to the sampling points described on the summary tables of water sampling results (tables 3-4 through 3-18).

The priority pollutant data generated under the sampling program was reviewed for confirmation of expected removals of volatile organics. The results of this review are discussed below for surface water and ground water supplies.

The most notable aspect of volatile organic generation and removal at surface water treatment plants is the effect chlorination has on the generation of chlorination by-products, particularly trihalomethanes. In addition, some incidental removal of the synthetic volatile organics was evident in the raw water.

Chlorination By-products

Trihalomethanes were generally not detected in the treatment process train, except following chlorination. After chlorination, significant levels of THMs were generated at the two surface water treatment plants sampled. Under most circumstances, the presence of a free chlorine residual at any point in the treatment process resulted in continued formation of THMs.



① = Sample locations

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Figure 3-7

Schematic Flow Diagram - Plant A
Surface Supply

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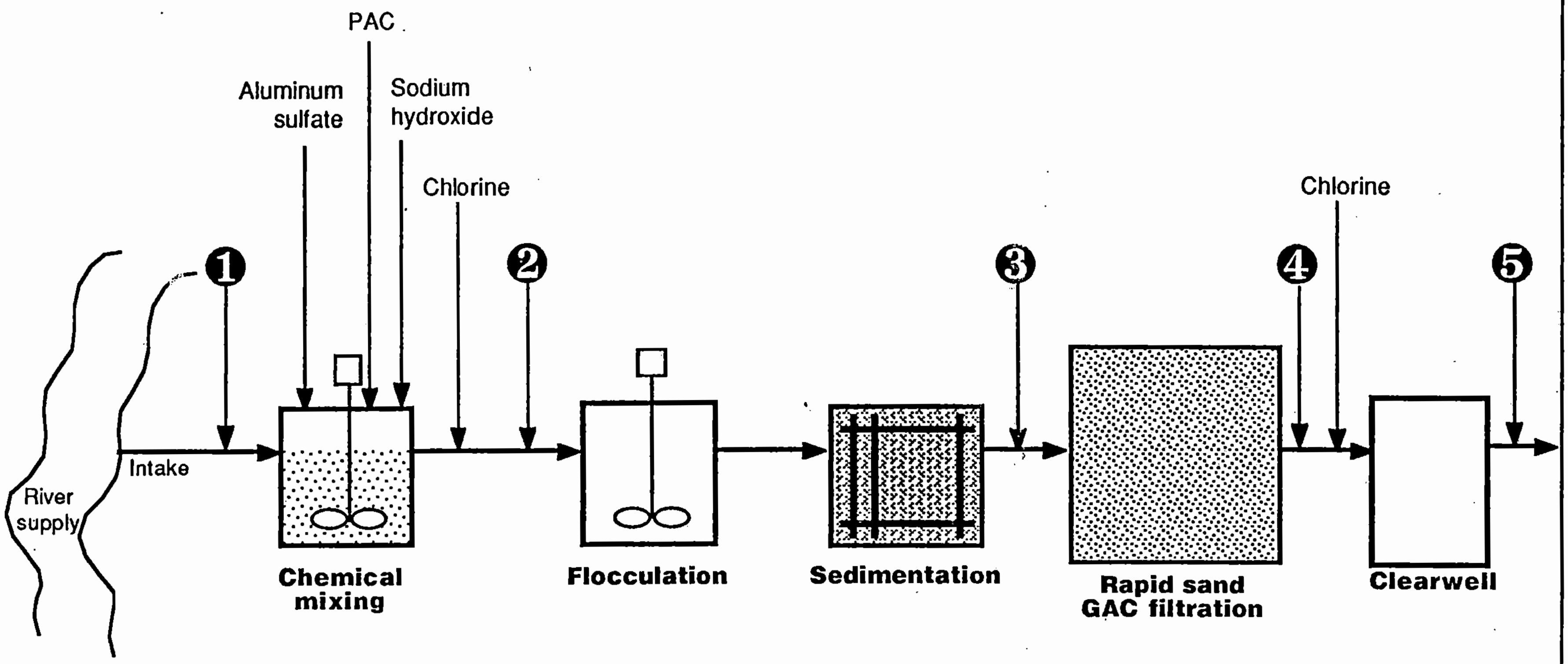

① = Sample locations

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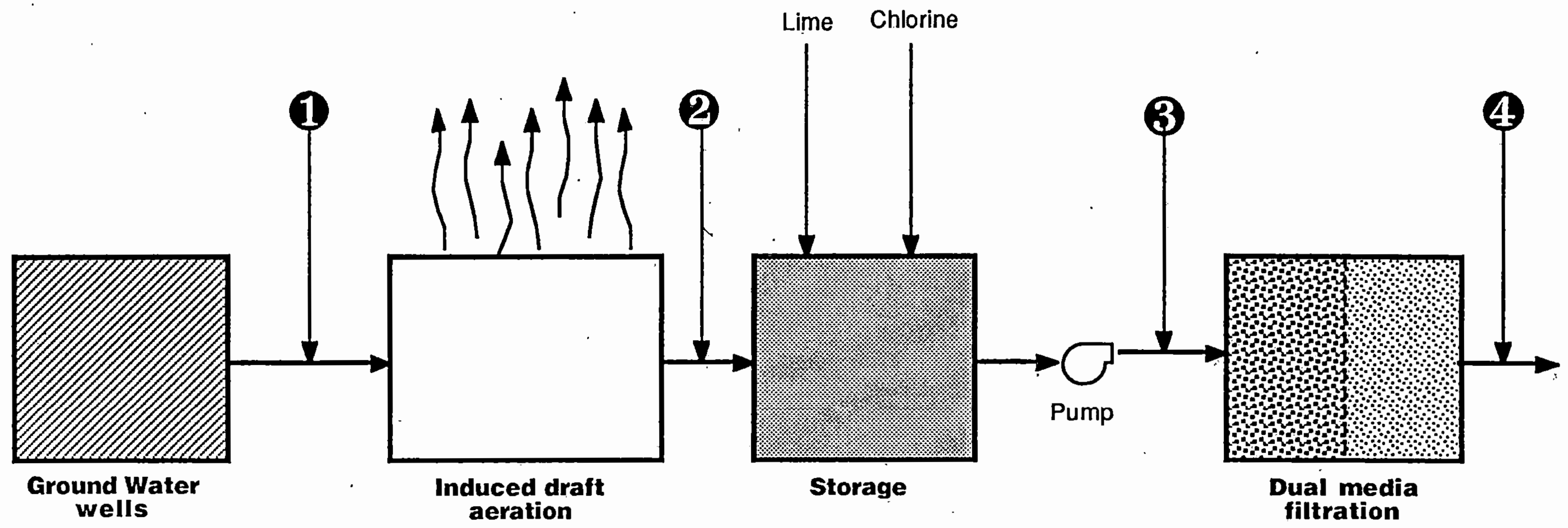
Figure 3-8

Schematic Flow Diagram - Plant B
Surface Supply

Special Water Treatment Study - Phase II



1 = Sample locations

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Figure 3-9

Schematic Flow Diagram - Plant C
Ground Water Supply

Special Water Treatment Study - Phase II

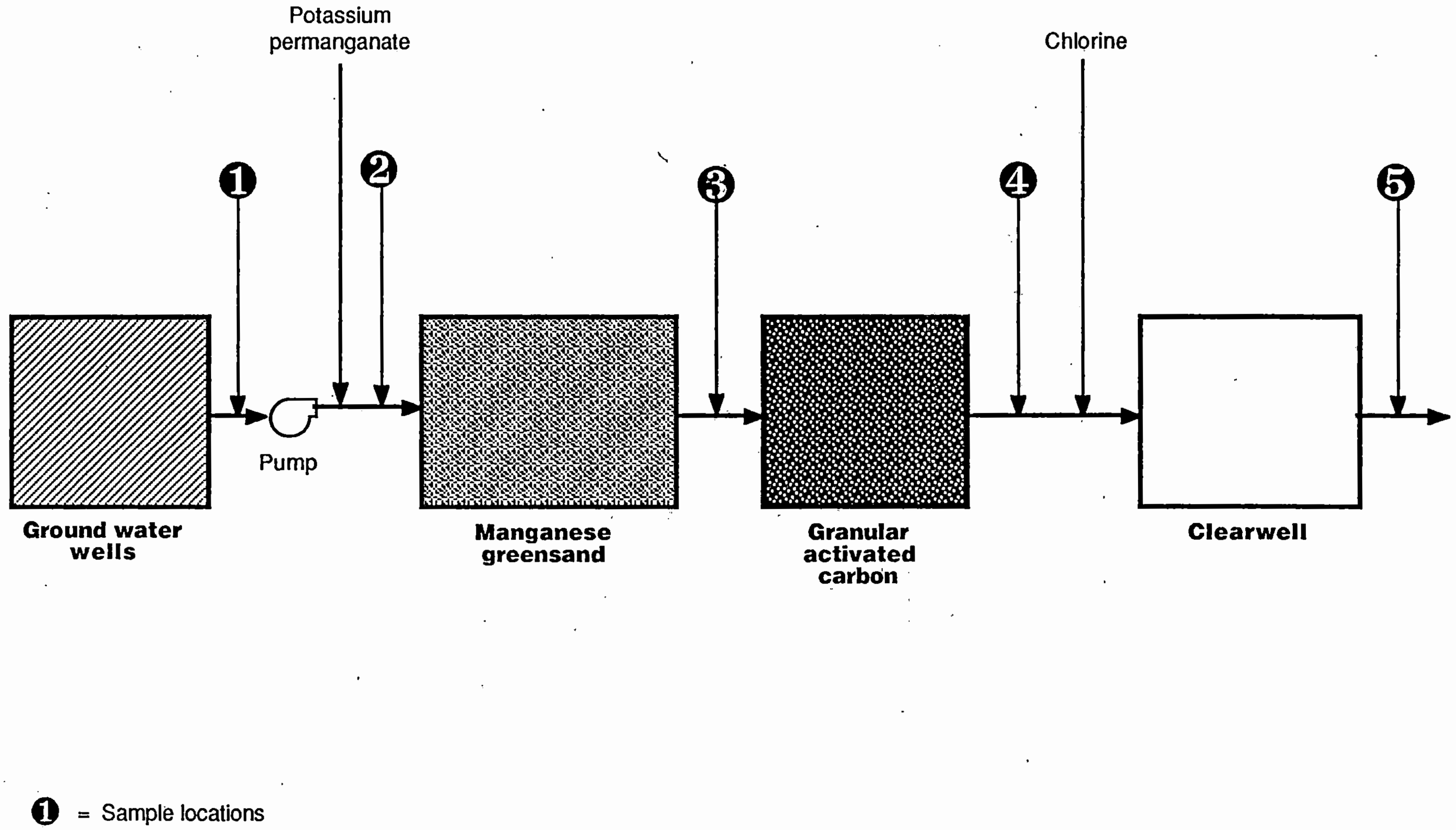

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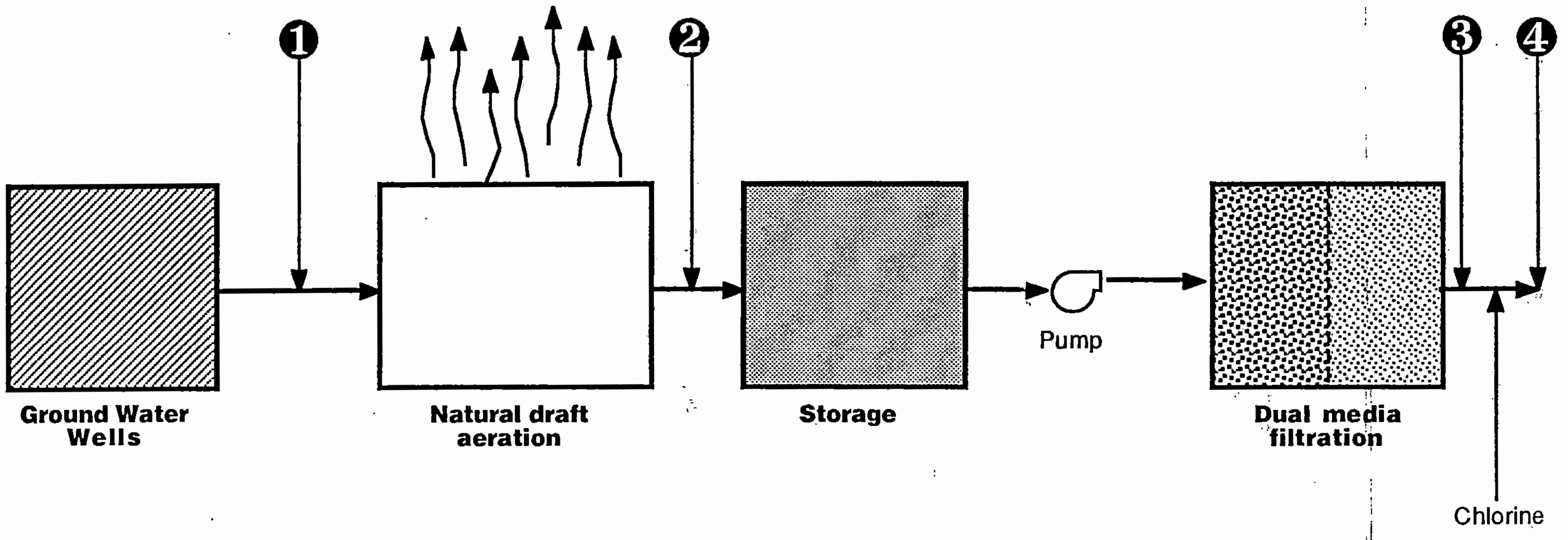
Figure 3-10

Schematic Flow Diagram - Plant D
Ground Water Supply

Special Water Treatment Study - Phase II



① = Sample locations

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Figure 3-11

Schematic Flow Diagram - Plant E Ground Water Supply

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TABLE 3–4

TYPICAL SAMPLING RESULTS—WINTER SURFACE WATER TREATMENT PLANT A

(February 1986)

Compound		Raw water	After alum, and chemical mixing	After flocculation and sedimentation	After filtration
Priority pollutant volatiles					
Chlorodibromomethane	mcg/l	<0.62	0.62	2.66	3.21
Chloroform	mcg/l	<0.32	0.32	22.5	28.2
Dichlorobromomethane	mcg/l	<0.44	<0.44	8.01	10.1
Methylene chloride	mcg/l	<0.56	2.92	3.30	3.02
Trichloroethylene	mcg/l	4.80	<0.38	3.28	3.45
Trichlorofluoromethane	mcg/l	<2.0	<2.0	<2.0	<2.0
Ground Water conventionals					
Total organic halides (TOX)	mcg/l	31.5	37.4	234.3	282.9
Total organic halides (TOX)	mcg/l	27.9	38.4	264.5	280.2
Total organic carbon	mcg/l	4.4	6	4.6	2.9
Total coliform	C/100	300	—	0	0
Miscellaneous parameters					
Alkalinity as $CaCO^3$	mg/l	76	62	57	55
Chlorine, free	mg/l	<0.02	<0.02	2.20	2.00
Chlorine, total	mg/l	<0.02	<0.02	2.50	2.50
Color, apparent	Co/Pt	20	—	6	<5
Dissolved oxygen	ppm	—	11.4	11.4	11.60
Iron	mcg/l	400	—	<300	<300
Manganese	mcg/l	120	—	110	<4
NV total organic carbon	mg/l	4.4	5.9	4.4	2.9
NV total organic carbon	mg/l	4.5	6.1	4.8	2.9
Temperature	deg. C	1.95	2.41	2.72	3.02
Turbidity	NTU	3.9	—	2.7	0.39
pH (field)	std	7.65	7.25	6.85	6.85

Notes: Chemical addition at Surface Plant A during winter sampling

- Aluminum sulfate, 20 mg/l
- Pre-chlorine, 5.0 mg/l

Plant A consists of coagulation flocculation, sedimentation and dual media filtration.
BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3–5

RESULTS OF TOTAL TRIHALOMETHANE FORMATION POTENTIAL TEST—WINTER SURFACE WATER TREATMENT PLANT A

THM	S1 raw water	After alum and chemical mixing	After flocculation and sedimentation	After filtration
Chloroform	264.28	241.70	174.87	143.22
Bromodichloromethane	42.53	39.74	46.35	38.81
Dibromochloromethane	5.78	5.53	11.22	9.07
Bromoform	ND	ND	ND	ND

Notes: The concentrations of THMs shown above do not exist in the raw water, but are a result of adding chlorine to the water and holding it for 5 days at 20°C before analysis. This was done to force the maximum THM formation achievable under laboratory conditions.

ND = Parameter not detected

TABLE 3–6

TYPICAL SAMPLING RESULTS—SUMMER SURFACE WATER TREATMENT PLANT A

(August 1986)

Compound		Raw water	After alum.	After flocculation and sedimentation	After filtration
Priority pollutant volatiles					
Chlorodibromomethane	mcg/l	ND	ND	10	20
Chloroform	mcg/l	ND	ND	50	50
Dichlorobromomethane	mcg/l	ND	ND	30	40
Methylene chloride	mcg/l	ND	2	3	1
1,2-*trans*-Dichloroethylene	mcg/l	0.8	ND	ND	ND
1,1,1-Trichloroethane	mcg/l	0.9	ND	ND	BMDL
Trichloroethylene	mcg/l	10	5	2	3
Ground Water conventionals					
Chloride	mg/l	50.4	49.7	57.5	57.9
Total organic halides (TOX)	mcg/l	26	28.6	334.3	259.8
Total organic halides (TOX)	mcg/l	27	27.1	275.3	236.4
Total organic carbon	mg/l	3.6	4.83	3.01	2.93
Total organic carbon	mg/l	3.3	4.98	3.14	2.92
Field parameters					
pH (field)	std	7.20	6.90	6.90	6.90
Temperature	deg. C	19.03	19.23	19.42	19.42
Turbidity	NTU	14	21	2.3	1.1
Miscellaneous parameters					
Alkalinity as $CaCO^3$	mg/l	120	100	—	92
Chlorine, free	mg/l	<0.01	<0.01	2.26	1.37
Chlorine, total	mg/l	0.01	<0.01	2.95	1.69
Color, apparent	Co/Pt	22	—	—	<5
Dissolved oxygen	ppm	6.20	6.20	7.40	7.55
Hardness as $CaCO^3$	mg/l	—	—	—	160
Manganese	mcg/l	—	—	—	5.7
NV total organic carbon	mg/l	3.6	4.83	3.01	2.93
NV total organic carbon	mg/l	3.3	4.98	3.14	2.92
Purgeable organic halides (POX)	mcg/l	96	<50	84	78
Purgeable organic halides (POX)	mcg/l	92	<50	88	82

Notes: Chemical addition at surface plant A during summer sampling
- Aluminum sulfate, 26 mg/l
- Prechlorine, 5.6 mg/l

BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3-7

RESULTS OF TOTAL TRIHALOMETHANE FORMATION POTENTIAL TEST—SUMMER SURFACE WATER TREATMENT PLANT A (August 1986)

Compound	Raw water	After alum.	After flocculation and sedimentation	After filtration
Chloroform	190	160	160	150
Bromodichloromethane	37	36	35	34
Dibromochloromethane	ND	ND	ND	ND
Bromoform	ND	ND	ND	ND

Notes: The concentrations of THMs shown above do not exist in the raw water, but are a result of adding chlorine to the water and holding it for 5 days at 20°C before analysis. This was done to force the maximum THM formation achievable under laboratory conditions.

ND = Parameter not detected

TABLE 3–8

TYPICAL SAMPLING RESULTS
SURFACE WATER TREATMENT PLANT A
AFTER STORM EVENT
(November 1986)

Compound		Raw water	After alum.	After flocculation and sedimentation	After filtration
Priority pollutant volatiles					
Chloroform	mcg/l	ND	ND	73.8	66.8
Dichlorobromomethane	mcg/l	ND	ND	7.53	6.08
Methylene chloride	mcg/l	ND	ND	2.53	6.88
1,1,1-Trichloroethane	mcg/l	ND	BMDL	ND	ND
Trichloroethylene	mcg/l	0.956	ND	ND	ND
Ground Water metals					
Iron	mcg/l	3,600	—	—	BMDL
Ground Water conventionals					
Chloride	mg/l	26.5	27.5	34.2	33.6
Total organic halides (TOX)	mcg/l	32	—	—	350
Total organic halides (TOX)	mcg/l	34	—	—	422
Total organic carbon	mg/l	13.8	11.3	6.6	6.2
Total organic carbon	mg/l	12.4	11.5	6.1	5.6
Total coliform	C/100	IND	IND	<1	<1
Field parameters					
pH (field)	std	6.80	6.50	6.40	6.30
Temperature	deg. C	9.04	9.13	9.13	9.04
Turbidity	NTU	28	—	2.8	0.36
Miscellaneous parameters					
Alkalinity as $CaCO^3$	mg/1	21	—	—	9
Chlorine, free	mg/l	< 0.01	< 0.01	2.22	1.53
Chlorine, total	mg/l	< 0.01	< 0.01	2.79	1.90
Chlorophyll a	mg/l	0.352	—	—	< 0.010
Color, apparent	Co/Pt	66	5	< 5	< 5
Dissolved oxygen	ppm	10.2	10.2	10.2	10.4
Hardness as $CaCO^3$	mg/l	57	—	—	53
NV total organic carbon	mg/l	13.8	11.3	6.6	6.2
NV total organic carbon	mg/l	12.4	11.5	6.1	5.6

Notes: BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3-9

TYPICAL SAMPLING RESULTS—WINTER SURFACE WATER TREATMENT PLANT B

(February 1986)

Compound		Raw water	After pre-chlorination	After flocculation and sedimentation	After filtration	After post chlorination
Priority pollutant volatiles						
Chlorodibromomethane	mcg/l	<0.62	<0.62	<0.62	<0.62	<0.62
Chloroform	mcg/l	<0.32	6.85	21.2	15.3	32.4
Dichlorobromomethane	mcg/l	<0.44	<0.44	2.19	3.94	6.56
Methylene chloride	mcg/l	<0.56	1.97	1.34	<0.56	<0.56
Tetrachloroethylene	mcg/l	1.82	1.71	2.14	1.93	1.79
1,1,1-Trichloroethane	mcg/l	1.07	0.998	1.07	1.02	0.984
Trichloroethylene	mcg/l	1.27	1.26	< 0.38	1.51	<0.38
Trichlorofluoromethane	mcg/l	<2.0	<2.0	< 2.0	< 2.0	<2.0
Priority pollutant base/neutrals						
Naphthalene	mcg/l	<1.6	—	—	—	11.6
Ground Water conventionals						
Total organic halides (TOX)	mcg/l	33.4	330.5	290.4	238.7	206.6
Total organic halides (TOX)	mcg/l	35.9	319.9	335.7	201.8	172.2
Total organic carbon	mg/l	5.9	5.2	4.1	3.7	3.1
Total organic carbon	mg/l	5.3	—	—	—	—
Total organic carbon	mg/l	5.6	—	—	—	—
Total coliform	C/100	47,000	—	0	0	—
Miscellaneous parameters						
Alkalinity as $CaCO^3$	mg/l	55	19	19	17	49
Ammonia as N	mg/l	1.1	—	—	—	—
Chlorine, free	mg/l	<0.01	2.64	2.52	0.90	1.13
Chlorine, total	mg/l	<0.01	5.47	3.86	1.84	1.58
Chlorophyll a	mg/l	4.27	—	<1	<1	—
Color, apparent	Co/Pt	20	—	5	6	—
Dissolved oxygen	ppm	11.2	11.6	11.4	11.9	12.0
Iron	mcg/l	600	—	<200	<200	—
Manganese	mcg/l	120	—	110	80	—
NV total organic carbon	mg/l	—	4.8	3.9	3.7	2.9
NV total organic carbon	mg/l	—	5.5	4.2	3.7	3.0
Purgeable organic carbon	mg/l	<1.0	<1.0	<1	<1	4.0
Temperature	deg. C	2.36	2.26	2.41	2.57	—
Turbidity	NTU	6.2	—	2.9	2.4	—
pH (field)	std	7.25	6.15	6.05	6.05	7.25

Notes: Plant B consist of chemical coagulation, flocculation, sedimentation and rapid sand/GAC filtration. Average chemical usage is 10 mg/l prechlorine, aluminum sulfate 10 mg/l, sodium hydroxide 8 mg/l, post-chlorine 1 mg/l.
BMDL = Below method detection limit
ND = Parameter not detected
"—" = Parameter not tested

TABLE 3-10

TYPICAL SAMPLING RESULTS—SUMMER SURFACE WATER TREATMENT PLANT B (August 1986)

Compound		Raw water	After pre-chlorination	After flocculation sedimentation	After filtration	After post chlorination
Priority pollutant volatiles						
Chlorodibromomethane	mcg/l	ND	3	5	5	7
Chloroform	mcg/l	4	100	90	70	100
Dichlorobromomethane	mcg/l	1	20	30	30	40
Dichlorodifluoromethane	mcg/l	4	ND	ND	ND	ND
Methylene chloride	mcg/l	5	0.9	6	5	3
1,1,1-Trichloroethane	mcg/l	3	ND	BMDL	ND	ND
Trichloroethylene	mcg/l	0.5	0.6	ND	BMDL	0.5
Ground Water conventionals						
Chloride	mg/l	47.5	50.3	52.4	51.9	50.6
Total organic halides (TOX)	mcg/l	59.2	454.2	510.6	329.7	290
Total organic halides (TOX)	mcg/l	51.2	467.7	522.1	332.4	412
Total organic carbon	mg/l	5.68	6.09	4.63	3.97	3.51
Total organic carbon	mg/l	5.22	6.89	4.77	4.17	3.75
Total coliform	C/100	18,000	—	—	—	<2
Field parameters						
pH (field)	std	7.20	5.65	6.10	6.10	6.85
Temperature	deg. C	23.05	22.06	22.16	22.16	23.34
Turbidity	NTU	14	19	3.2	0.35	1.0
Miscellaneous parameters						
Alkalinity as $CaCO^3$	mg/l	58	—	—	—	48
Chlorine, free	mg/l	<0.01	2.16	2.42	0.64	1.29
Chlorine, total	mg/l	0.02	3.02	3.10	1.06	1.70
Color, apparent	Co/Pt	18	<5	<5	—	<5
Dissolved oxygen	ppm	5.2	5.8	5.6	6.1	7.0
Iron	mcg/l	1,100	—	—	—	ND
Manganese	mcg/l	130	—	—	13	—
NV total organic carbon	mg/l	5.68	6.09	4.63	3.97	3.51
NV total organic carbon	mg/l	5.22	6.89	4.77	4.17	3.75
Purgeable organic halides (POX)	mcg/l	<50	82.0	112	84	100
Purgeable organic halides (POX)	mcg/l	<50	72.0	108	78	92

Notes: BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3-11

TYPICAL SAMPLING RESULTS
SURFACE WATER TREATMENT PLANT B — AFTER STORM EVENT
(December 1986)

Compound		Raw water	After pre-chlorination	After flocculation sedimentation	After filtration	After post chlorination
Priority pollutant volatiles						
Chlorodibromomethane	mcg/l	<0.62	<0.62	<0.62	<0.62	1.16
Chloroform	mcg/l	<0.32	77.1	34.6	37.5	91.6
Dichlorobromomethane	mcg/l	<0.44	9.96	6.36	6.13	11.9
1,1-Dichloroethane	mcg/l	3.10	<0.94	<0.94	<0.94	<0.94
Methylene chloride	mcg/l	<0.56	6.54	6.36	9.09	16.4
Tetrachloroethylene	mcg/l	<0.82	1.46	<0.82	<0.82	1.07
Toluene	mcg/l	<1.2	<1.2	<1.2	<1.2	<1.2
1,1,1-Trichloroethane	mcg/l	<0.76	4.15	<0.76	<0.76	2.47
Ground Water metals						
Iron	mcg/l	1,700	—	—	—	—
Ground Water conventionals						
Chloride	mg/l	22.4	29.8	26.1	26.5	27.3
Total organic halides (TOX)	mcg/l	27	433	—	—	284
Total organic halides (TOX)	mcg/l	26	439	—	—	290
Total coliform	C/100	10,000	—	—	—	—
Field parameters						
pH (field)	std	7.00	5.90	5.40	5.80	8.50
Temperature	deg. C	7.36	7.26	7.16	7.36	9.13
Turbidity	NTU	32	—	5.2	0.68	—
Miscellaneous parameters						
Alkalinity as $CaCO^3$	mg/l	31	—	—	—	35
Chlorine, free	mg/l	<0.01	3.25	1.40	0.61	0.63
Chlorine, total	mg/l	<0.01	5.04	2.76	1.10	0.81
Chlorophyll a	mg/l	0.269	—	—	—	<0.010
Color, apparent	Co/Pt	45	—	—	—	—
Dissolved oxygen	ppm	8.35	8.50	8.80	9.30	8.50
Hardness as $CaCO^3$	mg/l	54	—	—	—	48
NV total organic carbon	mg/l	5.77	5.57	3.58	2.68	3.32
NV total organic carbon	mg/l	6.02	6.15	3.57	2.78	3.03

Notes: BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3–12

RESULTS OF TOTAL TRIHALOMETHANE FORMATION POTENTIAL TEST —SURFACE WATER TREATMENT PLANT B (February 1986)

THM	Raw water	After pre-chlorination	After flocculation/ sedimentation	After filtration	After post chlorination
Chloroform	269.23	286.52	174.74	182.99	166.66
Bromodichloromethane	34.96	45.04	31.33	28.90	32.56
Dibromochloromethane	5.20	5.10	4.62	4.17	5.00
Bromoform	ND	ND	ND	ND	ND

Notes: The concentrations of THMs shown above do not exist in the raw water, but are a result of adding chlorine to the water and holding it for 5 days at 20°C before analysis. This was done to force the maximum THM formation achievable under laboratory conditions.

BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3–13

RESULTS OF TOTAL TRIHALOMETHANE FORMATION POTENTIAL TEST
SURFACE WATER TREATMENT PLANT B
(August 1986)

THM	Raw water	After pre-chlorination	After flocculation/ sedimentation	After filtration	After post chlorination
Chloroform	590	330	220	190	210
Bromodichloromethane	46	43	36	42	41
Dibromochloromethane	ND	ND	ND	ND	ND
Bromoform	ND	ND	ND	ND	ND

Notes: The concentrations of THMs shown above do not exist in the raw water, but are a result of adding chlorine to the water and holding it for 5 days at 20°C before analysis. This was done to force the maximum THM formation achievable under laboratory conditions.

BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3-14

TYPICAL SAMPLING RESULTS—WINTER GROUND WATER TREATMENT PLANT C

(January 1986)

Compound		Raw water	After aeration	After lime and chlorine	After filtration
Priority pollutant volatiles					
Chlorobenzene	mcg/l	2.03	2.06	<1.2	<1.2
Chloroform	mcg/l	1.76	1.95	0.710	1.25
1,1-Dichloroethane	mcg/l	3.16	3.46	1.53	1.67
1,2-Dichloroethane	mcg/l	14.7	17.0	9.81	9.86
1,1-Dichloroethylene	mcg/l	2.63	1.72	0.601	0.733
Methylene chloride	mcg/l	4.19	9.55	2.90	0.892
Tetrachloroethylene	mcg/l	4.19	6.38	6.32	7.53
1,2-trans-Dichloroethylene	mcg/l	7.09	7.95	4.16	4.44
1,1,1-Trichloroethane	mcg/l	0.858	<0.76	<0.76	<0.76
1,1,2-Trichloroethane	mcg/l	<1.0	<1.0	<1.0	<1.0
Trichloroethylene	mcg/l	49.5	43.1	24.2	25.5
Ground Water conventionals					
Total organic halides (TOX)	mcg/l	68	78.7	46.2	70.5
Total organic halides (TOX)	mcg/l	72.6	76.0	48.1	64.9
Field parameters					
pH (field)	std	5.95	6.55	7.45	5.95
Temperature	deg. C	13.44	12.73	14.11	14.79
Turbidity	NTU	3.6	5.1	1.0	0.43
Miscellaneous parameters					
Alkalinity as $CaCO^3$	mg/l	48	73	74	77
Chlorine, free	mg/l	<0.02	<0.02	0.15	0.45
Chlorine, total	mg/l	<0.02	<0.02	0.55	0.55
Color, apparent	Co/Pt	<5	14	<5	<5
Dissolved oxygen	mg/l	3.8	8.9	9.4	9.5
Hardness as $CaCO^3$	mg/l	130	130	150	160
Iron	mcg/l	1,000	900	900	400
Manganese	mcg/l	290	396	280	388
NV total organic carbon	mg/l	1.8	3.1	1.9	1.8
Total dissolved solids (TDS)	mg/l	280	330	310	300

Notes: Plant process consists of induced draft aeration, chlorination and lime addition followed by dual media horizontal pressure filtration. Average chlorine dosage 0.9 mg/l; average lime dosage 16 mg/l.

BMDL = Below method detection limit

ND = Parameter not detected

— = Parameter not tested

TABLE 3–15

TYPICAL SAMPLING RESULTS—SUMMER GROUNDWATER TREATMENT PLANT C (August—September 1986)

Compound		Raw water	After aeration	After lime and chlorine	After filtration
Priority pollutant volatiles					
1,1-Dichloroethane	mcg/l	2	ND	ND	1
1,2-Dichloroethane	mcg/l	8	6	7	7
1,1-Dichloroethylene	mcg/l	2	BMDL	0.6	ND
Methylene chloride	mcg/l	30	2	ND	ND
Tetrachloroethylene	mcg/l	10	3	5	5
1,2-<u>trans</u>-Dichloroethylene	mcg/l	7	4	5	4
Trichloroethylene	mcg/l	40	20	20	20
Ground Water conventionals					
Chloride	mg/l	45.7	44.9	46.7	46.2
Total organic halides (TOX)	mcg/l	50.4	113.9	115.1	113.9
Total organic halides (TOX)	mcg/l	48.0	110.6	123.9	110.4
Total organic carbon	mg/l	3.51	1.50	1.67	1.51
Total organic carbon	mg/l	3.50	1.42	1.72	1.73
Field parameters					
pH (field)	std	5.70	6.55	8.85	7.40
Temperature	deg. C	15.10	14.62	15.20	15.20
Turbidity	NTU	2.7	—	—	1.4
Miscellaneous parameters					
Alkalinity as CaCO^3	mg/l	54	44	82	66
Chlorine, free	mg/l	< 0.01	< 0.01	0.19	0.26
Chlorine, total	mg/l	< 0.01	< 0.01	0.57	0.52
Dissolved oxygen	ppm	2.45	7.90	8.70	8.70
Hardness as CaCO^3	mg/l	—	130	—	150
Iron	mcg/l	1,500	1,300	1,400	BMDL
Manganese	mcg/l	320	260	290	60
NV total organic carbon	mg/l	3.51	1.50	1.67	1.51
NV total organic carbon	mg/l	3.50	1.42	1.72	1.73
Purgeable organic halides (POX)	mcg/l	78	36	74	54
Purgeable organic halides (POX)	mcg/l	70	24	62	52
Total dissolved solids (TDS)	mg/l	—	240	—	320

Notes: BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

TABLE 3–16

TYPICAL SAMPLING RESULTS—WINTER GROUND WATER TREATMENT PLANT D
(January 1986)

Compound		Raw water	After potassium permanganate	After greensand filtration	After GAC	After post-chlorination
Priority pollutant volatiles						
Chlorobenzene	mcg/l	1.80	1.92	< 1.2	< 1.2	< 1.2
1,1-Dichloroethylene	mcg/l	< 0.56	< 0.56	< 0.56	< 0.56	< 0.56
Tetrachloroethylene	mcg/l	14.5	14.9	15.5	14.7	10.5
1,2-trans-Dichloroethylene	mcg/l	1.62	1.65	1.54	1.47	1.03
1,1,1-Trichloroethane	mcg/l	6.69	6.98	6.88	7.03	7.53
Trichloroethylene	mcg/l	47.0	45.7	45.9	48.9	23.8
Priority pollutant base/neutrals						
Nitrobenzene	mcg/l	< 3.8	—	—	—	15.7
Ground Water conventionals						
Total organic halides (TOX)	mcg/l	39.0	61.6	16.8	68.2	41.8
Total organic halides (TOX)	mcg/l	40.3	54.5	14.5	61.5	41.7
Miscellaneous parameters						
Alkalinity as $CaCO^3$	mg/l	190	200	190	190	150
Chlorine, free	mcg/l	< 0.02	0.10	< 0.02	< 0.02	0.06
Chlorine, total	mcg/l	< 0.02	0.90	< 0.02	< 0.02	0.30
Color, apparent	Co/Pt	< 5	19	5	5	—
Dissolved oxygen	ppm	2.9	3.3	1.2	1.2	5.0
Hardness as $CaCO^3$	mg/l	270	260	270	260	210
Iron	mcg/l	200	200	< 200	< 200	—
Manganese	mcg/l	441	757	347	360	—
NV total organic carbon (TOC)	mg/l	3.7	4.3	4.1	3.6	—
Temperature	deg.C	14.85	14.85	14.90	14.96	14.40
Total dissolved solids (TDS)	mg/l	410	400	410	400	—
Turbidity	NTU	0.44	12	0.31	0.28	—
pH (field)	std	7.20	7.15	7.15	7.10	7.10

Notes: Plant process consists of preoxidation with potassium permanganate, greensand pressure filtration, granular activated carbon adsorption and post chlorination. Typical chemical dosages are chlorine, 1.2 mg/l and potassium permanganate, 0.5 mg/l.

BMDL = Below method detection limit

ND = Parameter not detected

— = Parameter not tested

TABLE 3-17

TYPICAL SAMPLING RESULTS—SUMMER GROUNDWATER TREATMENT PLANT D (August—September 1986)

Compound		Raw water	After potassium permanganate	After greensand filtration	After GAC	After post-chlorination
Priority pollutant volatiles						
Methylene chloride	mcg/l	2	0.6	8	4	ND
Tetrachloroethylene	mcg/l	20	10	10	10	10
1,2-<u>trans</u>-Dichloroethylene	mcg/l	ND	1	ND	ND	ND
1,1,1-Trichloroethane	mcg/l	6	7	5	6	5
Trichloroethylene	mcg/l	40	40	30	40	20
Ground Water conventionals						
Chloride	mg/l	75.8	76.5	75.6	76.0	54.8
Total organic halides (TOX)	mcg/l	88.6	50.8	42.1	60.7	66.8
Total organic halides (TOX)	mcg/l	64.8	52.6	35.9	59.0	65.8
Total organic carbon	mg/l	3.31	2.97	3.63	3.52	1.72
Total organic carbon	mg/l	3.31	2.99	3.42	3.50	1.75
Field parameters						
pH (field)	std	7.00	7.00	7.00	7.00	7.00
Temperature	deg. C	14.71	14.81	15.01	15.01	14.62
Turbidity	NTU	1.3	0.95	1.1	—	0.6
Miscellaneous parameters						
Alkalinity as CaCO^{3}	mg/l	200	200	200	170	140
Chlorine, free	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	0.28
Chlorine, total	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	0.71
Color, apparent	Co/Pt	—	—	—	—	< 5
Dissolved oxygen	ppm	2.80	1.40	1.55	1.90	6.15
Hardness as CaCO^{3}	mg/l	—	250	—	260	—
Manganese	mcg/l	402	635	190	—	71
NV total organic carbon	mg/l	3.31	2.97	3.63	3.52	1.72
NV total organic carbon	mg/l	3.31	2.99	3.42	3.50	1.75
Purgeable organic halides (POX)	mcg/l	< 50.0	< 50.0	< 50	< 50	< 50.0
Purgeable organic halides (POX)	mcg/l	< 50.0	< 50.0	< 50	< 50	< 50.0
Total dissolved solids (TDS)	mg/l	—	—	—	—	340

Notes: Plant process consists of preoxidation with potassium permanganate, greensand pressure filtration, granular activated carbon adsorption and post chlorination. Typical chemical dosages are chlorine, 1.2 mg/l and potassium permanganate, 0.5 mg/l.

BMDL = Below method detection limit

ND = Parameter not detected

— = Parameter not tested

TABLE 3–18

TYPICAL SAMPLING RESULTS—WINTER GROUNDWATER TREATMENT PLANT E (January 1986)

Compound		Raw water	After aeration	After filtration	After chlorination
Priority pollutant volatiles					
Methylene chloride	mcg/l	< 0.56	1.29	2.25	< 0.56
Tetrachloroethylene	mcg/l	< 0.82	3.41	< 0.82	< 0.82
1,2-<u>trans</u>-Dichloroethylene	mcg/l	1.96	< 0.32	< 0.32	0.382
Trichloroethylene	mcg/l	64.9	23.1	3.89	7.17
Ground Water conventionals					
Total organic halides (TOX)	mcg/l	38.8	12.8	15.6	25.5
Total organic halides (TOX)	mcg/l	37.0	11.2	15.7	26.6
Total coliform	C/100	—	0	0	—
Miscellaneous parameters					
Alkalinity as $CaCO^3$	mg/l	8	< 5	5	7
Chlorine, free	mg/l	< 0.02	< 0.02	< 0.02	0.04
Chlorine, total	mg/l	< 0.02	< 0.02	< 0.02	0.10
Color, apparent	Co/Pt	< 5	< 5	< 5	—
Dissolved oxygen	ppm	4.7	9.4	9.8	9.8
Hardness as $CaCO^3$	mg/l	31	21	23	31
Iron	mcg/l	400	400	< 300	—
Manganese	mcg/l	95	99	94	—
NV total organic carbon	mg/l	1.6	< 1.0	1.6	—
Temperature	deg. C	13.28	12.59	13.90	10.86
Total dissolved solids (TDS)	mg/l	64	52	68	—
Turbidity	NTU	1.3	1.0	0.50	—
pH (field)	std	5.55	5.95	6.20	6.35

Notes: Plant Process consists of natural draft tray aeration followed by pressure sand filtration and post chlorination.
BMDL = Below method detection limit
ND = Parameter not detected
— = Parameter not tested

Total Trihaolmethane Formation Potential (TTHMFP) testing at each sampling point in the treatment process indicated that TTHMFP tends to be reduced by every unit process. Measured instantaneous concentrations of THM formed in the plant may be subtracted from THMFP concentrations to indicate the potential for THM formation in the distribution system. TTHMFP removal by conventional treatment from raw water to finished water was found to be in the range of 30 to 50 percent. The most significant removals occurred at the flocculation/sedimentation step and at the filtration step, in that order. Therefore, the sampling data confirmed the general approach to THM control that has been taken by many water purveyors in response to the current MCL of 0.10 mg/l. Essentially, this approach consists of relocating the point of predisinfection from the intake to the plant to the point immediately following sedimentation, and then adding chlorine at a point of lowered TTHMFP.

Surrogate Parameters. In addition to sampling for priority pollutants (including trihalomethanes) and conventional parameters (metals, inorganics, pH, and others) sampling of potential nonspecific or surrogate parameters was performed (see chapter 7 for a discussion of surrogate parameters). In particular, analysis of each sample for total organic halides (TOX), purgeable organic halides (POX), total organic carbon (TOC) and nonvolatile total organic carbon (NVTOC) was performed.

TOX and POX were reviewed because of their possible application as surrogates for the volatile organics and/or the trihalomethanes. However, as with all surrogates, any relationship to a specific parameter must be established on a site-specific basis. For example, at Rahway it was found that, under most circumstances, total THMs represent approximately 10 to 30 percent of TOX. At the Passaic Valley treatment plant, this surrogate relationship was less well identified. The results of the sampling there showed a marked increase in both TOX and THMs at the point of predisinfection. However, the results also showed that, whereas THMs increased through the treatment process, TOX tended to show some moderate removals. This observed difference may be caused by the use of GAC for organic removal at this point. Other researchers have shown that THM formation is favored at pH>7 while TOX formation is favored at pH<7.

At water supplies relying on ground water, the relationship between volatile organics and TOX was much less evident. In addition, THMs generated by chlorination are at much lower concentrations than found at surface water plants, if they are generated at all. Therefore, TOX does not appear to be an indicator of THMs in ground water. It is also not determined if TOX is indicative of the presence of other toxic compounds.

Monitoring of purgeable organic halides is an analytical method designed to measure the volatile portion of TOX. It has also been identified as a potential surrogate for organic contamination and for THMs. In this study, POX did not show a consistent relationship to TOX. As previously mentioned, TOX appears to be a surrogate for THM generation, but not THM removal. POX appears to show a similar relationship to THMs, but not as marked a one.

3.4 SUMMARY OF CONCLUSIONS

Detailed and specific analytical results of the sampling program are included in task reports and laboratory results on file at NJDEP. Sampling data generated by this study indicates the following:

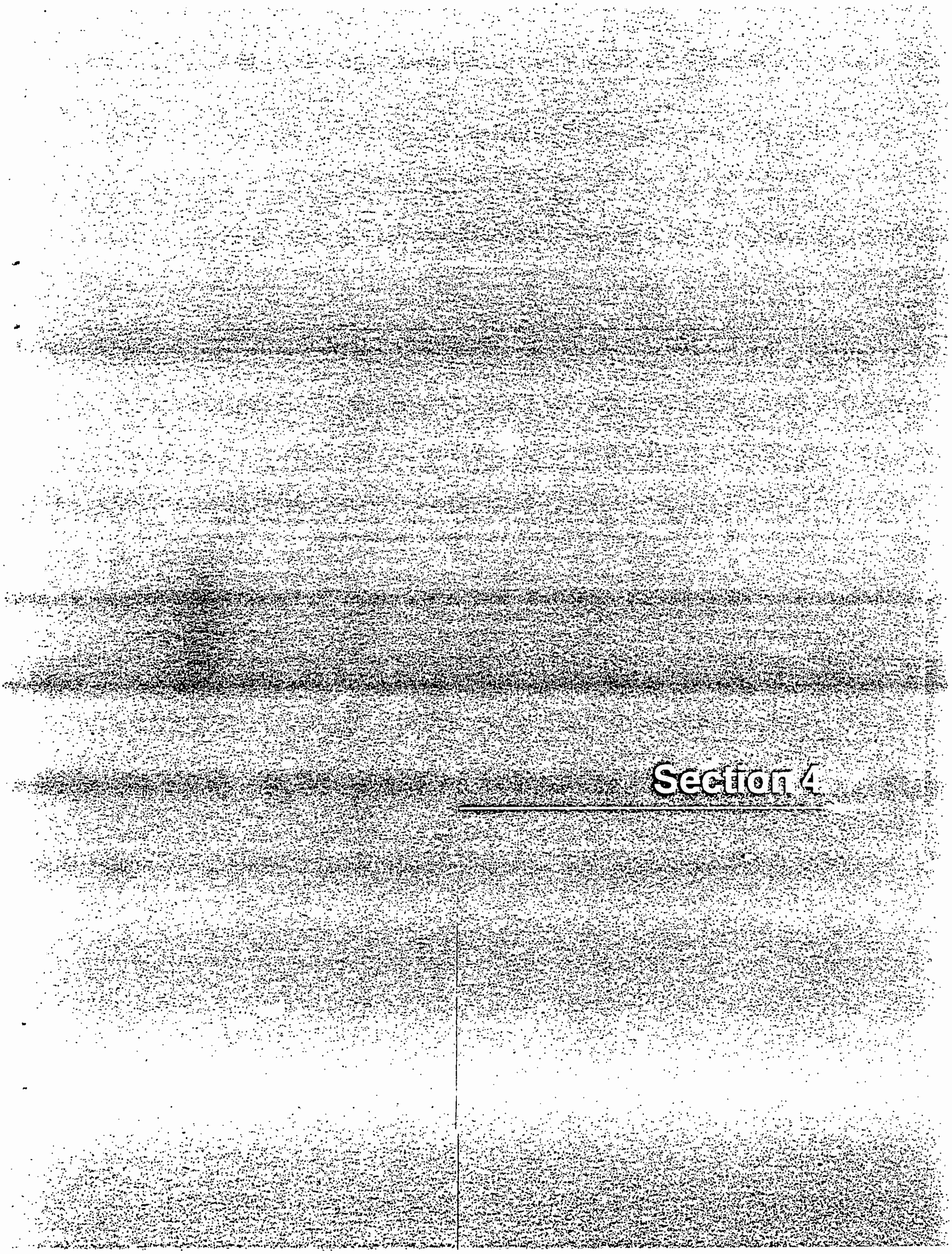
- All plants sampled, regardless of time of year or weather conditions, showed evidence of volatile A-280 compounds. In some cases, the concentrations of the A-280 compounds were low enough that the traditional processes removed these organics to below detectable limits in the finished water.
- The raw water concentrations of volatile A-280 compounds in surface water supplies is relatively variable. A-280 compounds that were evident at very low concentrations during the morning sampling period were not evident in the afternoon sampling on the same day. In addition, further variability in raw water quality from season to season is evident.
- The raw water concentrations of A-280 compounds in ground water are not as variable -- seasonally or based on time of day -- as in surface water.
- Without deliberate application of an aeration process, it appears that high removals of volatile organics cannot be achieved. However, reductions of volatile organics in the range of 20 to 40 percent can be achieved without use of special aeration processes.

- Trihalomethanes and their precursors were lowest in the winter, moderate during the summer, and highest following a fall storm, as expected. Aside from this variation, no major seasonal variations in THMs were noted.

- Trihalomethane precursors were found to be reduced in concentration by nearly all unit processes.

- The most significant reductions in trihalomethane precursors were generally found earlier in the treatment system where the major removal of organic solids and other dissolved and suspended materials occurred. Typically, this reduction occurs at the influent screens or during the passage of water through the flocculation/sedimentation basins.

(6)



Section 4

4.0 APPLICATION OF LEADING TREATMENT TECHNOLOGIES TO REMOVAL OF A-280 COMPOUNDS

SUMMARY OF FINDINGS

This chapter presents a detailed assessment of the two leading treatment technologies for removal of synthetic organics from drinking water supplies -- air stripping and carbon adsorption -- and evaluates the ability of each of these technologies to remove the compounds regulated under New Jersey Assembly Bill A-280. A generalized approach is provided for selecting an appropriate process for a given contamination scenario, and for sizing and estimating the cost of an appropriate treatment system.

Based on this assessment, the following A-280 compounds are defined as highly amenable to removal by air stripping:

Carbon tetrachloride
Vinyl chloride
1,1-Dichloroethylene

The following A-280 compounds are defined as highly amenable to removal by activated carbon adsorption:

Chlordane
Polychlorinated biphenyls

The remaining compounds now regulated under A-280 are all removable by either air stripping or carbon adsorption. By analyzing each particular case, using the approach suggested in this chapter, the reader will be able to identify an appropriate treatment scheme.

Some A-280 compounds not currently regulated show resistance to removal by both air stripping and activated carbon filtration. These include methyl ethyl ketone (MEK), formaldehyde and some components of kerosene. MEK will represent a difficult treatment problem when it becomes regulated.

4.1 INTRODUCTION

Two technologies are generally accepted for use in treating water contaminated with volatile organics: air stripping by packed column aeration, and granular activated carbon (GAC) adsorption. This section assesses the applicability of both technologies to the removal of volatile organic compounds (VOC) from drinking water; it is divided into four major subsections:

Section 4.2 Air Stripping
Section 4.3 Carbon Adsorption
Section 4.4 Multiple-Process Approaches
Section 4.5 Implications for A-280 Compounds

Sections 4.2 and 4.3 each consist of a process overview, followed by a detailed discussion of each process application, performance, configuration, advantages and disadvantages. Practical considerations related to design, construction, operation, and special regulations are also reviewed. Each subsection closes with a discussion of the costs of each process, and explains procedures to determine the relative cost of treatment for particular contamination scenarios. Section 4.4 presents a generalized approach to the evaluation of treatment alternatives involving combined use of air stripping and carbon adsorption. Section 4.5 restates the conclusions of this chapter.

4.1.1 SUMMARY OF TECHNOLOGY ASSESSMENT PROCESS

A comprehensive technology assessment was conducted to evaluate the appropriateness and feasibility of air stripping and carbon adsorption for removal of volatile organics to meet the maximum contaminant levels (MCL) allowable under New Jersey law A-280. The technology assessment consisted of a thorough review of published and unpublished research, vendor information, and process and operational data from available sources.

Site visits to several operating air stripping and/or carbon adsorption facilities in New Jersey were also conducted to gain additional information about actual operation of such facilities. Existing air stripping and GAC water treatment facilities in New Jersey include the following:

Air Stripping

- Rocky Hill
- Rockaway Township
- Borough of Denville
- East Hanover Water Department
- South Brunswick
- Fairlawn
- Elizabethtown Water Company (uses GAC treatment for stripper off-gas)

Granular Activated Carbon

- Rockaway Borough
- Rockaway Township
- South Brunswick Water Department
- New Jersey Water Supply Co. (Delaware District)
- New Jersey Water Supply Co. (Washington District)
- Boonton
- Park Ridge

Six full-scale facilities were visited. Operational staff at the six facilities were interviewed and any studies performed for these facilities were reviewed. This operational experience was used in conjunction with the research and literature reviews to assure that the recommendations of the Special Water Treatment Study - Phase II reflect actual operating experience in New Jersey.

4.1.2 OBJECTIVES AND RESULTS

This chapter is intended to serve as a brief "design manual" for use by water purveyors, engineering consultants, and State officials. It identifies the best approaches to process design for air stripping and carbon adsorption facilities, and describes commonly encountered operational problems. It provides guidance to

1. Small and medium-sized water purveyors, in implementing VOC removal technologies
2. Engineering consultants, previously unfamiliar with the surveyed technologies, in designing and costing such facilities
3. State officials, in identifying appropriate technologies to mitigate VOC contamination in water supplies
4. Both purveyors and engineers, in preparing cost estimates for VOC removal treatment systems

The overall goal is to give the user enough information to make planning decisions on the applicability of these technologies to specific treatment needs.

The technology assessment demonstrated that, in most cases, it is feasible to remove volatile organic contaminants by air stripping, carbon adsorption, or a combination of the two processes. Both processes also have wide applicability to removal of many other natural and synthetic organic compounds.

The assessment also revealed that conventional contaminants -- such as iron, manganese, pH and hardness -- can cause problems in the air stripping or carbon adsorption processes. Pretreatment to remove or reduce these conventional contaminants should be considered for use prior to the air stripping or activated carbon processes, in order to achieve maximum treatment efficiency and cost-effectiveness.

4.2 AIR STRIPPING

4.2.1 OVERVIEW OF AIR STRIPPING METHODS

In water treatment applications, air stripping refers to the process whereby water and air are placed in intimate contact, allowing contaminants to move from the liquid into the air. Technically speaking, air stripping permits the diffusion of contaminants from the liquid phase to the gaseous phase. There are four basic methods for providing the necessary contact between the air and water:

1. Diffused aeration
2. Spray aeration
3. Tray aeration
4. Packed column aeration

Effective air-to-water contact is very important in removal of A-280 compounds from water. Some methods are superior to others in this respect.

Diffused Aeration

In a diffused aeration system, air is injected into the water through a diffuser, producing fine bubbles. (Compressed air is usually used.) Transfer of contaminant molecules (mass transfer) occurs across the air-water interface of the bubble surfaces. Diffused aeration usually takes place in a contact chamber, and less frequently in a holding pond. In practice, diffused aerators have VOC removal efficiencies in the range of 70 to 90 percent. They are generally used only where existing basins are available. When higher removal rates are required, diffused aerators may not be practical because they do not provide efficient air-to-water contact.

Spray Aeration

Spray aeration usually involves use of nozzles located on a grid or network of piping over a basin. The nozzles spray the contaminated water into the air. Mass transfer of the contaminant takes place across the air-water surface of the droplets.

Transfer efficiency can be increased by passing the water through the nozzles several times. Since this approach substantially increases the sizing of the system, and thus the cost, it is not commonly used. Spray aeration has several disadvantages. For spray ponds, large land area may be needed and large amounts of mist, which could be carried into nearby residential areas, are produced by the process. The possibility of ice formation on the nozzles and icing caused by the mist reduces the usefulness of this technique in colder climates. The removal efficiency of this type of system is typically above 70 percent.

A major disadvantage of this treatment method is the difficulty of air pollution control. To control air pollution from a basin, the entire basin would have to be covered with a structure high enough to accommodate the arc of the spraying. The interior air would have to be replenished and the discharge air would have to be treated, requiring additional equipment. In those instances where air pollution control is required, spray aeration is relatively impractical. A spray aeration system can also be designed to spray vertically downward through an enclosed space (such as a tank or tower), which facilitates air pollution control. However, the treatment efficiency obtained with this method is even lower than that of the more traditional approach. Because of these disadvantages, spray aeration is not widely employed for volatile organics removal.

Tray Aeration

Tray aeration is a simple, low-maintenance treatment method with greater removal efficiency than is typically attainable by diffused and spray aeration. Water is passed down through a column of perforated trays while air is blown up through the trays. The trays break the water into small droplets, creating a large surface area across which mass transfer can take place. For removal of volatile organics, efficiencies vary greatly. As with diffused aeration, this method generally cannot be used where very low contaminant concentrations in finished water are required.

Packed Column Aeration

Packed column aeration is accomplished by cascading water over a bed of packing media -- which creates the large surface area needed for efficient mass transfer -- while forcing air to flow through the media in the opposite direction.

Because packed columns achieve very effective air-to-water contact, they are capable of achieving the very high removals necessary to meet the levels contemplated by A-280. Removal efficiencies in excess of 99 percent commonly can be obtained. Since packed column aeration is the only air stripping technology with sufficient capability to meet most A-280 treatment levels, it was selected for detailed investigation in this study. A typical packed column is shown in figure 4-1.

4.2.2 PROCESS AND THEORY DESCRIPTION[1]

Application and Performance

Many A-280 compounds are amenable, in different degrees, to air stripping, as is indicated in the following list.

Benzene	Intermediate strippability
Carbon tetrachloride	Very strippable
Chlordane	Not strippable
Chlorobenzene	Intermediate strippability
Dichlorobenzene	Intermediate strippability
1,2-Dichloroethane	Intermediate strippability
1,1-Dichloroethylene	Very strippable
cis-1,2-Dichloroethylene	Intermediate strippability
trans-1,2-Dichloroethylene	Intermediate strippability
Ethylene glycol	Unknown
Formaldehyde	Unknown
n-Hexane	Unknown
Kerosene	Unknown
Methyl ethyl ketone	Unknown
Methylene chloride	Intermediate strippability
Polychlorinated biphenyls	Not strippable

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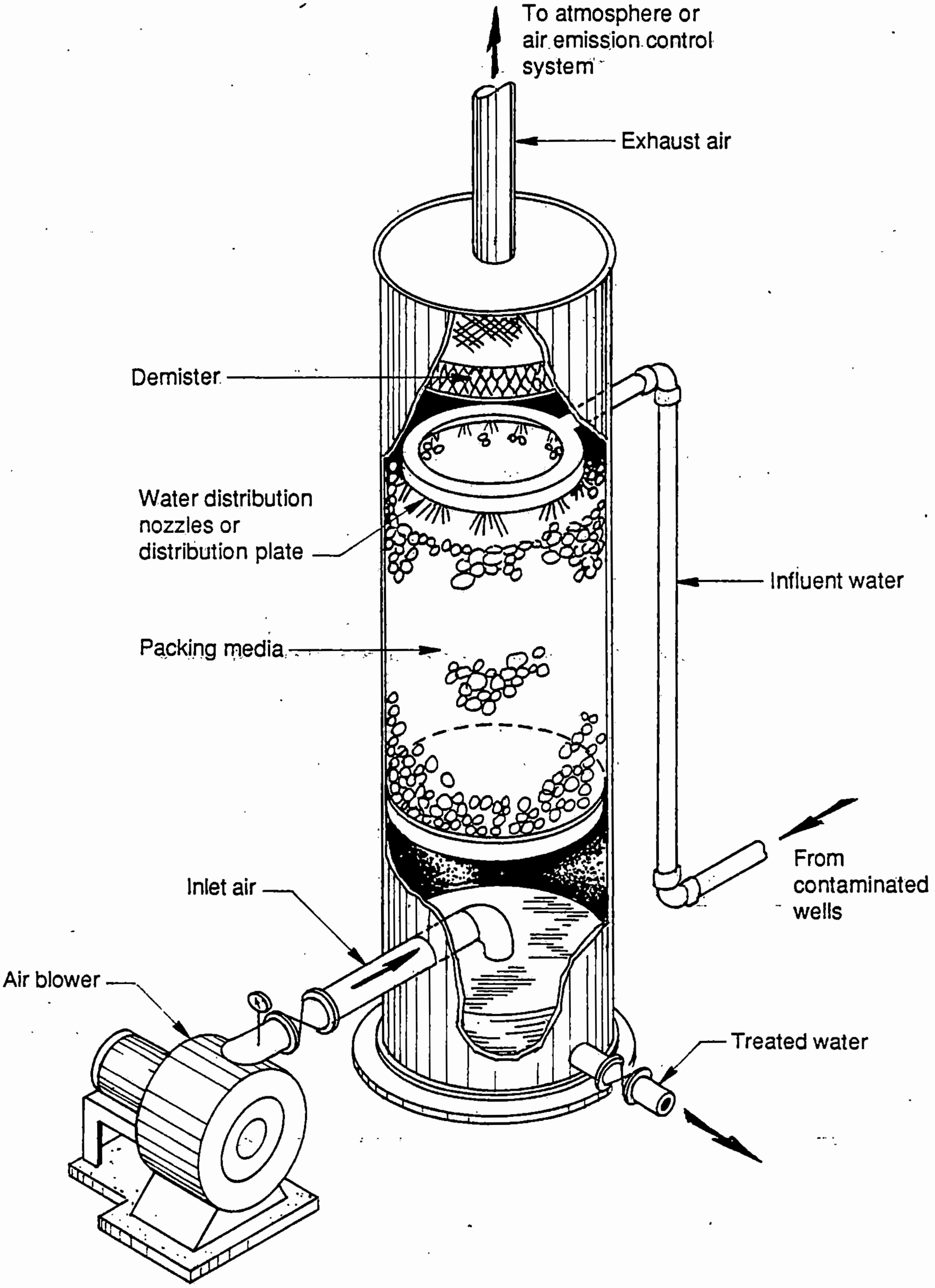
[1] This subsection requires some understanding of chemical engineering terminology and mathematical concepts. Readers not familiar with this terminology will be able to understand the concepts involved, if not the mathematics.



CDM

environmental engineers, scientists, planners & management consultants

Figure 4-1

Typical Packed Column Air Stripper

Tetrachloroethylene	Intermediate strippability
Trichlorobenzene	Intermediate strippability
1,1,1-Trichloroethane	Intermediate strippability
Trichloroethylene	Intermediate strippability
Vinyl chloride	Very strippable
Xylenes	Intermediate strippability

In cases of low-level contamination, where low percentages of removal are required to insure compliance, the most cost-effective process for the removal of a given compound may not necessarily be packed column aeration. In most cases, however, high levels of removal (greater than 95 percent) will be required to comply with water quality standards. Only packed towers provide the necessary process efficiencies. They can achieve in excess of 99.9 percent removal of the A-280 compounds amenable to air stripping. Packed columns may also be used in conjunction with other treatment processes, particularly treatment processes designed to remove or neutralize other, more traditional contaminants.

It is generally true that the more volatile a contaminant is, the more amenable it is to removal by air stripping. However, volatility and the ability to remove a contaminant by air stripping (strippability) are not synonymous. The volatility of an organic substance generally is a function of boiling point or vapor pressure, while strippability is a function of both the compound's volatility and solubility in water. The combination of these properties are described by the compound's Henry's Law constant, the one number that best characterizes a compound's strippability. These theoretical concepts are discussed in the following section.

Theory of Mass Transfer

The mechanism of contaminant transfer in a packed tower is governed by Henry's Law: when a gas and a liquid are in equilibrium, the same number of molecules of a gas will pass in both directions through a unit area of the liquid surface in a unit of time.

For example, if air is in contact with a very dilute solution of trichloroethylene in water, equilibrium is reached when as many trichloroethylene molecules leave the solution as enter the solution in a given time. Henry's Law can be expressed mathematically as:

$$P_A = H_A X_A \qquad \text{(Equation 1)}$$

where:

P_A = partial vapor pressure of compound A dissolved in water when in equilibrium with air (atm)

H_A = Henry's Law constant (atm)

X_A = mole fraction of compound A in water (mole/mole)

The phenomenon that permits an air stripper to remove volatile organic compounds from water can best be described as a controlled disequilibrium based on Henry's Law. Because the air is being continuously replenished, the contaminant molecules predominantly move from the water to the air. Cascading water through a random packing increases the effective surface area of the liquid in contact with air, enhancing the removal of contaminants.

The Henry's Law constant, as expressed in the chemical engineering literature, is a theoretical constant. It is also a constant that is difficult to measure in practice. Measurements of this constant by various researchers have produced varying results for the same compound. Although the literature generally refers to the Henry's Law constant, it is understood that this constant, as used in air stripping process design, may also be used to compensate for other phenomena such as the surface tension and ionic strength of the water. Though the practice of referring to this constant as the Henry's Law constant will be continued in this report, it is understood that the value used may be more appropriately referred to as a "coefficient." That is, it may also take into account surface tension effects and other phenomena.

The Henry's Law constants can be presented in three different sets units. The following equations can be used to convert to other systems of units:

$$H \text{ "atmospheres"} = H \text{ ("dimensionless")} \times 4.57 \times T\ (^\circ K) \qquad \text{(Equation 2)}$$

$$H \text{ "atmospheres"} = H \left(\frac{m^3 H_2O \cdot atm}{\text{mole air}} \right) \times 55{,}600 \qquad \text{(Equation 3)}$$

The set of units commonly referred to as "atmospheres" are actually:

$$\text{(atmospheres of pressure)} \frac{\text{(moles of water)}}{\text{mole of air}}$$

The set of units commonly referred to as "dimensionless" are actually:

$$\text{(atmospheres of pressure)} \frac{\text{(cubic meter of water)}}{\text{(cubic meter of air)}}$$

The 55,600 factor in equation 3 is based on the number of moles of water per cubic meter. The Henry's Law constant is not always available directly from the literature, but vapor pressure and solubility data are often available. If such information is available, the following equation can be used to estimate the dimensionless Henry's Law constant:

$$H = \frac{16{,}034\ M\ V}{S\ T} \qquad \text{(Equation 4)}$$

where:

M = molecular weight
V = vapor pressure (mm Hg) at the operating temperature
S = solubility (mcg/l)
T = operating temperature (^oK)
H = Henry's Law constant (dimensionless)

Design Equations

The fundamental equation for packed column design for removal of VOCs in a counter-current-flow, packed tower is a complex function of the required removal efficiency, the volatility of the contaminant, the air-to-water ratio, the water loading rate, temperature, and the concentration of other contaminants present in the water. For most dilute solutions, contaminants behave independently. In other words, the removal of one is not interfered with by the other. The theory of packed column operation has been presented in many publications. Perry's Chemical Engineers' Handbook is one good source (see the bibliography in appendix F of this report for the full reference).

These equations for packed column design can be expressed fundamentally as:

$$Z = (NTU)\,(HTU) \qquad \text{(Equation 5)}$$

where:

$$NTU = \frac{R}{R-1} \ln \frac{(Xi/Xo)(R-1) + 1}{R} \qquad \text{(Equation 6)}$$

$$R = \frac{H}{P_t} \frac{G}{L} \qquad \text{(Equation 7)}$$

$$HTU = \frac{L}{K_L a} \qquad \text{(Equation 8)}$$

and where:

Z = packing height (m or ft)

NTU = number of transfer units (dimensionless)

R = stripping factor (dimensionless)

H = Henry's Law constant for compound to be removed (dimensionless)

P_t = ambient pressure (atm)

HTU = height of a transfer unit (m or ft)

L = water loading rate (m^3/m^2/sec or ft^3/ft^2/sec)

G = air loading rate (m^3/m^2/sec or ft^3/ft^2/sec)

K_La = product of overall diffusion coefficient, K_L(m/sec or ft/sec), and the specific interfacial area, a (m^2/m^3 or ft^2/ft^3), commonly reported as an overall factor, K_La (sec^{-1})

Xi = influent concentration of the compound to be removed (mcg/l)

Xo = effluent concentration of the compound to be removed (mcg/l)

The number of transfer units is related to the volatility of the compound, the treatment objective, and the air-to-water ratio. The height of a transfer unit relates to the overall design and the water loading. These values are theoretical and are meant to increase the understanding of the air stripping process. The diameter of the column is determined from a straightforward calculation based on the liquid loading rate and the total flowrate.

Henry's Law constants are commonly referred to as being "dimensionless." They actually have the following dimensions:

$$\frac{(\text{atm-total})(\text{m}^3\,\text{H}_2\text{O})}{(\text{m}^3\,\text{air})}$$

A mathematical analysis of these units reduces the dimensions of this form of the Henry's Law constant to simply "atmospheres." However, in the factor H/P_t used to determine the stripping factor, P_t is assumed to be equal to 1.0 atmosphere. Therefore, the Henry's Law constant is modified so that it is dimensionless, and the stripping factor equation (equation 7), therefore, becomes:

$$R = \frac{HG}{L}$$

4.2.3 DESIGN AND CONSTRUCTION

Design Considerations

The design, construction and operation of an air stripping system is relatively simple. The materials of construction are readily obtainable. The process itself, once placed on line, requires minimal operator attention. The mechanical equipment used is relatively simple, consisting mainly of blowers and pumps, both of which are routinely found in other water treatment applications.

Typical questions that must be answered before proceeding with design of a packed column air stripper include these:

- What is the concentration of volatile organics in the raw water?
- What flowrate(s) should be used in establishing the design capacity?
- What is the potential for fouling of the packing due to precipitation, scaling or biogrowth?
- What is the best approach to optimize capital, operating, and maintenance costs?
- Is field piloting necessary?
- What air-to-water ratio will be used in the design of the stripper?
- What type of packing should be used?
- What are the most appropriate construction materials?
- Should any precautions be taken to protect intake air quality?
- What is the level of dependability and redundancy necessary, i.e., is the particular water supply essential or projected to be essential?
- What planning period should be used in evaluating the cost of the system?
- How should air quality be protected?
- What requirements should be used for process design by consulting engineers and for design review by State agencies?
- Have the applicable design standards been verified with the New Jersey Department of Environmental Protection?

The water purveyor and consulting engineer, in conjunction with the New Jersey Department of Environmental Protection (NJDEP), should be prepared to answer these questions before implementing the final design. Subsequent discussions in this report have been framed to assist the reader in doing this.

Major design considerations relate to the secondary impacts of the process. New Jersey's air pollution regulations categorize the discharge from an air stripping column as a source subject to control under air pollution control regulations. The control of the discharge of volatile organics may become very common because of the stringency of the State's air pollution regulations. Packed column facilities also may have an adverse aesthetic impact. The tower itself, especially when located in a residential area, could be perceived as unattractive. In addition, the necessary blowers and/or pumps could, without proper sound suppression, create an adverse noise impact.

Design Water Quality. When designing an air stripping system, the "worst-case" water quality should be considered. If worst-case conditions are not considered during design, then the treatment system size may be inadequate for removing contaminants over a long period. Because air stripping columns remove VOCs by a fixed percentage, regardless of the raw water concentrations of the contaminants, worse-case water quality conditions would constitute raw water with the highest anticipated contaminant concentrations and finished water with the lowest contaminant levels expected to be enforced.

To determine the highest expected contaminant concentrations, use of a computer-generated ground water flow and contamination model is helpful. These models are most often created when the source of contamination is known. If a model has not been developed at the time of decision to provide treatment, it is usually not cost-effective to perform the modeling for the sole reason of obtaining raw water design criteria. When the source of contamination is not known, and a computer model has not been created, it is difficult to accurately predict contaminant movement.

A typical contamination scenario might involve continued evidence of volatile organic compounds in the raw water over several months or years. In such cases, trends in the analytical data may be discerned. The maximum design concentration usually should exceed existing raw water concentrations. If the data indicates a clear rising trend, then the design concentrations should reflect double, triple, or even greater influent concentrations over the current level. Where the amount of analytical data is sufficient to determine that no up or down trend in concentrations are evident, it is still sound judgment to design for a raw water concentration at least double the present concentration. Even in a situation where declining concentrations are readily discernible, a generous margin of safety should be allowed.

To determine the lowest MCLs anticipated to be enforced, a designer should consult existing state and federal regulations governing the maximum contaminant levels for volatile organics (see section 1.1). Possible future modifications to the regulations also should be taken into account. An appreciation for the changing regulatory environment will help prevent construction of facilities that become prematurely obsolete.

These guidelines for raw water design criteria represent only one of a variety of potential approaches. Other approaches are valid when coupled with professional judgment and experience.

<u>Design Flowrate</u>. The designer must also consider the maximum flowrate in evaluating how well an air stripping column will meet the treatment objectives. If the column is to operate at a variety of flowrates, the predominant flowrate should be designed most cost-effectively. Operation of the column under conditions differing from this design flow, however, will be less cost-effective. Under such conditions, neither pumps nor blowers will operate at their most efficient design points.

The designer must also consider liquid loading (the liquid loading multiplied by the cross-section surface area of the interior of the tower equals the flowrate). When the Henry's Law constant of a compound is high and the removal efficiency required is moderately low, a cost-effective design can result in relatively high liquid loadings. Experience suggests that liquid loadings be maintained between 35 gpm/sq ft and 10 gpm/sq ft to avoid flooding or excessive pressure drop and to provide adequate wetting of the packing.

Optimization of Capital and O&M Costs. On a present-worth basis, the operation and maintenance (O&M) cost of an air stripping facility usually represents a larger part of the total present worth cost than does the capital cost. A design usually should seek to reduce O&M costs, even at the expense of increased capital costs. While such an evaluation should be made on a case-by-case basis, maximization of capital cost over O&M costs generally will result in a more cost-effective design.

Because the cost of power to operate the air blowers is a very significant component of the total O&M cost, an air stripping column should be designed to minimize pressure drop through the packing media. Therefore, for cost-effective design, packing type should be selected on the basis of pressure drop and mass transfer characteristics, rather than on the basis of capital cost. Relatively low incremental pressure drops through media (less than 100 $N/m^2/m$ or 0.12 inches of water column per foot of packing) are generally used as a basis for design.

Although less significant than packing media type in affecting pressure drop, inlet and exit losses can also represent an important component of pressure drop. It is important to estimate these losses during design and to minimize their magnitude. Under some circumstances, these losses can significantly impact the sizing and design of the blowers.

Need for Field Piloting. Piloting is performed to gain information on raw water treatability that cannot be obtained by other means. It is important to determine whether the possible cost saving on a full-scale system warrants the expense of a pilot test.

There are four basic reasons for piloting an air stripper:

1. To confirm or more firmly define the operating mass transfer parameters (Henry's Law constant and K_La).
2. To define the operating mass transfer parameters in situations where the compound of interest is not well known and/or the background water presents a complex treatability matrix.
3. To justify a design approach.
4. To determine fouling potential.

In the first case, piloting is only justified when the cost of the pilot study will clearly produce cost savings by defining the mass transfer parameters more accurately. In the second case, a pilot study is usually required, unless the treatment engineer has piloting data from another location with a similar contamination matrix. In the third case, contaminants with which NJDEP has limited experience should be piloted. In the fourth case, laboratory analysis or field piloting will be helpful.

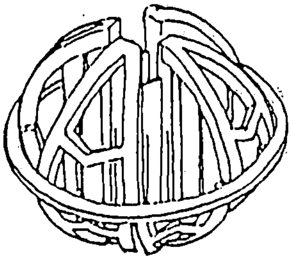
The treatment engineer should discuss the need for a pilot study with NJDEP prior to proceeding with the design.

Packing Type. In an air stripping system, the water is distributed over, and trickles down through, the packing, exposing a large surface of water to contact with the air. The packing itself should

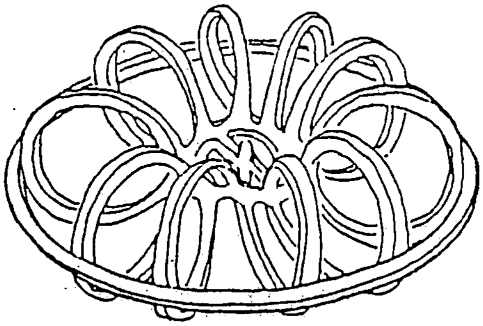
1. Provide a large surface between the water and the air.
2. Possess desirable water-flow characteristics. (The packing must permit passage of large volumes of water through relatively small tower cross sections without flooding and facilitate low air pressure drop. Flooding results when a reverse in phases occurs, i.e., instead of the water trickling down through the column, the air bubbles up; this is an undesirable situation.)
3. Remain chemically inert to all waters likely to be encountered.
4. Possess the structural strength to allow easy handling and installation.

In general, there are two classes of tower packing used in water treatment: dumped packing and stacked packing. Towers utilizing dumped packing are filled with randomly oriented pieces of the packing that are simply dumped into the tower during installation. Some typical dumped tower packings are shown in figure 4-2. Many different brands and configurations are available.

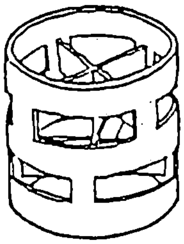
Dumped packing used for water treatment applications are usually made of a temperature- and chemical-resistant thermoplastic, typically polypropylene. Other plastics, stainless steel and ceramics are also used. Saddle and cylindrical ring shapes are widely available and cost less than dumped



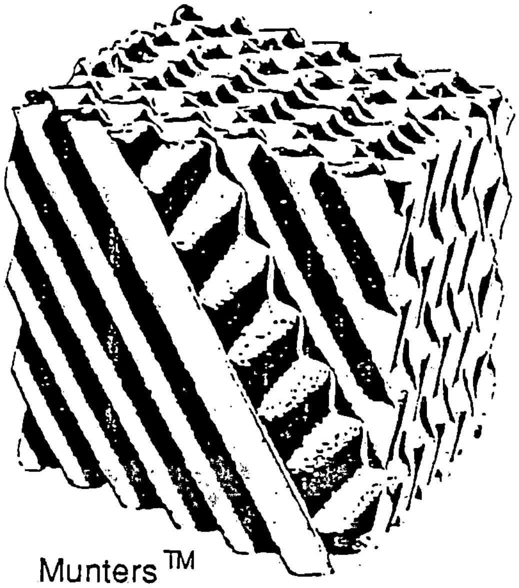
Tripack™
(full scale)
Dumped packing



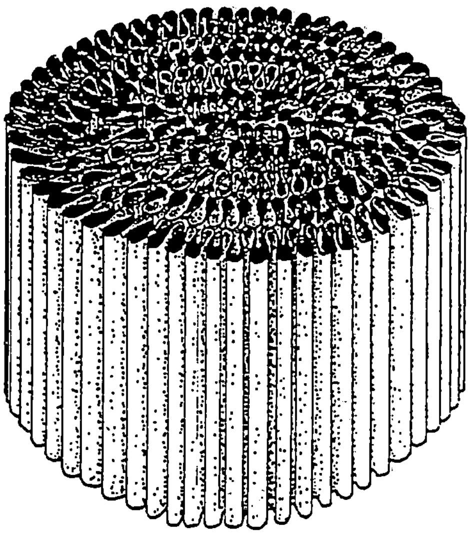
Tellerette™
(full scale)
Dumped packing



Pall Ring ™
(full scale)
Dumped packing



Munters™
(not to scale)
Stacked packing



Munters™
(not to scale)
Stacked packing

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Figure 4-2

Typical Tower Packings

Special Water Treatment Study - Phase II

packings of other shapes, but they generally have poorer pressure drop characteristics than do other types such as Tripacks, Tellerettes, and pall rings. Because improved pressure-drop characteristics can translate into lower operating costs, much of the research and development effort of packing manufacturers has been devoted to cost-effective methods of reducing the pressure drop.

Stacked packings are less commonly used. These packings, manufactured in large sections for placement into the packed tower, are not packed randomly. They are stacked in an ordered fashion. Typical stacked tower packings are also shown in figure 4-2. These packings permit slightly lower pressure drop and greater water flow rates. Typical stacked packings are made from plastics (either woven gauze or corrugated sheets) or sheet metal that is corrugated and formed into an integral unit.

While pressure drop is assumed to indicate good transfer, it may not if the liquid phase drop is greater than 60%. Furthermore pressure drop mass transfer is limiting. In general, if pressure drop increases then liquid holdup may result in film breakdown. Operation is typically designed to be less than 60% of flow that floods the column.

Materials of Construction. The designer should consider the properties of the water to be treated before selecting materials to be used in the column. Generally, uncoated carbon steels are not recommended because they are susceptible to corrosion. The use of painted carbon steel for interior tower surfaces is also not recommended because it presents a hidden long-term O&M cost owing to a potential for internal tower deterioration. The tower would have to be taken out of service periodically and the packing and internals removed to allow for painting. This procedure can be costly.

Aluminum is commonly used but, under some conditions, it is susceptible to corrosion when exposed to aggressive waters. When aluminum is inappropriate, the designer should consider fiberglass or stainless steel. Either can be used under a wide variety of circumstances. Fiberglass is especially used when consideration is given to in-place acid cleaning of packing.

The use of reinforced concrete towers is acceptable, particularly for installations of capacities greater than 1.0 mgd, that also require aesthetic embellishment. However, concrete in constant exposure to water may require periodic maintenance such as patching or painting. Use of a stainless steel or aluminum liner may relieve this problem.

Redundancy and Dependability. Many water supplies are not essential; they can be taken out of service at any time because alternative water supplies can satisfy demand. However, if a water supply source is essential, even part of the year, consideration should be given to providing redundant components in the treatment system, in particular the following:

1. Blower for packed tower
2. Blower for air pollution control system
3. Influent pump
4. Clearwell pump
5. Auxiliary power

It occasionally is necessary to provide two complete treatment systems so that one system can provide treatment while the other system is down for maintenance. This scheme is especially applicable when process interferences will make it necessary to periodically remove the packing for cleaning. Another approach is to provide redundant blower capacity, since blowers require frequent maintenance.

Redundant equipment also increases a facility's ability to adapt to changed conditions. In defining design criteria, the technical judgment made is that raw water concentrations are unlikely to exceed the design concentrations. Nevertheless, unexpectedly high raw water concentrations may occur. Multiple blowers, for example, can be used to vary the air-to-water ratio. If concentrations rise, the back-up blower may be operated in parallel with the lead blower, effectively boosting the air-to-water ratio and the removal capability of the packed tower.

Planning Period. Life-cycle costs for water treatment plants and equipment are usually evaluated on a 20- to 50-year replacement basis. If the designer has no information to the contrary, the present worth costs should be evaluated on this basis. However, if a computerized ground water model has been developed for a particular site, it is useful to run the model into the future to determine whether there is an endpoint to the contamination at fewer than 20 years. If this is found to be the case, the optimization of capital and O&M costs may be evaluated over this shorter time period.

Mechanical Components

The operation and general layout of an air stripping system is illustrated in figure 4-3. Each of the major components is discussed below.

Air Blowers. The typical blower used in air stripping applications is a high-efficiency industrial airfoil fan. This kind of fan is appropriate for both forced air and induced draft applications. These fans should have steep pressure characteristics, so that if actual system pressure is higher than initially estimated, delivered air volume will not be substantially reduced. Since system efficiency can be affected, selection of an operating pressure is important. Induced air fans located on the top of a column have been used with success in two applications in New Jersey. If air pollution control is needed, then the location of the blower needs to be reconsidered.

Use of such blowers also will accommodate variations in system pressure caused by changes in flow through the packing. If variations in removal requirements are expected, the use of multi-speed or variable-speed blowers may be warranted.

Pumps. Under most ground water supply situations, the existing well pumps are "high head." That is, they are designed to pump either directly into the distribution system or to an elevated storage tank. High-head pumps generally are not appropriate for pumping water to the top of a stripping column. It sometimes is necessary to replace the well pumps, well pump motors or both to meet the lower head conditions needed to pump the water to the top of the column.

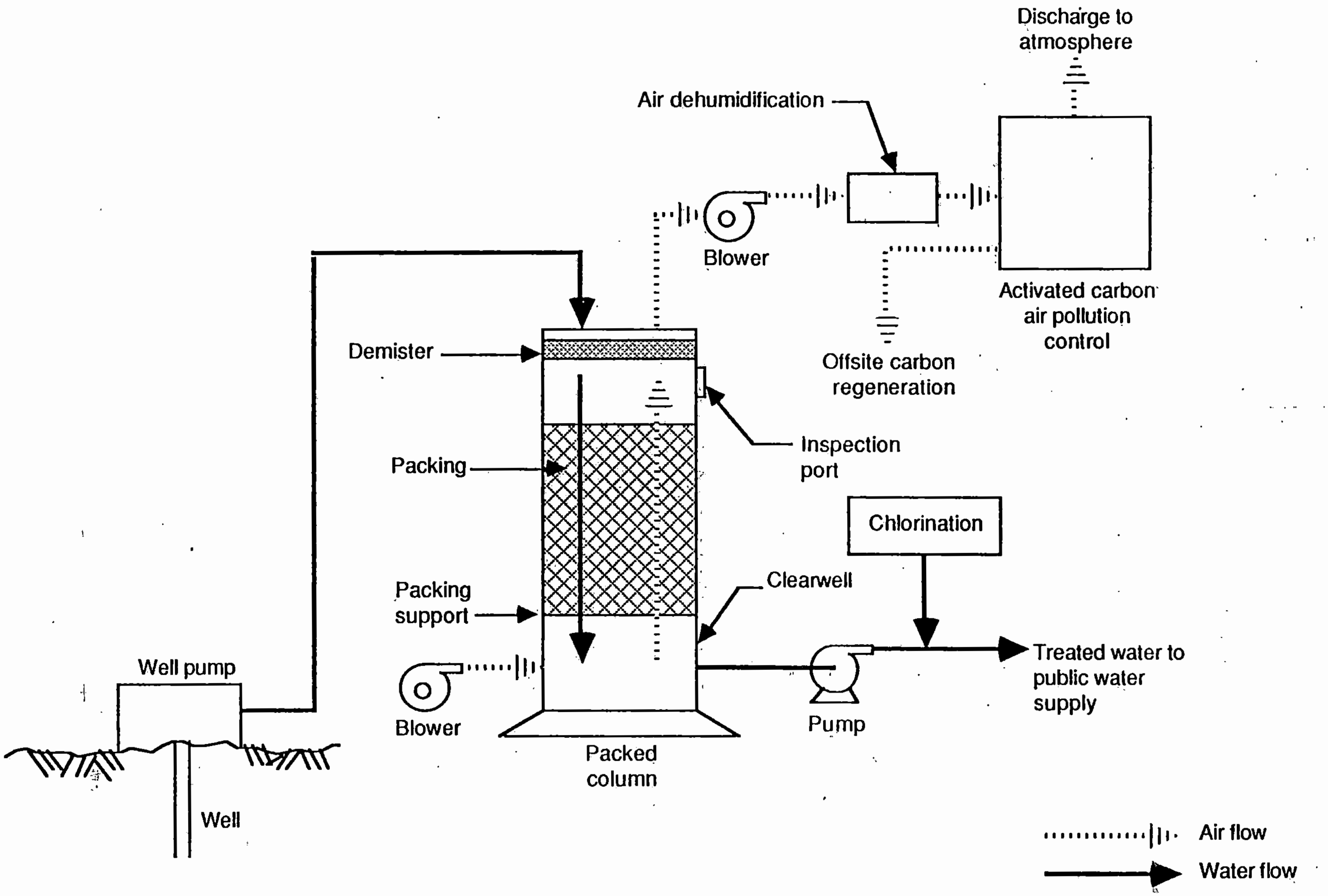

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Figure 4-3

Typical Air Stripping Process Schematic

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Unless water in the clearwell can flow by gravity into the storage or distribution system, it is usually necessary to pump the treated water into the distribution system. This process -- pumping the water to the stripper and then out of the treated water clearwell -- is referred to as "double pumping." Double pumping is usually more costly than direct well pumping in terms of power costs. Much of the increase in O&M cost associated with air stripping can also be ascribed to double pumping.

Demister. It is usually desirable to eliminate from the air exhaust the fine water droplets carried up by the air stream. A mat of fine plastic mesh or other material 4-inches to 12-inches thick is placed in the air stream above the water distribution system. The air easily flows around the mesh filaments, but the relatively heavier water droplets, which cannot change course so readily, impact the filaments. Because the mesh is relatively porous, a droplet may penetrate deeply into the mesh before meeting a filament directly in its path. Surface tension causes the water to adhere to the filament. Collected droplets coalesce into larger drops, which flow down the filaments and eventually to drip from the bottom of the mesh pad in the form of drops too large to be carried up again.

Because these droplets often contain contaminants, it is undesirable to emit them into the air because they could cause localized precipitation in the vicinity of the air stripping tower. In cases where air pollution control is used, the demister protects the air pollution control equipment from possible water damage.

Packing Support. An open space at the bottom of the packing is necessary to ensure good initial distribution of the air into the packing. Some type of packing support system or support plate must be provided. The support plate can be a custom design or one of several standard designs available from vendors. The primary purpose of the packing support is to retain the packing without excessive restriction of air and water flow.

Clearwell. An air stripping tower usually is supported on a combination air well/clearwell. The clearwell maintains the treated-water pump in a primed and flooded condition. Typically, the clearwell is sized for a minimum of 2 feet clearance between the maximum water surface elevation and the bottom of the packing support plate. This open area serves as an air plenum for the introduction and distribution of forced air from the blowers.

Inspection Port. An inspection port should be provided on the exterior of an air stripping column to allow for observation of the condition of the packing and interior of the column. This inspection port can consist of a removable plate or a fixed window. It should be designed flush to the interior surface of the column. If the inspection port creates a significant cavity in the interior of the air stripper, biological activity or deposition of metals could occur there.

Planning and Construction Considerations

Siting constraints can significantly impact the design of an air stripping tower. In a residential area, sound levels and overall aesthetic impact require careful consideration. If sound levels are expected to be high, blowers and pumps should be placed in enclosed structures. This is particularly important where higher-than-usual horsepower (hp) is required for the blowers. Most packed column installations will require blowers of less than 50 hp. On occasion, motors exceeding 50 hp or even 100 hp may be needed. The designer should obtain an estimate of the decibel levels anticipated for the particular design, and evaluate the impact of these sound levels. State and local noise control regulations should also be reviewed.

If the facility has a substantial visual impact, special architectural treatment should be considered. This is especially important when a tall metal or fiberglass tower would be undesirable. Architectural treatment could include the use of brickface, the construction of a wood structure with shingles, or other acceptable treatment. Columns that are too tall in relation to their surroundings can be constructed as several columns in series. This would require additional pumping between columns, increasing operational costs.

Minimum Suggested Guidelines for Design and for State Regulatory Review. The following minimum requirements for the design of air stripping systems are recommended:

Air-to-Water Ratio. The air-to-water ratio usually should not be lower than 20:1. At lower ratios localized areas of short circuiting of the water flow may occur within the column, resulting in lower mass transfer rates than intended. As a practical matter, a designer may use a minimum ratio of 25:1 to provide a margin of safety. Air-to-water ratios exceeding 100:1 should only be used in unusual circumstances, e.g., when the compound(s) to be removed are either present in high concentrations or have very low strippability. Since air handling and treatment equipment costs increase with volume, minimizing the air to water ratio is a design consideration.

Predisinfection. The capability of adding chlorine or another oxidant or acid for cleaning the media is important.

Column Structure. The column structure should be designed with sufficient strength to resist all anticipated wind loads. In addition, it should be of sufficient strength to resist the hydrostatic pressures that would occur in the unusual event that the tower were to fill with water. The structural strength can be reduced if a fail-safe system, such as a blowout portal, is provided in case of flooding.

Air Intake Location. The fresh air intake should not be placed close to the gas phase discharge from the top of the facility. The performance of a column can be severely impaired if the intake air is not clean.

Protective Screens/Filters. Protective screens should be provided at both the intake and discharge of the facility. The intake screens in particular should protect the equipment and interior of the packed column from all types of extraneous matter including leaves, papers, small animals, and insects. Consideration should also be given to providing air filters to protect against pollen, dust, and other particulates.

Redistribution. In order to avoid channeling of water along the inside wall of the tower because of lower flow resistance there, it is customary to provide for distribution at every 20-foot interval. Wipers or redistributers are often used at the perimeter of the packed column. Guidelines for the provision of redistribution indicate that, for packing-to-column-diameter ratios lower than 1:10, wall wipers are required. When this ratio is between 1:10 and 1:15, wipers should be considered. Regardless, redistribution should be provided for at every 20-foot interval.

Sampling Taps. Sampling taps should be provided on the raw water line to the stripper and at the treated water clearwell.

Appropriate ports should be provided on the air ductwork so that air quality sampling can be performed and flow measurement devices can be inserted into the air stream.

Air Treatment Capability. Towers should be designed for future incorporation of an air treatment system.

Pilot Studies. Where waters contain a complex matrix of background organics and synthetic organics whose strippability is not well understood, a pilot study should be performed to determine an appropriate design sizing.

4.2.4 OPERATIONS AND MAINTENANCE CONSIDERATIONS

In comparison to the other unit processes used in water treatment, an air stripping process is simple to operate. Many operational problems that may occur can be anticipated during the design phase and addressed at that point.

Operational/Design Issues

Freezing. Air stripping towers and equipment may be exposed to subfreezing temperatures, sometimes for extended periods. If the system is expected to be in continuous operation, design features to prevent freezing may not be needed, particularly since a ground water supply remains at constant temperature throughout the year. Under continuous operation, the water flowing through the pipes, pumps, and stripper never becomes quiescent enough to freeze. If the air stripper, for any reason, is expected to be out of service during the colder times of the year, however, consideration should be given to providing automatic drains and electrical heating elements, and to housing pumps and piping that could be damaged by freezing.

Under the extreme case of operation during extended periods of sub-zero temperatures, ice may form in the demister, partially blocking the exit of the air from the stripper. As this happens, the blower's ability to force air through the tower decreases while the pumps continue to pump water through the tower at a constant rate. In order to avoid release of water that has been inadequately treated, the blower back-pressure should be monitored when there is potential for icing in the demister.

Biological Growth. Under some circumstances, the interior of an air stripping column presents an excellent environment for biological growth. A large surface area is available, there is a generous level of fresh oxygen, and at least some organic material is present. The occurrence of biological activity in air stripping columns is relatively difficult to predict, though certain characteristics of the raw water could indicate this possibility. While the volatile organics themselves are usually not of a high enough concentration to promote biological activity, any naturally occurring organics also present in relatively high concentration can enhance the chance of biological activity. The level of total organic carbon (TOC) and biochemical oxygen demand (BOD) should be noted as part of the assessment of the possibility of biological activity. If any chemicals are used preceding the air stripping process, their ability to act as a nutrient source for biological growth should be assessed.

Regardless, circumstances that appear favorable to biological growth do not preclude the use of air stripping as a treatment process. Pretreatment to remove the naturally occurring organics can assure that biological growth will not occur. The engineer may choose to design the system without pretreatment for natural organics. However, provision should be made to add the necessary pretreatment units after operations have commenced, if problems become evident.

Generally, pretreatment can consist of either of two different approaches: predisinfection or substrate removal. Of these two approaches, predisinfection is more commonly used. While chlorine is the usual predisinfection agent, ozone may be preferable. Chlorine, in combination with other organics, can form organohalide compounds. Particularly in cases of ground water contamination by synthetic organics, the addition of chlorine may create halogenated by-products of unknown treatability and with unknown health effects. The by-products of ozonation are not halogenated and are thought to be less toxic than the halogenated by-products, although they too may have unforeseen treatability and health effects. Unlike chlorine, ozone does not leave a disinfectant residual and will not maintain its ability to disinfect through the packed column.

An alternative approach to predisinfection is substrate removal. The organic substrate that feeds the biological growth can be removed by the classical water treatment process of chemical addition and sedimentation or filtration. Chemicals may be added either to coagulate the substrate or to chemically change the substrate to enhance subsequent removal. Provision to add these chemicals should be made during design.

Inorganics. Inorganics also can interfere with the air stripping process. Iron and manganese, in particular, may precipitate when aerated, causing the tower packing to become clogged. This can be prevented by pretreating the water with any one of a number of processes appropriate for removal of these metals. If inorganics must be removed in conjunction with volatile organics, it is usually preferable to place the traditional processes for inorganics removal ahead of the air stripping column.

Operational Flexibility. While there are many aspects to operational flexibility, this term is generally used to indicate the degree to which a system can accommodate different operational modes. To some extent, operational flexibility is related to redundancy (see section 4.2.3).

In the design phase, a particular column's ability to operate under the entire range of flow and contamination scenarios should be assessed. If, for example, an expected operational scheme falls outside the recommended limits for a column, the use of multiple air-to-water ratios or even the use of multiple columns should be considered. At very low flows, the loading may be below the recommended minimum loading of 10 gpm/ft^2. In this case, operational flexibility would be improved if two strippers of smaller diameter were operated in parallel so that, at reduced flows, only one column would be used. Additional operational flexibility, and O&M cost savings, can be obtained through the use of multiple blowers on each column so that, given a change in the contamination scenario, varying the air-to-water ratio is possible.

Cleaning. Occasionally, the tower packing and internal components may require cleaning, particularly if low levels of iron or hardness have precipitated in the column. If this occurs, the column should be taken out of service and rinsed with a mild acid solution. The packing can be replaced, removed and cleaned separately, or cleaned in place. With aggressive waters, it may be necessary to replace the plastic packing entirely after 5 to 10 years. It is recommended that one or more portals be provided to monitor the condition of the internals and packing.

4.2.5 AIR POLLUTION CONTROL

Air Pollution Regulations

The gaseous-phase discharge from the top of a packed column represents a potential air pollution impact. According to the New Jersey Administrative Code (NJAC), an operating permit is required for any waste treatment or water treatment equipment treating water that contains any toxic volatile organic substance (TVOS) in excess of 100 parts per billion (ppb) or when the total concentration of volatile organic substances (VOS) in the water to be treated exceeds 3,500 ppb. Additionally, no source is permitted to emit to the air greater than 0.1 pound per hour of any single TVOS. An exemption is granted to any water treatment facility with an average daily flow of less than 100,000 gallons per day.

Those substances defined by NJAC 7:27-17.3 as TVOSs are listed in table 4-1. At this writing, an additional list of TVOSs has been proposed to be added to this regulation (table 4-2). These tables include many compounds likely to be present in contaminated ground water supplies. At higher levels of raw-water contamination, control of the air discharge from an air stripper becomes necessary. Figure 4-4 can be used to determine the TVOS emission rate for a given water flowrate and concentration in water.

When the total TVOS emissions exceed 0.1 ppm, NJAC requires an air modeling simulation to ascertain the level of risk. If the cancer risk of any single contaminant does not exceed a 10^{-6} cancer risk over a 70-year lifetime at the property line, then no air discharge control is required.

TABLE 4–1

TOXIC VOLATILE ORGANIC SUBSTANCES DEFINED IN AIR POLLUTION REGULATIONS[a]

Benzene[b] (benzol)
Carbon tetrachloride[b] (tetrachloromethane)
Chloroform (trichloroethane)
Dioxane (1,4-diethylene dioxide)
Ethylenimine (aziridine)
Ethylene dibromide (1,2-dibromomethane)
Ethylene dichloride[b] (1,2-dichloroethane)
1,1,2,2-Tetrachloroethane (symtetrachloroethane)
Tetrachloroethylene[b] (perchloroethylene)
1,1,2-Trichloroethane[b] (vinyl trichloride)
Trichloroethylene[b] (trichloroethene)

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[a] Listed in NJAC 7:27–17.3.
[b] Listed in A–280.

Note: Nomenclature errors are as recorded in the regulations. Alternate nomenclature appears in parentheses.

TABLE 4–2

PROPOSED ADDITONAL TOXIC VOLATILE ORGANIC SUBSTANCES TO BE REGULATED

Acrylonitrile
bis (2-ethylhexyl)phthalate
Chlorobenzene[a]
Formaldehyde[b]
Maleic anhydride
Methylene chloride
Nitrobenzene
Toluene-2,4-diisocyanate
ortho-Toluidine
Vinyl chloride[a]

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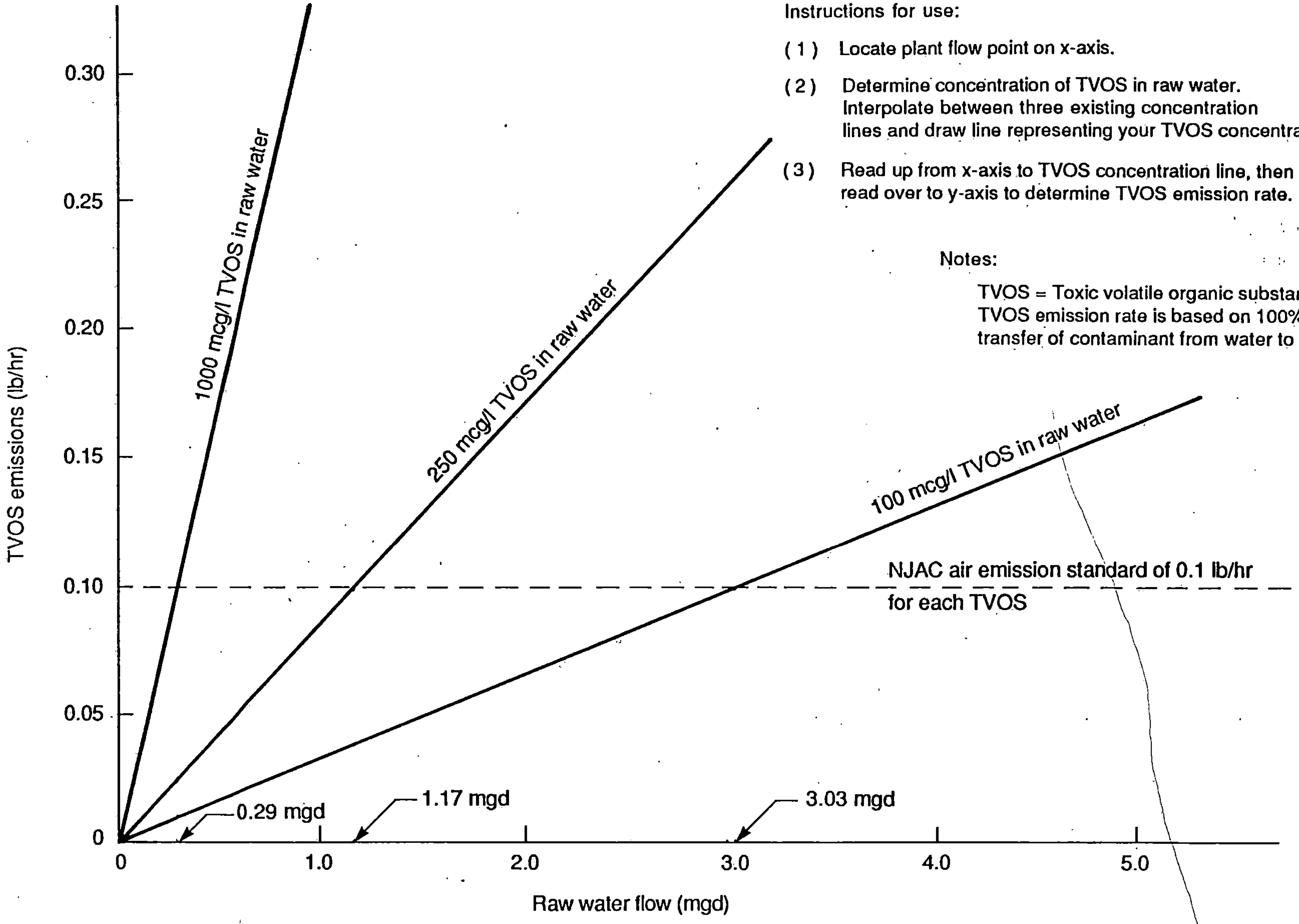
[a] Regulated under A–280.
[b] Listed, but not presently regulated, under A–280.



Instructions for use:

- (1) Locate plant flow point on x-axis.
- (2) Determine concentration of TVOS in raw water. Interpolate between three existing concentration lines and draw line representing your TVOS concentration.
- (3) Read up from x-axis to TVOS concentration line, then read over to y-axis to determine TVOS emission rate.

Notes:

TVOS = Toxic volatile organic substance
TVOS emission rate is based on 100% transfer of contaminant from water to air.

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Figure 4-4

Determination of TVOS
Mass Emissions from Air Strippers

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A 40-foot minimum stack height stipulation applies when the 0.1-pound-per-hour requirement is surpassed. In addition, there should be no discernible odor at the property line.

Generally, the NJDEP Division of Environmental Quality (DEQ) seeks to define the air pollution impacts on the basis of a worst-case scenario: the highest expected flow rate coupled with the highest expected influent concentration(s). DEQ uses the following policies in defining the worst case:

1. For the purpose of analyzing the air discharge, all air stripping facilities are assumed to achieve 100 percent removal of TVOS.

2. To define the 100 ppb permit exemption concentration, the peak sample concentration of the worst-case well in the wellfield is used.

3. To define the 0.1-pound-per-hour maximum discharge limit without control, a weighted average of the maximum flow of each of the supply wells for the set of worst-case concentrations for the wellfield is used.

Two additional NJAC requirements affect design:

1. An air stripping tower discharge must be a minimum of 40 feet above grade and a minimum of 20 feet higher than any area of human use or occupancy within 50 feet horizontally. (These requirements may be exempted if state-of-the-art air pollution control is utilized.)

2. The air discharge directed vertically upward must not exceed a velocity of 3,600 feet per minute (an uncommonly high velocity for an air stripping tower).

Because of the strictness of this regulatory framework, an exemption from air pollution control will be relatively rare in New Jersey. In most cases, both planning and design should proceed on the assumption that air pollution control will be needed. Since the problem of volatile organics in the atmosphere is of concern to both the State and federal governments, it is also possible that air pollution control, though not required now, may be required in the future by a change in regulations.

Air Pollution Control Systems

Various techniques have been employed to control the discharges of volatile organics from packed columns. These techniques include:

- GAC adsorption
- Catalytic oxidation
- Thermal oxidation
- Condensation

Granular activated carbon adsorption is the most commonly used technology for air pollution control; catalytic oxidation follows in frequency of use. These two technologies are discussed below.

GAC Systems. GAC systems make use of the tendency for contaminants to transfer from the gaseous phase air stream to the solid phase carbon granule. The designer of a system using a vapor-phase carbon air pollution control system should determine the following: (1) type of carbon to be used, (2) influent and effluent VOC concentrations, (3) anticipated carbon usage rate, (4) carbon-bed approach velocity, and (5) the method of carbon regeneration or replacement.

A major consideration with the use of GAC for air pollution control is the need to periodically replace the activated carbon as its capacity to adsorb contaminants becomes exhausted. There are three general approaches to activated carbon replacement or regeneration:

1. The spent carbon can be shipped to an activated carbon vendor where it is regenerated and returned or is replaced by new virgin carbon.

2. The carbon can be regenerated on site, usually within the contactor. Specially designed contactors capable of tolerating the 600 °F steam temperatures necessary to regenerate vapor-phase carbon are available. A boiler must be provided. Vapor phase carbon can also be regenerated with steam in the range of 240-300 °F.

3. The spent carbon can be disposed of in a secure landfill. Because this type of carbon may be defined as a hazardous waste under NJDEP's regulations, care should be taken to ensure that all appropriate permits for disposal have been

> obtained. This approach to vapor-phase carbon replacement is usually not cost-effective since the purveyor has to pay twice -- to have the spent carbon disposed of and to purchase virgin carbon at full price.

Air discharged from the packed column is saturated with water. In general, since the relative humidity of the off-gases must be below 50 percent for proper adsorption to occur, dehumidification of the air discharge is necessary. (The water molecules in the air tend to occupy adsorption sites on the carbon that could otherwise be occupied by contaminant molecules.) However, where VOC concentrations require lower removal efficiencies, periodic carbon repalcement may be less expensive than dehumidification.

Dehumidification can be accomplished in one or two steps. In the more common one-step process, the water-saturated air exiting the air stripping column is heated to a temperature appropriate to induce a change in relative humidity to below 50 percent. The increase in temperature also reduces the efficiency of the vapor-phase carbon somewhat. When this reduction in efficiency is unusually great, it may be necessary to use a two-step process. In this process, the air discharge is initially passed through a cooler. The cooler is usually configured so that cooling water circulates through a jacket surrounding the gas exhaust duct. Because it facilitates the collection of condensate, a horizontal configuration is preferable. (This condensate may contain a portion of the contaminants and thus be defined as a liquid hazardous waste by NJDEP.) After cooling and condensation, the air stream is then heated to further reduce the relative humidity, and is subsequently applied to the carbon for contaminant removal. The two step process of cooling-heating is rarely applied.

Biological growth in a vapor phase GAC contactor is generally not considered a problem.

<u>Catalytic Oxidation System</u>. A less common method of off-gas control is catalytic oxidation. In this process the gas stream is exposed to an appropriate catalyst. The entire gas stream is preheated to between 350 °C (622 °F) and 550 °C (1,022 °F). The catalyst, coupled with the elevated temperature, chemically changes the contaminants, primarily to carbon

dioxide, water vapor and nitrogen. The catalyst should be inexpensive, long-lasting, able to function at a reasonably achievable temperature, and capable of being formed into shapes necessary for proper contact with the air. Higher-molecular-weight hydrocarbons are more easily catalyzed than those of lower molecular weight. The cost of preheating the gas stream must be taken into account when considering this alternative.

4.2.6 ESTIMATING SIZES AND COSTS OF AIR STRIPPING SYSTEMS

4.2.6.1 Estimation of Costs

The cost of an air stripping system depends on a number of factors: contaminant concentrations, flowrate, plant design and process configuration, and choice of construction materials.

The capital cost of a new facility usually is estimated on the basis of a preliminary design. Equipment quantity takeoffs can be estimated from this preliminary design, and a cost estimate developed. A quantity takeoff is performed by measuring materials and equipment from drawings, design reports, or specifications accompanying a conceptual design.

The cost of the packing for the stripping column is an important factor. It will vary depending on the size of the column, the type of packing, and the design conditions of the plant. Although packing is also available in ceramic and metallic forms, plastic is most commonly used. Plastic packings generally show better durability than other types. In some applications where usually high liquid loadings are desirable, the use of structured (engineered) media may result in some operational cost savings owing to the lower pressure drop characteristics of this type of packing. Under most common design conditions, randomly dumped plastic packings will be more economical on a capital cost basis. However, the selection of packing to optimize air flow, pressure drop and contaminant removal can be more important than capital cost.

Another major cost factor is the material used to construct the column. Concrete, aluminum, fiberglass, or various types of steel may be used, as long as the material chosen is compatible with the process, will not be subject to corrosion or deterioration, or need early repair or replacement. Generally, aluminum or fiberglass is used because of relatively lower cost. Concrete, often with brick facing, is used when special architectural treatment is needed. Stainless steel is used when the source water is aggressive, or when extra durability or strength is required of the tower.

Power requirements can vary depending on the size of the system and the means of conveying flow from process to process. The cost of power can also vary as a function of geographic location, power supply source, or power availability. New Jersey is served by two major power companies: Jersey Central Power and Light (JCP&L) and Public Service Electric and Gas (PSE&G). Power costs for each of these utilities are presented in table 4-3. An average of these power costs was used in developing blower and pump operating cost curves (see section 4.2.6.2).

The two major power costs associated with an air stripping column are the costs of operating the pumps and blowers. Typically, the water has to be double pumped -- first to the top of the air stripping tower, then again out of the tower clearwell into the distribution system. If possible, gravity flow should be used to avoid double pumping.

Because blower power costs often predominate over other O&M costs, the designer should focus on the total air pressure drop through the entire system. Although a major component of the pressure drop is that induced by the packing, it is also important to seek, during design, to minimize the pressure drop through the entire stripping system, including the column's internal components and air pollution control system.

The cost involved in the construction of an air stripping column or carbon adsorption unit (or both) should also provide for other, contingent costs such as engineering, legal services, financial costs, and other miscellaneous costs during construction. Experience has shown that these extra costs can be taken into account by adding a fixed percentage -- commonly between 30 and 45 percent -- to the cost of the materials and installation.

TABLE 4–3

POWER COSTS OF NEW JERSEY UTILITIES

	Residential	Industrial
	(cents per kw-hr)	
Public Service Gas & Electric	11.0	7.7
Jersey Central Power & Light	10.6	8.7

4.2.6.2 Conceptual Sizings

Generic conceptual sizings were developed to provide guidance to water purveyors on the relative sizing and cost of air stripping columns (see appendix A). Although they do not take into account site-specific water quality parameters that may influence air stripper performance, the approximate size and the relative cost of implementing a packed column treatment scheme can be estimated by using these conceptual sizings. **These sizings are conceptual only, however; they are not intended to replace a detailed engineering analysis of a specific contamination problem.**

Conceptual sizings of air stripping columns for treating various flowrates and various raw water concentrations were developed for each of the A-280 compounds. The treatment objective selected for each compound was the interim concentration for action level 1 as proposed by NJDEP in January 1986 on an interim basis. These interim levels do differ from the final MCL adopted by NJDEP.

For each compound, a Henry's Law constant was selected on the basis of a literature search. Henry's Law constants derived from best-fit correlations of field packed-column piloting data were used if available. Otherwise, Henry's Law constants were obtained from direct measurements reported in the literature or derived from vapor pressure and solubility data. In all cases, the Henry's Law constant was adjusted to a temperature typical for New Jersey ground water, 13 °C (55 °F). Where multiple and/or conflicting Henry's Law constants were available, an engineering judgment was made as to which constant had the necessary validity and conservatism for the analysis.

With all other parameters constant, the sizing of a packed column will be governed by the Henry's Law constant. When the Henry's Law constant is very low, comparatively large sizings result. This is particularly true with the chlorinated pesticides such as chlordane and PCBs. (In fact, air stripping usually is not a recommended treatment process for this class of compounds.) When the tower diameters derived are excessively large, it may be appropriate to use several smaller towers equivalent in area to a single tower. Although some of the conceptual sizings in appendix A show sizings that may not be cost-effective (particularly for the chlorinated pesticides) when compared to alternate treatment processes (such as carbon adsorption) these sizings have been included for illustration purposes.

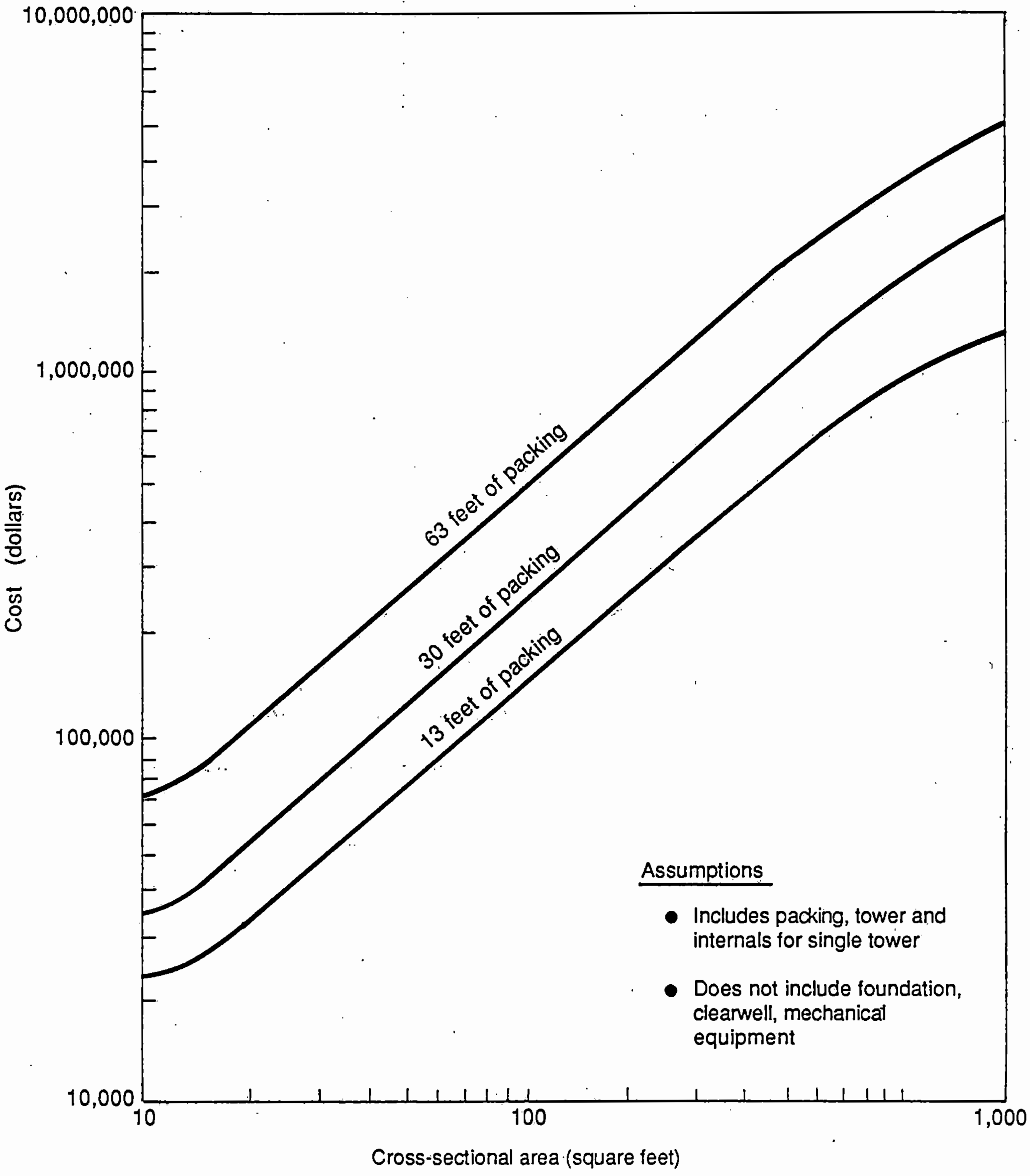
In this exercise the minimum air-to-water ratio was set at 25:1. Typical mass transfer coefficients were derived for each scenario presented in the conceptual sizings. After derivation of the theoretical sizings, appropriate factors of safety were applied to the resultant designs.

Several criteria were assumed to be constants in all the conceptual designs. A standard incremental pressure drop of 75 Newtons per vertical meter of packing height per square meter of cross-sectional area of packing ($N/m/m^2$) or 0.092 inches water column per foot (in. W.C./ft) was selected as a reasonable, economical design value. The indication is that, at this low incremental pressure drop, total blower power is minimized. The most cost-effective stripping factor (the ratio of the operating air-to-water ratio to the theoretical minimum air-to-water ratio) is usually between 3 and 4; however, air-to-water ratios below 20:1 may result in designs that are not cost-effective. Mass transfer characteristics also may be inhibited at air-to-water ratios below 20:1.

Cost Curves

The conceptual sizings can be used to develop a preliminary cost estimate for a particular treatment scenario. Each of the cost curves (shown in figures 4-5 through 4-10) represent a different portion of the total cost of an air stripping column. All curves include 30 percent for field engineering, legal, financial, and contingencies. Users of these cost curves should bear in mind that design engineering costs can vary widely, depending on the detail of the treatment alternatives analysis performed, the other unit processes being used, and the need for air pollution control.

Packed tower costs (figure 4-5) include costs for a steel or aluminum shell, an influent valve, support plates, influent flow distributors,



May 1986 ENR CCI = 4229

Adapted from Singley, et al.

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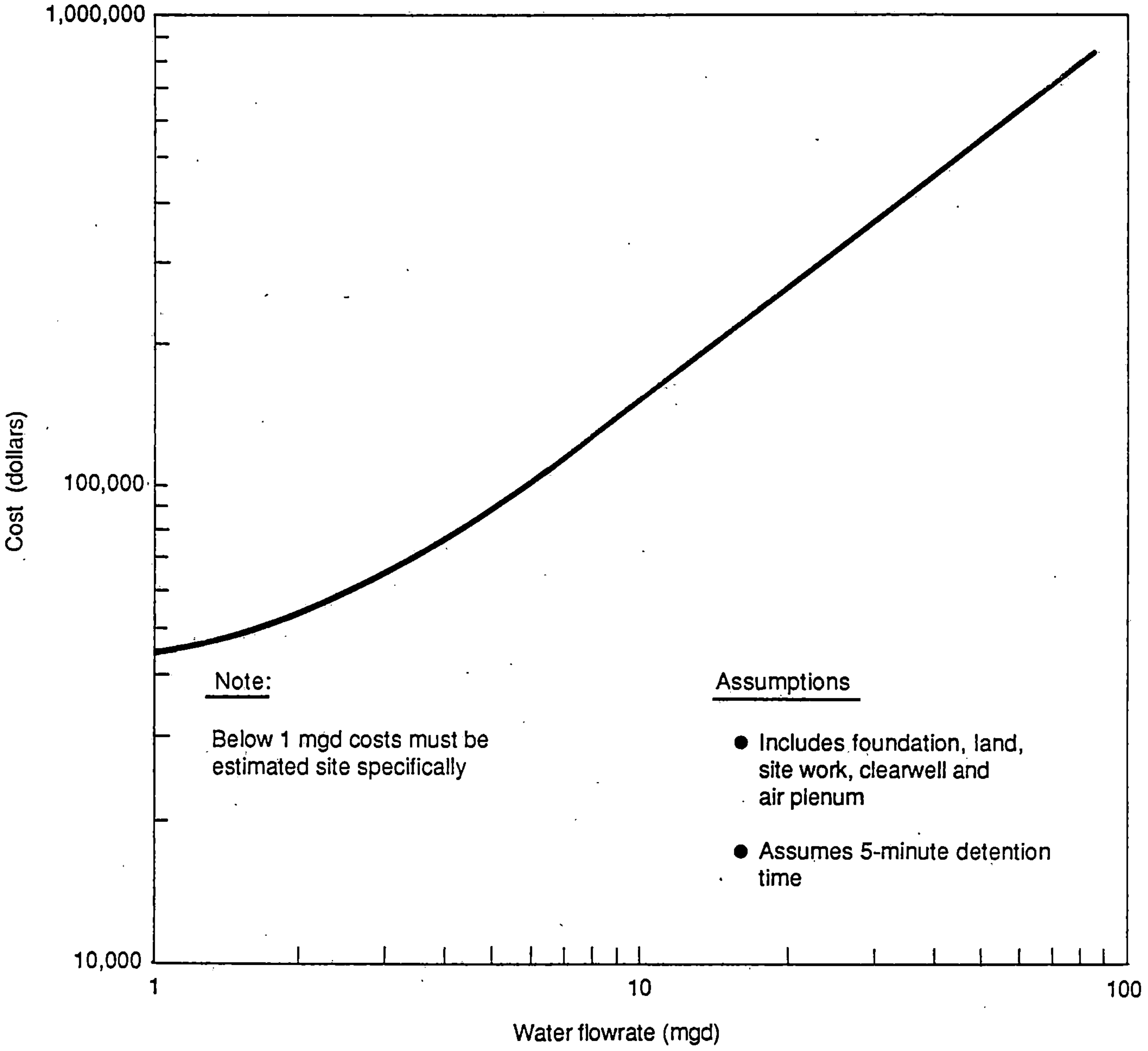
Figure 4-5

Packed Tower Costs

Special Water Treatment Study - Phase II



Note:

Below 1 mgd costs must be estimated site specifically

Assumptions

- Includes foundation, land, site work, clearwell and air plenum
- Assumes 5-minute detention time

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Figure 4-6

Clearwell Capital Costs

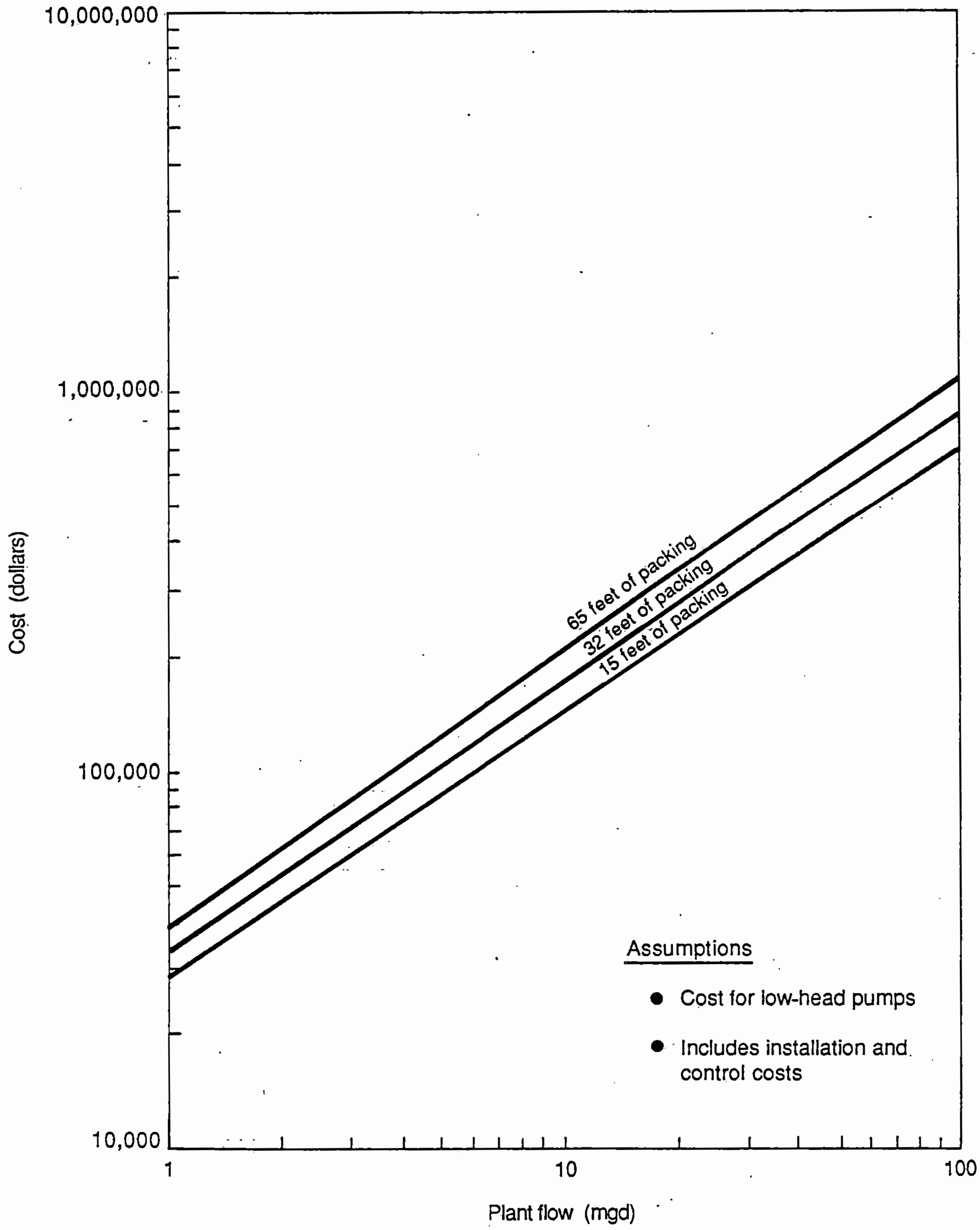

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Figure 4-7

Pump Capital Costs

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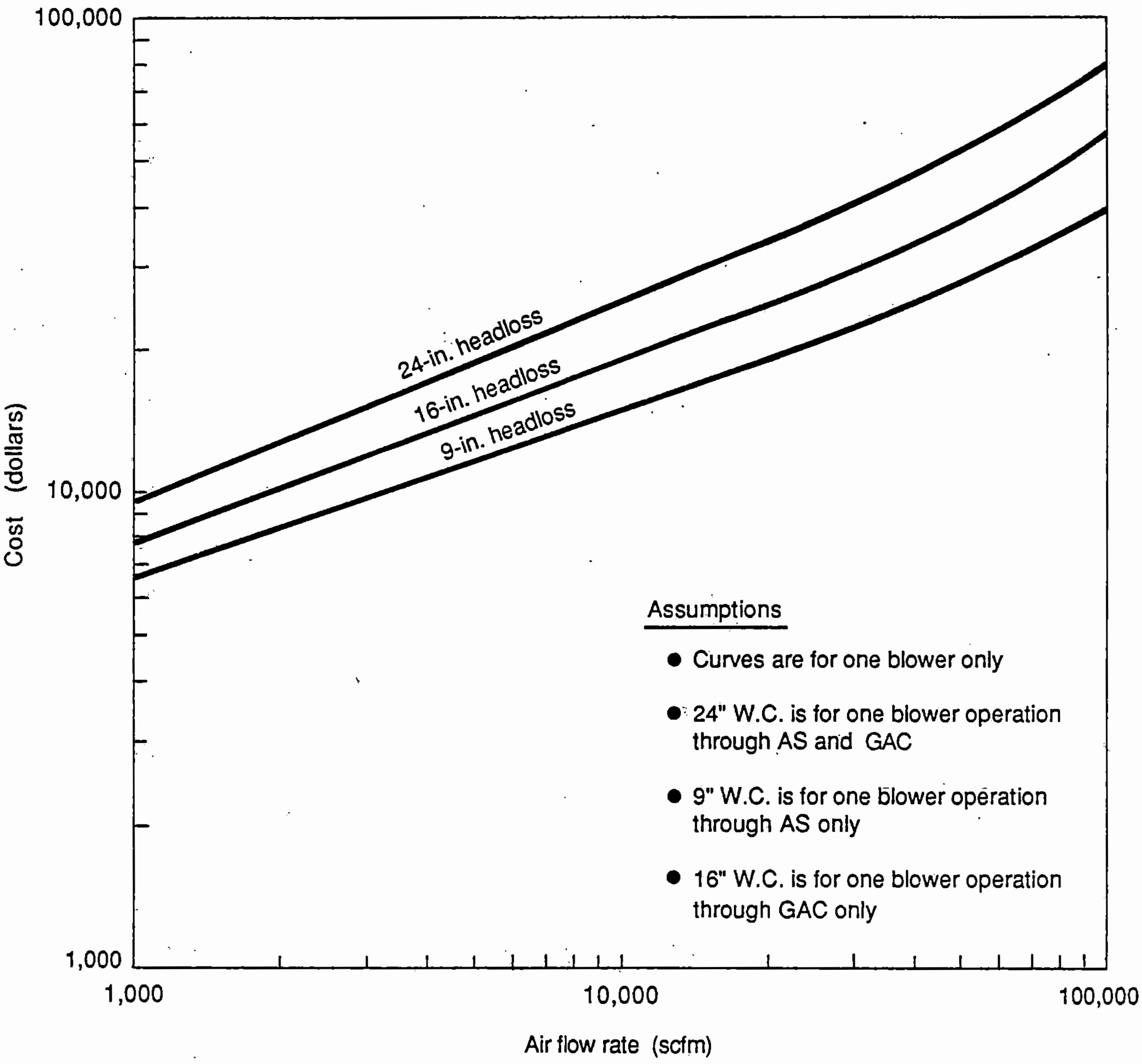

Assumptions

- Curves are for one blower only
- 24" W.C. is for one blower operation through AS and GAC
- 9" W.C. is for one blower operation through AS only
- 16" W.C. is for one blower operation through GAC only

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Figure 4-8

Blower Capital Costs

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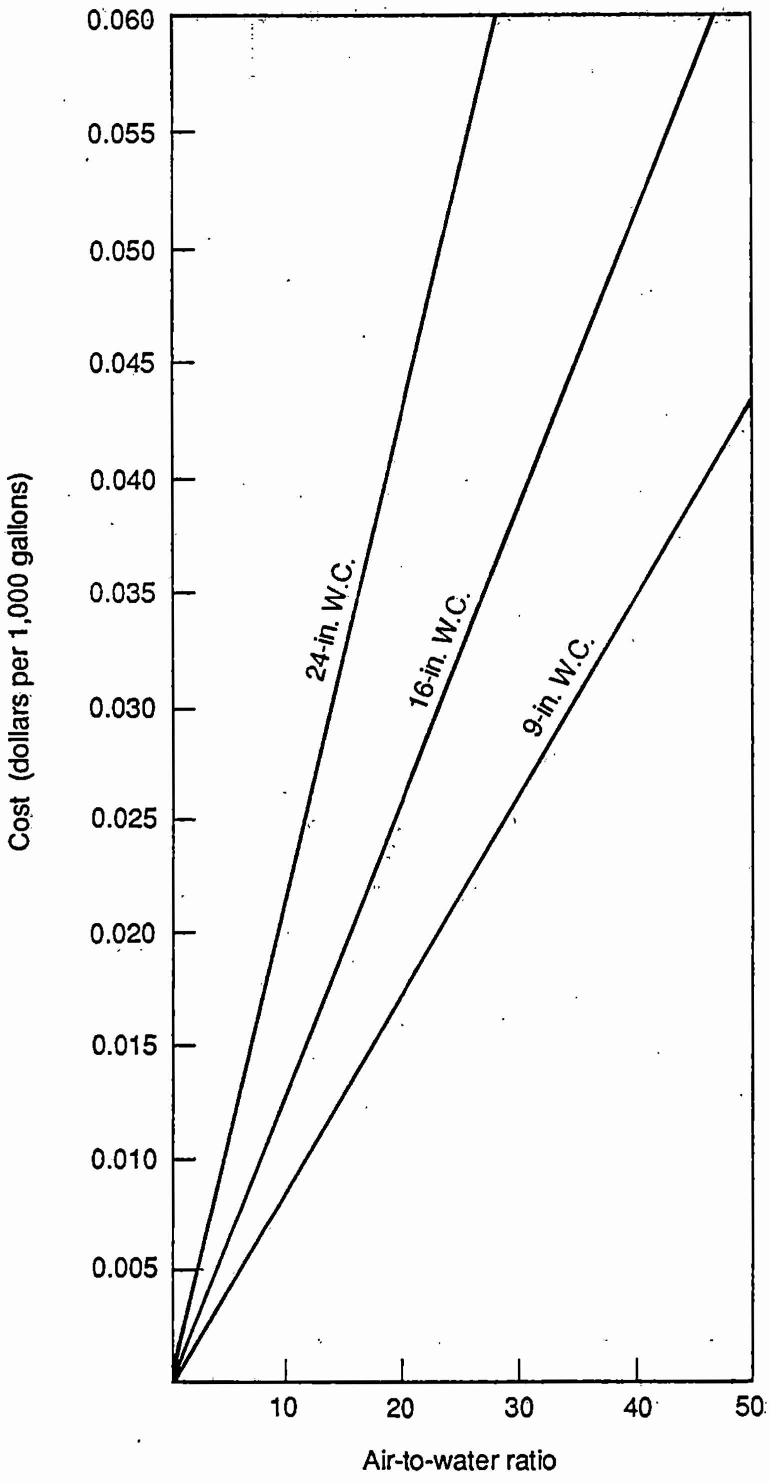

Power cost = 9.6¢ / kW-hr

Adapted from Singley, et al.

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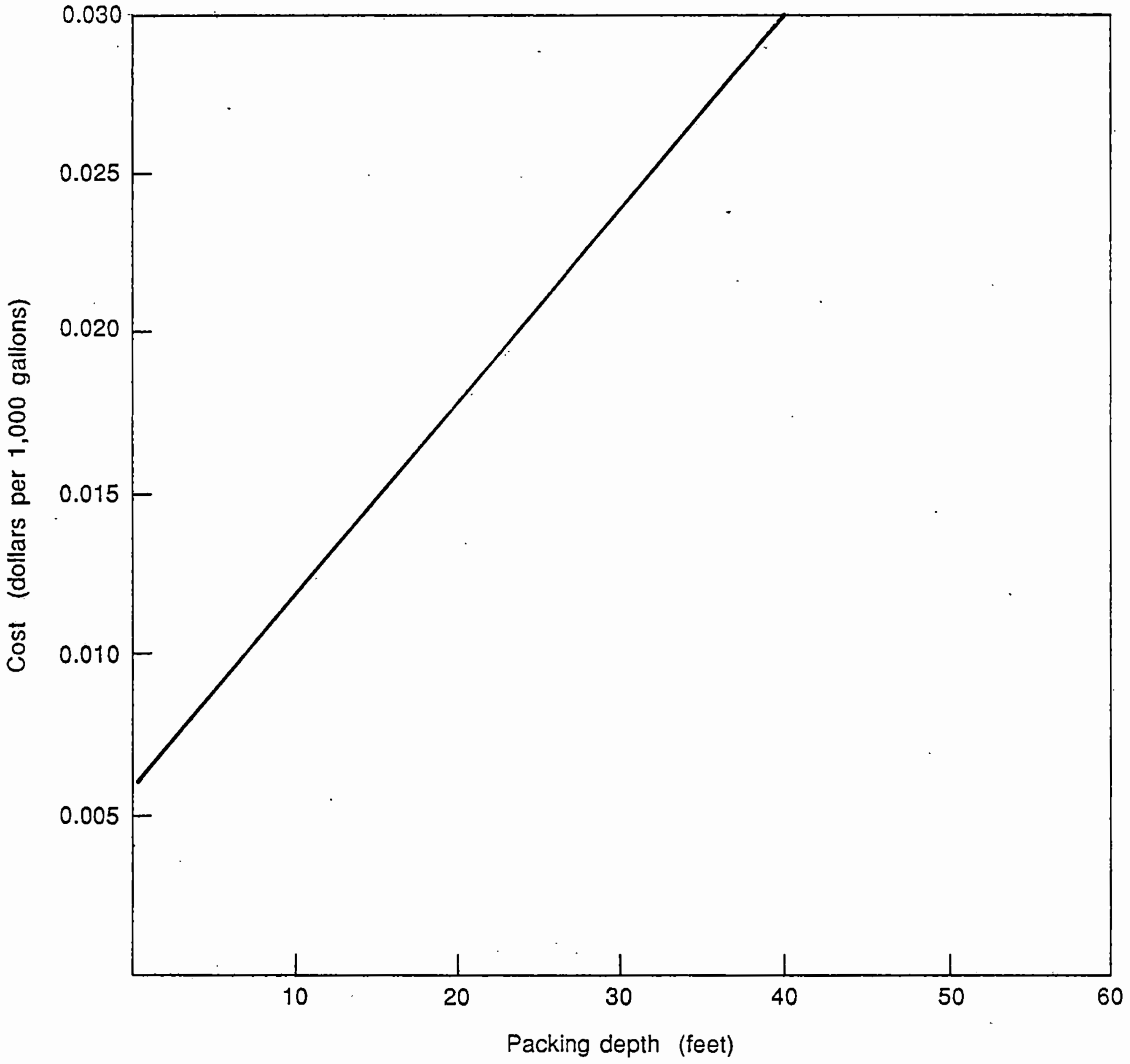
Figure 4-9

Blower Operating Costs

Special Water Treatment Study - Phase II



Power cost = 9.6 ¢ / kW-hr

Adapted from Singley, et al.

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Figure 4-10

Pump Operating Costs

Special Water Treatment Study - Phase II

plastic packing, and a demister. The influent distributors are assumed to be 2 feet above the packing. The packing support is assumed to be 1 foot above the top of the clearwell.

The clearwell costs (figure 4-6) are based on underground concrete construction with no unusual subsurface conditions. It is assumed that the clearwell also serves as an air plenum and has a support structure sufficient for placing the air stripping column above the clearwell. An allowance of $2,000 per acre is included for the cost of land.

Pump costs (figure 4-7) are based on installed costs for cast iron pumps using either single- or dual-staged impellers, depending on the total head required. Horsepower allowance has been made for 5 feet of suction lift and the appropriate frictional losses. The pumps in this cost analysis are assumed to pump out of an existing clearwell or reaction tank to the top of the packed column. If well pumps are already in place, these pumps need to be converted to low-head pumps that are capable of pumping from the ground water well to a pre-air-stripper clear well. The alternative of providing a single pump to pump water from the well to the top of the air stripping column (such as a new multiple-stage vertical turbine well pump) would generally incur a higher cost than shown in this cost analysis.

The blower costs (figure 4-8) are based on use of a forced draft system. Blower costs were developed using blower discharge static heads of 9 and 24 inches of water. Nine inches static head is typically used for conservative design for a packed column without air pollution control, while 24 inches is typical where a single blower is intended to push the air through both the packed column and vapor phase carbon units. However, it is usually appropriate to use a primary blower to provide air to the packed column, and a secondary blower to force the air through the air pollution control units, in which case the pressure drop through the air pollution control unit alone is about 16 inches W.C. The blower horsepower required for the 9-inch static head ranges from 5 to 125 horsepower, and for the 24-inch static head, from 20 to 250 horsepower. All blowers were costed assuming carbon steel construction with totally enclosed, fan-cooled motors.

Operation and maintenance costs are based on three separate components: (1) blower operation costs (figure 4-9), (2) pump operation costs (figure 4-10) and (3) labor and materials costs. In this study these costs were developed using a power cost of $0.096 per kilowatt hour and an ENR Construction Cost Index of 4230.

Blower and pump operation cost curves are largely a function of the cost of the energy required to run them. The labor and materials costs are the predominate operation costs for other unit processes.

Figures 4-6 (Clearwell Capital Costs) and 4-7 (Pump Capital Costs) do not illustrate the expected costs at all flowrates. Below a flowrate of one million gallons per day, site-specific conditions become more important considerations in the cost of the clearwell and pumps than at higher flowrates. For estimating clearwell and pump costs at flowrates below 1 mgd, the following guidelines should be used:

- Clearwell Capital Costs
  - Between 0.5 mgd and 1.0 mgd, use $20,000
  - Below 0.5 mgd, use $10,000
- Pump Capital Costs
  - Between 0.5 mgd and 1.0 mgd, use $15,000
  - Below 0.5 mgd, use $8,000

4.2.7 EXAMPLE PROCEDURE USING SIZING AND COST TABLES FOR AIR STRIPPING

The sizing and cost methodology presented in this report can be used for any scenario where compounds regulated under A-280 are evident. The sizing tables apply to flowrates ranging from 0.05 mgd to 5.0 mgd and to raw water contaminant concentrations ranging from 10 mcg/l to 1,000 mcg/l. The cost curves are applicable for flowrates from 1.0 mgd to over 10 mgd. At flowrates below 1.0 mgd, reasonable assumptions can be made in developing an estimate of capital cost.

This cost estimating procedure is simple and efficient. It allows the reader to estimate sizes of systems needed for any number of possible situations. What-if analyses can be quickly performed. The following example illustrates the use of this cost estimating system.

Example of Air Stripping Cost Estimating Procedure

An existing ground water treatment facility with a design flowrate of 2.0 mgd has exhibited the following average and peak volatile organic concentrations to date:

Compound name	Average (mcg/l)	Peak (mcg/l)
Tetrachloroethylene (PCE)	15	50
Trichloroethylene (TCE)	100	200
1,1,1-Trichloroethane (TCEA)	5	25
Total organics	120 mcg/l	275 mcg/l

At this point we should note that the stripping of compounds from water when their concentrations are at these low levels is generally assumed to occur independently, i.e., that the removal of one particular contaminant does not interfere with the removal of any other contaminant. The engineer selects the most difficult-to-treat compound and designs the treatment system to remove that contaminant. The more treatable contaminants will be concurrently removed to below regulatory limits.

Initially, it is unknown which compound concentration is the most difficult-to-treat and, hence, will govern in determining the sizing of the air stripper. However, after reviewing the above contamination scenario in conjunction with the conceptual sizings in appendix A, several preliminary judgments can be made. Under average concentration conditions, it appears that trichloroethylene is the limiting compound. Trichloroethylene requires 24 feet of packing, while tetrachloroethylene and 1,1,1-trichloroethane require approximately 20 feet and 5 feet, respectively. (When conceptual sizings do not appear for concentrations of interest, it is appropriate to interpolate between adjacent sizings.) However, at the peak concentrations it appears that tetrachloroethylene requires the most packing (28 feet) while the trichloroethylene and the 1,1,1-trichloroethane require 26 feet and 5 feet, respectively.

Design Criteria. On the basis of this kind of information, an engineering judgment must be made on the raw water concentration design criteria. Generally, the treatment system should be expected to perform under all expected conditions, particularly if it represents a component of an essential drinking water supply. If a history of increasing concentrations can be established, then design raw water concentrations may be even higher than the observed peak. If concentrations have been relatively steady, then a design criterion slightly above the peak concentration would be appropriate. If a clearly established declining trend is evident, then design concentrations at or slightly below the observed peak are generally appropriate. In all cases the actual design should provide a sufficient factor of safety for even the worst expected case.

Therefore, assuming concentrations have been steady for all compounds of concern, a raw water design concentration of 75 mcg/l of tetrachloroethylene would be appropriate.

Conceptual Sizing. Based on the conceptual sizings, one can interpolate an approximate sizing based on the four sizings adjacent to the 2.0 mgd and 75 mcg/l tetrachloroethylene design criteria. The four sizings applicable to this particular scenario, taken from appendix A, are presented below.

Raw water concentration	Flowrate	
	1.0 mgd	5.0 mgd
50	Ht = 28 ft Dia = 5 ft A:W = 25:1	Ht = 28 ft Dia = 12 ft A:W = 25:1
100	Ht = 32 ft Dia = 5 ft A:W = 25:1	Ht = 32 ft Dia = 12 ft A:W = 25:1

Therefore, based on an interpolation of this data, the conceptual design sizing applicable to this situation, rounded to the nearest even diameter, is

Packing height = 30 feet
Diameter = 8 feet
Air-to-water ratio = 25:1

Packed Tower Costs. To determine the overall cost of this system, subtotals are generated on the basis of each separate cost curve contained in figures in this section. To use figure 4-5, Packed Tower Costs, it is necessary to calculate the cross-sectional area of the tower and to use this value to enter the horizontal axis.

$$A = \pi (4\ \text{ft})^2 = 50\ \text{square feet}$$

Cost for single tower = $130,000

Clearwell Costs. The clearwell costs are determined on the basis of flowrate (see figure 4-6, Clearwell Capital Costs):

Clearwell cost at 2.0 mgd = $50,000

Pump Cost. On the basis of the packing depth, an approximate pump cost is determined. Where necessary, an interpolation between the curves is performed (see figure 4-7, Pump Capital Costs):

Pump at 2.0 mgd = $50,000

Blowers. In order to determine the blower cost, the air flowrate must be calculated:

2.0 mgd is equivalent to 186 cfm

$$\text{Air flowrate} = \frac{25}{1}\ \text{(air-to-water ratio)} \times 186\ \text{cfm} = 4{,}650\ \text{cfm}$$

Reviewing figure 4-4, Mass Emissions from Air Strippers, it is apparent that tetrachloroethylene emissions in this example do not violate the New Jersey standard of 0.1 pound per hour. However, trichloroethylene emissions at the observed peak concentration of 200 mcg/l do violate this criterion. Therefore, it is assumed that air pollution control is needed. The engineer at this point makes a design decision: use either two separate blowers, one each for the stripper and air pollution control system, or one large blower to force the air through the entire system. If one blower is selected, the 24-inch W.C. headloss curve is used. If two blowers are selected (one primary and one secondary) then the primary blower receives an 9-inch W.C. headloss. The secondary blower, which forces air through the air pollution control system, receives a headloss of 16 inches W.C.

In this example, two blowers will be used:

One blower at 4,650 cfm and 9-in. W.C. = \$12,000
One blower at 4,650 cfm and 16-in. W.C. = \$16,000

Total cost of blowers = \$28,000

Vapor-phase granular activated carbon contactors are fabricated with either a single bed of carbon in each contactor or two beds in each contactor (dual beds). Each bed of GAC can handle up to 10,000 cubic feet of air per minute.

Without redundancy on the air pollution control system (that is, no standby capacity), a typical single-bed contactor costs about \$100,000 installed, without carbon, while a typical dual-bed unit costs about \$120,000 installed. Both costs include the cost of an air dehumidification system. It is assumed that only a single-bed contactor is required in this example because the treatment system can be taken out of service for carbon changeout:

One vapor-phase GAC contactor installed = \$100,000

The initial charge for activated carbon should also be included in the capital costs. Since 20,000 pounds of carbon are required for a single-bed contactor, and the price of carbon is about \$0.70 per pound,

20,000 lb at \$0.70 per lb = \$14,000

All capital costs have now been derived. The minimum cost of a packed tower, without equipment redundancies, elaborate controls, or a shelter is shown below.

Tower	$130,000
Clearwell	50,000
Pumps	50,000
Blowers	28,000
GAC contactor	100,000
GAC initial charge	14,000
Total cost	$372,000

If backup systems are required for the pumps and blowers, then the estimated additional cost is $78,000, for a total cost of $450,000.

Operation Costs. Using the same design example as above, the operating costs of the pump(s) can be determined (from figure 4-10), as follows:

30 feet of packing = $0.024 per 1,000 gallons

Using a primary blower at 9-inches W.C., a secondary blower at 16-inches W.C., and an air-to-water ratio of 25:1, then the cost to operate the blowers is (from figure 4-9)

Primary blower = $0.022 per 1,000 gallons
Secondary blower = $0.035 per 1,000 gallons

Cost = $0.057 per 1,000 gallons

Periodic operator attention is assumed to be a part of well head and pump station operation.

The cost of carbon replacement should also be taken into account. Assuming replacement twice a year by an outside contractor at a net cost of $0.60 per pound, then

Cost = 2 x 20,000 pounds x $0.60 per pound
Cost = $24,000 per year
Cost = $0.033 per 1,000 gallons

An allowance of $0.02 per 1,000 gallons, in addition to the aforementioned costs, provides for the cost of labor and materials. The total operation and maintenance costs are as follows:

	Cost per 1,000 gallons
Pumping	$0.024
Blowers	0.057
Activated Carbon	0.033
Labor and materials	0.020
Total O&M cost	$0.134

The amortization of the capital cost is usually carried in the rate base. Therefore, the equivalent cost per 1,000 gallons for the capital expenditure must be determined. First, the annual payment (R) must be determined that would amortize the debt (A) over a period of n years with a uniform interest rate (i). The following equation applies:

$$R = \frac{Ai}{1-(1+i)^{-n}}$$

For this example, the total capital cost, A, is $372,000; the capital cost recovery period, n, is 20 years; and the interest rate, i, is 8%. Therefore,

$$R = \frac{372{,}000 \times 0.08}{1-(1+0.08)^{-20}} = \$37{,}900 \text{ per year}$$

Next, this payment is determined on a 1,000 gallon basis. Given that a 2.0-mgd facility will produce a maximum of 730 million gallons of water in a year, the amortization of this capital cost over the entire year is $0.052 per 1,000 gallons. Combining this cost with the operation and maintenance cost, the total cost impact is $0.186 per 1,000 gallons.

Financial impact on the consumer can be estimated by using a figure of 275 gallons per day as the typical water use per household. This results in a typical water bill increase of $4.67 per quarter. If a higher water use rate is assumed for areas with greater unaccounted-for water, i.e., 400 gallons per household per day, then the cost impact could be as high as $6.79 per quarter.

4.3 CARBON ADSORPTION

4.3.1 OVERVIEW OF CARBON ADSORPTION

Adsorption is a natural process in which molecules of a dissolved compound adhere to the surface of an adsorbent solid. Activated carbon, the most commonly used adsorbent, is effective in removing organic compounds from water. Its very large surface area maximizes the tendency of molecules to physically adsorb to its surface.

This large surface area -- typically 500 to 1,400 square meters per gram of carbon -- is made possible by the carbon's internal pore structure, which consists of relatively large pores, called macropores, and relatively small pores, called micropores (see figure 4-11).[2] Raw carbonaceous material such as coal, wood or coconut shells is activated by being charred at high temperature in an oven. This activation process develops the carbon's internal pore structure.

Application

Two major product alternatives exist for adsorption application: activated carbon and polymeric adsorbent resins. Of these, activated carbon has the longest history of use and is the most widely used. A general purpose adsorbent, activated carbon has application in a wide variety of fields. It can be made from a number of raw materials and by a variety of manufacturing processes that produce carbons tailored to specific applications. Activated carbon is commonly supplied in the granular form known as GAC (granular activated carbon). GAC granules are similar in size to coarse sand. Activated carbon is also available in the powdered form known as PAC

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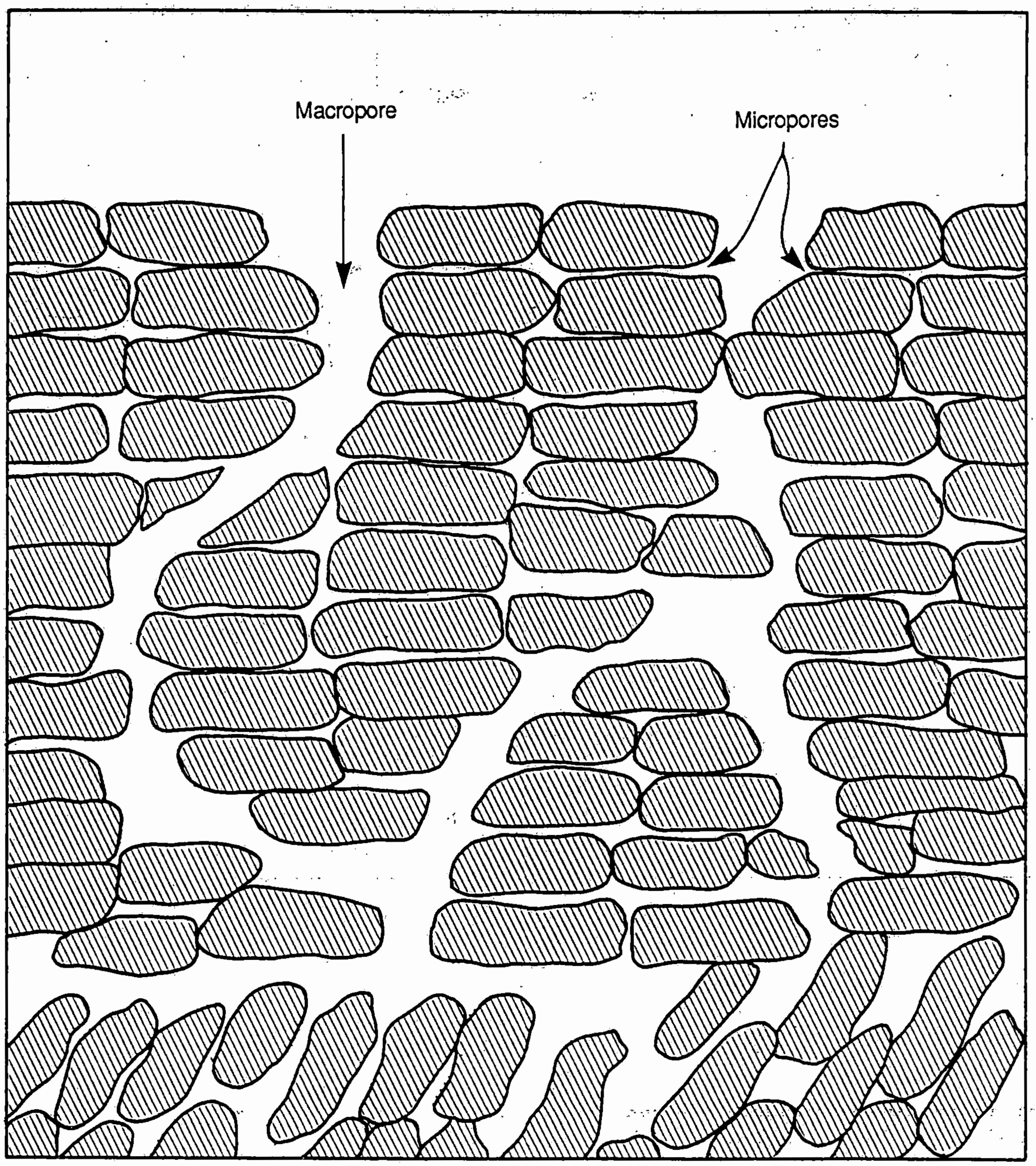
[2] Macropores are arbitrarily defined as those pores greater than 100 Angstroms (A or 10^{-10}m) in diameter; micropores range between 10 and 100 A. The micropores are largely responsible for the large surface area of activated carbon.



Courtesy: Dr. S. Faust, Rutgers University

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Figure 4-11

Microscopic Representation of an Activated Carbon Particle

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(powdered activated carbon). PAC is generally not used for removing synthetic organics from contaminated water owing to unfavorable economics.

For water treatment applications activated carbon may be placed in either an open, gravity-fed filter or in a large vessel called a pressure contactor. A typical GAC pressure contactor is shown in schematic in figure 4-12.

In almost all cases, activated carbons have a wide range of affinity for materials in solution, making them susceptible to competitive adsorption. Competitive adsorption complicates design because presence of a variety of contaminants can make it difficult to predict what contaminants will be adsorbed, and at what rates. Synthetic polymeric adsorbent resins were developed to be more contaminant specific, to provide greater surface area, and to be used for specialized applications. Competitive adsorption also has to be considered in their use; however, their specialized properties can mitigate this problem.

In general, activated carbon is the least expensive type of adsorbent, especially when reused after thermal reactivation. The polymeric resins lend themselves particularly well to chemical regeneration and adsorbate recovery in specific instances where the presence of materials that would foul the resins can be controlled or eliminated. They have wide applicability to industrial water and wastewater treatment. However, for municipal water treatment applications, resins are rarely used, primarily because of their high cost and competitive effects that lead to desorption of contaminants.

4.3.2 PROCESS AND THEORY DESCRIPTION

Adsorption Isotherms

The capacity of an activated carbon to adsorb organics from a water solution is expressed simply by an equation called an adsorption isotherm. This equation plays a critical role in the analysis and design of an activated carbon system.

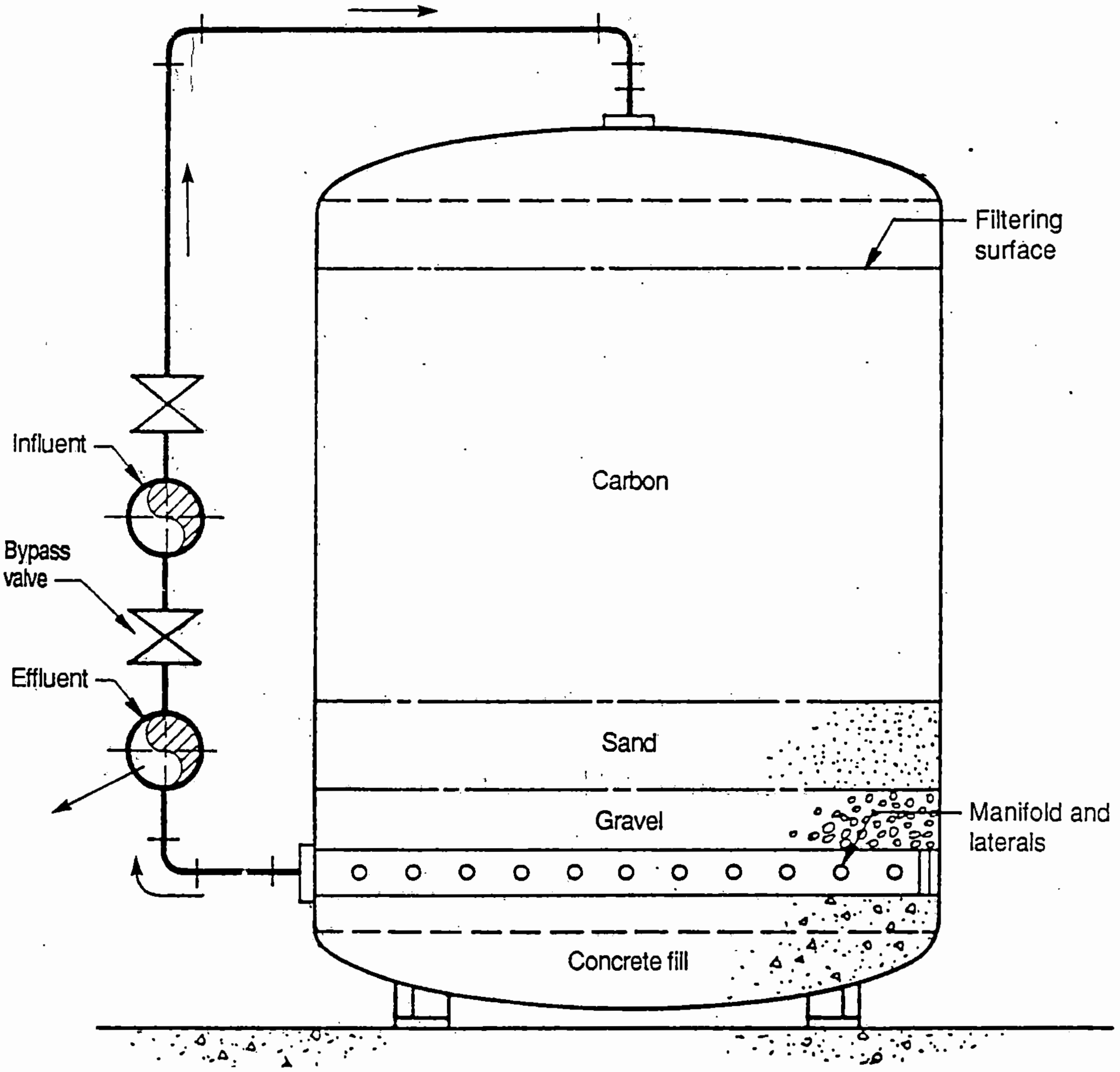

Figure 4-12

Typical Carbon Contactor

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The adsorption isotherm relates the amount of contaminant adsorbed on carbon to the equilibrium of the contaminant concentration in the liquid phase. The term "isotherm" stems from the fact that these functions are temperature specific and are measured in the laboratory at a constant temperature. Isotherms are also affected by pH, hardness, and many other chemical and physical properties of the water.

The commonly used Freundlich equation used, in generating adsorption isotherms, has the general form:

$$q = KC^{1/n}$$

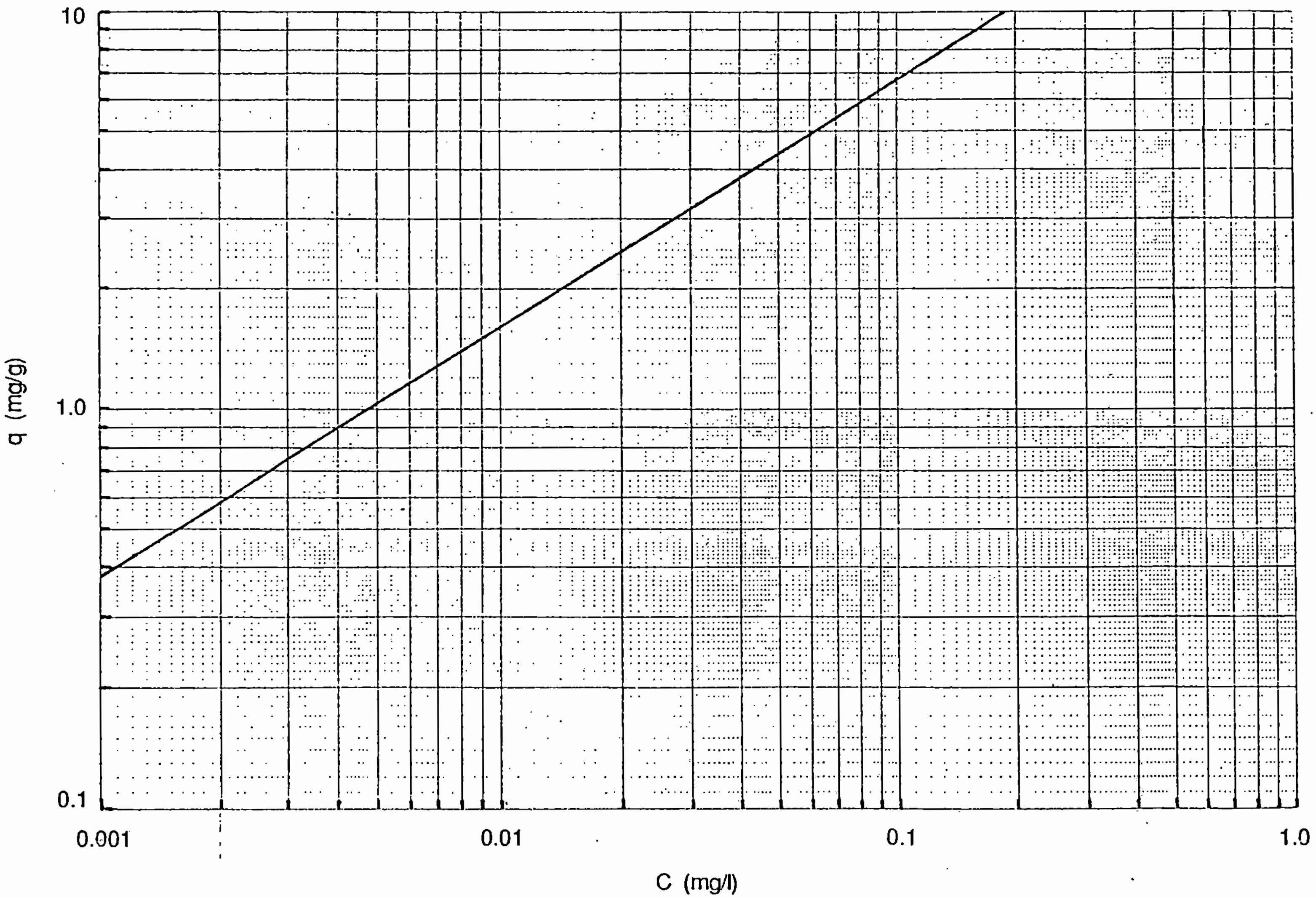
where:

q = amount of contaminant adsorbed per unit weight of activated carbon, or q (sometimes known as x/m) = milligram of compound/gram of carbon
K, $1/n$ = empirical (experimentally determined) constants
C = residual contaminant concentration (mg/l)

The literature presents most isotherms in the Freundlich format. This format is used for convenience. The Freundlich constants are easy for experimenters to measure, for designers to use, and are widely available.

The Freundlich isotherm function will graph as a straight line on a log-log plot. The x-axis is presented as the residual concentration of the contaminant, while the y-axis represents q, the total amount of contaminant adsorbed on the carbon. For single-solute situations, these log-log plots are typically linear (see figure 4-13). The slope of these plots is 1/n, and the y-intercept is equal to K as utilized in the Freundlich equation. Therefore, any particular isotherm can be described by its respective K and 1/n.

Isotherms are specific to particular adsorbents, although there is some comparability among the products of different manufacturers of activated carbon. Isotherms are also specific to a particular water quality. Therefore, site-specific isotherm tests can assist in assessing the treatability of a particular contamination scenario.



Source: Dobbs & Cohen

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Figure 4-13

Linearized Freundlich Isotherm Plot (Trichloroethylene)

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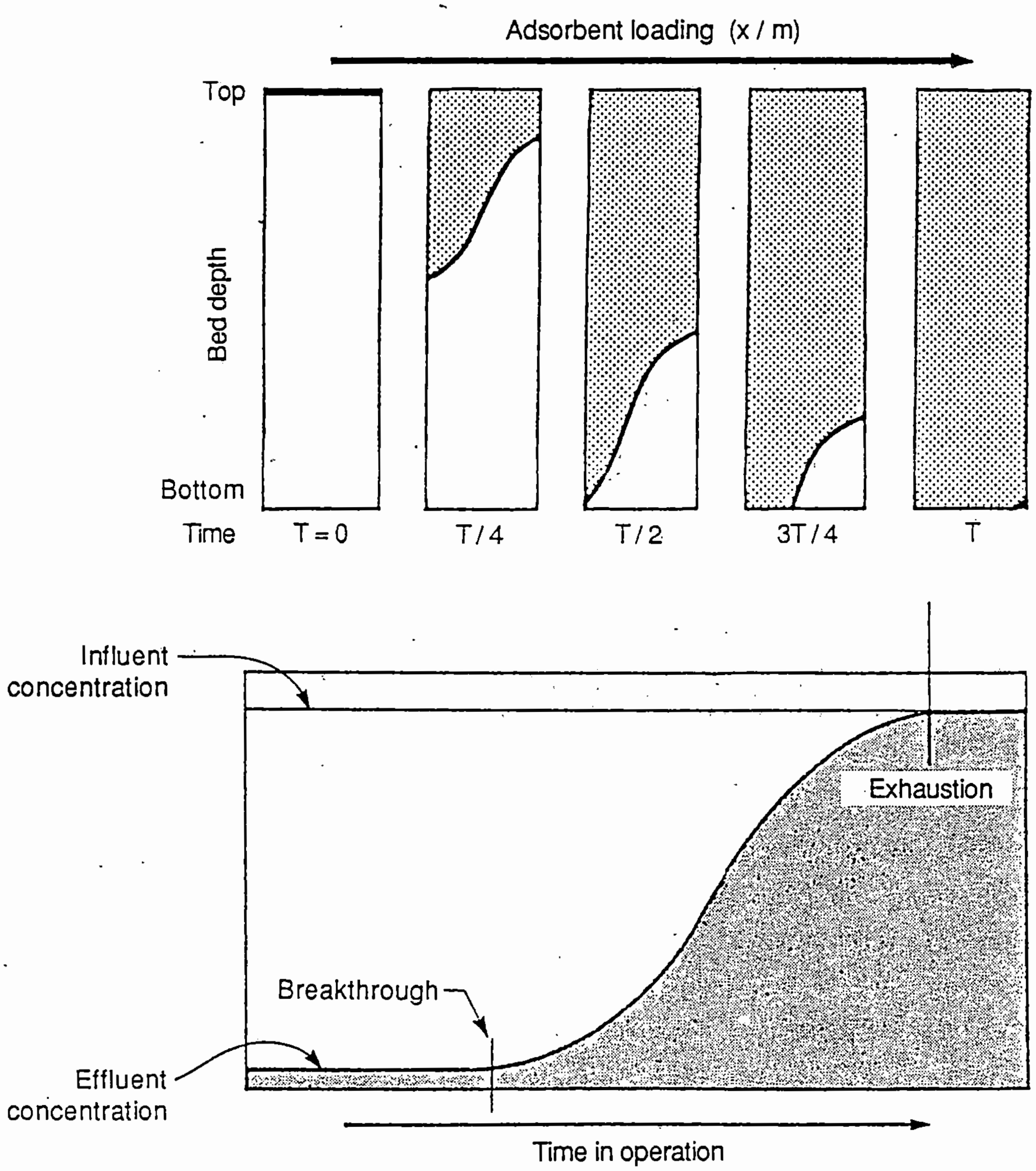
Mass Transfer in Activated Carbon

Carbon has a limited service period. Once it has become fully saturated with adsorbate, the carbon is no longer useful. The period of service is called carbon longevity or the useful life. The longevity of granular activated carbon in an adsorber depends on the concentrations and types of organic compounds present in the water. It also depends on the type and volume of carbon in the contactor. For purposes of cost estimating the useful life is considered to be no more than eighteen months.

Mass transfer zone concepts are used to theoretically describe the process by which GAC becomes exhausted on a compound-specific basis. Three distinct theoretical zones exist within the GAC bed: (1) the equilibrium zone, (2) the mass transfer zone, and (3) the unused bed zone. Between the equilibrium zone (where the adsorptive capacity of the carbon has been exhausted) and the unused zone, the adsorbate loading of the GAC follows a gradient from a maximum to a minimum. This gradient, known as the mass transfer zone, and its length are controlled by many factors including the characteristics of the contaminant being adsorbed, the characteristics of the adsorbent, hydraulic factors, and the competitive effects of other organics present in the water. In practice, these mass transfer boundaries fluctuate owing to variances in influent water concentrations and resulting multicontaminant competitive adsorption effects.

The depth of the mass transfer zone represents the cumulative resistance to mass transfer. The mass transfer zone moves down through the carbon contactor over time. Eventually the leading edge of the mass transfer zone will intersect the effluent end of the adsorber. The graphic presentation of the effluent concentration versus time plot for a single contaminant in water (figure 4-14, bottom) is defined as the breakthrough curve. Its typical shape is that of an S-curve. A designer will usually use piloting data to design the GAC beds so that their sizing will coincide with a preselected effluent concentration. The mass transfer zone may be disrupted by backwashing or other adsorption/desorption phenomenon occurring in the contactor.



Source: Treatment Techniques for Controlling Trihalomethanes

CDM

environmental engineers, scientists, planners & management consultants

Figure 4-14

Simplified Theoretical Adsorption Column Performance for Single Compound

Special Water Treatment Study - Phase II

Multicontaminant Adsorption. Of concern in multicontaminant adsorption is the "chromatographic effect," named for the chemical effect known as chromatography. Because different compounds adsorb in varying degrees to the GAC, the respective mass transfer zones of the various contaminants migrate through the adsorber at different rates and are separated as they emerge. Molecules that are adsorbed more strongly migrate through the adsorber more slowly than less strongly adsorbed molecules. As a result, when the mass transfer zone of the more strongly adsorbable compound passes through an area of exhaustion for the less adsorbable compound, this second compound can desorb (i.e., no longer remain adsorbed). Desorption often occurs to the extent that the second compound's effluent concentration will increase, sometimes actually exceeding the influent concentration for a period of time. As a result of this phenomenon, the theoretical S-shape of the mass transfer zone is rarely observed in practice.

The performance of GAC for reducing the concentration of a particular organic depends on the contaminant concentration, the treatment goal and the presence of other organics that may compete for adsorption sites within the carbon. This competition for sites is termed "competitive adsorption." The more strongly adsorbed organics can "displace" the more weakly adsorbed compounds. For example, tetrachloroethylene can displace, or compete, with benzene if both are present. Typically, 1,1,1 TCEA is easily displaced by TCE.

Carbon has a limited number of adsorption sites. Each site theoretically accommodates one molecule; once the site is filled, no other molecules can adsorb there. Waters with many contaminants will increase the overall carbon usage rate significantly because of competitive adsorption. An influent containing many compounds will have a carbon usage rate roughly similar to the sum of the usage rates of the individual compounds.

The breakthrough characteristics for each influent stream are important in determining the appropriateness of GAC as a treatment technique. Breakthrough occurs when the affinity for adsorption of the carbon for a particular compound is exhausted, and that compound begins to appear in the effluent. Because different compounds have adsorptive capacities and influent concentrations that vary, compounds will "break through" at different rates.

Carbon Exhaustion Determination. When the carbon has become exhausted, breakthrough occurs and the carbon must be replaced. In theory, breakthrough occurs when the edge of the mass transfer zone just reaches the effluent end of the carbon contactor, and treated water begins to show evidence of contamination. In practice, however, breakthrough usually refers to a point in time when the effluent reaches a certain level, or threshold, of contamination. The level is usually set at a point which is based upon regulations, such as maximum contaminant levels. The threshold level of contamination in the effluent may refer to the total of all volatiles in the water or to a specific compound or compounds that the design and operation is based on.

When the threshold level is based on a single contaminant, it may be the compound in the influent stream that is the first to break through, or it may be the compound considered most hazardous. Frequently, the compound that has the earliest breakthrough is used as an indicator for carbon change. This is especially true in cases where the effluent is to be used for drinking water. For example, for the Borough of Park Ridge, a requirement of the Permit to Construct and Operate a GAC pressure contactor contained such a provision. When any of the A-280 organics break through the carbon contactor at that facility and are measured above 5 mcg/l or the MCL, whichever is lower, in the treated water in two consecutive samples, then the carbon must be replaced.

Estimating Carbon Bed Life. On the basis of isotherm data, it is possible to determine roughly when breakthrough will occur. An approximation of the amount of GAC required can be made from Freundlich isotherm data. On the basis of five general parameters, an estimate of the carbon bed life can be made. These five parameters are

1. Flowrate
2. Carbon bed volume, or empty bed contact time (EBCT)
3. Isotherm data (K and 1/n)
4. Treatment objective
5. Contamination level in raw water

These five parameters are applied in a four-step procedure to estimate the sizing of an adsorption system. This procedure often is repeated iteratively before an appropriate conceptual sizing is determined, as follows:

Step 1: Apply the Freundlich equation to determine the loading, q. Obtain K and 1/n from isotherm tests.

Step 2: Determine a theoretical carbon usage rate, based on the loading on the carbon derived in step 1, in pounds per 1,000 gallons.

Step 3: Apply a safety factor to the usage rate based on a judgment of the water quality, particularly considering competitive effects from other organics.

Step 4: In an iterative manner, tentatively size and determine the time to exhaustion of the carbon bed, based on the carbon usage rate and a minimum empty bed contact time.

An example of this conceptual sizing method is presented below.

Example Conceptual Sizing

For this example sizing, the following input conditions exist:

Flow Rate = 1.0 mgd

Compound of concern: tetrachloroethylene (PCE)

Influent concentration (average) = 25 mcg/l = 2.5×10^{-3} mg/l

Effluent concentration, Ce (treatment goal) = 1.0 mcg/l = 1×10^{-3} mg/l

Freundlich constants: K = 50.8 mg/g
1/n = 0.56

Using the Freundlich isotherm relationship to determine the theoretically achievable contaminant loading on the carbon,

$$q = KC_e^{1/n} = (50.8)\,(1 \times 10^{-3})^{0.56}$$

$$q = 1.06 \frac{\text{mg PCE}}{\text{g carbon}}$$

To obtain the theoretical minimum carbon usage rate, divide the influent concentration by the carbon loading rate and appropriate unit conversions:

$$\frac{25 \times 10^{-3} \text{ mg PCE}}{1 \text{ water}} \times \frac{\text{g carbon}}{1.06 \text{ mg PCE}} \times \frac{3.785 \text{ l}}{\text{gal}} \times \frac{\text{lb}}{454 \text{ g}}$$

$$= 2.0 \times 10^{-4} \frac{\text{lb carbon}}{\text{gal water}}$$

or, stating in commonly used units, 0.20 pounds per 1,000 gallons.

This usage rate is approximate; it would be observed only under real conditions when the isotherms were carefully derived from experiments with the actual water to be treated. Many isotherms found in the literature have been derived under controlled conditions under which competitive adsorption effects have been minimized. Therefore, a safety factor is normally applied to the usage rate to account for competitive effects. For waters containing no other synthetic organic compounds and with low levels of natural background organics (i.e., typically lower than 10 mg/l), a minimum safety factor of four is recommended. Higher or lower safety factors are a matter of scientific and engineering judgment. Therefore, using a safety factor of four, a more conservative value for the theoretical minimum carbon usage rate is obtained:

$$4 \times \frac{0.20 \text{ lb carbon}}{1{,}000 \text{ gal water}} = \frac{0.80 \text{ lb carbon}}{1{,}000 \text{ gal water}}$$

Some designers maintain that a safety factor of 2 is more appropriate if a 20 minute EBCT is used and a factor of 4 for 10 minute EBCT.

In addition to the usage rate, it is necessary to size the contactor for an appropriate empty bed contact time (EBCT). EBCT is a measure of the residence time of the water in the carbon bed if there were no carbon placed in the bed. EBCT is a convenient measure of bed residence time because it avoids taking into account the volume occupied by the carbon granules, which varies as a fraction of the empty bed volume for different manufacturers' carbons. For removal of volatile synthetic organics, a reasonable minimum EBCT is 20 minutes, while for removal of nonvolatile synthetic organics that tend to be more adsorbable (such as pesticides and PCBs) a reasonable minimum EBCT is 15 minutes. Therefore, based on a 1.0-mgd flowrate, the minimum volume of carbon bed is

$$1.0 \text{ mgd} \times \frac{694.4 \text{ gpm}}{\text{mgd}} \times \frac{\text{ft}^3}{7.48 \text{ gal}} \times 15 \text{ min} = 1{,}400 \text{ ft}^3$$

Since premanufactured steel contactors are sized to accommodate 20,000 pounds (750 cubic feet) of carbon, then two contactors operating in parallel are appropriate for this example. Given the usage rate of 0.80 pounds per 1,000 gallons, the estimated time between carbon replacements is

$$40{,}000 \text{ lb carbon} \times \frac{1{,}000 \text{ gal water}}{0.80 \text{ lb carbon}} \times \frac{\text{day}}{1 \times 10^6 \text{ gal water}} = 50 \text{ days}$$

Fifty days is the estimated time between activated carbon replacements. For facilities with flow rates greater than 1 mgd, carbon replacement intervals of 3 months or greater are generally desired. Therefore, it would be prudent to double the number of contactors (giving four contactors of 20,000-pound capacity GAC each) and obtain an estimated carbon replacement interval of 100 days.

Design Issues

Several factors must be considered when using the above equations to design a carbon adsorption system. First, the isotherm data and Freundlich isotherm equations should generally be considered as preliminary design tools. The above equations can help the designer determine the feasibility of using GAC treatment at a particular site, the appropriate size for a pilot study unit, or the order-of-magnitude cost for a GAC system.

In most design situations, a full-scale pilot study using contaminated water from the site should be conducted over the expected raw water temperature range. In fact, a pilot study may be required by NJDEP before an operating permit is issued. Better predictions of breakthrough time and bed service life will be gained from pilot studies. In practice, most contaminant situations involve multiple contaminants. Since most research has dealt with only one- and two-contaminant systems, the database needed to develop design criteria for multicontaminant activated carbon adsorption from theoretical equations is simply not available. This is the fundamental reason why field piloting is usually performed when designing activated carbon systems for treatment of contaminated water supplies.

The commonly accepted design approach currently encompasses three phases: definition, piloting, and design. The definition phase refers to definition of the pertinent characteristics of the water. In defining these characteristics it is extremely important that the concentrations of VOCs -- as well as conventional parameters such as pH, dissolved oxygen, hardness, buffer capacity, and iron and manganese concentrations -- be specified, along with their associated effects on the activated carbon and process equipment. The next phase of the design approach is the pilot study. The pilot study is designed based on the definition of water characteristics. Several carbon contacting columns may be set up in series or in parallel in order to test different operating configurations. Pilot studies also should be run at several contact times. Carbon bed service life is a direct, linear function of bed depth. Greater bed depths give longer contact times and longer contact times result in smaller mass transfer zones and, hence, longer carbon life. Data is collected regarding carbon bed depth and the influent concentration and the time until breakthrough for the contaminants of concern. This data is plotted and, from this, parameters can be developed upon which final design computations can be based.

In situations where water conditions pose an imminent health hazard, the rather lengthy procedure of performing a pilot study is commonly avoided. Temporary adsorbers are installed that are purposely oversized in order to ensure adequate removal of the contaminants. This oversizing results in added capital and operating costs that would be avoided if adequate time were available to perform pilot studies.

Emerging Design Techniques. There are several development activities under way in academia and private industry that are attempting to describe the multicomponent adsorption phenomenon better than the common Freundlich isotherm equation. If these programs prove successful, then mathematical computations may become adequate for the design sizing of carbon adsorption systems, and lengthy pilot studies may not be needed.

Two well-known systems under development are the Michigan Adsorption Design and Applications Model (MADAM) developed by the University of Michigan, and the Homogeneous Surface Diffusion Model (HSDM) developed by Michigan Technological University. Both involve a sophisticated mathematical computer model. The designer first uses the model, along with isotherm data and engineering judgment, to roughly estimate the design criteria. The designer then tests the water on a minicolumn of the carbon to be used in the design. The results of this test, which can be provided in less than two weeks, are used to verify and calibrate the initial model. The calibrated model is then used to develop the final design criteria. This approach takes less time than a pilot study and helps the designer understand how changing conditions that may occur in the future can alter the design requirements. This, in turn, enables the designer to incorporate an appropriate safety factor. This computerized approach to design is now in the developmental stage. Neither MADAM nor HSDM is currently in use for design.

The performance of "minicolumn studies" are a service offered by some activated carbon manufacturers and universities. A several-gallon sample of the water is taken to the laboratory where it is treated under high pressure in a miniature activated carbon column. These studies may provide data useful in reducing the extent of full-scale pilot studies. This service consists of a short-duration test (typically less than two weeks) that makes it possible to estimate the relative adsorbability of the water matrix to be treated and to estimate the competitive effects of the various contaminants. While the test does not provide the detailed assessment achievable with full-scale pilot studies or with the computer models, it does provide information in enough detail to calibrate a computer model or to make a better informed engineering judgment.

Another technique for understanding GAC performance involves the concept known as "frontal chromatography." Chromatography describes how the adsorbed organics move through the carbon bed over time. It is a phenomenon that is involved in competitive effects of multicomponent adsorption.

During a field pilot study designed to measure this effect, water samples are taken periodically at a series of locations at varying bed depths. The samples are analyzed for concentrations of various organics of concern. For each organic compound, a series of plots can be drawn showing the concentration of the organic in the water stream vs. the depth of the carbon bed. A number of curves are plotted representing concentrations at increasing time periods. These plots will show the concentration wave front of a contaminant moving through the bed over time. When the wave front reaches the end of the bed, breakthrough has occurred. When the plots for different compounds are compared, it may be seen how a new compound introduced into the influent stream may cause the desorption of a previously adsorbed compound.

4.3.3 DESIGN AND CONSTRUCTION

Two primary factors enter into the selection of the type of activated carbon contactor to be used: (1) the amount of carbon and (2) the adsorptive and physical properties of the carbon. The volume of the carbon may dictate the specific type of contactor needed, while the properties of the carbon will determine the materials of construction.

The choice between open or closed activated carbon contactors is chiefly determined by the location of the carbon filtration process in the treatment train. If sufficient gravity head exists, the preference should be for open concrete filters, particularly at water treatment plants larger than about 4 mgd, for reasons of overall cost.

Where head is required for the processes following carbon filtration, or where double pumping would be required, pressure filters -- constructed as closed steel tanks with an interior protective coating -- are generally used. These are particularly useful for well supplies that are presently untreated. These well supplies typically have well pumps that provide sufficient head to deliver the water either directly to the distribution system or to an elevated storage tank. If the pump can still provide sufficient head to the distribution system or storage tank after the installation of the pressure contactor(s), then the pump may not have to be replaced. Use of a pressure contactor also may simplify design and construction since the only equipment replacement necessary to provide sufficient head may be the well pump motor. Where aggressive waters are evident, it is sometimes appropriate to use open concrete filters rather than steel filters because of the corrosion problems that may arise with steel. Special coatings should be used to protect both steel and concrete filters from corrosion.

In the case of open concrete filters, design and construction are complicated by the need to remove and replace the carbon. Generally, the most effective means of removing carbon from large concrete contactors is to educt (i.e., transport as a slurry) the carbon through a trough at the bottom of the filter while fluidizing the media by use of the backwash system. Carbon is also removed from converted dual-media or sand beds through an eductor system. Motive water is supplied to the eductor system to withdraw carbon from the bed at a minimum rate of 1 pound of carbon per gallon of water to form a carbon slurry. The carbon is discharged to a spent carbon tank whose contents, in turn, are discharged periodically, either to a regeneration facility on site or to a vendor for reclamation in exchange for virgin GAC. (The State of New Jersey does not allow offsite regeneration of GAC used for water treatment.)

Because some activated carbon is corrosive, selected contactor systems should be lined with a corrosion-resistant material. For steel contactors not made from 316 grade stainless, the lining usually is made of glass, plasticized PVC, resin or a similar material. A less expensive cement mortar or painted lining, under most circumstances, will not provide sufficient durability. Any flaw or fault that develops in such linings could induce corrosion.

Granular activated carbon is available from several manufacturers. Most of the types of GAC used in water treatment have substantially the same adsorptive capacity. Pore volume may have an impact on a specific carbon's ability to adsorb large or small molecules. Similarly specified carbon is generally available from each manufacturer. Table 4-4 presents a table of typical GAC properties.

Minimum Suggested Guidelines for Design and for State Regulatory Review. The following minimum requirements for the design of carbon adsorption systems are recommended:

Empty Bed Contact Time. The empty bed contact time usually should not be less than 20 minutes for the volatile organic compounds. Many synthetic nonvolatile organic compounds (e.g., pesticides and PCBs) tend to be more adsorbable than the volatile organics. The recommended minimum EBCT for these compounds is 15 minutes.

Backwashing. The carbon contactor(s) should have the capability to be backwashed. This capability should be provided even when the GAC also is used as a filtration medium. A minimum backwash rate of 12 gpm/ft^2 of media surface area is suggested; 20 gpm/ft^2 is typical for hydraulic design. A surface wash is recommended.

Pressure Relief. In the case of pressure contactors, pressure relief should be provided to protect against the unlikely event of over pressurization.

Chlorination. Because carbon dechlorinates water, post-disinfection should be provided following the carbon contactor.

Sampling Taps. Sampling taps should be provided on the untreated water line to the carbon contactor, at the treated water discharge line, and on the exterior of the contactor. A number of taps should be spaced in a vertical line to facilitate monitoring of the progress of the mass transfer zone.

Surface Hydraulic Loading. Surface hydraulic loading should be maintained within the same range as commonly used in filter design, i.e., 2 to 6 gpm/sq ft.

Prevention of Carbon Abrasion. Since carbon is easily abraded, transport systems should be designed to minimize carbon breakup.

TABLE 4–4

TYPICAL PROPERTIES OF GRANULAR ACTIVATED CARBON

Property	Value
Surface area (m^2/gm)	600-1200
Iodine number	500-1200
Tannin value (mg/l)	650 maximum
Pore volume (cc/gm)	0.6-1.2
Apparent density (gm/cc)	0.4 minimum
Sieve size	8 × 30 to 12 × 40
Effective size (mm)	0.55-1.4
Uniformity coefficient	2.4 maximum
Mean particle diameter (mm)	0.85-1.7
Abrasion number (RoTap)	70 minimum
Moisture content (weight %)	2 maximum

4.3.4 OPERATION AND MAINTENANCE CONSIDERATIONS

Activated carbon adsorption requires attention to several operational considerations -- need for backwashing, effects of biological growth, effects of inorganics, and methods of carbon transport and regeneration.

GAC and Filtration. GAC has been used to filter particulate out of water while also removing dissolved contaminants. When GAC is used as a particulate filter, the need for backwashing is essential and frequent. However, this practice is not recommended when the system is designed to remove A-280 contaminants down to the very low Interim Action Levels. Backwashing presents a major disadvantage because it periodically disrupts the mass transfer zone of adsorption, or it prevents this zone from becoming fully established. The GAC bed is initially backwashed after filling to establish bed stratification. The fully spent carbon, normally confined above the mass transfer zone, becomes distributed evenly throughout the carbon bed by the agitation and mixing of the backwash cycle. As the mass transfer zone reestablishes itself, there is a tendency for organics to desorb from the spent carbon situated below the new mass transfer zone. This situation can be undesirable, particularly if the level of desorption of organics results in contaminant levels exceeding the MCL.

An additional disadvantage of using GAC as a particulate filter is that time between backwashings tends to be shorter than with conventional filter media. Therefore, it is usually appropriate to provide conventional filtration, where needed, as a pretreatment process, prior to carbon adsorption, in order to maximize the process efficiency for removing organics.

Biological Growth. In the presence of biodegradable organics, biological growth can occur within a carbon contactor. Low to moderate levels of biological growth are not normally a concern. Biological activity can improve carbon longevity. The biological activity can often break down larger, less adsorbable organic molecules into smaller, more biodegradable molecules. Where this process is encouraged in the carbon, the GAC is referred to as biologically active carbon (BAC). In practice, a disinfectant is always applied to the water at some point after treatment with activated carbon.

Under some circumstances the biological activity in a carbon contactor can become excessive, leading to increased biological activity in the treated water as well as the need for frequent backwashing. To mitigate this situation, it may be necessary to improve the biological stability of the water before it reaches the carbon contactor. This may be accomplished by improving the coagulation, settling, filtration or chemical oxidation of the influent water. Free chlorine residual resulting from use of chlorine, however, will adversely affect carbon life. Nevertheless, excessive biological activity is not likely in water treatment, and undue concern about this possibility should not hinder implementation of a GAC treatment scheme.

Inorganics. Several inorganic metals exhibit some tendency toward adsorption with activated carbon; however, most common inorganic cations and anions found in natural waters (for example, calcium, sodium, orthophosphate, and nitrate) are not readily adsorbed. Among the metals showing some adsorbability are the following:

Arsenic
Tin
Lead
Silver
Organic mercury
Cobalt

Although these metals could utilize adsorptive capacity that otherwise would be available for organics, they are usually present in such low concentrations that they are not of concern.

Of special significance, however, is the potential for iron and manganese constituents, which are relatively common in New Jersey ground waters, to adsorb onto activated carbon. Because some ground waters do have appreciable levels of these metals, they can have an adverse effect on the adsorptive capacity of the activated carbon by disrupting the carbon stratification.

Ground waters containing significant levels of soluble iron and manganese (generally above 1 mg/l) should be treated to remove these compounds prior to GAC treatment. If the iron and manganese are not removed before treatment with GAC, they will precipitate onto the carbon, cause increasing head loss, and eventually prevent flow through the carbon.

Another problem with inorganics in GAC treatment is scaling. Biological activity within a GAC contactor tank tends to reduce the oxygen concentration and increase the carbon dioxide concentration. This, in turn, lowers the pH. Lowered pH may cause scaling within the carbon contactor. Proper operation and maintenance can reduce scale formation.

Activated carbon has been used for dechlorination of water. However, the interaction between the free chlorine (as HOCl) and the carbon surface results in a surface oxide group, caused by an oxidation process that destroys adsorption sites. Therefore, this practice is not recommended for systems designed to remove A-280 organics.

Carbon Transport. As previously discussed, carbon is usually transported in the form of a slurry. However, as it is pumped from one location within a facility to another, or to a carbon transport vehicle, there is an inevitable abrasion of carbon against other surfaces and between the granules themselves. Though activated carbon granules have a high relative hardness, the abrasion losses can be significant enough to warrant minimizing unnecessary carbon transport. Carbon transport is normally limited to filling and removing operations only.

The logistics and problems associated with carbon changes should also be considered during the design period. If the water supply is essential, then it may be necessary to provide two adsorbers so that one adsorber can remain on line while the GAC in the other adsorber is replaced.

Regeneration of Activated Carbon. There are five basic technologies for the regeneration of spent activated carbon:

1. Multiple-hearth furnace
2. Fluidized-bed reactor
3. Electric infrared furnace
4. Steam stripping
5. Hot gas reactivation

The most common means of granular activated carbon regeneration is thermal processing. Adsorbent-laden GAC (spent GAC) is heated to high temperatures in a controlled environment to decompose the adsorbate and return the carbon to a near virgin state. The thermal regeneration involves three steps incorporating three primary reactions:

Drying

$$\text{GAC adsorbate} + H_2O + \text{heat} \longrightarrow \text{GAC adsorbate} + H_2O$$

Pyrolysis

$$\text{GAC adsorbate} + \text{heat} \longrightarrow \text{GAC} + \text{char} + \text{volatilized organic compounds}$$

Regeneration

$$\text{GAC} + \text{char} + H_2O + \text{heat} \longrightarrow \text{GAC} + CO + H_2$$

In the drying step, the excess moisture in the spent carbon is evaporated at a process temperature of 250 °F to 300 °F. In the pyrolysis step, the dried, spent GAC is heated to between 1,000 °F and 1,400 °F in a controlled atmosphere.

At this temperature, some adsorbate in the GAC decomposes to volatile organic compounds, which are driven from the carbon surface, and the remaining adsorbate (10 to 50 percent of the original adsorbate) forms a carbonaceous char residue, which remains in the pores of the carbon. The final step is regeneration, in which the process temperature reaches 1,500 °F to 1,800 °F and steam is introduced. The steam reacts with the char, forming carbon monoxide and hydrogen, which are driven off the GAC.

Thermal regeneration of spent GAC requires careful control of the composition of the atmosphere present during the regeneration process, specifically in regard to excess oxygen, to minimize carbon losses caused by oxidation of the original GAC.

The fluid-bed regeneration system is another system used today for the thermal regeneration of granular activated carbon. In a fluid bed, heated fluidizing gases are blown through a bed material (in this case GAC), keeping the material to be regenerated completely exposed to the gas stream, and producing thermal reactions. The fluid-bed regeneration system utilizes a two-stage, fluid-bed furnace: drying occurs in the upper bed, and pyrolysis and regeneration occur in the lower bed. The furnace is typically a refractory-lined, steel-shell vessel consisting of two stationary constriction plates that distribute the fluidizing gases over the entire area of the bed while also supporting the beds.

The off-gases generated in the pyrolysis/regeneration zone contain a high concentration of volatile organic compounds, carbon monoxide, and hydrogen, which must be burned prior to atmospheric venting. These gases are introduced to the incineration zone of the furnace, where the auxiliary burner completes the combustion of the volatile organics, carbon monoxide, and hydrogen. Off-gases from the drying zone are recycled to the incineration zone for burning. Thus, any organics volatilized in the drying process are destroyed in the combustion zone before exiting the system.

The infrared furnace is a comparatively new development in the thermal regeneration of activated carbon. The carbon is carried at a high temperature on a woven nickel-alloy wire conveyer belt. As it passes through the furnace, the carbon is heated by infrared radiation, which is generated by silicon-carbide electric heating elements. Furnace temperature, residence time, and atmosphere are closely controlled to provide consistent, repeatable regeneration results.

Prior to being fed to the furnace, the carbon is dewatered to a moisture content of approximately 50 percent. Since the exhaust gas and carbon flows are concurrent, the steam generated in drying the carbon provides the activating atmosphere for the final stages of the process. Exhaust gases leave the furnace at the carbon discharge end.

To assure complete destruction of the hydrocarbons released in the regeneration process, an afterburner is provided that may be equipped with a gas pilot or a bank of infrared electric heating elements. The products of combustion are cleaned in a Venturi-type stainless steel scrubber before discharge into the atmosphere through a demister and a vendor-furnished exhauster.

Because the carbon is not mechanically agitated as it passes through this type of furnace, attrition losses are low. Oxidation losses are minimized because of the close control of the gas environment and the absence of oxygen associated with the combustion of fossil fuels. These factors also reduce the potential for air pollution since both the quantity of particulate matter and the volume of exhaust are minimal.

Steam stripping is another regeneration technology. However, it is suitable for removing only low-boiling-point organics. Heavy-molecular-weight organic compounds are not volatilized in steam stripping systems. The regeneration systems described above can heat carbon to very high temperatures (1,400 °F to 1,800 °F), produce a reaction of carbon dioxide or water vapor (injected steam) with the char resin left in the pores of the carbon, and remove this char as carbon monoxide. Since steam stripping systems cannot perform this critical regeneration reaction, and since the adsorbate on carbon is likely to contain a wide variety of heavy-molecular-weight organics, steam is not usually an appropriate regeneration system for liquid-phase carbon.

The most proven system for liquid-phase carbon regeneration is the multiple-hearth furnace. Many units have been built for this type of service, most with generally good operational histories. The other carbon regeneration methods are less thoroughly proven.

The New Jersey Bureau of Safe Drinking Water will allow regeneration of activated carbon used for water treatment, only if the regeneration is done at the water treatment plant site, and only if the GAC from that plant is used in the regeneration process. Offsite regeneration is not acceptable.

Onsite regeneration of activated carbon is rare in the water supply industry. Only two such facilities are in service, both of which are fluidized beds. All water utilities in the state now contract with carbon vendors for removal of spent GAC used for VOC removal and replacement by virgin carbon. The vendors regenerate spent water treatment carbon for use in other industries.

Regeneration of Vapor Phase Carbon. Onsite regeneration of vapor phase carbon is economically justified only when highly contaminated raw waters -- from landfills or hazardous waste sites, for example -- are being treated by air stripping. For the common case where community wellfields have been found to have relatively low levels of organic contamination, yet still require air stripping treatment, the most economic installation of vapor phase carbon is a system in which the GAC would be replaced with new GAC when it becomes exhausted. The GAC would not be regenerated on site.

For highly contaminated raw water, onsite regeneration of vapor phase GAC would be economically justified. Steam stripping is an appropriate regeneration process. Typically, a single vessel is used for holding the GAC both during treatment of the contaminant-laden air and during regeneration of the GAC. Steam is injected into the vessel at about 15 psi and 240 °F for approximately one hour during regeneration. The frequency of regeneration and the degree of regenerated adsorptive capacity recovered is dependent on the compounds that have been adsorbed to the carbon.

4.3.5 HAZARDOUS WASTE REGULATIONS

Under some circumstances spent activated carbon may be defined as a hazardous waste. This possibility applies both to liquid-phase activated carbon and to vapor-phase activated carbon used for pollution control with packed column air strippers. In fact, vapor-phase carbon, because of its greater adsorptive capacity, is much more likely to be defined as hazardous than is liquid-phase carbon. Classification of spent carbon as a hazardous waste would require special handling and testing prior to shipment for regeneration or, under extreme circumstances, rejection of the material for regeneration.

If spent activated carbon were found to contain 1 to 5 percent hazardous constituent by weight (NJAC 7:26-8.16), it would be classified as a hazardous waste in New Jersey. Procedures for determining whether the constituent is hazardous in a particular case are outlined in NJAC 7:26-8.6 and 8.7. Test methods are specified by NJDEP, but generally are based on EP Toxicity or similar tests. The percentage by weight of the constituent in the spent carbon may be based upon this analytical method. Because the acetic acid wash prescribed in this test may not desorb all the constituents of interest, the carbon may not qualify as a hazardous waste, regardless of its percent weight of hazardous constituents, because it passes the test procedure.

If a particular water matrix results in the spent activated carbon being defined as a hazardous waste, the purveyor may choose to replace or regenerate the carbon when it reaches a contaminant loading just below the hazardous waste definition. This would be an alternative to allowing breakthrough to occur.

Defining spent activated carbon as a hazardous waste creates logistical complications because regulations governing the storage, transport, and treatment of hazardous waste will apply. If the spent activated carbon is defined as a hazardous waste, it is critical that the applicable manifesting and transport procedures that apply be determined. Under some circumstances, particularly if any PCBs are present, the carbon supplier will not accept the carbon for regeneration. Therefore, the water purveyor will have to pay full price for replacement carbon, and the spent carbon will have to be disposed of in an acceptable RCRA-approved waste disposal facility.

4.3.6 ESTIMATING SIZES AND COSTS OF CARBON ADSORPTION SYSTEMS

4.3.6.1 Estimation of Costs

A number of issues must be considered prior to developing an estimate of cost to construct and operate a carbon adsorption system. An alternatives analysis should be performed to select the method of carbon adsorption, or any other process, as the most appropriate, cost-effective process for a particular application. The most appropriate process configuration will be highly dependent on specific site conditions, the concentrations of all different parameters in the raw water, the concentrations of the contaminants of interest, and the flowrate.

The method of transporting water through a treatment plant, for example, will have an effect on the cost of carbon adsorption. The transport of the plant flow by gravity to and through the activated carbon contactors would reduce the operating costs by eliminating the need for pumping.

The materials of construction also will have a significant impact on the overall cost. Each material selected will have a different capital and operational cost associated with it. The materials used also must be compatible with the selected process in order to prevent corrosion, deterioration and need for early repair or replacement. Carbon contactors can be constructed of concrete or lined steel. They may operate by gravity or under pressure. Since activated carbon is highly corrosive, this should be taken into account when developing costs.

The appropriate method to determine the capital cost of any proposed facility is to develop a preliminary design and make quantity takeoffs. The estimate of cost should also provide for other, contingent costs such as engineering, legal services, financial costs, and other miscellaneous costs during construction. Experience has shown that these extra costs can be taken into account by adding a fixed percentage -- commonly between 30 and 45 percent -- to the cost of the materials and installation.

4.3.6.2 Conceptual Sizings

Conceptual sizings for carbon adsorption systems developed as part of this study are provided in appendix B. As with the air stripping sizing provided in appendix A, these conceptual sizings provide the basis for estimating the approximate sizes and relative costs of activated carbon treatment schemes for various contamination scenarios. These sizings, and the cost estimates associated with them, are conceptual only. They are not intended to replace a detailed engineering analysis of a specific contamination problem.

Implementation of a carbon adsorption treatment system usually requires a pilot study to better define the expected carbon usage rate. In the case of this study, however, isotherm data was used to provide a basis for the conceptual sizings of carbon contactors. Isotherm data developed by Dobbs and Cohen of the U.S. Environmental Protection Agency (EPA) and data developed by Calgon Corporation were used to generate carbon usage rates for the conceptual design sizings. A factor of safety of four was used to account for the competitive effects of other organics and conventional parameters.

In performing the conceptual sizings, the following boundary conditions were established:

- The minimum acceptable empty bed contact time was set at 20 minutes for volatile organics and 15 minutes for PCBs and pesticides.
- The maximum acceptable empty bed contact time was set at 90 minutes for systems with flow rates up to 1 mgd and 60 minutes for systems with flow rates greater than 1 mgd.
- The carbon life (time between replacements) was set between 1 and 18 months for systems with flow rates up to 1 mgd and between 3 and 16 months for systems with flow rates greater than 1 mgd.

A period of eighteen months has been used in this study as the practical maximum time between carbon replacements. Though calculations and/or pilot-plant data would indicate that activated carbon may have a replacement frequency greater than 18 months, from a practical perspective this may not be appropriate. The background natural organics or other synthetic organics may, in practice, fully exhaust the adsorption capacity of the carbon. A sudden change in the water quality matrix, under such conditions, could induce undesirable desorption of a regulated organic compound into the treated water.

The minimum times between carbon replacements were selected as practical values. It was considered impractical and generally not cost-effective for carbon deliveries and replacements to occur more often.

Because pesticides and PCBs usually exhibit greater adsorbability than volatile organics, it is usually not necessary to provide as long an EBCT for the pesticides as for the volatile organics. Thus, the specified minimum EBCTs for pesticides and PCBs are lower than for the volatile organics.

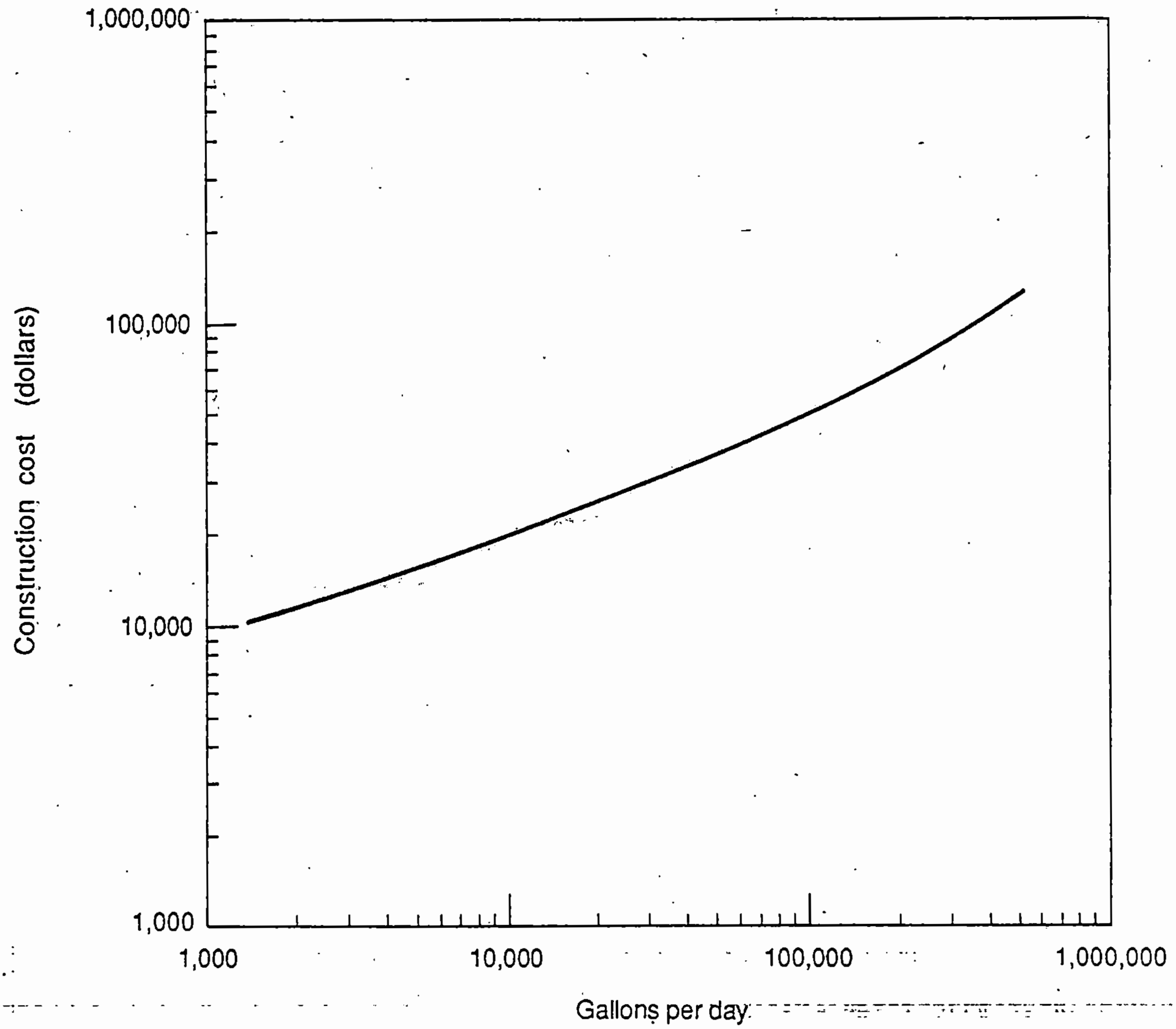
The maximum empty bed contact times were specified as practical values. Systems designed with longer EBCTs are considered to be generally not cost-effective

Cost Curves

Cost curves are provided in figures 4-15 through 4-18 for the following types of contactors:

1. Low-capacity package contactors
2. Pressure contactors
3. Steel, gravity-fed contactors
4. Concrete, gravity-fed contactors

These cost curves include the costs for vessels, valves, piping, controls, and a temporary building. All curves include a 30 percent contingency for field engineering, legal services during construction, construction



May 1986 ENR CCI = 4229

From EPA, 1979.

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Figure 4-15

Construction Cost
Low-Capacity Package Contactors

Special Water Treatment Study - Phase II

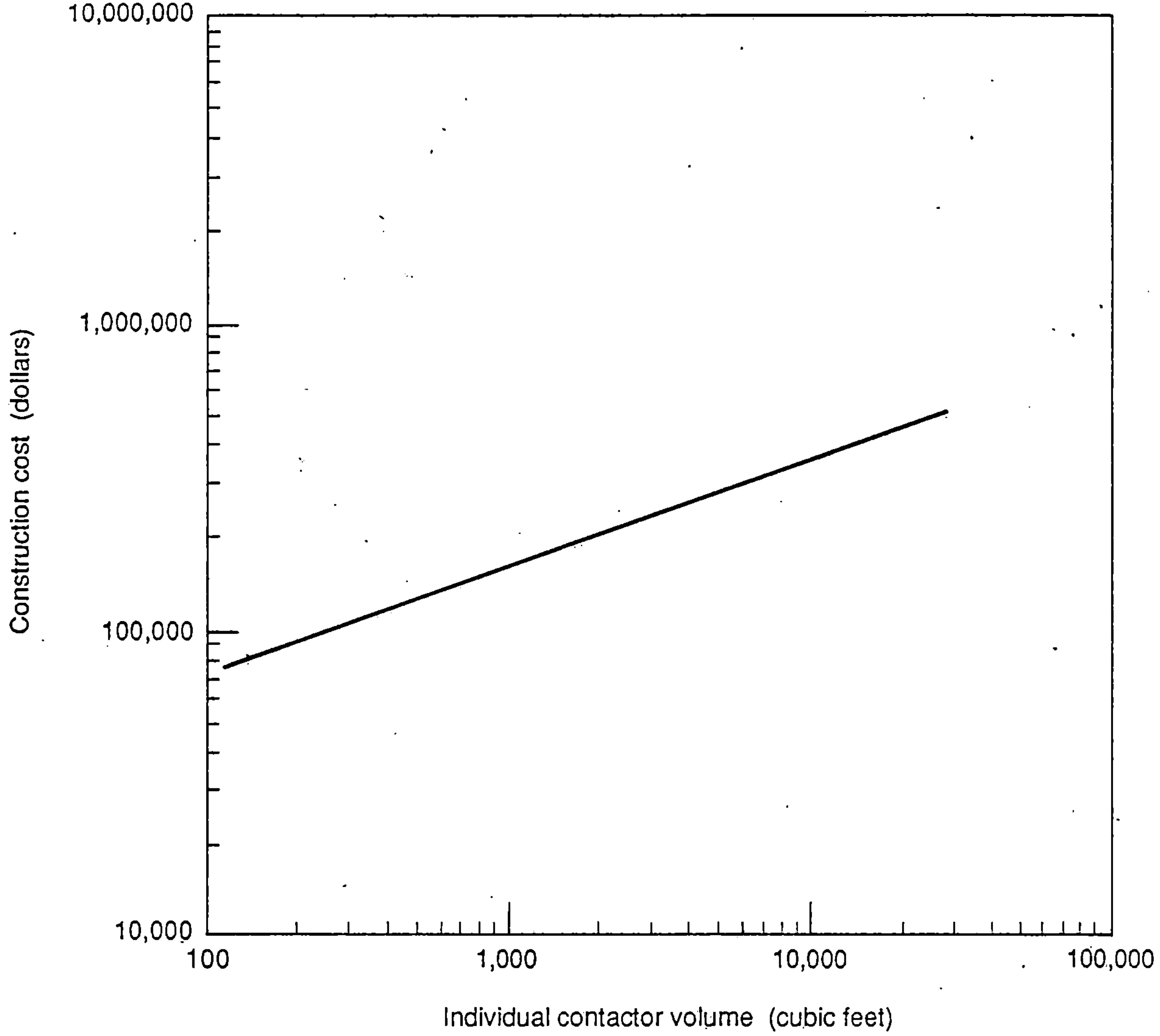

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Figure 4-16

Construction Cost
Pressure Contactors

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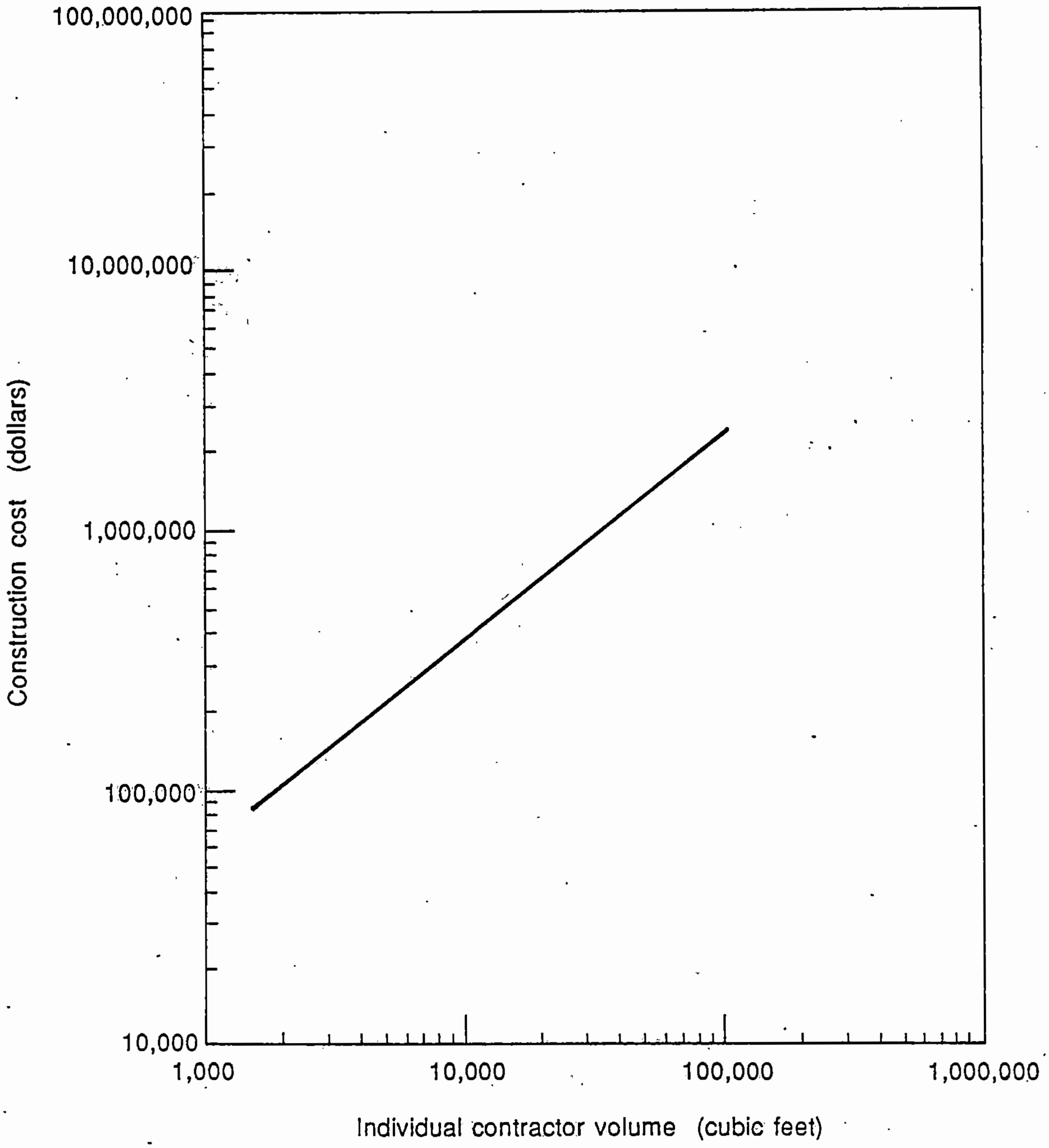

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Figure 4-17

Construction Cost
Steel, Gravity-Fed Contactors

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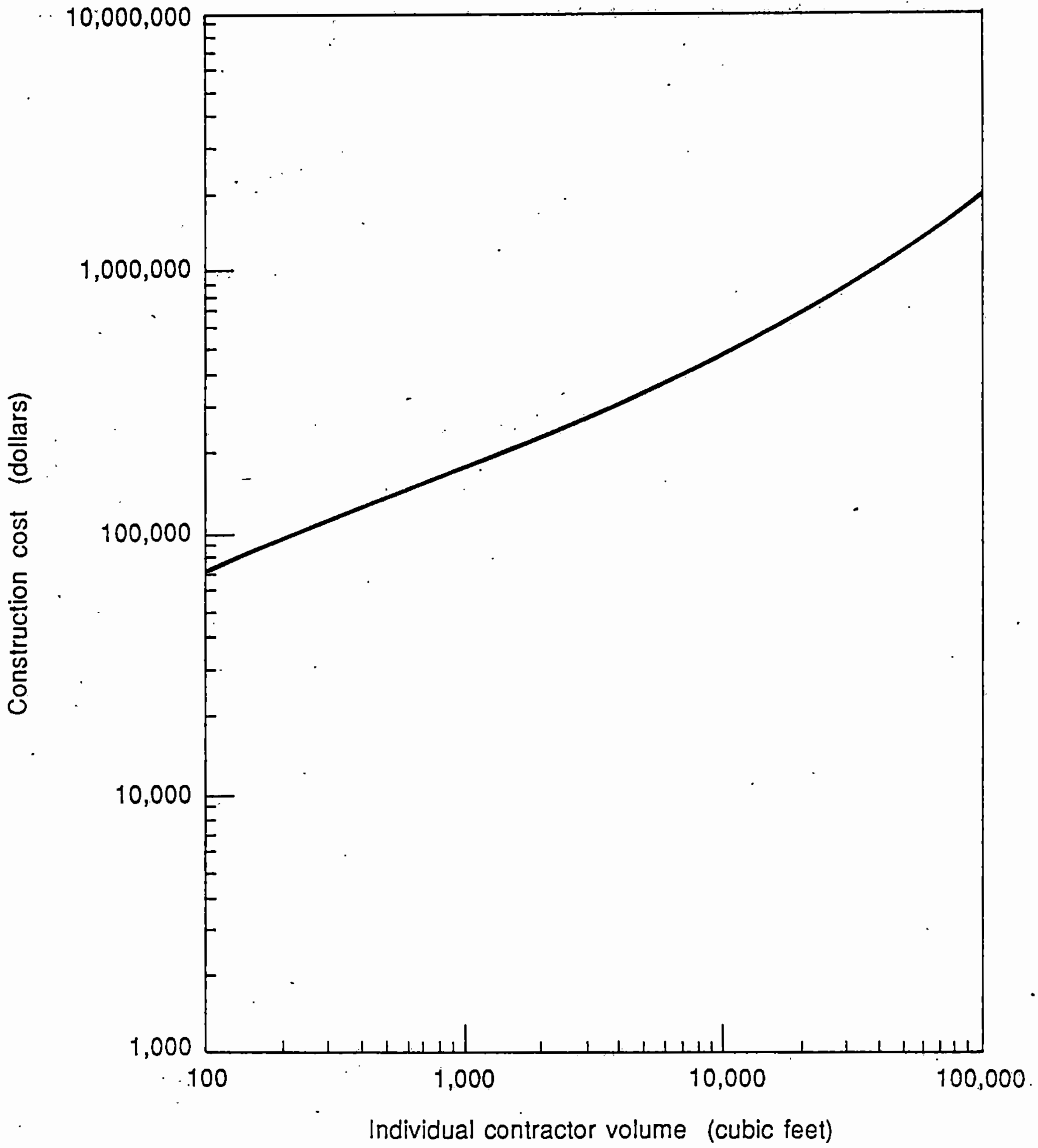

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Figure 4-18

Construction Cost
Concrete, Gravity-Fed Contactors

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financing costs, and other miscellaneous costs. The cost curves do not include the cost of design engineering, nor do they include the cost of the initial charge of activated carbon.

Low-Capacity and Pressure Contactors. Costs for both low-capacity package contactors and pressure contactors are based on pressurized down-flow operation using cylindrical ASME code pressure vessels with a design working pressure of 110 psi. Costs were updated using the ENR Construction Cost Index of May 1986 (ENR CCI = 4229).

Steel, Gravity-Fed Contactors. For carbon treatment facilities requiring in excess of about 30,000 cubic feet of carbon volume, the use of large-diameter, field-erected, steel, gravity contactors may offer an economic advantage over smaller-diameter, factory-built, pressure carbon columns. A carbon bed depth of 20 feet, with an overall vessel height of 35 feet, was used in the cost analysis for gravity-fed contactors. The units are designed for down-flow operation, and the system hydraulics were sized using an application rate of 5 gpm/ft^2.

This type of vessel is constructed of factory-formed steel plates erected at the job site. Units are provided with a nozzle-style underdrain, eliminating the need for a supporting gravel layer. For regeneration, carbon is removed from each contactor through multiple carbon drawoff pipes in the underdrain support plate. Regenerated carbon is returned to the top of each contactor through a piping system.

The costs presented are for a complete carbon contacting facility including vessels, face and interconnecting piping, access walkways, cylinder-operated butterfly valves on all hydraulic piping, manually operated ball or knife-type valves on the carbon handling system, flow control and other instrumentation, a master operations control panel, and a building to house the contactors.

Not included in the construction costs are carbon contactor supply pumping, surface wash and backwash pumping, the initial activated carbon charge, spent or regenerated carbon handling facilities (exclusive of piping within the contactor building) or carbon regeneration or preparation facilities.

Concrete, Gravity-Fed Contactors. The cost of a concrete, gravity-fed contactor system includes the following: contactor system construction; virgin GAC storage construction; construction overhead; initial GAC storage; contactor system electric, maintenance, material, and labor costs; labor for onsite carbon transport; and overhead on labor.

The costs presented are for a complete carbon contactor facility, including the contactor structure, cylinder-operated butterfly valves, liquid and carbon handling piping with headers in a pipe gallery, flow measurement and other instrumentation, master operations control panel, and building. Housing requirements were developed assuming that the entire carbon contactor structure is enclosed.

Not included in the cost estimate for the carbon contactor are backwash pumping, the initial activated carbon charge, spent or regenerated activated carbon handling outside the contactor pipe gallery, and carbon regeneration and preparation facilities.

4.3.7 EXAMPLE PROCEDURE USING SIZING AND COST TABLES FOR ACTIVATED CARBON

An example of the use of the conceptual sizing and costing procedures for activated carbon adsorption follows. As with the cost procedures presented for air stripping, these procedures produce a relative, approximate cost and are not intended to provide a definitive engineering cost estimate.

The following example case is used. An existing ground water treatment facility with a design flowrate of 0.80 mgd is contaminated with trichloroethylene. A raw water concentration design criteria of 75 mcg/l is assumed.

Conceptual sizings for trichloroethylene are summarized in appendix table B-12. The relative sizing for this particular example is not shown on that table; however, an estimate based on the values presented can be performed by interpolation. The interpolated estimate is:

Amount of carbon: 60,000 pounds
Carbon life: 2 months
Empty bed contact time: 30 minutes

Pressure carbon contactors were selected for use in this application. Pressure contactors typically are used where the existing high-pressure pumps will not be replaced. Pressure drops through pressure contactors are usually on the order of 5 to 10 psi; therefore, existing high-head well pump systems that discharge either directly to the distribution system or to an elevated storage tank are often acceptable for this kind of contactor.

Given the above, and that the density of drained GAC is about 27 pounds per cubic foot, then the total minimum required volume of activated carbon is estimated to be approximately 2,200 cubic feet. Since the practical maximum limit on the volume of a single prefabricated pressure contactor is 1,500 cubic feet (carbon bed 10 feet in diameter by 20 feet deep), the minimum number of contactors required is two. However, the typical arrangement of a prefabricated pressure contactor is for a volume of 750 cubic feet (10 feet in diameter by 10 feet high) which is equivalent to 20,000 pounds of GAC, or one truckload of drained GAC. Therefore, three 750 cubic feet contactors are selected for this example based on the cost curve for pressure contactors:

Cost per contactor (750 cubic foot) = $140,000
Cost for three contactors (750 cubic foot) = $420,000

Therefore, the estimated total capital cost for this 0.8-mgd facility is $420,000.

To determine the operation and maintenance cost, two major items must be considered: materials and labor. On the basis of the conceptual sizing tables, the estimated time between carbon replacements is 2 months. Therefore, the cost of carbon replacement on an annual basis is

$$\frac{12 \text{ months}}{2 \text{ months}} \times \$0.80 \text{ per pound} \times 60{,}000 \text{ pounds for replacement carbon}$$

$$\text{Cost of carbon} = \$288{,}000 \text{ per year}$$

The second cost is for labor, which can be defined on the following basis:

Essentially unmanned operation: $0.01/1,000 gallons
Daytime manned operation: $0.02/1,000 gallons
24-hour manned operation: $0.04/1,000 gallons

Typically, an activated carbon contactor is operated as an essentially unmanned operation, i.e., a qualified individual(s) is charged with periodically checking its operation.

In larger facilities, particularly those using concrete, gravity-fed contactors, it is usually advisable to provide closer oversight of the process. Depending on the circumstances, different cost allowances would apply.

In this example, essentially unmanned operation is assumed. Therefore, the approximate labor costs are

$$\$0.01 \text{ per } 1{,}000 \text{ gallons} \times \frac{0.80 \times 10^6 \text{ gallons}}{1{,}000 \text{ gallons}} \times 365 \text{ days}$$

$$\text{Labor cost} = \$3{,}000 \text{ per year}$$

Therefore, the total estimated yearly operation cost, not including miscellaneous materials (which under most circumstances do not exceed 5 percent of the total operating cost) is

Carbon	$288,000 per year
Labor	$ 3,000 per year
Total	$291,000 per year

It must be kept in mind, however, that the carbon replacement rate defined in the conceptual sizings is an order-of-magnitude estimate only. Consequently, the appropriate measurement of the carbon usage rate is critical to the overall cost of a carbon system. On a cost-per-1,000-gallon basis, the $291,000 per year operating cost is equivalent to $1.00 per 1,000 gallons.

A second cost that occurs on an annual basis is the principal and interest on the funds borrowed to pay for the new treatment installation (amortization of capital). The annual payment (R) must be determined that would amortize the debt (A) over a period of n years with a uniform interest rate (i). The following equation applies:

$$R = \frac{Ai}{1-(1+i)^{-n}}$$

For this example, the total capital cost, A, is $420,000; the capital cost recovery period, n, is 20 years; and the interest rate, i, is 8%. Therefore,

$$R = \frac{420,000 \times 0.08}{1-(1+0.08)^{-20}} = \$42,800 \text{ per year}$$

On a per-1,000-gallon basis, the amortization of capital for this 0.80-mgd facility is $0.15 per 1,000 gallons. Combining this cost with the operation and maintenance cost, the total cost impact of this treatment system is $1.15 per 1,000 gallons. Financial impact can be estimated by using a typical water use per household of 275 gallons per day. This results in a typical water bill increase of $28.86 per quarter. If a higher water use rate is assumed for areas with greater unaccounted-for water, e.g., 400 gallons per household per day, the cost impact is $41.98 per quarter.

4.4 MULTIPLE-PROCESS APPROACHES

Often the concentrations and types of contaminants in a raw water matrix dictate that a combination of processes be used to address a contamination problem. These special circumstances take the following three general forms:

1. A mix of highly adsorbable/nonstrippable and highly strippable/nonadsorbable contaminants
2. Difficult-to-treat compounds
3. Presence of compounds in unusually high concentrations

Mix of Highly Adsorbable/Nonstrippable and Highly Strippable/Nonadsorbable Contaminants. Under some circumstances, the raw water contains a mix of compounds, some of which are more amenable to air stripping, and others of that are more amenable to carbon adsorption.

Consider the following case. Pesticides such as chlordane are normally considered to be highly amenable to carbon adsorption while volatile organics such as carbon tetrachloride are usually amenable to air stripping. If these two compounds appear together, any single process selected would probably have to be oversized in order to remove the inappropriate compound. An adsorption system would have to be oversized to remove the relatively nonadsorbable compound, carbon tetrachloride, while an air stripping system would have to be oversized to remove the relatively nonstrippable compound, chlordane. The solution is to use both processes in series. The air stripping system would precede the carbon adsorption system because it would reduce the influent concentration to the carbon of the adsorbable compound, resulting in a reduction in the carbon usage rate and a net cost savings.

Difficult-to-Treat Compounds. Some organics are not particularly amenable either to carbon adsorption or to air stripping. However, they may be somewhat amenable to removal by either process. The appropriate approach to this problem is to provide both processes in series. A compound on the A-280 list that may fall into this classification is 1,2-dichloroethane.

Some compounds are so difficult to treat that the combination of air stripping and carbon adsorption used in series still would not be appropriate. Many of the compounds classified as alcohols, ketones, and aldehydes fall into this category.

The A-280 compounds that show a resistance to removal by current treatment technologies are methyl ethyl ketone (MEK) (also known as 2-butanone), formaldehyde and some components of kerosene. The usual approach to removal of MEK is high-temperature air stripping. In this process, contaminated water containing MEK is heated to a minimum of 120 °F and passed through a packed column with a minimum air-to-water ratio of 150:1. However, these minimums provide a removal rate of only 85 to 90 percent. Even higher temperatures and air-to-water ratios may be needed to meet a cancer-risk-based MCL in water. This treatment process is relatively expensive and could conceivably present a difficult treatment problem when NJDEP proposes an MCL for this compound.

Unusually High Raw Water Concentrations. Raw water concentrations alone are sometimes high enough to warrant use of both processes regardless of whether the best single process for a particular contaminant is air stripping or carbon adsorption. This is particularly true for compounds that, at low concentrations, are amenable to carbon adsorption, but that, at high concentrations, rapidly deplete the carbon, resulting in high carbon cost.

4.4.1 DECISION TREE

A generalized approach to the evaluation of treatment alternatives was developed as part of this study. This generalized approach takes the form of a "decision tree" -- a series of logical steps that can be executed to produce an appropriate outcome. In this case, the steps produce an appropriate process selection and sizing of a treatment system to remove volatile organics from drinking water.

The Decision Tree for Synthetic Organic Chemical Removal is illustrated in figure 4-19. As with any decision tree, a particular event initiates a series of decisions. In this case the initiating event is a letter from NJDEP indicating that a primary MCL has been exceeded. However, two other types of events may initiate action:

1. Recognition, by either the purveyor or NJDEP, that the concentration levels of a presently unregulated organic contaminant are unacceptable
2. Conclusive evidence, regardless of whether NJDEP has taken action, that a violation of an MCL is impending or has occurred, but has not as of yet been reported

If the decision tree is initiated by an NJDEP decision that an MCL has been exceeded, NJDEP will generally provide a grace period of several months before taking any formal action to address the situation. At this point the purveyor faces a critical decision: Should the water supply continue to be used until a treatment process is installed, or should it be temporarily or permanently shut down? Continued use of the water on a short-term basis supply may be justified if the short-term health risks are deemed acceptable and if:

1. The water supply is essential, i.e., no viable alternative supplies presently exist.
2. The consulting engineer needs additional water quality data to further define remedial design criteria or to run a pilot study.
3. The purveyor and consulting engineer are aware that the contamination is very localized, in which case the contamination can be remediated in a relatively short time.

If a decision to continue the use of a water supply is made, then an opportunity exists to gather additional water quality data. This data should be used to better define the present water quality and define

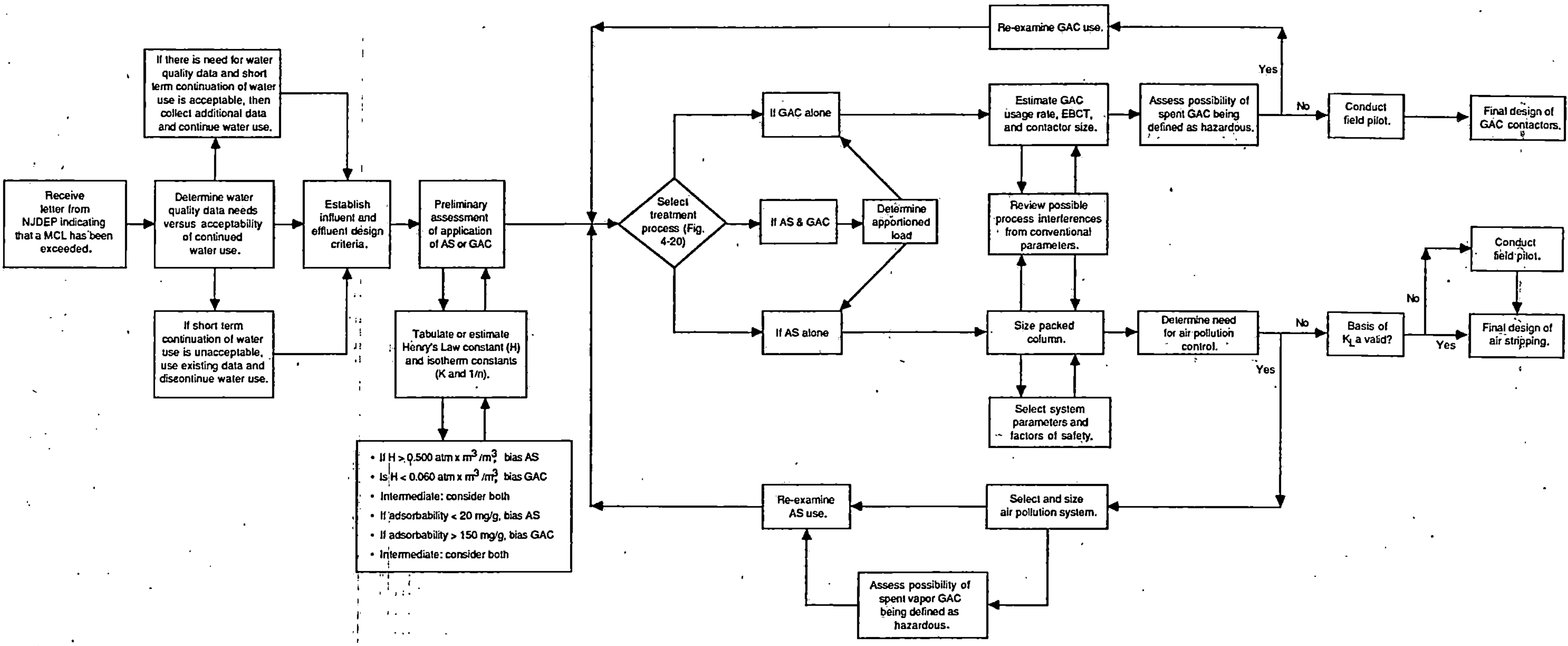

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Figure 4-19

Decision Tree for Synthetic Organics Removal

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any water quality trends so that appropriate design criteria can be established.

Appropriate design criteria should take into account all foreseeable flow and contaminant concentration conditions and regulatory goals. Without the assistance of a ground water flow model, it is largely a matter of judgment as to what raw water design criteria are appropriate. If increasing concentrations are evident, then design criteria should normally be set considerably higher than the present concentrations. Often, design criteria concentrations are set at two times, three times, or an even greater factor above the existing concentrations, particularly when rising raw water concentrations are evident.

Where steady or declining concentrations of organics in raw water are evident, lower factors of safety may be appropriate. It is usually not appropriate for the design criteria to be lower than existing concentrations.

For each contaminant in the raw water, influent and effluent design criteria are established separately. After establishing the design criteria, it is then necessary to tabulate the Henry's Law constant (H) for each compound. These values will assist in ascertaining the relative strippability of each contaminant of interest. (See section 4.2.2 for a discussion of the relationship between Henry's Law and strippability.) Similarly, isotherm constants (K and 1/n) are also tabulated. To determine the relative ranking of the compounds, the Freundlich equation is executed with a value of C equal to 1.0 mg/l (1,000 mcg/l). (See section 4.3.2 for a discussion of the Freundlich equation.) The q values resulting from the Freundlich equation can then be tabulated. These q values measure the relative adsorbability of each compound.

Consequently, each compound can be classified according to the following six suggested criteria (which are based on experience and industry practice):

1. If H is greater than 0.500, then the compound is considered <u>strippable.</u>

2. If H is less than 0.060, then the compound is considered *difficult to strip*.

3. If H is between 0.060 and 0.500, the compound is of *intermediate strippability*.

4. If the adsorbability q on the basis of C = 1.0 mg/l, is greater than 150 mg/g, then the compound is considered *adsorbable*.

5. If q on the basis of C = 1.0 mg/l, is less than 20 mg/g, then the compound is considered *difficult to adsorb*.

6. If q on the basis of C = 1.0 mg/l, is between 20 mg/g and 150 mg/g, then the compound is of *intermediate adsorbability*.

These six guidelines should not be used as enforceable standards. They are intended only to assist in assessing a contamination scenario.

On this basis, it is possible to classify all the contaminants of concern into two of six categories based on the adsorbability and strippability criteria outlined above. Referring to the Treatment Selection Chart (figure 4-20) it is possible to make a tentative process selection. For each compound of concern, enter the chart from appropriate locations on the axes labeled "adsorbability" and "strippability," then record the process located at the intersection of the two axes. Continue this process for each contaminant of concern, tabulating each selected process. Then, on the basis of the predominant appropriate processes, make an overall process selection, remembering that all processes selected by this method are tentative. If one particular contaminant is of primary importance compared to the remaining contaminants, base the overall process selection on that contaminant.

On the basis of the treatment process selection, continue with the selected branch of the decision tree. With one exception, for each decision box on the decision tree, guidance has been provided in the previous sections of this chapter. The box requiring further explanation is labeled "Determine Apportioned Load." Here the user of the decision tree should make a preliminary judgment of the relative sizing of an air stripper to treat the water prior to carbon adsorption. An estimate of the removal efficiency is made based on the conceptual design sizings for air stripping.

	STRIPPABILITY		
ADSORBABILITY	HIGH	LOW	INTERMEDIATE
HIGH	Use Most Cost-Effective Process	Adsorption	Adsorption or Both
LOW	Stripping	Special Process Application	Stripping or Special Process Application
INTERMEDIATE	Stripping or Both	Adsorption or Special Process Application	Both

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Figure 4-20

Air Stripping Versus Carbon Adsorption
Treatment Selection Chart

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Next, a conceptual design sizing for the carbon contactor is selected for additional removal of the contaminant down to the required effluent concentration. Several interpolations may be required to ascertain the most cost-effective sizing(s) of both the air stripper and carbon contactor.

4.5 IMPLICATIONS FOR A-280 COMPOUNDS

This chapter has presented a detailed assessment of the two leading treatment technologies for removal of synthetic organics from drinking water supplies. Based on the criterion presented in section 4.4.1, the following A-280 compounds are defined as clearly strippable, i.e., their Henry's Law constant is greater than 0.500:

Carbon tetrachloride
Vinyl chloride
1,1-Dichloroethylene

Based on the same criteria, the following A-280 compounds are defined as clearly adsorbable, i.e., their adsorbability is greater than 150 mg/g when the residual concentration is 1.0 mg/l:

Chlordane
Polychlorinated biphenyls

The remaining compounds now regulated under A-280 are all removable by either air stripping or carbon adsorption. An analysis of each particular case, along the approach suggested in this chapter, will result in an appropriate treatment scheme. As noted previously, methyl ethyl ketone, which is listed but not presently regulated, represents a difficult treatment problem.

(5)

Section 5

5.0 ALTERNATIVE TREATMENT TECHNOLOGIES

In addition to air stripping and carbon adsorption, ozonation and reverse osmosis were selected for further assessment as processes for removal of A-280 organics. These two processes have shown limited applicability to the destruction and/or removal of synthetic and naturally occurring organics.

5.1 OZONATION

5.1.1 OVERVIEW OF OZONATION

Ozone has been used continuously in Europe for more than 80 years as a disinfectant in water treatment, principally for municipal water supplies.

Ozone is the familiar term for the O_3 form of the oxygen molecule. Because it is unstable, it will produce a series of instantaneous reactions when brought in contact with oxidizable substances. For this reason, ozone cannot be stored and distributed in containers; but must be generated on site. Electrical generation is the only practical method.

An ozone generator (ozonator) incorporates a series of electrodes mounted in a gas-tight container. Most ozonators consist of series of horizontal tubes (dielectric tubes) in a sealed container. Each element of the ozonator consists of two tubes, one inside the other, separated by an annular space. A typical ozonator is shown in figure 5-1. Electric current passes through this annular space from one tube to the other, producing ozone. The source gas, either dried air or pure oxygen (O_2), is passed into the generator and through a narrow gap separating two electrodes. A glow (corona) is produced in the gap. Some oxygen is dissociated and reforms as O_3 following the reaction:

$$3\ O_2 = 2\ O_3\ (-68.2\ \text{Kcal})$$

The resulting product is an ozone-bearing gas containing up to 6 percent ozone by weight. Using air as the source gas, the typical ozone concen-

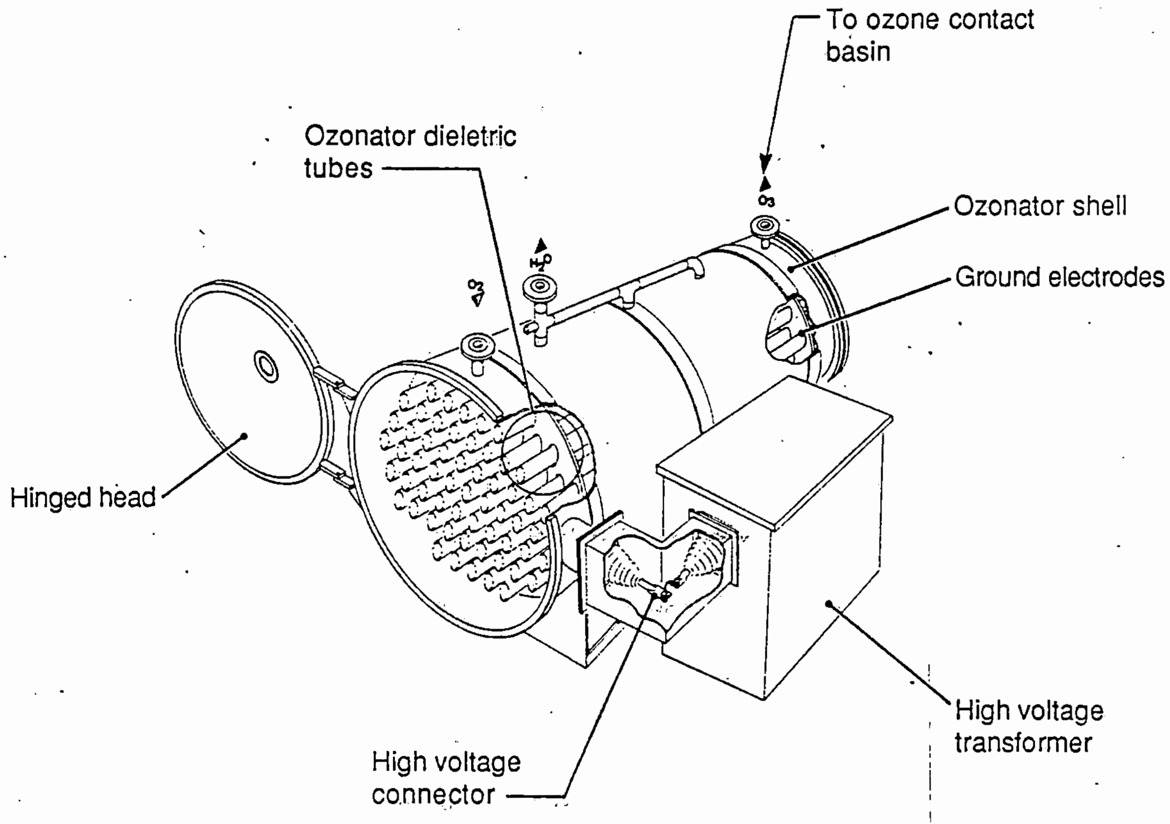

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Figure 5-1

Typical Ozonator

tration is 1.5 to 2 percent by weight. Using pure oxygen, the typical concentration is 3 to 4 percent.

Ozone is typically applied at two locations within the water treatment process. Ozone can be used for pretreatment as raw water reaches the plant, prior to the additions of chemicals for coagulation and settling. Approximately 1 mg/l ozone dosage is typically applied at this stage.

Ozone can also be used to complete the oxidation of ozone-oxidizable organics and as the main germicidal dose to be applied to the water. In this use, ozone is applied at a rate of 3 to 5 mg/l as an aid to microflocculation. (Microflocculation is the term used to describe the use of ozone to enhance the coagulation-flocculation process that follows preozonation.) This dose is designed to be applied after flocculation and sedimentation, but before filtration. Because the ozone is introduced following sedimentation, a large fraction of the water's organic matter has already been removed, thus enhancing the germicidal effectiveness of the second ozone application. Its location before the filters ensures the opportunity for biochemical oxidation of ozonation products before the water is finally chlorinated and distributed to users. Final chlorination then ensures complete disinfection and a chlorine residual before water distribution. In addition, the ozone in the microflocculation step conditions the flocculation chemicals so that a smaller amount of chemicals can be used (because the floc that is formed is more tenacious). This results in better filter performance.

As ozone bubbles rise through the ozone contact tank, up to 98 percent ozone transfer to the water is possible, depending on water quality and the applied dosage. A certain amount of ozone, however, passes through the water column and collects as "off-gas" in the upper portion of the ozone contact tank. The ozone is destroyed prior to venting to the atmosphere. Ozone destruction equipment can utilize either direct thermal means or catalytic means to convert the off-gas ozone back to oxygen. Off-gas fans are generally provided so that a slight negative pressure is maintained in the top of the ozone contact tanks.

5.1.2 APPLICABILITY TO REMOVAL OF SYNTHETIC ORGANICS

For the past few years evidence has been accumulating to strongly indicate that ozone and granular activated carbon perform mutually supportive and complementary functions in the treatment of water supplies for the removal of organic matter. Ozone tends to react most vigorously with the natural organic materials in water supplies, oxidizing the humic materials that cause color and converting the odorants like geosmin, which impart noxious tastes and odors, to smaller molecular structures that are colorless and tasteless. At an intermediate stage in this process, the humic materials may be rendered more easily removable by coagulation. Granular carbon is uniquely valuable because of its ability to adsorb, and thus remove, noxious organic chemicals, particularly those that are resistant to chemical and biological attack such as pesticides, phthalic esters, chlorinated hydrocarbons, PAHs, PCBs, nitrophenolics and others.

Ozone followed by GAC adsorption may result in a biologically active system in which synthetic organics are oxidized by ozone into a more biodegradable form. Biological degradation of the organics then takes place within the carbon pores themselves. However, many volatile halogenated organics remain unaffected by the ozonation step. In fact, breakthrough for some volatile halogenated organics has been reported to occur earlier in ozone-GAC systems than in GAC systems above. A plausible explanation of this phenomenon is that the lower molecular weight organic by-products of ozonation compete with preexisting organics for adsorption sites.

5.1.3 ADVANTAGES AND DISADVANTAGES

When the water is treated with ozone at a dosage of 1 to 5 mg/l prior to carbon adsorption, very little direct reduction in the total organic carbon, 10 percent or less, occurs. On the other hand, the trihalomethane formation potential may be reduced by as much as 30 to 40 percent, and even greater indirect benefit may result when ozonation stimulates more effective coagulation, leading to greater fractional removal of humic material in this step.

Thus, ozonation at a dosage of 1 to 5 mg/l prior to carbon adsorption may increase the useful life of the carbon between regenerations by a factor of 2 to 5, depending on the parameter used to judge performance and the breakthrough level chosen. Useful life for adsorption of chlorinated synthetic organic chemicals is extended more than that for adsorption of total organic carbon. So, prior ozonation can improve and extend the performance of granular activated carbon, in addition to the beneficial effects it contributes directly in improving water quality through control of natural odorants, enhancement of coagulation, dechlorination of water, and positive viral destruction.

The use of granular activated carbon filtration following ozonation also extends the benefits and improves the performance of the ozonation step. Dosage of ozone in the 1 to 5 mg/l range produces organic acids and other oxygenated organic compounds as by-products. These oxidation by-products, in contrast to the initial humic substances, are readily oxidized and utilized microbially. Therefore, biological growths and resultant deterioration in water quality tend to occur in the distribution system when ozonated water passes directly to the mains and when these by-products are not removed by additional treatment with activated carbon.

When ozonation is followed by filtration through GAC, these products undergo adsorption and biological oxidation in the contactors. In this instance, the adsorption does not cause an ultimate decrease in adsorptive capacity for synthetic organic chemicals because subsequent biological oxidation within the activated carbon granual frees the surface again for fresh adsorption. Therefore, the carbon's longevity is extended. In addition, of course, the GAC provides the means for removing those noxious compounds that cannot be oxidized effectively by ozone.

Because of the enhanced effectiveness of this combination of treatment steps, most new or redesigned large water treatment plants in western Europe that use major rivers or other similarly polluted waters as their sources employ both ozonation and GAC filtration as treatment steps. This is true for Zurich in Switzerland, Paris and Rouen in France, Rotterdam in Holland, and several cities along the Rhine and Danube in West Germany. It is found, in general, that use of this combination of processes provides for greater overall removal of organic matter than can be practically attained by extension or intensification of either one of the individual processes.

The combination of ozone and activated carbon also provides for greater flexibility and versatility than can be achieved with a single treatment process. A wider range of taste and odor problems is better handled by a combination of ozone and activated carbon than can be controlled by either process alone.

5.1.4 COSTS

To compare ozone by itself to other disinfectants or oxidants on a process-versus-process basis is not entirely reasonable. On this basis, ozone usually proves not to be cost-effective. However, the properties of ozone are such that reduced chemical feed of coagulants and coagulant aids, and increased activated carbon life, can result. The estimated cost savings from these advantages should be weighed against the capital cost in this cost analysis.

The recommended dosage of 1 to 5 mg/l requires an ozone generation capacity of 45 pounds a day for each 1.0 mgd of water treated. For low ozone generation capacity (10 to 500 pounds per day) typical capital costs are about $80,000 per million gallons of capacity. Above 500 pounds per day, these costs decline to about $50,000 per million gallons of capacity. These costs include installation and assume the use of dried air feed to the ozonators.

5.2 REVERSE OSMOSIS

5.2.1 OVERVIEW OF REVERSE OSMOSIS

Reverse osmosis (RO) is a process in which the semipermeable (molecular selective) characteristics of a membrane are used to separate contaminants from feed water under high pressure. RO is most widely used for treating brackish water.

RO is based on the natural phenomenon of osmosis. Osmosis occurs when solutions of two different total dissolved solids (TDS) concentrations are separated by a semipermeable membrane. Water (solvent) tends to pass through the membrane from the more dilute side to the more concentrated side. An ideal osmotic membrane permits the passage of water molecules but prevents the passage of ions (solutes or contaminants). The net transfer of water from one side of the membrane to the other continues until equal TDS concentrations exist on both sides of the membrane or until the differential hydraulic head (water pressure) is large enough to prevent any net transfer of the water to the more concentrated solution. For example, if a brine solution is separated from pure water by a semipermeable membrane, water will pass through the membrane in both directions, but it will pass more rapidly in the direction of the brine solution. At equilibrium, the quantity of water passing in either direction is equal, and the differential head is defined as the osmotic pressure of the solution having that particular concentration of TDS.

If pressure greater than the osmotic pressure is applied on the more concentrated solution side of the semipermeable membrane, the flow of water will be reversed, and flow will be toward the dilute solution. This condition is called reverse osmosis.

The osmotic pressure of a solution increases with the concentration of the solution. A rule of thumb, based on sodium chloride solutions, is that the osmotic pressure of a solution increases by approximately 1.0 pound per square inch (psi) for each 100 mg/l of TDS. This approximation works well for most natural waters. To overcome the osmotic pressure of the solution and provide sufficient driving force to obtain economical water production rates, RO systems are typically operated at 400 to 500 psig on brackish water. Low-pressure (250 psig) membrane systems are becoming available.

RO membrane materials fall into two broad categories: cellulose acetate and polyamide. Cellulose acetate is the most widely applied type of membrane. The major drawback of cellulose RO membranes is their limited pH range (i.e., 4.0 to 7.5). The main advantage of the polyamide membranes is their ability to operate over a wide pH range (3 to 11). Polyamide's major drawback is that it is oxidized by free chlorine.

There are also two primary membrane configurations: spiral wound and hollow fine fiber. Each is available in both membrane materials. A spiral-wound membrane element consists of two or more membrane sheets seated together to make an envelope formed by enclosing a channelized water-carrying material between two large, flat membrane sheets. The membrane envelope is sealed on three edges with a special adhesive and attached with the adhesive to a small diameter pipe, which has openings to collect the permeate. The envelopes are wound around the pipe to form a cylinder up to 8 inches in diameter and up to 40 inches long. A polypropylene screen is used to form the feed-water channel between the membrane envelopes. A wrap is applied to the membrane element to maintain the cylindrical configuration. The center pipe serves as the permeate-collecting tube, and several elements are connected in series within a single pressure level.

In a hollow fine-fiber membrane element, the membrane and pressure vessel form an integral unit. The polyamide hollow fibers have diameters of 85 microns with the inside diameter being about one-half the outside diameter. Triacetate fibers are estimated to have an outside diameter of 200 to 300 microns. The fibers are formed into a U-shaped bundle, with the open ends of the fibers rooted in an epoxy tube sheet. The bundle attached to the tube sheet is contained in a cylindrical pressure valve. Feed water enters the center of the vessel through a porous or perforated pipe and is distributed readily through the fiber bundle. Under pressure, the water flows into the hollow fine fibers and out through the capillaries.

5.2.2 APPLICABILITY TO SYNTHETIC ORGANICS

The molecular weights of typical volatile organics and THMs may be too low for removal by RO. RO should be evaluated on a case-by-case basis for appropriateness to removal of volatile organics. Typically, 95 percent of all organic materials with molecular weights higher than 400 cannot pass through an RO membrane.

Some volatile organics can, through electrochemical forces, become associated with naturally occurring high-molecular-weight humic substances. Therefore, some volatile organics may be removed. In research performed at Water Factory 21 in California, it was found that, based on an influent concentration of 7.0 mg/l of total organic carbon, 63 percent removal of TOC was measured. However, only a small portion of the total synthetic organics become associated with the natural organics and, in turn, only a portion of the natural organics are removed. Therefore, RO is not generally directly applicable to the removal of synthetic volatile organic substances.

5.2.3 ADVANTAGES AND DISADVANTAGES

RO has several disadvantages. Frequent cleaning of the membrane, even when adequate pretreatment is provided, is often necessary. Cleaning more than once a month generally indicates inadequate pretreatment. This condition will result in fouling of the membrane. Fouling involves the trapping of some type of material within the pores or on the surface of the membrane.

The significant advantage to reverse osmosis is its ability to remove a wide variety of dissolved solids of all different types including organics. However, the cost of the membranes, the constant attention required for operation, and the high level of pretreatment place this system at a significant cost disadvantage.

5.2.4 COSTS

Reverse osmosis represents a relatively expensive treatment process. For small installations, construction costs in excess of $1.0 million for each 1.0 mgd of capacity are not uncommon. This cost takes into account facility housing, structural steel, tanks, piping, valves, pumps, RO membranes, polyphosphate feed equipment (for pH control) and membrane cleaning equipment. It does not include the additional cost of appropriate pretreatment equipment or processes.

5.3 DISCUSSION

Both ozonation and reverse osmosis have limited applicability to the removal of synthetic volatile organics from drinking water. These processes should be applied with the recognition of their limitations in regard to the removal of A-280 contaminants. It is recommended that when these two processes are considered, pilot testing be performed prior to design and construction.

(14)

Section 6

6.0 NONPUBLIC WATER SUPPLIES

SUMMARY OF FINDINGS

The need exists to establish a comprehensive testing program for organic contamination in nonpublic single-user wells. Although the total number of nonpublic wells statewide, and the cost of organic testing, may prohibit the sampling of all wells at once, a phased sampling program of some type is recommended. To effectively manage the large number of test results and coordinate the implementation of a statewide management program, a centralized reporting and data management system may be necessary.

As the cases of organic contamination are identified, the affected homeowners and local agencies would then be advised by the regulatory authority of the recommended action to be taken. In cases where alternative sources of water supply or treatment must be provided, a review of alternatives and treatment technologies must be performed. It is recommended that the New Jersey Department of Environmental Protection (NJDEP) provide guidance in this evaluation of alternatives. However, the actual review and evaluation would be performed and administered by a local entity. The local entity could be a water authority, water quality district, or local health department.

Alternative sources of water supply and centralized water treatment are the preferred corrective measures in cases of high levels of organic contaminants of health concern. In general, point-of-use treatment and use of bottled water are only recommended as an interim solution or for cases of low levels of organic contamination.

The use of point-of-use (POU) treatment to reduce contaminants of health concern poses specific problems with respect to unit selection and testing, ownership, monitoring and maintenance, and funding. A local entity should be established to address these specific concerns associated with POU treatment. The local entities identified previously, including existing water authorities, local health departments, or newly created water quality districts, could perform in this capacity.

Because the availability and resources of existing water authorities and county or local health departments will vary throughout the state, no single type of local entity has been identified to exclusively perform this role. Instead, it is recommended that sufficient flexibility be provided to permit local water authorities and health agencies to assume this role where they have sufficient resources.

In the absence of these agencies flexibility should be provided for the formation of new water quality districts. New legislation, however, may be needed to allow the formation of new water quality districts to manage POU devices for nonpublic wells. The formation of water quality districts and their operations should be regulated and reviewed by either NJDEP or the State Department of Health.

6.1 INTRODUCTION

Nonpublic water supplies are subject to contamination from spills, leaks from underground tanks, industrial lagoons, and disposal of chemicals from septic systems. Throughout New Jersey, individuals have been faced with contamination problems that require financial and technical resources beyond their means. The following discussion is meant to form the basis for developing policies to address this situation.

A nonpublic water supply is defined by the USEPA as any water system that has either fewer than 15 service connections, or regularly serves fewer than 25 individuals. Reference to nonpublic water supplies is usually understood to mean single-user wells.

The goal of assessing organic contamination in nonpublic wells is to provide a framework whereby persons receiving their drinking waters from private wells can be afforded the same protection as those on public systems.

The implications of the present lack of information are far reaching. Many sources of contamination cannot be identified or have not been detected. Unless a homeowner perceives a problem, no testing is performed and a large percentage of the incidences of contamination goes undetected. The sampling that is performed comes about as a result of known situations, spills, or other environmental problems.

Since there may be incidents of contamination that a homeowner is unaware of, a formal water quality testing program for nonpublic wells is essential to assess and characterize the extent of organic contamination of single-user wells. Counties that already have these programs in place could provide guidance and assistance in establishing a statewide program.

Data could be shared among the various health agencies and centrally stored for each county in a computer database or manual filing system. This would allow coordination and a better exchange of information between the local county health departments and the New Jersey Department of Environmental Protection (NJDEP). Table 6-1 presents available data concerning volatile organic contamination of nonpublic wells. Because there is no formal testing program for nonpublic wells, however, the data is not truly representative of the character and extent of this problem.

6.2 POINT-OF-USE TREATMENT

Economics often prohibit the construction of a public water supply system with centralized treatment, or extending neighboring public water supply systems to service small groups of contaminated nonpublic wells. One alternative available to individual residences on nonpublic wells is to treat the water at its point of use (POU). In fact, POU treatment units in general are more cost-effective than centralized treatment for communities of under 100 homes. However, the long-term maintenance and monitoring of these devices pose certain institutional problems.

Point-of-use treatment is provided at the home on one or more water lines. Traditionally used for aesthetic treatment purposes, such as removal of iron and hardness (i.e., as water softeners) these devices have recently been employed for the removal of organic contaminants that are of health concern. Point-of-use devices can be faucet-mounted, can provide a separate treated water line (line bypass), or can provide whole-house

TABLE 6-1

DATA REVIEW OF NJDEP SUMMARIES OF VOLATILE ORGANICS IN NONPUBLIC WELLS

County	Number of households served by non-public wells (1980 Census)	Average number of persons per household (1980 Census)	Estimated population served by non-public wells by county	Total Total number of NJDEP samples	Percent of wells with contaminants detected (based on NJDEP data)
Atlantic	21,013	2.66	55,900	67	Less than 1%
Bergen	8,146	2.79	22,700	33	1%
Burlington	21,065	3.01	63,400	36	Less than 1%
Camden	9,687	2.88	27,900	21	Less than 1%
Cape May	12,288	2.47	30,400	47	1%
Cumberland	15,678	2.91	45,600	46	Less than 1%
Essex	1,423	2.79	4,000	24	5%
Gloucester	14,161	3.03	42,900	102	2%
Hudson	94	2.65	250	-	-
Hunterdon	18,686	2.98	55,700	24	Less than 1%
Mercer	9,579	2.77	26,500	20	Less than 1%
Middlesex	7,435	2.93	21,800	88	3%
Monmouth	13,656	2.90	39,600	54	1%
Morris	25,500	3.02	77,000	87	1%
Ocean	29,165	2.67	77,900	112	1%
Passaic	10,353	2.87	29,700	5	Less than 1%
Salem	8,218	2.86	23,500	2	Less than 1%
Somerset	18,870	2.95	55,700	54	Less than 1%
Sussex	21,427	3.08	66,000	15	Less than 1%
Union	470	2.81	1,300	-	-
Warren	10,412	2.83	29,500	41	1%

treatment. Faucet-mounted units treat water from a single tap. Line bypass units are typically larger and provide treated water through a separate line at the sink. Whole house units treat all of the water entering the home and are specifically called point-of-entry treatment (POET) devices. They have been proposed where the types and levels of contaminants pose a potential health risk from multiple routes such as skin contact, bathing, ingestion, inhalation and other pathways.

A variety of POU water treatment devices available, are reported to remove organic, inorganic, and bacterial contaminants. This study focuses on their use in the removal of synthetic organic compounds identified under the A-280 legislation.

There are presently no national or state regulatory standards governing the performance and use of POU treatment devices. However, several studies have addressed the selection, performance, and testing of POU devices. An extensive evaluation of POU devices is contained in the recent document entitled "Guide to Point-of-Use Treatment Devices for Removal of Inorganic/Organic Contaminants from Drinking Water" prepared for NJDEP.

The procedural steps for evaluation and selection of POU devices is as follows:

1. Identification of contaminants
2. Comparison of POU and other alternatives
3. Consideration of institutional issues
4. Selection of treatment equipment
5. Laboratory and field testing
6. Monitoring and maintenance

These procedural steps were applicable primarily to cases involving contamination of nonpublic wells at levels of health concern rather than aesthetics.

6.3 STATEWIDE PROGRAM RECOMMENDATIONS

This section presents recommendations for a statewide program is New Jersey to address institutional, financial, and technical issues related to contamination of nonpublic water supplies. The key to these program recommendations is prompt, reliable remediation at a cost that is reasonable to homeowners and to the responsible health agency.

Comprehensive Monitoring Program for Nonpublic Wells

Nonpublic wells have been sampled for various contaminants in an unregular fashion. A need exists for the implementation of a comprehensive, uniform monitoring program for nonpublic wells in the State of New Jersey. This is an essential step towards implementing a sound program for the regulation of water quality in nonpublic water supplies.

The monitoring program could initially consist of sampling at a select number of nonpublic wells, and in any known problem areas, for A-280 and traditional contaminants. This information could be computerized and entered into a central database. Trends in this water quality data for nonpublic wells could be correlated by the following parameters:

- Number of wells contaminated in a particular area
- The areal extent of contamination at a particular location
- Type(s) of appropriate POU treatment device(s)
- Level of concentration of contaminants

A determination could be made as to the frequency of additional testing for those wells found to have contaminants at unacceptable levels. Another round of testing could be performed for any new wells in high-risk areas that came into existence since the initial monitoring and testing. An additional opportunity for testing may exist at the time of transfer of ownership of a home. As a condition of sale of a home serviced by a nonpublic water supply, an analytical test for A-280 contaminants could be performed. If the water is unacceptable, either the seller or the buyer could be required to install treatment. The responsibility for any subsequent testing and proposed corrective measures could also be delegated to a designated authority.

The total cost of the initial sampling and testing program could be substantial. According to various county health departments, the average cost for a volatile organic compound (VOC) scan is approximately $75.00. An additional test using gas chromatography/mass spectroscopy (GC/MS) is in the range of $150 per test. The cost to perform these tests for a county with an average of 4,000 nonpublic wells would be approximately $375,000 for VOC scans, and an additional $750,000 to run GC/MS tests. Statewide, there are at least 100,000 nonpublic wells (based on the 1980 U.S. census data). The cost to perform these tests statewide would be a minimum of $23 million. These costs only include the actual analysis; they do not include the costs of sampling and transport of the samples to the lab.

Based on these cost assumptions, it is recommended that the sampling be limited to those areas considered to be at risk (e.g., in the vicinity of underground storage tanks). A risk assessment of health effects versus cost of analysis and remediation should be performed to determine the most appropriate method for sampling nonpublic wells.

Adoption of a Uniform Statewide Policy

NJDEP has implemented a series of Interim Action Levels to address the problem of contamination in public water supplies. A similar approach to be utilized for nonpublic wells is outlined in table 6-2, which shows the various recommended actions to be taken for contaminant levels found in nonpublic wells. The MCLs to be issued by NJDEP will likely be structured into a series of action levels, in a similar fashion to the existing transitional regulatory framework. Therefore, the institutional strategy proposed here could be applied to a future regulatory framework.

Category A -- relating to aesthetic problems and/or very low levels of organic contamination -- could be associated with NJDEP Interim Action Level I for public water supplies (and ultimately to the MCLs). The re-

TABLE 6-2

RECOMMENDED ACTION LEVEL RESPONSES FOR NONPUBLIC WATER SUPPLIES

Category	Type of contamination	Action level (for public supplies)	Recommended action for nonpublic wells
A	Aesthetic quality and/or very low levels of organic contaminants	I	Continued monitoring of organic contaminants on a semi-annual basis to determine if levels increase. More frequent sampling may be required at discretion of regulatory agency. POU treatment is optional and up to discretion of homeowners. Device monitoring and maintenance are also up to homeowner.
B	Low level of health-related contaminants	II, III (at or above Health Advisory Levels for nonregulated contaminants of MCLs)	Confirmation sampling and frequent monitoring (e.g., monthly). Investigate alternate water sources or treatment. Provide alternate water source or treatment within one year. POU devices acceptable. Existing or new local entity established to monitor and maintain POU devices. Program to be approved by regulatory agency.
C	High levels of health-related contaminants	IV	Immediately cease use of water for potable purposes. Immediate confirmation of sampling. Immediate investigation of alternate water sources. Identification of PRP and use of NJDEP Spill Fund for alternate source. At this level of contamination, POU devices are recommended on an interim basis only, until another source of supply is constructed. Existing or new local entity established to monitor and maintain POU device. Local or State agency to approve and regulate POU treatment.

commended action for Category A is continual monitoring of organics on a semiannual basis to determine if there is an increase in contaminant levels. More frequent sampling may be required at the discretion of the designated regulatory agency. Point-of-use treatment is optional and at the discretion of the homeowner. The monitoring and maintenance of the POU device are also the responsibility of the homeowner.

Category B would be associated with nonpublic wells with a low level of health-related contaminants. This category corresponds to NJDEP Interim Action Levels II or III for public supplies. This category could also include contaminants presently not regulated by A-280, which are at or above Health Advisory levels[1]. The recommended action for Category B could be confirmation of the sampling result and frequent monitoring (e.g., monthly). The investigation of alternate water sources or treatment methods should also be undertaken. Recommended action might also include providing an alternate water source or treatment method within one year of discovery. The implementation of POU devices would be considered an acceptable treatment strategy for this level of contamination. A new or existing local entity could be established to monitor and maintain the POU devices. The monitoring and maintenance program would have to be approved by a regulatory agency.

Category C could correspond to NJDEP Interim Action Level IV and would involve regulated A-280 compounds in samples having high levels of health-related contaminants. The recommended action for this category would be immediate cessation of water use for potable purposes, confirmation of sampling results and investigation of alternate water sources. Additional action would require identification of the potential responsible party or parties (PRP) and possible use of the NJDEP Spill Fund to subsidize the cost of an alternate water supply. The use of POU devices at this level of

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[1] Health advisories are a product of the USEPA's Office of Drinking Water. This non-regulatory program provides information on health effects, analytical methodology and treatment technology useful in dealing with specific drinking water contaminants. In the future, the U.S. Center for Disease Control will assume the role as preparer of risk assessment data.

contamination is recommended on an interim basis only, until such time as another supply source is installed or a public water system connection is possible. A new or existing local entity would be established to monitor and maintain the POU devices, and establish a water treatment district. A local or State agency could be required to approve and regulate the POU treatment districts.

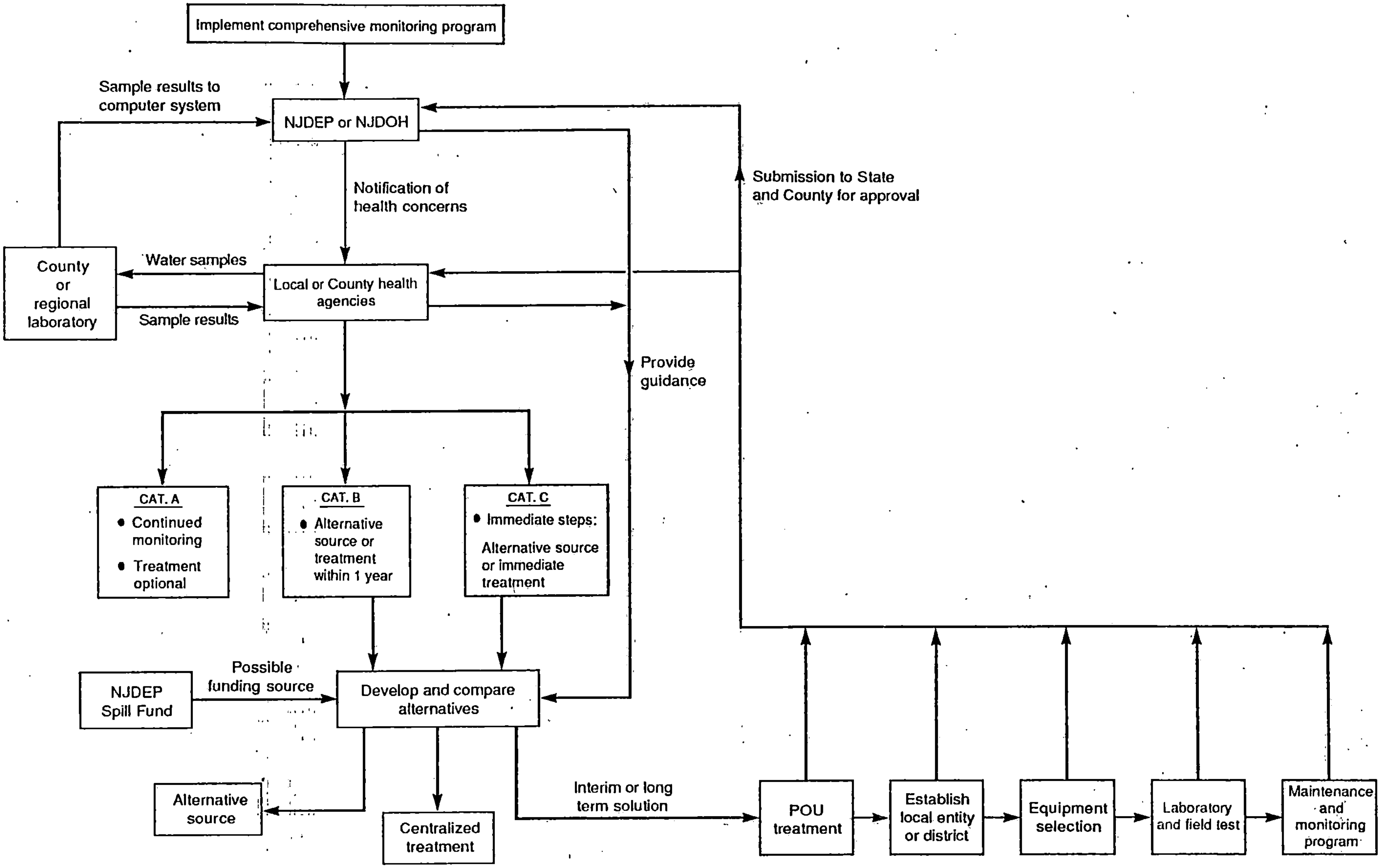
6.4 INSTITUTIONAL RECOMMENDATIONS FOR POU MANAGEMENT

Institutional factors must be considered when making recommendations for the management of POU systems or water quality districts. These factors include financing the treatment district or system, procurement of the treatment devices, and assessing and levying charges for operation and maintenance of the devices. Other requirements would include a long-term monitoring and maintenance program for the devices and administration of the treatment district.

As stated previously in this report, the objectives of this task include recommending institutional strategies for restoring the quality of water utilized by the nonpublic water supply consumers. The recommended overall control strategy, process and regulatory relationship for nonpublic wells are shown in figure 6-1. The first step would be to implement a comprehensive monitoring program. This program would be statewide. The sampling data would be incorporated into one centrally stored database.

The NJDEP or State Department of Health could notify the local or county health agencies of any samples with contaminants at levels of health concern. The sample results would then be grouped into the different action categories as discussed above. In extreme cases, the NJDEP Spill Fund could be used as a possible funding source. For categories requiring alternative supply sources or treatment, the next step would be to develop and compare alternatives.

As indicated in the flow diagram, three options can be taken for supplies with contaminant problems: finding an alternative source; using centralized treatment; or implementing POU treatment as an interim or long-term solution.



CDM

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Figure 6-1

Overall Control Strategy for Nonpublic Wells

Special Water Treatment Study - Phase II

The selection process for POU treatment would involve several phases, each to be followed by submittals to the State and county health departments for approval and guidance. The initial step would involve establishing a local entity or water quality district to be the responsible agent for overseeing the institutional considerations, operation and maintenance processes, laboratory and field testing, and monitoring and maintenance program.

The formation of a local authority or water quality district could result from either amending the present laws relating to water quality and public health, or by using and expanding the New Jersey County Environmental Health Act (CEHA). The CEHA allows county departments or other local entities to provide environmental health services under the direction of a full-time employee trained and experienced in managing environmental health programs. The environmental health services would normally be provided by any municipal or regional health agency certified by the Commissioner of NJDEP. Under many circumstances, county health departments would have to hire or contract with the necessary qualified personnel to oversee the implementation of this program.

6.5 SUMMARY OF RECOMMENDATIONS

Although the review of available NJDEP sampling data indicated that, in most cases, less than one percent of the nonpublic single-user wells were subject to synthetic organic contamination, it must be emphasized that the number of cases and percentages are based on very limited testing. There appears to be a rising trend in the organic contamination of nonpublic wells, and the problem is beyond that documented in NJDEP sample results, as indicated by several local and county health agencies. The need exists to establish a comprehensive testing program for organic contamination in nonpublic single-user wells. Although the total number of nonpublic wells statewide, and the cost of organic testing, may prohibit the sampling of all wells at once, a phased sampling program of some type is recommended. To effectively manage the large number of test results and coordinate the implementation of a statewide management program, a centralized reporting and data management system may be necessary. A centralized data system for organic testing results could be established under the supervision of NJDEP.

As the cases of organic contamination are identified, the affected homeowners and local agencies would then be advised by the regulatory authority of the recommended action to be taken. The implementation of a uniform statewide policy on corrective actions for nonpublic wells is based on the concentration and types of organic contaminants found. The various categories and recommended actions for nonpublic wells are summarized in table 6-2.

In cases where alternative sources of water supply or treatment must be provided, a review of alternatives and treatment technologies must be performed. It is recommended that NJDEP provide guidance in this evaluation of alternatives. However, the actual review and evaluation would be performed and administered by a local entity. The local administrative authority presently responsible could be a water authority, water quality district, or local health department.

Alternative sources of water supply and centralized water treatment are the preferred corrective measures in cases of high levels of organic contaminants of health concern. In general, point-of-use treatment and use of bottled water are only recommended as an interim solution or for cases of low levels of organic contamination (Categories A and B in table 6-2).

The use of POU treatment to reduce contaminants of health concern poses specific problems with respect to unit selection and testing, ownership, monitoring and maintenance, and funding. A local entity should be established to address these specific concerns associated with POU treatment. The local entities identified previously, including existing water authorities, local health departments, or newly created water quality districts, could be used in this capacity.

Because the availability and resources of existing water authorities and county or local health departments will vary throughout the state, no single type of local entity has been identified to exclusively perform this role. Instead, it is recommended that sufficient flexibility be provided to permit local water authorities and health agencies to assume this role where they have sufficient resources. The CEHA provides much of the framework for managing health programs and services and could be expanded to include the management of POU systems. In the absence of these agencies flexibility should be provided for the formation of new water quality districts. New legislation, however, may be needed to allow the formation of new water quality districts to manage POU devices for nonpublic wells. The formation of water quality districts and their operations should be regulated and reviewed by NJDEP.

The recommended overall control strategy for organic contamination of nonpublic wells is summarized in figure 6-1. The implementation of a comprehensive monitoring program for nonpublic wells for organic contamination acts as a starting point from which identification of contamination problems and evaluation of alternatives should proceed. The selection process and potential roles of the regulatory agencies are also shown in figure 6-1. The interrelationships and general process shown in the figure represent a preliminary framework from which a more comprehensive control program could be developed and implemented.

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Section 7

7.0 ALTERNATIVE MONITORING TECHNIQUES

Cost-efficient and reliable monitoring techniques are needed to help water purveyors continue to provide a safe supply of drinking water at reasonable cost, while meeting new regulatory requirements under New Jersey Assembly Bill A-280. In anticipation of this need, two alternative approaches to traditional laboratory analysis were evaluated: (1) use of surrogate parameters and (2) use of biological monitoring systems.

SUMMARY OF FINDINGS

Surrogate Tests

Investigations have indicated that surrogate tests can probably not be used to meet specific monitoring requirements for individual organic compounds at this time. Until other techniques are refined, gas chromatography is probably still the best analytical procedure for quantifying individual organic compounds.

Although some of the nonspecific and individual organic analyses hold promise as possible surrogate parameters at certain installations, no one test has been found to be universally or generally applicable for the monitoring of organic water quality or treatment unit performance in all situations. Application of a surrogate for routine monitoring should be based upon tests and correlations established at the specific water treatment facility. Surrogates are generally used only as a routine monitoring tool; more detailed analyses should be performed if a problem is detected.

Biological Monitoring Systems

An extensive literature search was undertaken to assess the applicability and usefulness of such biological early warning systems for the purpose of monitoring raw drinking water. In addition to the literature research itself, information regarding recent technical developments was obtained.

Sixteen response variables and sensors that either have been used or considered for use in an early warning system have been identified. Most of these systems have not specifically examined the effects of the A-280 compounds. Each field-tested system was evaluated on the basis of reliability, sensitivity to toxicants, degree of skill required for use, degree of maintenance required, and approximate cost. The results of these evaluations indicated that fish ventilatory/activity monitors hold the most promise as a biological early warning system for assessing raw drinking water.

Based on the conclusions from the literature search and information survey, several recommendations were made with respect to future research and testing.

7.1 SURROGATE PARAMETERS

Laboratory analysis for synthetic organic compounds can be costly, particularly when large numbers of analyses must be performed. Alternatives that will reduce these costs are of obvious benefit. This section explores the use of substitute, or surrogate, parameters that will provide reliable information equivalent to that provided from more costly analyses.

In the monitoring of water quality, a surrogate parameter refers to a parameter that is used to replace another parameter whose measurement usually requires a more specific and time-consuming chemical test. The surrogate parameters used to monitor organics in water treatment are typically collective parameters that measure groups of compounds (e.g., total organic carbon). Ideally, tests for surrogate parameters can be performed relatively quickly and inexpensively. The potential for reducing time and cost by using collective or nonspecific analyses -- such as a surrogate test for more complex analysis of individual organic compounds by gas chromatography (GC) and mass spectroscopy (MS) methods -- is the primary reason for attempts to apply surrogate tests in routine monitoring.

Surrogate tests that are collective in nature, however, could probably not be used in practice to meet specific monitoring requirements for individual organic compounds at this time. Until other techniques are refined, gas chromatography is probably still the best analytical procedure for quantifying individual organic compounds. These analyses may be performed in house if the purveyor has acquired a GC instrument (a variety of models including portable units are available) or they may be performed at an outside laboratory.

History of Use

Detailed investigations have been conducted into the use of nonspecific analysis of surrogate parameters for the routine monitoring of organics in raw water quality, treatment unit performance, pilot unit evaluation, and removal efficiencies. In the routine monitoring of raw water quality, surrogate parameters could be used to detect possible spills of organic contaminants and to measure the seasonal fluctuations in water quality that may affect treatment plant operations. Monitoring of surrogate parameters within a treatment plant may also be used for operational control of a unit process, to evaluate removal efficiencies, and to rapidly detect the failure of a treatment process. Much of the work involving the use of surrogates for monitoring organics has been associated with research projects and pilot-plant studies. Varying degrees of success have been reported in correlating these collective measurements, or surrogate parameters, to the specific organic chemical groups of concern.

Surrogate parameters have also been used to monitor demonstration treatment facilities for water reuse. Water reuse facilities typically treat wastewater effluent to obtain a high quality water that may be used indirectly for drinking or other practical purposes. Extensive monitoring in these facilities is normally performed for a variety of organic parameters. Surrogate monitoring can provide valuable control information and reduce monitoring costs.

The monitoring of collective organic surrogate parameters has also been applied in pilot testing in order to measure total organic loading and removal efficiencies. The collective nonspecific total organic carbon (TOC) analysis to evaluate unit loadings has frequently been monitored in granular activated carbon (GAC) pilot-plant studies.

Many surrogate tests for organics are nonspecific organic analyses that measure collective groups of organic compounds. Thus, a change in the concentration of a given collective parameter during treatment represents the total change in the concentrations of all the contaminants measured by the parameter. An advantage of a collective parameter is that a single measurement determines what is happening to many different compounds. A disadvantage is that the removals and the concentrations of the individual organic compounds may vary within the collective measurement. Some organic compounds may be removed to a lesser degree and others to a greater degree than reflected by the collective parameter. **Therefore, surrogate tests that are collective in nature could probably not be used in practice to meet specific monitoring requirements for individual organic compounds.** However, surrogates may be useful in daily water quality evaluation and for monitoring treatment process operation.

7.1.1 SELECTION OF SURROGATES

Ideal guidelines for selecting possible surrogates as cited by several researchers are listed below:

1. The surrogate parameter should be present in the monitored water stream in a sufficiently high concentration for reliable, routine monitoring.
2. The concentration of the surrogate parameter should reflect the concentrations and removals of the specific organic compound or group of compounds of concern.
3. The surrogate should be removed by the treatment process at an efficiency that is similar to, and correlates well with, the removal of the specific compounds for which it is a substitute.
4. The influent concentration and the removal efficiency of the surrogate should be relatively constant so a major change in the treatment performance could be easily detected.
5. The surrogate test should be one that can be performed with relative ease and with reasonable accuracy and precision.
6. Interferences for the selected surrogate test from other background chemical constituents in the water should be minimal.

7. The surrogate parameter should ideally be adaptable to automated sampling and continuous monitoring.

In most water monitoring applications, it is difficult for a single surrogate parameter to meet all of these guidelines. A frequent problem with using a collective parameter (e.g., TOC, UV absorption) as a surrogate is that the specific organics of concern may represent only a small fraction of the compounds quantified by the total collective parameter. If the organics of health concern typically represent a small fraction of the total surrogate measurement, the removal of these specific organics would be difficult to accurately predict. Another problem is that the removal rates of individual organics and total collective parameters can vary within a treatment process. The percent removal of individual organics affected by a particular treatment process may be quite different from the percent removal of the collective parameter; this can make removal correlations difficult. These differences can create problems in monitoring the removal rates of specific compounds through collective surrogate parameters, especially if the background water quality is changing, as is often the case with surface waters.

Seasonal changes in raw water quality are common in surface water supplies. These seasonal changes in raw water quality can result in changes to the collective surrogate measurements and the observed removal rates. These fluctuations make the correlation between surrogates and specific groups of organics unpredictable. Differences in background water quality, chemical properties of organic constituents, treatment unit performance, and possible interferences from other inorganic and organic components make the application of surrogate parameters highly site specific. What may prove to be an effective surrogate parameter at one facility may not be effective or useful at another.

Several of the organic surrogate tests can be performed by automated equipment. Presently, automatic analyzers are available for TOC, ultraviolet absorbence, and fluorescence. Such automatic analyzers offer the advantages of fairly rapid results and continuous monitoring ability.

A surrogate parameter does not have to conform to all the ideal conditions to be a useful monitoring tool. In fact, an ideal surrogate parameter for monitoring organics in drinking water supplies that meets all the criteria has not been found or reported to date. Potential surrogate parameters should meet as many guideline criteria as possible, and should be evaluated carefully along with other factors including cost, speed of analysis, and correlations established on a site-specific basis between the parameter of interest and the proposed surrogate.

7.1.2 COMMON SURROGATE PARAMETERS

Several surrogate parameters have been investigated for application in the routine monitoring of organics in water. Most of the reported surrogate parameters are collective measurements that analyze for groups of compounds. The most commonly applied organic surrogate tests are listed below along with their standard abbreviations.

Surrogate test	Abbreviation
Total organic carbon	TOC
Dissolved organic carbon	DOC
Nonvolatile total organic carbon	NVTOC
Total organic halogens	TOX
Total organic halogen formation potential	TOXFP
Purgeable organic halogens	POX
Total trihalomethane formation potential	TTHMFP
Color	-
Ultraviolet absorbence	UV absorbence
Fluorescence	-
Chemical oxygen demand	COD

7.1.3 APPLICABILITY OF SURROGATE PARAMETERS

The application of surrogate parameters for monitoring organics in raw water and for monitoring treatment unit performance has been investigated by numerous researchers at water facilities throughout the United States and Europe. Although some of the nonspecific and individual organic analyses hold promise as possible surrogate parameters at certain installations, no one test has been found to be universally or generally applicable for the monitoring of organic water quality or treatment unit performance in all situations. Application of a surrogate for routine monitoring should be based upon tests and correlations established at the specific water treatment facility. Other important factors include the types of organics being treated, their treatment and removal levels, known variations in background water quality, and interference from naturally occurring organics and background inorganics. The use of surrogate parameters should, therefore, be site specific.

Surrogates are generally used only as a routine monitoring tool, and more detailed analyses are performed if a problem is detected. They are not generally used as a regulatory tool.

Table 7-1 summarizes the potential applications, possible surrogates, advantages and disadvantages associated with the surrogate tests, interferences, and facilities where the surrogates were applied or tested. Table 7-2 summarizes detection limit and test accuracy for the various surrogate tests. A detailed discussion of each category is presented below.

Monitoring Raw Water Quality

The use of surrogate parameters for monitoring organics in raw water comprises two categories: those parameters evaluated for monitoring THM precursors in raw water sources, and those suggested as possible surrogates for organic spill detection.

The principal analyses suggested as surrogates for monitoring THM precursors in water supplies are UV absorbance, fluorescence, TOC, and NVTOC.

TABLE 7–1

SUMMARY OF POSSIBLE SURROGATE APPLICATIONS

Application	Possible surrogate parameters	Advantages	Disadvantages	Interferences	Facilities applied/tested
MONITORING RAW WATER QUALITY					
1. For THM precursors in in surface water	UV absorbance and fluorescence	• Amendable to continuous monitoring and automatic analysis • Several investigations have found fairly good correlations • Relatively inexpensive instrument cost	• Not all organic compounds absorb UV or fluoresce	• Nitrite and bromide ions • Colloidal particulates or turbidity	• North Carolina research project • Canton, NY, research project • Glenmore, Reservoir, Oneida, NY, research project • Massachusetts, research project
	TOC, NVTOC	• Several investigators have found fairly good correlations • Automatic analyzers are available	• Not amenable to continuous monitoring • Normal TOC range at mg/l level; nearly impossible to quantify trace (ppb) SOC levels • Fairly expensive instrument cost	• Carbonate and bicarbonate	• North Carolina research project • Canton, NY, research project • Glenmore reservoir, Oneida, NY, research project
2. For spill detection	TOX	• Detects halogenated organics that are frequently of health concern (including THMs) • Detection limit in the 5 ppb range • Automatic analyzers are available	• Does not detect nonhalogenated organics (e.g., benzene) • Not amenable to continuous monitoring • Fairly expensive instrument cost • Requires trained personnel for sample collection/preparation • All of the volatile organics may not be fully recovered and measured	• Inorganic chloride and bromide	• Under investigation at Columbine plant, CO

TABLE 7-1

SUMMARY OF POSSIBLE SURROGATE APPLICATIONS
(continued)

Application	Possible surrogate parameters	Advantages	Disadvantages	Interferences	Facilities applied/tested
	Odor	• Possible if monitoring for odor at plant already • Does not require expensive instrumentation	• Requires specially trained panelist • Still largely in research phase; limited correlation data available	• Naturally occurring tastes and odor, non-organic substances	• Being researched by Drexel University, Metro Water Dist. of Southern Calif., Phila. Water Dept., and LOE France
MONITORING TREATMENT PROCESS					
1. Coagulation/flocculation (THM precursor removal)	UV absorbance and fluorescence	• Amenable to continuous monitoring and automatic analysis • Some investigators have found fairly good correlations • Relatively inexpensive instrument cost	• Not all organic compounds absorb UV or fluoresce • Correlations not found at some facilities	• Nitrite and bromide ions • Colloidal particulates or turbidity	• Canton and Oneida plants, NY, research project
	TOC, NVTOC	• Some investigators have found fairly good correlations • Automatic analyzers available	• Not amenable to continuous monitoring • Correlations not found at some facilities • Fairly expensive instrument cost • Normal TOC range in mg/l level; nearly impossible to quantify trace (ppb) SOC levels	• Carbonate and bicarbonate	• Canton and Oneida Plants, NY, research project • Contra Costa, CA, research project • Illinois research project
2. Air Stripping (VOC removal)	Individual organic compounds (e.g., chloroform, 1,1,1-trichloroethane)	• Easier to monitor removal of single organics in lieu of a full VO scan • Does not reflect changes in other contaminant removals	• Requires a GC for analysis		• South Brunswick, NJ, operating facility • Miami, FL, research project

TABLE 7-1

SUMMARY OF POSSIBLE SURROGATE APPLICATIONS (continued)

Application	Possible surrogate parameters	Advantages	Disadvantages	Interferences	Facilities applied/tested
		• Reported to be fairly reliable if properly selected			• WPF-21 Orange County, CA
3. Granular activated carbon	TOC	• TOC steady state found to be a conservative measure for GAC replacement/regeneration • Automatic analyzers are available	• In many instances reported to be too conservative a measure (replacement before carbon is fully exhausted) • Normal TOC range in mg/l level; nearly impossible to quantify trace (ppb) SOC levels • No correlations found to individual organic removals	• Carbonate and bicarbonate	• Cinn., OH, pilot program
	TOX	• Detection to 5 ppb range (more accurate than TOC) • Detects halogenated organics that are frequently of health concern	• Has not been correlated to removal of individual organics • Does not detect nonhalogenated organics (e.g., benzene) • Requires trained personnel for sample collection/preparation • May not detect breakthrough of individual organic at low ppb levels • All of the volatile organics may not be fully recovered and measured	• Inorganic chloride and bromide	• Columbine Plant, Thornton, CO, research project • Jefferson Parish, LA, research project

TABLE 7-1

SUMMARY OF POSSIBLE SURROGATE APPLICATIONS
(continued)

Application	Possible surrogate parameters	Advantages	Disadvantages	Interferences	Facilities applied/tested
	Individual organics	• Easier to monitor removal of single organic that is expected to break through first, rather than full scan	• Does not reflect changes in other organic contaminant removals		• Jefferson Parish, LA, research project
	Taste and odor	• If treating for taste and odor control, this would be a useful/direct measurement			• Being researched by Drexel University, Metro Water Dist. of Southern Calif., Phila. Water Dept., and LOE, France
	TTHMFP[1]	• If treating for removal[a] of THM precursors, this is a useful/direct measurement	• Analysis requires 5 to 7 days to run	• Inorganic chloride and bromide	• Jefferson Parish, LA, research project
	COD	• Fairly easy and inexpensive to monitor • Automatic analyzers available	• Final value may be affected by amount of free CL_2 residual during test • Not as accurate as other measures; will not detect ppb changes • No correlations found to individual organics	• Inorganic ions (Cl NO_3)	• Water Factory 2, CA

[a] Possible surrogates for THMFP would be UV absorbance, fluorescence and TOC, which are described in the table under raw water quality monitoring.

TABLE 7-2

SUMMARY OF DETECTION LIMITS AND PRECISION OF SURROGATE TESTS FOR ORGANICS

Test	Detection limit	Precision
TOC	1 mg/l (normal) 5 mcg/l (special instrumentation)	1 to 2 percent
TOX	5 mcg/l	(a)
COD	1 mg/l	6.5 to 10.8 percent
Color UV absorbance Fluorescence	(b)	(b)
Odor	mcg/l range (c)	—

[a] Precision and accuracy of TOX depend on specific procedures, equipment, and analysis in accordance to Standard Methods (16th Edition). Precision and accuracy should be developed and routinely updated fcr each instrument configuration.

[b] Depends on particular correlation established for organic compound and surrogate.

[c] Detection is dependent upon type of organic compound, associated odor (if any), and training and smell sensitivity of panelist.

Source: *Standards Methods for the Examination of Water and Wastewater*, 16th Edition, 1985.

Good correlations between THM precursors or total THM formation potential (TTHMFP) and these collective parameters have been found by several researchers. Slightly better correlations for UV absorbance to TTHMFP have been reported and, in some instances, that of TOC to TTHMFP. However, correlations between the surrogate parameters and TTHMFP should be developed on a site-specific basis.

The reported research indicates in general that UV absorbance, fluorescence, TOC, and NVTOC are good potential surrogates for TTHMFP. Utilization of these parameters to predict TTHMFP would be of value in assessing raw water quality and loadings/operation of subsequent units. Automatic analyzers are available for these surrogate analyses. UV absorbance and fluorescence measurements also lend themselves to continuous monitoring; instrumentation costs for these two analyzers are relatively inexpensive.

TOX

The primary test suggested as a surrogate parameter to detect organic chemical spills is TOX. TOX is a collective measurement of the halogenated organic content of the water sample. Many of the halogenated organics are used by industries and are of health concern in water supplies. TOX analysis also reflects the combined concentrations of the majority (15 of the 22) of A-280 compounds. The TOX measurements, however, do not include seven other organic contaminants regulated under A-280, which are not halogenated, but are still of health concern (e.g., benzene, xylene). Furthermore, some volatile organic halogens may not be fully recovered and measured in the TOX analysis.

In spite of these shortcomings, TOX holds promise as a surrogate for monitoring raw water quality. Automatic TOX analyzers are available and have detection limits in the 5 mcg/l range. Monitoring of TOX as a surrogate parameter for industrial organic contamination in the raw water supply is presently being investigated by the City of Thornton, Colorado.

Application of TOX should be on a site-specific basis after careful review of the potential organic contaminants, concentration, and interferences.

The Ohio River Sanitation Commission (ORSANCO), which has been monitoring for spill detection in the Ohio River since 1979, does not use or measure TOX. Instead, a VOC scan including aromatics is performed daily at 11 locations by GC analysis. One of the reasons given for not considering TOX is that benzene is of major concern in the area monitored, and TOX does not detect this compound.

TASTE AND ODOR

Recent research has also reported correlations between taste and odor measurement and several organic compounds. With the development of correlations between odor and flavor types and specific types of organics, these measurements may be useful surrogates for monitoring raw water quality and for spill detection. Since trained panelists would be required to identify odor-causing compounds, this type of monitoring for organics would be more appropriate to those facilities already monitoring/treating for taste and odor problems. Sensory analysis to detect the presence of organic chemical groups is possible; however, it would not replace instrumental analysis to identify and quantitatively measure concentrations. Also, if contamination events are relatively frequent or of relatively high concentration, it may present a health hazard to the testers to routinely perform taste and odor analyses.

Monitoring Treatment Processes

The use of surrogate chemical analysis for monitoring the organic removals and unit performance has been reported for several treatment processes. The major organic treatment processes for which use of surrogates have been investigated include coagulation/flocculation (THM precursor removal), air stripping, and granular activated carbon.

Conventional Treatment. The coagulation/flocculation process followed by either sedimentation or filtration can remove organics (TOC precursors). UV absorbence/fluorescence, TOC, and NVTOC are possible surrogates measurements for TTHMFP. Monitoring of these collective parameters to evaluate and control the coagulation/flocculation process to maximize THM precursor removals has been reported at some facilities. However, correlation between these surrogate parameters and TTHMFP are not always found; these surrogate measurements should be applied on a case-by-case basis after laboratory tests have been performed.

Air Stripping. The use of individual organic compounds as surrogate parameters for monitoring the performance of air stripping units appears to be a viable alternative to monitoring for all organics on a routine basis. The application should again be made on a site-by-site basis. The indicator compound should be present at high enough concentrations for reliable routine monitoring, and its removal rate should be a conservative measure of the removals of the organics of concern. A disadvantage of monitoring a single organic compound is that changes in the other organic contaminant concentrations are not indicated. The measurement of an individual volatile organic compound requires a gas chromatograph.

Granular Activated Carbon. Individual organics and the collective parameters (TOC, UV absorbence, TOX, and TTHMFP) have been investigated by several researchers as surrogate parameters to evaluate the performance of granular activated carbon (GAC) columns. In most instances the research has centered around using these individual and collective parameters to determine the need to regenerate or replace the carbon. The selection of the possible surrogate parameter is related to the type of organics present and the treatment unit purpose. For example, UV absorbance and TOC have been investigated as surrogates where the parameters of concern were, respectively, THM percursor removal and individual organic compound breakthrough in carbon contactors.

The use of a single surrogate parameter (e.g., TOC) for evaluating the need to regenerate or replace carbon has been found to be too conservative a measure in many instances. Therefore, the monitoring of several surrogate parameters has been suggested. In Jefferson Parish, Louisiana, a research project monitors TOC, THM, TTHMFP, and the individual organic 1,2-dichloroethane. When predefined levels of any two of the four parameters are reached, the activated carbon is replaced. The use of more than one surrogate parameter for monitoring GAC performance may be necessary for the economical operation of GAC units in some situations.

In other situations where GAC is used to protect a water supply from sudden organic spills, a conservative measurement is necessary to ensure that the carbon contactor has enough capacity for sudden high concentrations of unknown organics.

7.2 BIOLOGICAL MONITORING

A biological early warning system, by definition, is a system in which living organisms (sensors) are monitored while being exposed to a particular water stream. These systems are designed so that operators are alerted to developing toxic conditions in the intake water (as evidenced by abnormal sensor behavior), allowing corrective action to be taken quickly.

The following discussion presents the findings of an extensive literature search designed to assess the applicability and usefulness of such biological early warning systems for the purpose of monitoring raw drinking water. In addition to the literature research itself, information regarding recent technical developments was obtained. In performing the literature/information search, six criteria were identified to meet the needs of water purveyors for early warning systems:

1. Rapid response (less than 1 hour) to the presence of a hazardous level of volatile organic compounds in raw drinking water is necessary.
2. Operation of the system should be continuous and automatic so as to continually monitor the raw water.
3. The system must be reliable. False alarms should be minimal and easily corrected.
4. Response data and alarm states from the early warning system should be easily interpretable and sensitive to the volatile organics of concern.
5. Sensors (organisms) used in early warning systems should be easily obtained and maintained at the site, and be sensitive to the volatile organic of concern.
6. The mechanical design and arrangement of the system should have minimum complexity and require as little daily maintenance as possible.

Sixteen response variables and sensors that either have been used or considered for use in an early warning system have been identified (table 7-3). The sensors ranged from bacteria and invertebrates (such as insects, crustacea, and paramecia) to vertebrates (several fish species). Response variables were biochemical in nature (oxygen consumption, blood composition, nitrification), physiological (respiratory activity, heart rate), and skeleto-muscular (locomotory activity, rheotaxis). Each of these were evaluated based on whether they were conceptually useful tools for an early warning system, and whether they were technically feasible for on-line monitoring.

Based on the evaluations given and the data available, sixteen different field-tested systems are presented in table 7-4. Most of these systems have not been specifically examined for the effects of the A-280 compounds. This is partly because (1) most systems to date have been field tested in surface waters or waste streams in which the specific contaminants were unknown or unidentified and (2) the A-280 compounds are relatively recent additions to the list of commonly regulated pollutants. Most systems have been tested using pollutants for which more extensive toxicological data already existed.

Each field-tested system was evaluated on the basis of reliability, sensitivity to toxicants, degree of skill required for use, degree of maintenance required, and approximate cost. Of the 16 systems discussed, four were fish ventilatory (breathing) systems, two were fish activity monitors, two were fish rheotaxis systems, one was based on bacterial oxygen consumption, and one was based on bacterial nitrification. Each of these systems was used as a continuous monitor for water quality assessment, using automated equipment.

The results of these evaluations indicated that fish ventilatory/activity monitors hold the most promise as a biological early warning system for assessing raw drinking water (see tables 7-5 and 7-6). This conclusion was based on the following criteria: (1) ventilatory/activity systems presently have greater sensitivity to toxicants than other systems that were field tested, (2) these systems have by far the largest database available on to-

TABLE 7-3

RESPONSE VARIABLES USED IN FIELD TESTED EARLY WARNING SYSTEMS AND THEIR APPLICATION

Response variable	Number of field systems (out of 16) in which response was used	Application(s) (actual field-tested sites)
Fish ventilatory rates	5	Wastewater, surface water, and water treatment works intake
Fish rheotaxis	4	Wastewater and surface water
Fish activity	2	Wastewater and surface water
Fish electric organ discharge	1	Water treatment works intake
Bacterial oxygen consumption	3	Wastewater
Bacterial nitrification	1	Surface water

TABLE 7-4

OVERVIEW OF POTENTIALLY USEFUL ORGANISMS AND BIOLOGICAL RESPONSE VARIABLES FOR BIOLOGICAL EARLY WARNING SYSTEMS

Response variable	Method of detection	Degree of skill required for operation	Sensitivity to toxicants	General response time	Suitable for continuous automation?	On-line field tests performed?
Bacterial oxygen consumption	D.O. probe, respirometer	Modest	Acute concentrations	Hours	Yes	Yes
Bacterial nitrification	NH_3 ion probe	Modest	Acute	Hours	Yes	Yes
Bacterial bioluminescence	Photometric instrument	Modest	Acute	Minutes	No - manual prep. and analysis on discrete samples required	No
Bacterial glucose uptake	Radio isotape	High - specific training with radio isotopes required	Acute	Minutes	No - analysis on discrete samples required	No
Aquatic insect oxygen consumption	Respirometer	Modest - for system operation, high - organism handling and culturing	Subacute	Days	Yes	No
Aquatic insect respiratory movements	Non-invasive electrodes and amplifier	Modest - system operation, high - organism culturing	Acute and subacute	Hours–days	Yes	No
Aquatic insect activity levels	Non-invasive electrodes and amplifier	Modest - system operation, high - organism culturing	Acute	Hours–days	Yes	No
Crayfish activity levels	Non-invasive electrodes and amplifier	Modest	Acute	Minutes–hours	Yes	No
Protozoan oxygen consumption	Respirometer	Modest - culture maintenance, high skill involved in system operation	Acute and subacute	Hours–Days	Yes	No
Fish ventilatory movements	Non-invasive electrodes	Modest	Chronic	Minutes	Yes	Yes

TABLE 7-4

OVERVIEW OF POTENTIALLY USEFUL ORGANISMS AND BIOLOGICAL RESPONSE VARIABLES FOR BIOLOGICAL EARLY WARNING SYSTEMS

(continued)

Response variable	Method of detection	Degree of skill required for operation	Sensitivity to toxicants	General response time	Suitable for continuous automation?	On-line field tests performed?
Fish activity	Ultrasonic echos, non-invasive electrodes	Modest	Acute	Hours	Yes	Yes
Fish rheotaxis	Light barrier interruption	Modest	Acute	Hours	Yes	Yes
Fish electric organ discharge	Non-invasive electrodes	High - skill required in organism culture maintenance	Acute	Hours	Yes	Yes
Fish heart rate	Attached electrodes	High - special technical skills required	Chronic	Days	No - techniques may require restraining fish	No
Fish blood composition	Blood sampling and chemical analysis	High - special sampling and chemical analysis skills required	Chronic	Days	No - analysis on discrete samples required	No

TABLE 7-5

SUMMARY OF DATA BASES FOR SOME FIELD TESTED BIOLOGICAL EARLY WARNING SYSTEMS

Response variable monitored	Location/ application	Length of operation	False alarms	Toxicant/exposure/ concentration	Response time	Source
Fish ventilatory rate	Industrial plant #1, New River, Virginia	4 months total on-line time	About 2 per day for controls, caused by outside disturbances	Acetone spike/96% of 96h LC50	1hr	Vander Schalie, et al. (1979)
Fish ventilatory rate	Industrial plant #2, New River, Virginia	3 months total on-line time	4 alarms in 70 tests	Complex industrial effluent/75%–125% 96H LC50	26 min (average)	Gruper, et al. (1985)
Fish ventilatory rate	Water treatment works intake, River Wensum, Norwich, England	3 months	<0.1%	Acute and chronic levels of formaldehyde pentachlorophenol, diesel oil	<1 hr	Evans, et al. (1986)
Fish ventilatory rate	Surface water monitor, Meuse River, Keizersueer, The Netherlands	1 year	Many due to ventilatory signal noise, high water turbidity	None reported		Sicof (1979)
Fish activity	Pulp and paper mill plant, Mandini River, Natal, South Africa and upstream surface water	1 year	None reported	Unknown/caused upstream fish kill	24th prior to fish kill	Morgan, et al. (1982)
Fish activity	5 km upstream of water treatment works intake, River Wear, County Durham, England	5 years	None reported (problems reported that could cause false alarms)	None reported		Wallwork (1980, 1983)
Fish rheotaxis	Surface water monitor, Rhine and Main Rivers, Federal Republic of Germany	Several months	None reported	Unknown/caused upstream fish kill	Several days prior to fish kill	Scharf (1979)

TABLE 7–5

SUMMARY OF DATA BASES FOR SOME FIELD TESTED BIOLOGICAL EARLY WARNING SYSTEMS

(continued)

Response variable monitored	Location/ application	Length of operation	False alarms	Toxicant/exposure/ concentration	Response time	Source
Fish rheotaxis	Surface water monitor, Rhine and Main Rivers, Federal Republic of Germany	3.5 years	None reported	None reported		Koeman, et al. (1978)
Fish electric organ discharge	Water treatment works, Goeppingen, Federal Republic of Germany	3 years	None reported	None reported		
Bacterial oxygen consumption	Municipal waste treatment facility	Several months	None reported	Complex industrial wastes with high diethylamine, HCN, and high or low pH (3–4 alarms)	Sufficient to prevent spill	Solyom (1977)
				Chloralkali plant wastewater (4 major alarms)	Allowed waste diversion to equalization pond	
				Pharmaceutical effluent spiked with an unidentified toxicant	8–10 min	
Bacterial nitrification	Surface water monitor, Rivers Severn, Bourne, Blythe, Cole and Tame, England	About 2 years total for all rivers	None reported	River water spiked with cyanide/0.1 mg/l and 0.5 mg/l	About 3h and about 1h	Stroud & Jones (1975)

TABLE 7–6

SUMMARY OF CHARACTERISTICS OF SOME BIOLOGICAL EARLY WARNING SYSTEMS (FISH VENTILATORY SYSTEMS)

	BMI (Gruper and Co-workers, 1985, 1986)	Morgan, et al., 1984	Evans, et al., 1986	Morgan, et al., 1982	Wallwork, 1980
Is response quantifiable through computer interfacing?	Yes, system used minicomputer	Yes, but computer has not been used	Yes, system uses minicomputer	Yes, but computer has not been used	Yes, computer used in system
Rapidity (sensitivity) of response to acute/chronic concentrations.	min./min-hrs.	hrs/days	minutes	min-hrs/unknown	Unknown
Potential of overall system sensitivity to N.J. A-280 drinking water contaminants.	0.05 - 0.3 mg/l /1 hr	Data not available/24 hr	0.05 - 5 mg/l /20 min	Data not available	Data not available
False alarm rate	0.4%	N/R	0.1%	N/R	N/R (situation occurs that could cause false alarms)
Statistical method used to assess abnormal response	Time series comparison based on normal values established for each run	Comparison based on predetermined baseline threshold value (± 95% C.I.)	Non-parametric percentile test between control and exposed sensors	Comparison based on predetermined baseline threshold value (± 95% C.I.)	Arbitrary
Degree of skill required to operate	Modest	Modest	Modest	Modest	Modest
Sensor availability	Readily available	Readily available	Readily available	Readily available	Readily available
Approximate cost/commercial availability	$50,000 commercially available	Initial $42,000/ not commercially available (components are available)	Not given	Initial $42,000 (components are available)	Approximately $300,000 for entire monitoring station with automatic physiochemical
System limitations	(1) Sensitivity of overall system not tested with contaminants of special concern	(1) System has not been adapted for computer interfacing	(1) Minicomputer-driven system may make the system prohibitively expensive	(1) Low temperature may cause false alarms	(1) Low temperature may cause false alarms
		(2) Sensitivity of overall system not tested with contaminants of special concern		(2) System has not been adapted for computer interfacing	(2) Proper data analysis method has not been developed

TABLE 7-6

SUMMARY CHARACTERISTICS OF SOME BIOLOGICAL EARLY WARNING SYSTEMS FISH VENTILATORY SYSTEMS (continued)

	Fish Rheotaxis Systems		Bacterial Nitrification System
	Poels (1975)	Scharf (1979)	Stroud and Jones (1975)
Is response quantifiable through computer interfacing?	Yes, but computer has not been used	Yes, but computer has not been used	Yes, but computer has not been used
Rapidity (sensitivity) of response to acute/chronic concentrations	Unknown	min-hrs/unknown	min-hrs/unknown
Potential of overall system sensitivity to N.J. A-280 drinking water contaminants	Data not available	Data not available	Data not available
False alarm rate	N/R	N/R (situations occurred that could cause false alarms)	N/R (situations occurred that could cause false alarms)
Statistical method used to assess abnormal response	Arbitrary	N/R	N/R
Degree of skill required to operate	Low	Low	Modest-high
Sensor availability	Readily available	Readily available	Naturally occurring
Approximate cost/ availability	N/R (estimated $50,000) (components are available)	N/R (estimated $50,000) (components are available)	N/R (estimated $50,000) (components are available)
System limitations	(1) Sensor may be unduely stressed	(1) Organisms may be unduely stressed	(1) Ammonia ion-probe may be insensitive
	(2) General insensitivity of response	(2) General insensitivity of response	(2) Response dependent on ambient ammonia levels
	(3) System has not been adapted for computer interfacing	(3) System has not been adapted for computer interfacing	(3) System has not been adapted for computer interfacing

xicant effects and sensitivities (including some of the A-280 compounds), (3) only ventilatory/activity systems have documented low false alarm rates indicating high overall reliability, and (4) these systems, once calibrated for site-specific conditions, responded more rapidly to toxicants than other systems presently available.

Based on the conclusions from the literature search and information survey, the following recommendations are made with respect to future research and testing:

1. Most of the field-tested systems to date appear to be rapid early warning monitors for use in those situations where acutely toxic conditions (such as chemical spills) might occur. A wide range of systems detected hazardous water-quality conditions in less than one hour of exposure, and many systems detected acutely toxic conditions in less than 30 minutes. However, few of these systems were directly tested with any of the A-280 compounds. Most of the systems tested were substantially slower in detecting subacutely toxic (chronic or sublethal toxicity) water quality situations. If the goal of a drinking water monitor is to protect against acutely toxic or hazardous water quality conditions, then a variety of systems may be applicable.

2. Since most of the field-tested systems to date have an insufficient database with respect to the A-280 compounds, testing of any system must first address sensitivity and reliability of the system to detect hazardous concentrations of these compounds.

3. Any biological monitoring system for drinking water should have simultaneous physiochemical monitoring capabilities for gross water quality parameters such as temperature, pH, dissolved oxygen, conductivity, and turbidity. This capability would be an important component of the overall early warning system and assist in the site-specific calibration process.

4. In the bench-scale testing, sensor organisms should be physically examined in detail (perhaps quarterly or semiannually). This would comprise a biological and physiological examination of a random sample of sensor organisms in order to assess the presence of chronic and subchronic effects that may have gone undetected by the early warning system. These types of analyses would be instrumental in the system calibration process and overall assessment of system reliability and sensitivity.

(JG/541)

Section 8

8.0 FUTURE NEEDS

SUMMARY OF FINDINGS

This chapter summarizes the needs for future work that have been identified as part of this study. Major new data needs include the following:

- Collection, analysis and presentation of data regarding the quality of water resources throughout the state
- Evaluation of the technologies available for the prevention and removal of chlorination by-products in drinking water
- Field studies of air stripping and activated carbon treatment specifically for removal of contaminants regulated, or to be regulated, by New Jersey Assembly Bill A-280
- Field or literature studies of advanced oxidation/disinfection and reverse osmosis treatment processes

8.1 NEED TO BETTER DEFINE WATER QUALITY

A goal of the Special Water Treatment Study - Phase II was to define the extent of the contaminants found in raw water supplies of the state. This study relied heavily on the finished water data generated by periodic sampling required under New Jersey law A-280. Existing raw water data, however, is insufficient and incomplete. The weak correlation found between raw and finished water quality makes it difficult to project the extent of raw water contamination.

Existing data on in-stream water quality pertaining to the A-280 compounds has been generated for specific studies and, on occasion, has been reported to the New Jersey Department of Environmental Protection (NJDEP). Water purveyors do not usually report raw water data to NJDEP since there are few regulations in place requiring such reporting.

A similar situation applies to ground water quality data. Many water purveyors have collected substantial amounts of data on A-280 contaminants and other substances in their raw water. However, this data has not been reported to NJDEP nor has the opportunity arisen to compare and analyze the information from different water purveyors.

A clear need exists for a uniform, high-quality database concerning the quality of raw water supplies throughout the state. Ultimately, a more complete understanding of the quality of raw water supplies in New Jersey will assist in predicting the vulnerability of water supplies to contamination by volatile organics. A survey of the prevailing raw water quality can, by its results, identify those supplies that are presently subject to low-level volatile organic contamination.

A survey of raw water quality could also establish a baseline useful for identifying problem watersheds and making comparisons among them. This baseline, in combination with other environmental, demographic, and socioeconomic data, could be used to help ascertain the level of protection or vulnerability of a watershed.

Water Supply Vulnerability

The vulnerability of a surface water supply to synthetic organic contamination is a function of many factors including the location and type of upstream wastewater dischargers, the generation of organic chemicals by nearby industries, the degree of industrialization, the use of pesticides, and other economic and land use patterns.

Ground water sources or ground-water-fed surface water supplies can be protected naturally by geological formations above the supply aquifer or by strict aquifer management practices. However, even geologically invulnerable formations can be contaminated by improper well construction. In addition, the complexity of hydrogeologic processes, makes it difficult to regulate and monitor ground water use as effectively as surface water sources. Rating the vulnerability of a ground water system or ground-water-fed surface water system would require characterizing the recharge areas through location of industrial facilities that handle wastes or use solvents, identification of geological structures that are porous or fractured, and location of abandoned wells and existing contaminated wells.

As part of the federal Safe Drinking Water Act Amendments of 1986, grants for state and local government programs to protect drinking water wells were established. The authority of states to establish wellhead protection programs (within 3 years of enactment) was also intended to define wellhead protection areas for public water supplies and to outline management programs to prevent well contamination.

Prior to enactment of the 1986 Safe Drinking Water Act Amendments, the Federal Register of November 13, 1985, "Guidance to Determine Vulnerability of Public Water Systems to Contamination by VOCs." The U.S. Environmental Protection Agency (EPA) includes this document in the information it provides to assist states in developing guidelines to classify the vulnerability of community (public) surface water supply systems. Once vulnerability criteria have been established, EPA and the states may use the criteria to prioritize water systems for implementation of a monitoring schedule and determining the frequency of repeat monitoring.

The evaluation of data available to EPA has shown that no single factor can predict the presence or absence of volatile or other synthetic organic chemicals in a surface water supply. However, EPA's studies indicate that population and proximity of a water source to VOC use increases the likelihood of contamination. This concept of proximity to VOC use can be extended to cover the nearby use of synthetic organic chemicals in general. Previous measurement of synthetic organic contaminants in a water supply is also indicative of vulnerability of the water source.

EPA suggests that three general criteria -- population, nearby use of VOCs, and degree of water source protection -- be used to develop more specific guidelines to classify the vulnerability of water systems. These criteria and the reasons for their use are summarized below.

> Population. The number of persons served by a public water system has been related to the occurrence of volatile and other synthetic organic contaminants in many drinking water sources. EPA considers systems serving populations of 3,300 or more as vulnerable.
>
> Systems can also be ranked based on the following information:

1. Previous measurements of VOCs in nonpotable water samples may be indicative of potential for later contamination of potable water supplies.

2. Proximity of a smaller public water system to a larger system may increase the vulnerability of the smaller system. This increase in vulnerability would result from nearby discharges into surface water or into ground water recharge areas, contaminating local drinking water supplies.

Nearby Use of VOCs. EPA suggests that a hierarchy of use can be established for a watershed area or ground water basin. EPA classifies the users as follows:

High Volume Use: Metal fabricators, solvent producers, electroplating plants, airfields, military bases, Superfund sites, closed wells, and a history of large wells. EPA suggests that these are all indicators of the potential for significant presence of volatile organic compounds (VOCs) and synthetic organic compounds (SOCs) in or near drinking water sources.

Light Volume Use: Electronic component, dry cleaners and small commercial users.

It is likely that more than one use category will apply to an area that is served by an individual public water system. Therefore, the effect of all of the uses on the nearby drinking water sources will have to be evaluated. Information concerning the number of users, types and volumes of chemicals, and methods of disposal can be used as one of the criteria in determining vulnerability.

Protection of the Water Source. A water supply source may be protected by natural factors or discharge controls. For surface water supplies, a sanitary survey and an examination of upstream wastewater dischargers can indicate the nature and extent of pollution activities that affect the vulnerability of a surface water system. In some cases, watersheds are protected by strict access and land use laws. Surface water systems could be ranked according to the extent of watershed protection provided by land use restriction, or distance of the source from VOC-based activities.

EPA suggests that these three criteria be used by individual states to devise specific guidelines for classifying water systems as vulnerable and initiating monitoring programs. The evaluation of all of the vulnerability criteria would require a comprehensive examination of the watershed above the surface water intakes. The data available at this time for the surface water supplies and from surface water monitoring stations is limited. Furthermore, the data that is generally and routinely collected by NJDEP is for finished water, not raw water.

We recommend that a strategy for developing vulnerability criteria be established as well as guidelines for monitoring schedules. In light of the limited data available for surface water supplies, it is critical that supplemental organic water quality data be acquired before additional evaluations of particular water supplies are made.

8.2 REMOVAL OF TRIHALOMETHANES FROM DRINKING WATER

In the early 1970's a number of researchers first reported the formation of chloroform in drinking water as a result of the chlorination process. Since then, the composition and health effects of some of the organics formed during the disinfection of water have become more clearly known. In particular, four primary trihalomethanes (THM) are commonly found in drinking water:

Chloroform ($CHCl_3$)
Bromodichloromethane ($CHBrCl_2$)
Dibromochloromethane ($CHBr_2Cl$)
Bromoform ($CHBr_3$)

All are presently regulated and are targeted for more stringent regulation.

Health effects research has indicated that these compounds may be animal carcinogens. As a result, the federal government has set a primary maximum contaminant level (MCL) of 0.10 mg/l of total trihalomethanes in finished waters. (The sum of chloroform, bromodichloromethane, dibromochloromethane, and bromoform expressed as a yearly running average of quarterly analyses must not exceed this level.) This present regulatory framework represents a level of risk over a 70-year human lifetime ranging from 1 in 100,000 to 1 in 10,000.

In May 1986, the President signed into law the Safe Drinking Water Act Amendments of 1986. As part of this law, EPA was directed to compare the public health effects associated with water treatment chemicals and their by-products to the public health effects associated with contaminants found in public water supplies. Ultimately, this could result in the federal government further assessing the public health impact of trihalomethanes and other chlorination by-products.

New Jersey Assembly Bill A-280 mandates that NJDEP develop a supplementary list of contaminants to be regulated. The initial list and the supplementary list are referred to as 2A and 2B, respectively, after the sections of the law where they are defined. NJDEP is to define and promulgate MCLs for "those carcinogens resulting from compounds with public health benefits." This statement is interpreted to include the by-products of disinfection, particularly the THMs generated by chlorination. It is expected that the THMs will be included on the 2B list by the New Jersey Drinking Water Quality Institute. In addition, the A-280 law requires that these levels be established "within the limits of practicability and feasibility."

During the late 1970's, when the 0.10 mg/l standard for THMs was initially set, there was a flurry of research into the technological feasibility and cost of meeting this standard. However, a substantial strengthening of the present standard, as will be required under A-280 and the federal Safe Drinking Water Act Amendments of 1986, creates a clear need for further research and study.

8.3 PACKED COLUMN AIR STRIPPER FIELD STUDIES

The use of packed column air strippers for the removal of volatile organic compounds from drinking water is a proven technology. However, it may be possible to develop more cost-effective air stripper designs. Design engineers take the common approach of using safety factors in their designs to account for unknown conditions and poorly defined theory. The use of safety factors is good because it results in the construction of strippers that perform as desired; however, some installations may be designed with excess capacity, resulting in unnecessary financial expenditures.

Further work is needed to better define the mathematical models of air stripping systems. To accomplish this, lab and field-scale studies should be conducted using a variety of raw water sources containing various levels of A-280 organic compounds. Specifically, special attention should be given to the development of a broad database of field measured Henry's Law constants for the A-280 organic compounds. The validity of the measured constants versus the theoretically derived constants should be determined.

Additionally, there is a need to develop a practical test to evaluate the performance of full-scale air strippers. Most air stripper installations are over-designed for organics removal; the levels of A-280 organic chemicals in the effluent stream are so low that they are not detectable by analytical instruments. Consequently, determination of the actual percent removal of the contaminants cannot be calculated. It is possible to spike the raw water to increase the A-280 organics to a higher level so that they would be detected in the stripper effluent. The percent removal achieved by the stripper could then be calculated; however, spiking may not be acceptable when working with actual drinking water sources. A possible solution may be to select an innocuous volatile compound that could be added to the raw water during a test, and to gauge the performance of a stripper based on its removal of that compound.

Another important operational issue regarding air strippers needs further investigation: the conditions under which demisters freeze in New Jersey. A demister is installed in the top of a packed column air stripper to remove water droplets from the air exhaust. At subzero temperature operating conditions, the droplets can freeze in the demister, restricting the exit of air from the stripper. When this occurs, the ability of the system to remove contaminants from the water stream is diminished. Field studies are needed to investigate the nature and extent of this problem, possibly through monitoring the blower back-pressure of several operating air strippers throughout the winter season, and potential solutions, possibly through operation of a pilot system fitted with various devices designed to solve the problem.

The relative economies of using induced draft blowers versus forced draft blowers on air stripping columns with GAC emission control systems should also be investigated.

The reported increase in the corrosiveness and pH of the finished water caused by removal of the carbon dioxide buffer by the stripping process should be investigated.

8.4 GRANULAR ACTIVATED CARBON ADSORBER FIELD STUDIES

Studies are needed to refine the theory of adsorption in order to provide more precise data for practical design of systems. For example, a broad database on the adsorptive performance of various GACs with respect to all the A-280 organic compounds, at various concentrations and for various combinations of raw water and background organics conditions, would be helpful.

Other studies are needed to refine the understanding of the following effects of multiple contaminants on the following:

- The longevity of GAC and predictive modeling of longevity
- Desorption of previously adsorbed organics caused by the non-steady state introduction of additional organics into the raw water stream
- Desorption of previously adsorbed organics and reduction of adsorptive capacity of the GAC caused by naturally occurring background organic material

Further investigations should also be made into the ability of GAC to remove oxidation products of ozonized A-280 organic compounds and to remove naturally occurring organic precursors to the formation of trihalomethanes. The extent to which biological activity within the GAC granule plays a role in reducing the level of organics in the finished water should be further defined.

8.5 ADVANCED OXIDATION/DISINFECTION TECHNIQUE RESEARCH

Certain uncommon treatment techniques in water treatment show promise for use as disinfectants and oxidants for the reduction of levels of A-280 organics in drinking water. Recent data indicates that treatment by a combination of ultraviolet light and ozonation, or a combination of ultraviolet light and hydrogen peroxide, is a powerful disinfectant and may be able to actually destroy A-280 contaminants in drinking water. Field pilot studies are recommended to assess these technologies.

8.6 REVIEW OF NEW REVERSE OSMOSIS MEMBRANES

The subject of reverse osmosis (RO) should be reviewed in light of recent technical advancements in RO membrane development. Recent work in Florida shows that new nanofiltration (NF) membranes show promise for the removal of volatile organics, THM precursors, and color from raw water. Field pilot studies are recommended to asses this new technology.

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