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New Jersey Department of Environmental Protection
Division of Water Resources

FINAL REPORT

New Jersey Special Water Treatment Study
Phase II

May 1988

EXECUTIVE SUMMARY

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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.

> **Chapter 1: Introduction. 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

<u>Treatment Technology Application</u>. 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.

> **<u>Chapter 3: Fate of Volatile A-280 Organics in Traditional Water Treatment Plants: Sampling Methodology and Results</u>. 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 perfofmed 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

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

- o 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

- o 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

- o 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

- o 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

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

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

- o 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.

<u>Chapter 4: Application of Leading Treatment Technologies to Removal of A-280 Compounds</u>. 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.

> **Chapter 6: Nonpublic Water Supplies. 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:

- o Collection, analysis and presentation of data regarding the quality of water resources throughout the state
- o Evaluation of the technologies available for the prevention and removal of chlorination by-products in drinking water
- o 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
- o Field or literature studies of advanced oxidation/disinfection and reverse osmosis treatment processes

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