United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-79-060
July 1979

Research and Development

Ozone and Ultraviolet Radiation Disinfection for Small Community Water Systems

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EPA-600/2-79-060
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OZONE AND ULTRAVIOLET RADIATION DISINFECTION FOR SMALL COMMUNITY WATER SYSTEMS

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first stop in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Replacing chlorination by the use of ultraviolet light and ozone as sole disinfectants of small community water systems has been strongly proposed by some but lacked sufficient actual experience to support this proposal. This report presents a comparison of these disinfection procedures.

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ABSTRACT

This research was initiated to determine the applicability of using ozone and ultraviolet light as disinfectants for small rural community water systems. Parameters such as disinfection capability, operation and maintenance requirements and costs were investigated and compared with a traditional chlorination facility.

Existing water systems using Lake Champlain were retrofitted with either ozonation or ultraviolet light disinfection equipment and operated for periods of from 3 to 21 months. Specific data collected and summarized in this report include coliform and standard plate count results for raw, finished and distribution samples, capital and maintenance costs for ozonators, ultraviolet light disinfection units, and sodium hypochlorite chemical feed equipment and problems encountered with the equipment while it was in operation.

This report was submitted in fulfillment of Contract 68-03-2182 by the Vermont Department of Health under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period April 3, 1975 to December 3, 1977, and work was completed as of January 25, 1978.

CONTENTS

FIGURES

TABLES

SECTION 1

INTRODUCTION

Chlorination has traditionally been used in the United States for disinfection because it is a well understood process, relatively simple, inexpensive, and provides a measurable residual resulting in a final barrier of protection to the water before it reaches the consumer. It has been the experience of the Vermont State Department of Health, Division of Environmental Health, that some small community water systems have difficulties in maintaining proper chlorination practice. Chlorination practice often results in inadequate disinfection in those small water systems where the operators are inadequately trained. The logistics involved in obtaining chlorine and the expertise required to properly add it are lacking in many of these systems.

Adequacy of disinfection is of concern because there are many water systems in Vermont using surface water without complete treatment. Of the approximately 420 water systems in Vermont nearly 30 percent use unfiltered surface water and 41 percent use springs as sources of supply. In many instances, due to the geology of the State, springs yield water contained within the upper few feet of the ground and are generally considered surface sources. These are mainly small systems which have limited economic, operational, and maintenance resources.

Claims had been made by various equipment manufacturers and suppliers that ozone or ultraviolet (UV) radiation would provide better disinfection capabilities than chlorination on small water systems. Ozone and UV radiation are produced on site, using only electrical power and thus the logistical problems of chemical supply are eliminated. Reportedly, taste and odor problems are nonexistent. When using ozone or UV, claims had also been made that ozone and UV radiation provided adequate disinfection without operation and maintenance problems.

There are several reports concerning the use of ozone disinfection on large water systems[1,2] and, based on a study by Huff et al,[3] UV radiation had been approved for water disinfection on U.S. ships. Unfortunately, there is a lack of information on the actual operating experience of small water systems using ozone or UV radiation for disinfection. To determine information on the adequacy of ozone or UV radiation for disinfection in small water systems we obtained a demonstration contract from the U.S. Environmental Protection Agency (EPA 68-03-2182). Commercial ozone and UV radiation disinfection units normally designed for installation in bottled water plants were installed in existing water systems and monitored. An existing chlorination unit in a water system was also monitored. Information was gathered on operation and maintenance requirements, performance reliability, capital and operating costs, and disinfection performance for the period from December, 1975, to September, 1977. We report on our findings in this paper.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

(1) Neither ozone nor UV disinfection offer an advantage over chlorination for small water systems. From an operation and maintenance standpoint, ozone and ultraviolet disinfection at the present state of the art are inferior to chlorine disinfection when used in this application. In this respect, we see no advantage to be gained in their use. More importantly, neither ozone nor UV disinfection provide a residual disinfectant to protect the water in the distribution system.

(2) The main problem with chlorination on small community water systems is inadequate operation and maintenance. Inadequate operation and maintenance is a general problem and it results in impairments to all aspects of small community water systems, not just chlorination. Further research is required to determine methods of greatly improving operation and maintenance of small water systems.

(3) UV disinfection directly at the point of use, the tap, appears to be theoretically possible and a need for this type of application exists. However, our findings have shown that further development is required even for this type of application. The effects of photoreactivation and dark field repair on drinking water disinfection need to be determined. Reliable UV intensity meters are required. Most importantly, detailed performance standards for UV disinfection must be developed.

(4) There is a possible research need for field evaluations of UV disinfection equipment of superior design that corrects for the equipment deficiencies cited in this study. Such field evaluations should be performed at locations with known coliform contamination problems.

(5) Although coliform contamination should exist in any future studies of this nature, the Standard Plate Count should be relied on as the primary means of measuring disinfection performance because of the certainty of the existence and density of these organisms in sufficient magnitude to measure disinfection effectiveness and distribution system water quality. Coliform examinations are also necessary because of their sanitary significance and their role in the Federal Primary Drinking Water Regulations. The uncertainty of regular coliform occurrence, however, restricts the use of this indicator organism as the primary measure of disinfection performance.

SECTION 3

BACKGROUND INFORMATION

UV RADIATION DISINFECTION

History

The germicidal effects of UV radiation have been known for many years and are well documented. In 1878, the first recorded discovery of the bacteriological effects of radiant energy was made, based on observations of the effect of sunlight on a mixture of microorganisms. It was concluded that radiation of short wavelength was responsible for their destruction.[4]

In the early 1900's the quartz mercury vapor arc lamp was developed. The first recorded attempt to utilize ultraviolet radiation (UV) for disinfection of water was in Marseilles, France, in 1910 where an experimental apparatus was used to treat 36 m^3/h (160 gpm). Jepson[5] has reported that between 1916 and 1928, UV disinfection was applied by at least four water authorities in the United States. The largest works reportedly supplied a population of some 12,000 and had a capacity of 96-135 l/s (1,522-2140 gpm).

However, the initial interest in UV radiation for the disinfection of drinking water waned considerably because of the difficulties experienced with reliability and maintenance of UV equipment and the relatively high costs of the process.

While UV installations for use on ships has been employed since 1916, reports of problems with this type of application continue even to the present.[6,7,8]

Principles of UV Disinfection

The principles of UV disinfection are well known, albeit not completely understood. While UV radiation extends from 15 to 400 nanometers (nm), it is in the range between 200 nm and 310 nm where UV has the most lethal effects on microorganisms. For most species the bactericidal effect as a function of wavelength is greatest at about 250 to 260 nm.[9]

The germicidal effect of UV radiation is thought to be associated with its absorption by various organic molecular components essential to the cell's functioning. The exact mechanism of destruction is still not completely understood but it points to the absorption of UV by a nucleic acid as the start of a photobiochemical reaction (or reactions) ultimately leading to the inactivation of the cell. Energy dissipation of excitation causing disruption of unsaturated bonds appears to produce a progressive lethal biochemical change. It appears that most of the photochemical damage caused by UV occurs as a result of lesions such as chain breakage produced in deoxyribonucleic acid.[3,5]

Several studies have demonstrated that microorganisms treated with UV radiation disinfection may be subsequently reactivated. Photoreactivation after UV treatment was discovered by Kelner in 1948.[10,11] Research progressed rapidly so that a considerable body of knowledge was available for review by 1955.[12] In 1975, Carson and Peterson reported on photoreactivation of Pseudomonas cepacia after UV exposure and concluded that this organism could be a potential source of contamination in UV treated waters.[13] Both photoreactivation and dark repair mechanisms have been described in a variety of microorganisms.[14,15] Conclusions concerning the impact of photoreactivation and dark repair mechanisms on the effectiveness of UV disinfection of drinking water have not yet been reached.

Characteristics of UV Lamps

For practical disinfection application, UV radiation is produced from specially constructed low pressure mercury vapor lamps which emit a considerable portion of their energy at the germicidal 253.7 nm wavelength. The lamps, constructed with 10-20 mm diameter clear fused quartz envelopes, have mercury vapor pressures of the order of 10^{-3} to 10^{-2} mm Hg, and can produce some 85-90% of the UV output at 253.7 nm. The lamp output intensities decrease with age usually due to internal darkening of the quartz envelope. They have, however, a relatively long effective life (7500 hrs.). A comparatively high starting voltage is required but full UV output is available after a brief 2-5 minute warmup period and the discharge can be stopped or started at will.[5]

The lamp, being the UV source, is a most essential part of the disinfection equipment and must provide the required intensity of radiation within the equipment. The temperature of the lamp is an important factor because decreased lamp temperature results in decreased UV output. For this reason, the lamp is normally located in a protective quartz tube 50 mm in diameter which runs the length of the disinfection chamber and through the use of seals extends through and beyond the ends of the chamber. The protective quartz tube eliminates direct lamp/water contact. This results in the lamp being kept dry, fully accessible, and maintained at an operating temperature of 40°C.

Characteristics of UV Disinfection Equipment

The disinfection chambers, which are generally horizontal cylinders, are usually constructed of stainless steel, although plastic chambers are also used. The inside of the disinfection chamber is maintained at the water system pressure, reportedly up to a maximum of 150 psi.

The disinfection chamber may be equipped with a monitoring port which allows for viewing the inside of the chamber through a quartz window. The monitoring port, in turn, may be equipped with a photo-electric cell to measure UV intensity.

Some disinfection chambers have facilities for the hydromechanical or chemical cleaning of the inside of the chambers.

Control equipment is required to maintain and monitor the voltage applied to the lamp(s). The control equipment may also incorporate a UV intensity meter if the disinfection chamber is equipped with a monitoring port and photoelectric cell. The control equipment may be mounted directly on the outside of the disinfection chamber or at some distance from the chamber.

Factors Affecting Germicidal Efficiency

The factors affecting UV germicidal efficiency may be grouped as those affecting the available UV intensity or those affecting the utilization of the available intensity. Age of lamp and coating on the outside of the protective quartz tube are those items which may affect the available UV intensity. The nature of the water is the primary factor affecting utilization of UV intensity.

Huff et al found that water with color at a maximum level of 5 units, or iron content up to 3.7 mg/l as interfering factors in UV transmission did not decrease efficiency of treatment. Turbidity levels up to 5 units, they found, did not decrease treatment efficiency below acceptable limits. However, they concluded that, generally, units of color and units of turbidity are not adequate measures of the decrease that may occur in UV energy transmission. The organic nature of materials present in water can give rise to significant transmission difficulties.[3]

OZONE

History

Ozone was first noted by Van Marum in 1785. Ozone's first important commercial use was in the disinfection of drinking water. As early as 1892, several experimental plants were in use; however, the first major plant placed into operation was in Nice, France, in 1906. Ozone underwent its peak development for water disinfection in Europe soon after its commercial introduction. By 1936, some 100 municipal installations were reported to be in operation in France with 30 to 40 more installations in other countries.[1] It was estimated that in 1972 more than 1,000 water treatment plants were using ozone.[2]

Very little use has been made of ozone as a water disinfectant in the United States. In 1940, Whiting, Indiana, began using ozone and has the longest operating experience with ozone of any U.S. city. Whiting, however, does not use the ozone for disinfection, but as an oxidant for taste and odor control.[16]

Disinfection Efficiency

Ozone is a very powerful disinfectant. Numerous studies have shown that relatively low concentrations of ozone (less than 0.5 mg/l) will destroy microorganisms including viruses in water.[17,18,19,20] Ozone concentrations of from 0.2 to 4.0 mg/l are usually used in water disinfection.

Ozone is a powerful oxidizing gas. Ozone's great ability to oxidize accounts for its ability to disinfect water. The mechanism of disinfection with ozone is the result of the decomposition of ozone to oxygen (O_2) and nascent oxygen ($\dot{O}$). The strong oxidizing potential is in the nascent oxygen atom.

Chemical/Physical Properties

Ozone, O_3, with a molecular weight of 48 has a characteristic pungent odor. Ozone is generally encountered in a dilute form in a mixture with air or oxygen. While ozone is more soluble in water than is oxygen, it is difficult to obtain more than a few milligrams per liter concentration under normal conditions of temperature and pressure because of a much lower available partial pressure.

Under normal temperature and pressure, ozone is naturally unstable and decomposes to oxygen. Heat accelerates this decomposition, and moisture and several chemicals catalyze this decomposition. Ozone may also be decomposed photochemically. From a practical standpoint, decomposition is slow enough to permit the use of ozone for water disinfection.

Production of Ozone

Due to its unstable nature, ozone must be produced on site. The production of ozone may be from air or oxygen. An ozone generation system consists of the following:

--An intake air filter and compressor, which maintains a positive pressure through the ozone generating system, are required for air feed units;
--A compressed air stream cooling system consisting of either a refrigeration unit or a water cooled heat exchange is required for air feed units;
--An air drying unit consisting of either silica gel or calcium chloride desiccators is required for air feed units;
--An ozone generator;
--An ozone/water mixer and contact chamber.

The compressed air stream must be cooled and dried because the vapor content of the air should not exceed 1.38 mg/l for maximum ozone production efficiency.[19]

The most common type of ozone generation consists of passing dry air or oxygen through a high tension electric discharge, referred to as a "corona glow", during which some of the oxygen present is converted into ozone. The electric discharge may take place across either plate or tubular units. A dielectric insulating material, usually glass, is used between the positive and negative electrodes. The voltage necessary for the high tension electric discharge ranges from approximately 5,000 to 25,000 volts. The high tension voltage discharge is accomplished by use of a transformer which receives feed voltage of 110 volts for small generating systems and up to 220 to 440 volts for larger units. Alternating current frequencies in the generator range from 1000 Hz to 2000 Hz, with the newer ozone generators operating at higher frequencies with reportedly increased efficiency.

The high tension electric discharge results in significant heat production and the generator must be cooled. The smaller ozone generators usually use air cooling. Larger ozone generators are water cooled.

Approximately 1%, weight concentration, of the air stream is converted to ozone requiring a total of 10 to 13 kilowatt hours to produce one pound of ozone. If oxygen feed is used, the power consumption is usually less than for air feed and approximately 2% weight concentration is converted to ozone. These power savings are however negated by the high cost of oxygen.

Dispersing and Dissolving Ozone in Water

Efficient use of ozone in water disinfection is dependent upon two main factors: 1) the mass transfer of ozone from the gaseous to the liquid phase where reaction can occur; and, 2) the rate of reaction of the ozone with the microorganisms in the solution. However, the rate of disinfection is not necessarily limited by the action of the residual ozone concentration alone. Disinfection can also occur at the contact of an ozone bubble with a microorganism. A contacting system should strive to achieve both, somewhat conflicting goals: 1) promoting ozone bubble contact by appropriate mixing conditions; and 2) avoiding gas-stripping so as to maintain sufficient ozone residual in the water for as long a period as possible.

Various mixing techniques are now in use.[19,21,22] In the Otto partial injection system ozonated air is pulled into a contact chamber as a result of a pressure loss across an injector, and then mixes with water in an upward verticle flow in a chamber. In the Kerag system a propeller with a perforated base rotates at high frequency in a wet chamber and ozonated air, which is fed through the hollow shaft of the propeller, is pulled into the water as a result of the rotation of the impeller. In the diffuser system, ozonated air is introduced through porous diffusers at the bottom of a deep contact chamber and mixes with the water.

There are, of course, various modifications of these basic techniques. In general, the type of ozone/water mixer and contact chamber must be matched to the specific application under consideration. An individual application may be very suitable for the use of one particular mixing device, while a slightly different ozone requirement cannot be adequately met with the same mixer. The goal must be high mixing efficiencies and present techniques reportedly achieve 90% mixing efficiencies.

SECTION 4

MATERIALS AND METHODS

Five existing small water systems in Grand Isle County, Vermont, were chosen for study. Permission for the study was obtained from the managing boards of each system. All of the systems studied were within a ten (10) square mile area and used Lake Champlain as their supply source. Two water systems, one filtered and the other unfiltered were equipped with UV radiation disinfection units. Ozone disinfection units were installed on two other systems, one filtered and the other unfiltered. The fifth system was unfiltered and continued to use its existing chlorination system.

Commercially available ozone and UV radiation equipment designed for disinfecting drinking water was obtained and installed by a local plumber and electrician. After the ozone and UV radiation units were installed, each system was visited once each weekday to determine operating and maintenance requirements. Once each week a series of samples for bacteriological analysis was obtained from each system. Raw, finished, and three distribution samples were obtained. The samples were analyzed physically for temperature and turbidity, chemically for pH, and chlorine and ozone residuals (as applicable), and bacteriologically for total coliform, fecal coliform and standard plate count.

Temperature was measured on site using a calibrated thermometer. pH was recorded on site with a Beckman pH meter and combination electrode. pH was also measured colorimetrically using bromthymol blue as an indicator. Turbidity samples were brought to the Vermont State Health Department Laboratory and were analyzed the same day with a Hach 2100A nephelometric turbidimeter. Total and fecal coliform samples were analyzed using the membrane filter technique in accordance with the 13th edition of Standard Methods.[23] Total bacteria samples were also processed in accordance with the 13th edition of Standard Methods, but were allowed to incubate for 48 hours instead of 24 hours. Bacteriological samples were processed within six hours.

UV RADIATION STUDY

An Ultraviolet Purification System's Inc. EP-160 unit was installed at Grand Isle Fire District Number 4 Water System, which provides simple filtration using pressure sand filters and serves 300 people. This EP-160 unit was installed after the filters. This unit was obtained by the use of competitive bidding using the U.S. Public Health Service's "Policy Statement for the Use of Ultraviolet Disinfection Units - 1966" in our specifications. The EP-160 unit was rated by the manufacturer as being capable of treating

10 l/s (160 gpm).

Another UV radiation disinfection unit was installed on the South Hero Fire District Number 2 North Water System. This system serves 40 people. An Ultraviolet Purification Systems, Inc. EP-50 unit with a rated treatment capacity of 3.2 l/s (50 gpm) was installed. This unit was obtained from U.S. Environmental Protection Agency, Region I, Office of Water Supply.

Ultraviolet light intensity was determined using the firm's "Water Quality Monitor".

OZONE DISINFECTION STUDY

Ozone disinfection units were installed on the South Hero Fire District Number 1 Water System which provides simple filtration using pressure filters and serves 180 people and on the Grand Isle Water Supply Company's system which provides no treatment and serves 185 people. Each system was equipped with a Welsbach W-15 ozone generator and a Welsbach 8C91 contactor, capable of disinfecting 3.2 l/s (50 gpm) of water with an ozone application dose of 2.5 mg/l with a three minute contact time. The unit on the South Hero Fire District Number 1 Water System was installed after filtration. The ozone disinfection units were obtained by competitive bids.

Ozone residuals were determined using N,N-diethyl-p-phenylenediamine (DPD).[24] On a routine basis, residuals were determined colorimetrically as opposed to titrating the sample.

CHLORINE DISINFECTION STUDY

The existing disinfection equipment was monitored at the Grand Isle West Shore Water System, which serves 100 people and does not filter. A Precision Control hypochlorinator (Model #12701-11) installed in 1975 was used to feed sodium hypochlorite solution into the water directly before the system's 3787 l (1000 gal) hydropneumatic tank. This arrangement provided a minimum 15 minute contact time before distribution to the first service.

Chlorine residuals were determined in the field by use of a Hach CN-66 DPD chlorine comparator.

SECTION 5

FINDINGS

SOUTH HERO FIRE DISTRICT #1 - BACTERIOLOGICAL MONITORING

Raw water at this water treatment plant was pumped through pressure filters with no pretreatment. Pressure filtration alone had little effect on standard plate count and total coliform count. Some decrease in turbidity was noted however. Filtered water seldom had a turbidity above 1.0 NTU. The filters usually afforded a 50% decrease in turbidity.

The water from the filters was then ozonated with a contact period of approximately three minutes. The treated water from the ozone contact chamber generally had an ozone residual of 0.4 mg/l. This residual ozone in the water quickly dissipated, and it was not detectable after standing between one to two minutes.

The ozonation system was on line for the period of May, 1976, to September, 1977. During this period, occasional malfunctions in the equipment forced a reversion to chlorine disinfection. A summarization of the data follows. (Table 1.)

TABLE 1. BACTERIOLOGICAL DATA - SOUTH HERO FIRE DISTRICT #1

	COLIFORM ORGANISMS PER 100 ML.				STANDARD PLATE COUNT PER 1 ML.		
SAMPLE	NUMBER SAMPLES	RANGE	MEAN	NUMBER > 4	NUMBER SAMPLES	RANGE	MEAN
SYSTEM USING OZONE DISINFECTION							
RAW	67	0-259	37.7	NA	65	1-3000	159
FINISHED	69	0-1	0.13	0	63	<1-74	6.4
DISTRIBUTION	198	0-45	1.2	9	189	<1-1700	116
SYSTEM USING CHLORINE DISINFECTION							
RAW	2	9-14	11.5	NA	2	14-39	26.5
FINISHED	2	0-0	0	0	2	25-33	29
DISTRIBUTION	6	0-0	0	0	6	2-19	10.3

(NA - NOT APPLICABLE)

Monthly averages of standard plate counts are shown in Figure 1.

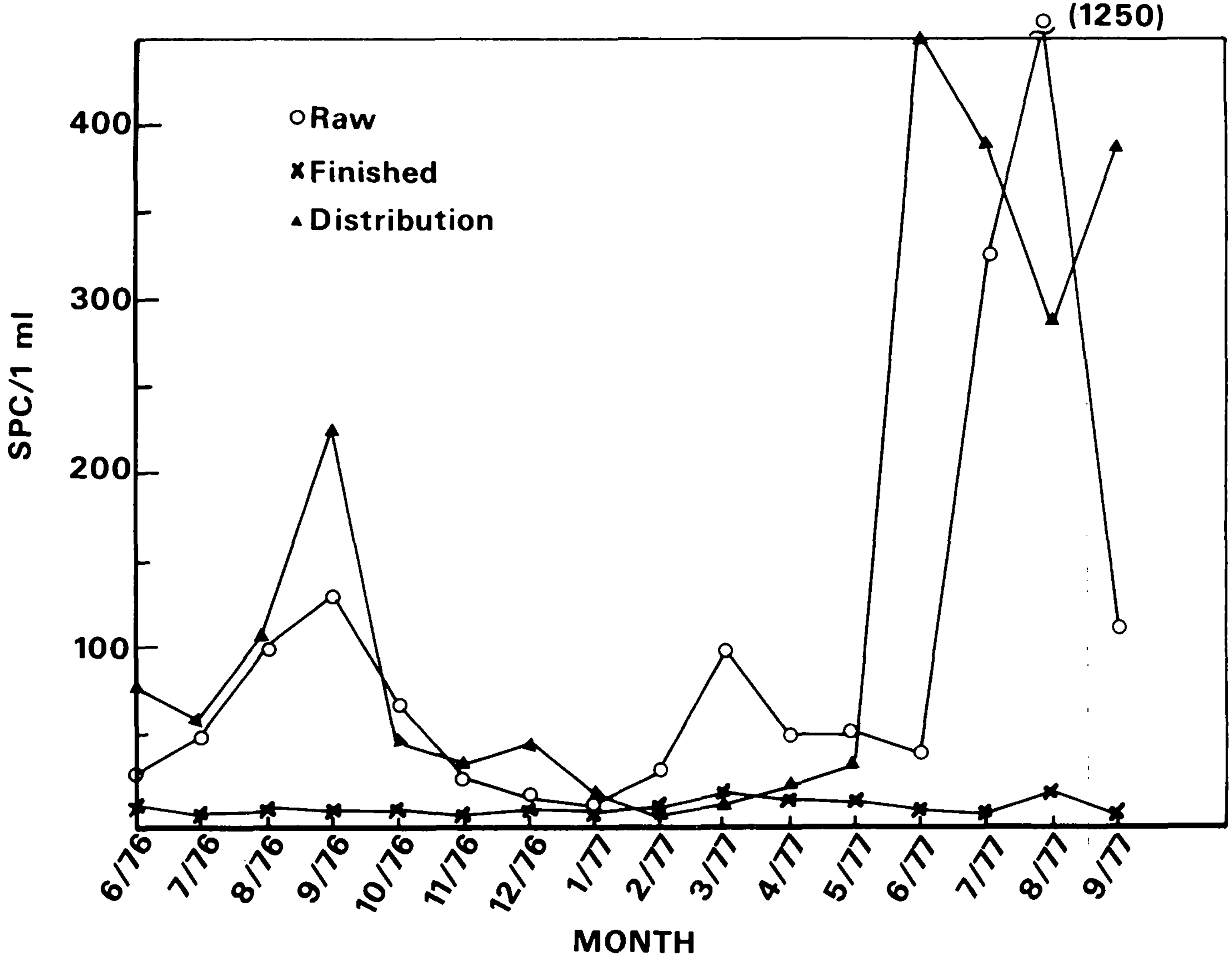

Figure 1. Monthly Standard Plate Count Average -- South Hero Fire District #1.

Instances of coliform contamination at South Hero Fire District #1 in finished and distribution water can be attributed to a number of factors. Simple failure of the ozone disinfection equipment soon after start up caused some contamination. In one case, a solenoid valve which allowed ozone to flow into the contact chamber burned out. Without any ozone being introduced into the water, coliform contamination in the distribution system resulted.

A basic design flaw during the first six months of operation resulted in an uncertainty as to where distribution system contamination originated. In the initial disinfection system configuration, ozone was introduced into the contactor at the same time that the water pumps started. This resulted in an extremely low ozone residual in the contact chamber initially. Although all the water in the contact chamber at this point should have been disinfected, the possibility existed that the incoming raw water could have short circuited through the contact chamber and not have been totally disinfected.

We found no evidence to support this during the first two months of operation in that little coliform contamination was noted in the distribution system. However, during August and September, 1976, some contamination was noted in the distribution system. The average coliform concentration in the distribution system during this time period was 5/100 ml. After September of 1976, coliform contamination of the distribution system ceased, and little contamination was noted in the distribution system until June 20, 1977. In this intervening period, the problem with low initial ozone residuals in the contact chamber was solved by automatically introducing ozone into the contact chamber before water flow commenced, but this had not completely eliminated distribution system coliform contamination.

Of 39 distribution samples taken between June 20, 1977, and September 12, 1977, thirteen (13) showed some coliform contamination. The minimum was 1/100 ml., and the maximum 25/100 ml. The mean contamination was 4/100 ml., the median contamination was 1/100 ml. It should be noted that ten of these contaminated samples were taken at the same point. This sampling point included the highest four instances of contamination. During this period, finished water samples showed no coliform contamination. Occurrence of coliform organisms past the point of disinfection could be the result of either the reactivation of organisms stressed by ozone (UV light) or regrowth of organisms in pipe sediments and not held in check by a disinfectant residual or the organisms could have been introduced through situations such as line repairs or cross connections.

Standard plate counts at this water system showed a significant seasonal variation. Generally, raw water counts were typically low during the winter months, and rose during months with a higher water temperature. Finished water standard plate counts showed little variation throughout the year. Additionally, there appeared to be no correlation between raw and finished water standard plate counts.

Standard plate counts in the distribution system showed a marked seasonal variation. With very low water temperatures, standard plate counts were much the same as those encountered in finished water during this time period. As water temperatures rose, however, standard plate counts in the distribution system rose dramatically. This is well illustrated for the period June - September, 1977 on Figure 1.

During the first two weeks of June, 1977, the ozonator became inoperative, and a reversion to chlorine disinfection took place. During this period, standard plate counts were as follows. (Table 2.)

TABLE 2. STANDARD PLATE COUNT - SOUTH HERO FIRE DISTRICT #1 6/2/77 & 6/6/77

	STANDARD PLATE COUNT/1 ML.	
	6/2/77	6/6/77
RAW WATER SAMPLE	39	14
FINISHED WATER SAMPLE	33	25
DIST. SAMPLE #1	14	2
DIST. SAMPLE #2	15	7
DIST. SAMPLE #3	19	5

Subsequently, ozone disinfection was reintroduced, and the following standard plate counts were obtained. (Table 3.)

TABLE 3. STANDARD PLATE COUNT-SOUTH HERO FIRE DISTRICT #1 6/14/77 & 6/27/77

	STANDARD PLATE COUNT/1 ML.	
	6/14/77	6/27/77
RAW WATER SAMPLE	32	44
FINISHED WATER SAMPLE	8	3
DIST. SAMPLE #1	15	1700
DIST. SAMPLE #2	46	650
DIST. SAMPLE #3	39	350

Chlorine disinfection appeared to suppress standard plate counts in the distribution system. Ozone disinfection did not.

GRAND ISLE WATER SUPPLY COMPANY - BACTERIOLOGICAL MONITORING

Water for this system was taken from the lake, ozonated, and pumped to a 7571 litre (2000 gallon) pressure storage tank. Several problems with the ozone system resulted in periods of intermittent chlorine disinfection during June and July, 1977. An inability to adequately control coliform contamination in the distribution system necessitated abandonment of the ozone disinfection system in July, 1977.

The ozone disinfection unit operated for the period of September, 1976, to July, 1977. A summary of the data follows. (Table 4.)

TABLE 4. BACTERIOLOGICAL DATA GRAND ISLE WATER SUPPLY COMPANY - OZONE

	COLIFORM ORGANISMS/100 ML.				STANDARD PLATE COUNT/1 ML.		
	NUMBER SAMPLES	RANGE	MEAN	NUMBER > 4	NUMBER SAMPLES	RANGE	MEAN
RAW	34	0-350	46.7	NA	30	<1-451	93.3
FINISHED	32	0-4	0.5	2	31	<1-145	20.4
DISTRIBUTION	102	0-13	1.4	8	93	1-1700	163

During this period, the chlorinator operated at times when the ozone system was not functioning. A summary of data while the system used chlorination is as follows. (Table 5.)

TABLE 5. BACTERIOLOGICAL DATA GRAND ISLE WATER SUPPLY COMPANY-CHLORINE

	COLIFORM ORGANISMS/100 ML.				STANDARD PLATE COUNT/1 ML.		
	NUMBER SAMPLES	RANGE	MEAN	NUMBER > 4	NUMBER SAMPLES	RANGE	MEAN
RAW	10	0-48	17.4	NA	10	5-107	56.6
FINISHED	10	0-0	0	0	10	<1-25	8.0
DISTRIBUTION	30	0-2	0.2	0	30	<1-99	14

Monthly averages of standard plate counts are shown in Figure 2.

Many of the problems encountered at this water system were the same as those encountered at South Hero Fire District #1.

Even after correction of the low initial ozone residual problems, significant coliform contamination of the distribution system was noted in the summer of 1977.

The following is a summary of coliform data for the period May 23, 1977, to August 23, 1977. (Table 6.)

TABLE 6. COLIFORM DATA GRAND ISLE WATER SUPPLY COMPANY 5/23/77 TO 8/23/77

	COLIFORM ORGANISMS/100 ML.						
	5/23/77	5/31/77	6/7/77	6/14/77	6/21/77	6/28/77	7/7/77
DISINFECTION METHOD:	OZONE	OZONE	OZONE	CHLORINE	CHLORINE	CHLORINE	CHLORINE
RAW	51	4	16	8	10	12	3
FINISHED	0	0	0	0	0	0	0
DIST. #1	1	0	0	0	0	0	0
DIST. #2	16	2	6	0	1	0	0
DIST. #3	0	2	2	0	1	0	0

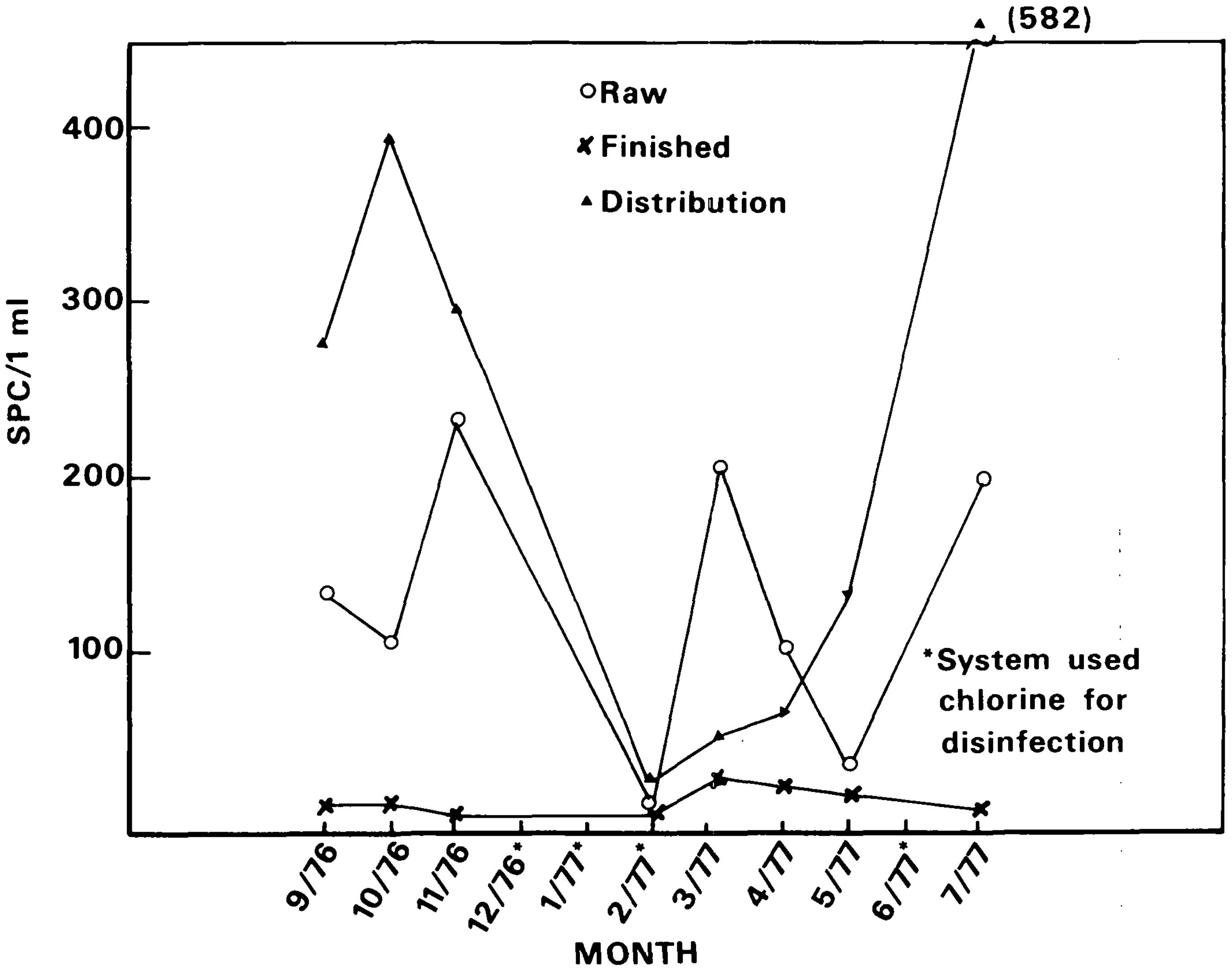

Figure 2. Monthly Standard Plate Count Average -- Grand Isle Water Supply Company.

TABLE 6.

	COLIFORM ORGANISMS/100 ML.			
	7/12/77	7/14/77	7/27/77	8/2/77
DISINFECTION METHOD:	OZONE	CHLORINE	OZONE	CHLORINE
RAW	19	0	1	0
FINISHED	0	0	0	0
DIST. #1	1	0	0	0
DIST. #2	1	0	5	0
DIST. #3	6	0	6	0

This data clearly shows that coliform contamination could not be controlled after the point of disinfection with ozone as the disinfectant.

Standard plate counts at this water system showed a similar pattern to those at South Hero Fire District #1. With increasing water temperatures, standard plate counts in the distribution system showed a marked increase. Using chlorine disinfection, no such increase was noted.

After July 27, 1977, all attempts at ozone disinfection were abandoned and chlorine was used exclusively for disinfection.

SOUTH HERO FIRE DISTRICT #2 (NORTH SHORE SYSTEM) - BACTERIOLOGICAL MONITORING

The North Shore System pumped water from the lake through a pressurized UV radiation unit to disinfect the water, into a 3785 litre (1,000 gallon) hydropneumatic tank and then to the distribution system. The distribution system consisted of a single 5.1 cm. (2") galvanized iron pipe approximately 0.8 km (0.5 mile) in length, serving ten houses.

The hydropneumatic tank was often waterlogged, because air recharge was done infrequently. This caused short cycling of the pump. Only about 7570 litres (2,000 gallons) were pumped per day.

The ultraviolet disinfection system was on line for the period of December, 1975, to September, 1977, except during August and September, 1976, when because of renovations to the system the South Shore System supplied chlorinated water to the North Shore system. A summary of the data for the periods when UV radiation was used follows. (Table 7.)

TABLE 7. BACTERIOLOGICAL DATA-SOUTH HERO FIRE DISTRICT #2 NORTH SHORE

	COLIFORM ORGANISMS/100 ML.				STANDARD PLATE COUNT/1 ML.		
	NUMBER SAMPLES	RANGE	MEAN	NUMBER > 4	NUMBER SAMPLES	RANGE	MEAN
RAW	79	0-302	25.2	NA	78	6-418	72.4
FINISHED	80	0-3	0.1	0	80	<1-170	14.9
DISTRIBUTION	240	0-14	0.2	3	234	1-400	29.2

Monthly averages of standard plate counts are shown in Figure 3.

At South Hero Fire District #2, North Shore System, there were several instances of coliform contamination between mid-July and late August, 1977. In all cases the unit's ultraviolet light intensity sensor indicated that the disinfection dosage was in the "safe" range. Below is a summary of data for this time period. (Table 8)

TABLE 8. COLIFORM DATA-SOUTH HERO FIRE DISTRICT #2 NORTH SHORE

COLIFORM/100 ML.

	7/18	7/25	8/1	8/9	8/15	8/22	8/29	9/6
RAW	0	1	6	2	49	9	100+	25
FINISHED	0	1	3	0	0	0	0	0
DIST. #1	3	2	2	0	0	0	9	0
DIST. #2	0	1	0	0	0	0	1	0
DIST. #3	0	3	0	1	0	0	14	0

The data indicates that in certain instances, coliform contamination was noted immediately after disinfection (7/25/77 and 8/1/77). Also, there were instances when contamination was noted in the distribution system although none was noted immediately after disinfection. Most notably, this occurred on August 29, 1977. It was difficult to ascertain whether breakthrough was occurring at the point of disinfection, or past the point of disinfection, or both.

Additionally two instances of coliform contamination were noted in 1976. Table 9)

TABLE 9. COLIFORM DATA-SOUTH HERO FIRE DISTRICT #2 NORTH SHORE 5/3/76 &7/27/76

COLIFORM/100 ML.

	5/3/76	7/27/76
RAW	11	10
FINISHED	0	0
DIST. #1	5	0
DIST. #2	2	3
DIST. #3	0	2

In both cases, the ultraviolet equipment appeared to be operating properly.

No significant trends were noted in standard plate counts in the distribution system. The highest counts were noted in October, 1976. This was just after the ultraviolet disinfection was reinstituted, and after some work had been done on the distribution network. There was a general rise in standard plate counts during the summer of 1977.

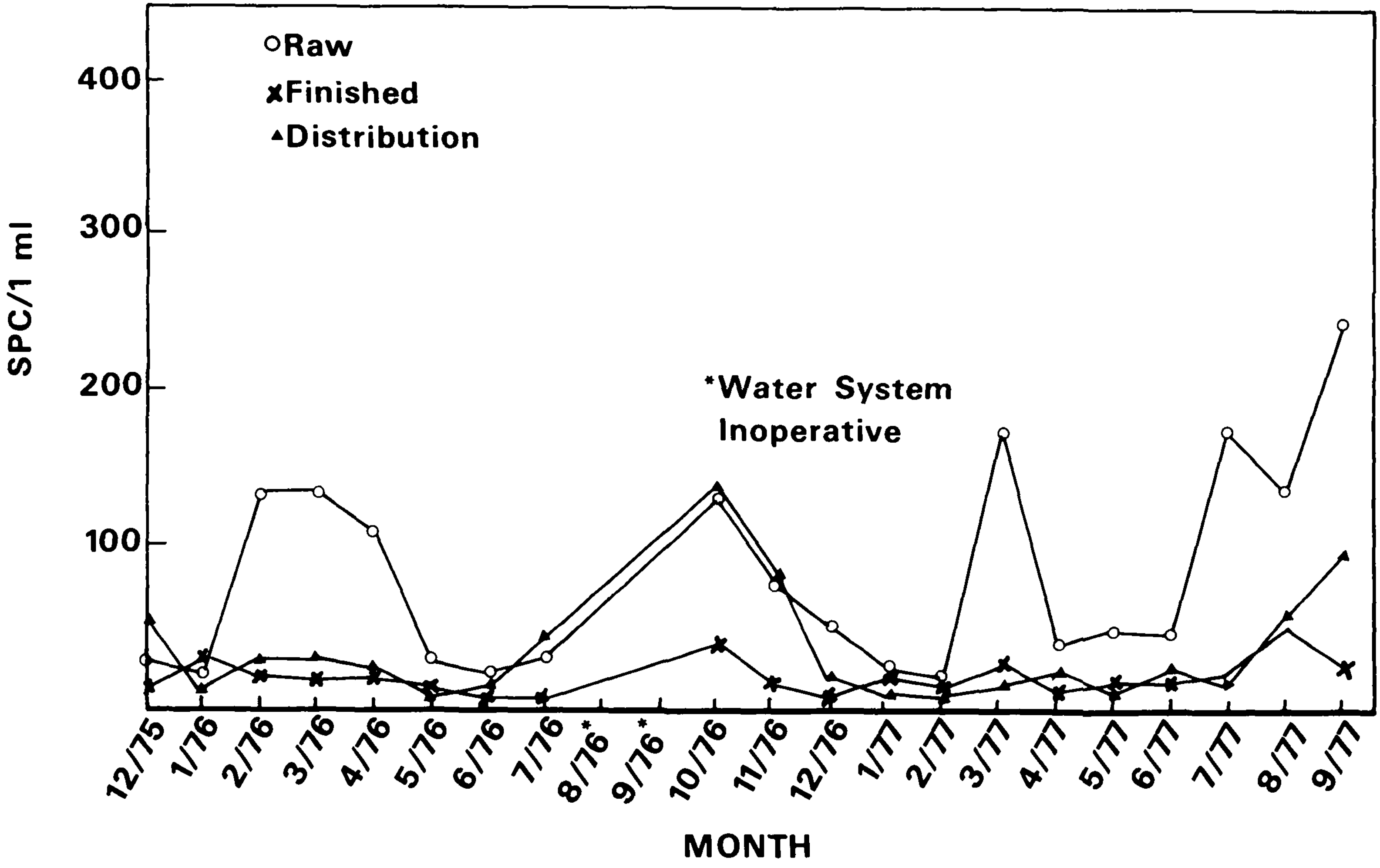

Figure 3. Monthly Standard Plate Count Average -- South Hero Fire District #2 North Shore.

GRAND ISLE FIRE DISTRICT #4 - BACTERIOLOGICAL MONITORING

This water system provided simple filtration and ultraviolet radiation disinfection. This disinfection system operated for the period of April 5, 1976, to July 16, 1976. After July 16, 1976, ultraviolet disinfection was discontinued because of equipment failure.

A summary of the data is as follows. (Table 10)

TABLE 10. BACTERIOLOGICAL DATA - GRAND ISLE FIRE DISTRICT #4

	COLIFORM ORGANISMS/100 ML.				STANDARD PLATE COUNT/1 ML.		
	NUMBER SAMPLES	MEAN	RANGE	NUMBER > 4	NUMBER SAMPLES	MEAN	RANGE
RAW	14	34	2-100	NA	13	50	< 1-280
FINISHED	14	3.5	0-33	3	13	26	< 1-140
DISTRIBUTION	42	3.5	0-100	3	39	23	3-110

Monthly averages of standard plate counts are shown in Figure 4.

Despite this short operating period, coliform contamination in the distribution system was noted on several occasions. Significant contamination is noted on the following table. (Table 11)

TABLE 11. COLIFORM CONTAMINATION-GRAND ISLE FIRE DISTRICT #4

	COLIFORM ORGANISMS/100 ML.			
DATE:	5/25/76	6/1/77	6/28/77	7/6/77
RAW	36	100+	87	5
FINISHED	8*	33*	8*	0
DIST. #1	3	28	3	0
DIST. #2	0	100+	0	0
DIST. #3	0	8	0	3

* SAMPLE TAKEN AFTER HYDROPNEUMATIC STORAGE TANK

All follow up samples taken showed no contamination. Additionally, followup samples taken directly after the ultraviolet unit showed no contamination.

No trends were noted in standard plate count results.

GRAND ISLE WEST SHORE-BACTERIOLOGICAL MONITORING

This water system used sodium hypochlorite for disinfection, with no filtration. After chlorination, water was delivered to a 3,785 litre (1,000 gallon) hydropneumatic tank. For the period January, 1976, to January, 1977, the local operator serviced the chlorinator. Results for this time period are as follows. (Table 12)

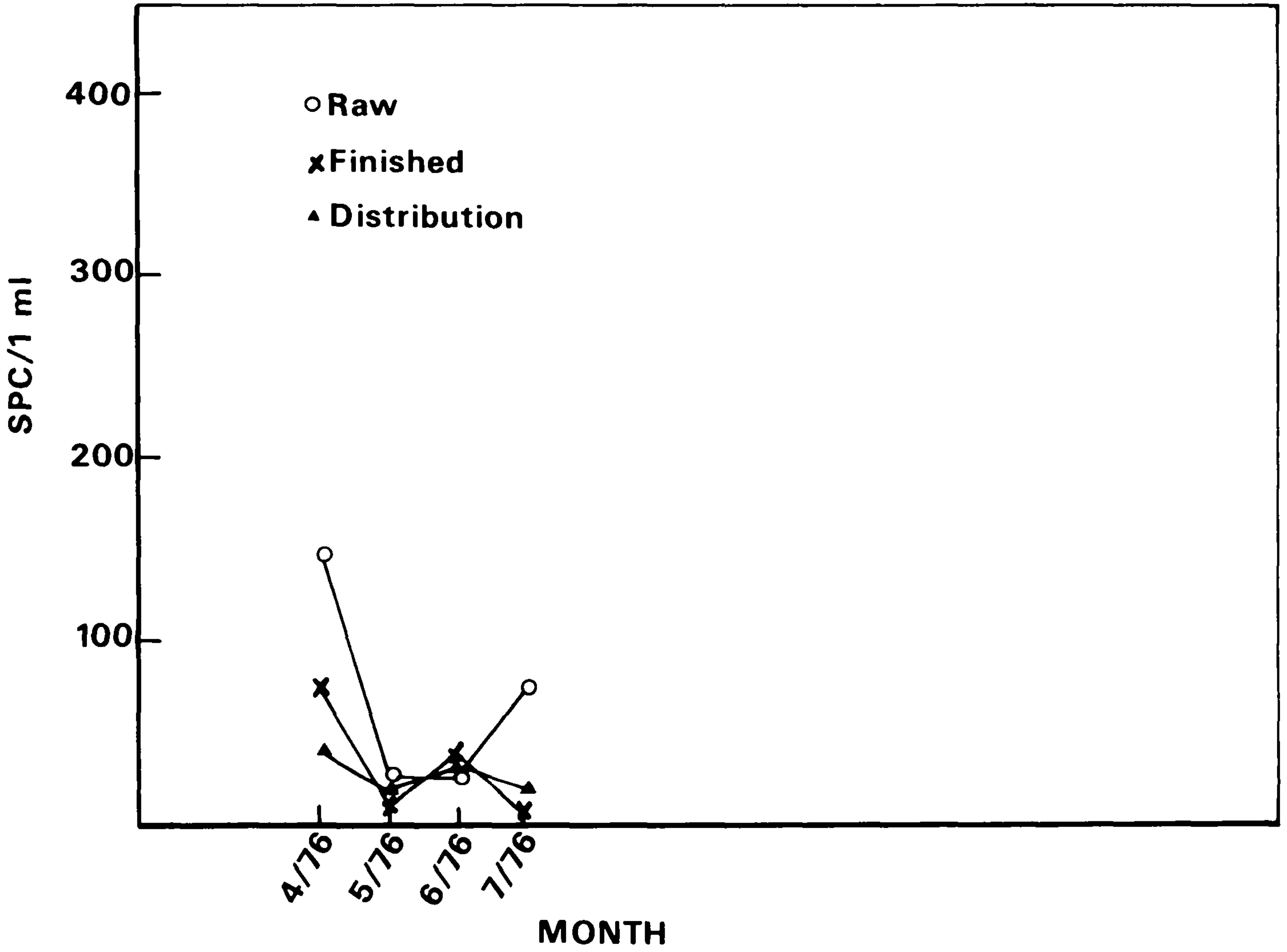

Figure 4. Monthly Standard Plate Count Average -- Grand Isle Fire District #4.

TABLE 12. BACTERIOLOGICAL DATA-GRAND ISLE WEST SHORE 1/76 TO 1/77

JANUARY 1976 - JANUARY 1977
OPERATOR MAINTAINED

	COLIFORM ORGANISMS/100 ML.				STANDARD PLATE COUNT/1 ML.		
	NUMBER SAMPLES	MEAN	RANGE	NUMBER > 4	NUMBER SAMPLES	MEAN	RANGE
RAW	47	66.3	1-311	NA	45	128.5	9-850
FINISHED	46	5.7	0-100	4	44	52.8	>1-330
DISTRIBUTION	138	2.1	0-97	10	135	104.8	>1-850

Coliform contamination occurred frequently at this water system for the period January, 1976, to January, 1977. The main cause of this was inadequate chlorination practice. On five separate occasions, no chlorine was present in the distribution system or finished water. This was caused by an unfilled chlorine solution feed tank. Subtracting these results from the mean coliform density for the period, a mean concentration of .06 coliform/100 ml. in the distribution system results.

Additionally, finished water was collected at a point which generally afforded short chlorine contact time. This would account for occasional coliform contamination in the finished water even when chlorine was present.

For the period February, 1977, to September, 1977, we controlled the chlorination practice and attempted to maintain a free chlorine residual throughout the distribution system. Results for this time period are as follows. (Table 13)

TABLE 13 - BACTERIOLOGICAL DATA - GRAND ISLE WEST SHORE 2/77 TO 9/77

FEBRUARY 1977 - SEPTEMBER 1977
PROJECT MAINTAINED

	COLIFORM ORGANISMS/100 ML.				STANDARD PLATE COUNT/1ML.		
	NUMBER SAMPLES	MEAN	RANGE	NUMBER >4	NUMBER SAMPLES	MEAN	RANGE
RAW	31	34.0	0-204	NA	31	117.5	6-650
FINISHED	31	4.1	0-128	1	31	53.1	1-390
DISTRIBUTION	93	1.1	0-73	4	31	27.4	<1-328

Disinfection during this period was generally successful, except for a period in late March and early April when a constriction in the chlorine line caused very low residuals in the finished water. Still, this did not cause any coliform contamination in the distribution system. It did, however, elevate standard plate counts and result in a count of 128 coliforms per 100 ml. in a finished water sample. (High bacterial counts in finished water samples are explained later in this section.) Additionally, one case of heavy coliform contamination occurred on June 21, 1977. The following

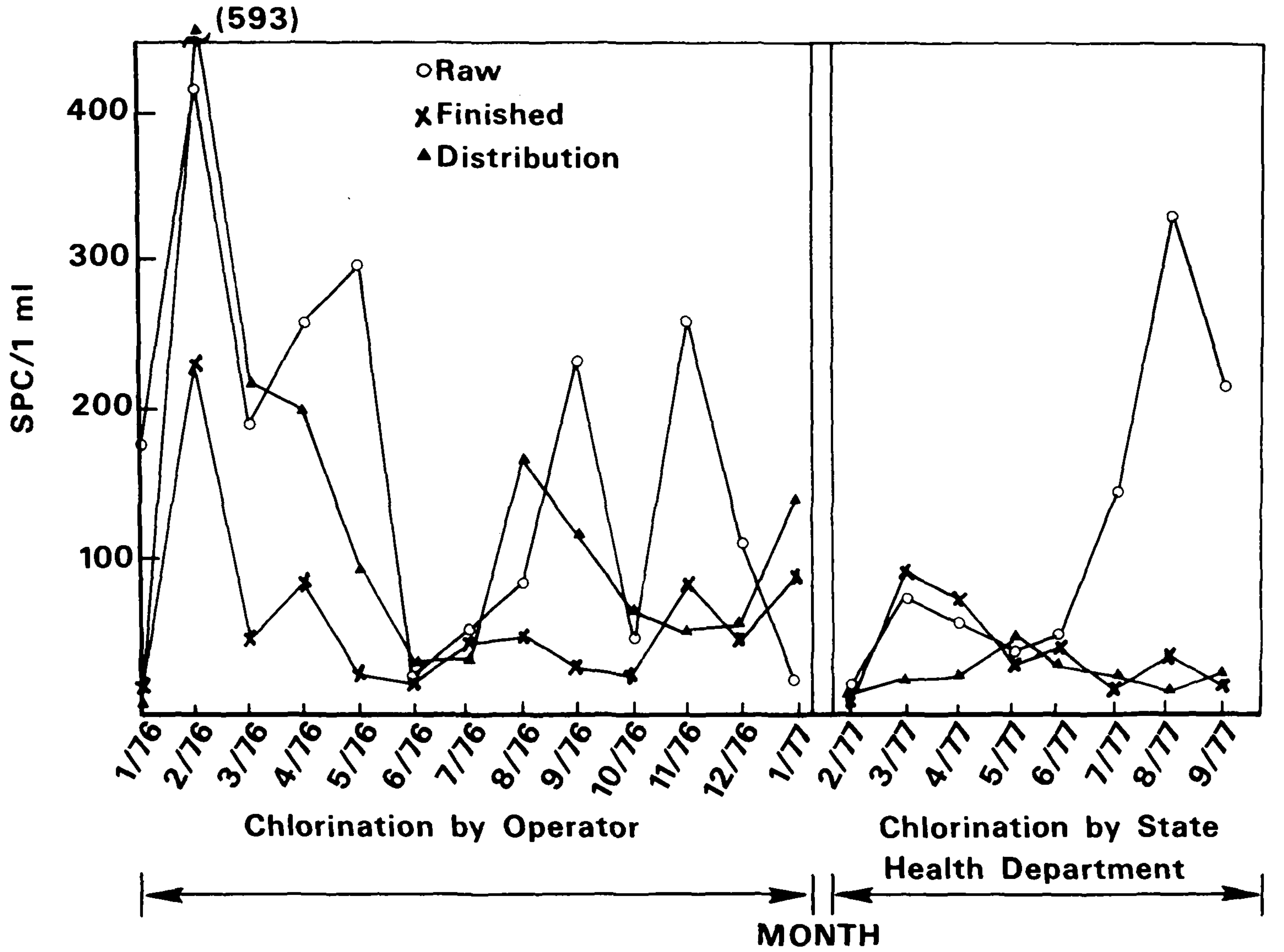

Figure 5. Monthly Standard Plate Count Average -- Grand Isle West Shore.

sample results were obtained. (Table 14)

TABLE 14 - BACTERIOLOGICAL DATA-GRAND ISLE WEST SHORE 6/21/77

	CL_2 RESIDUAL	COLIFORM/100 ML.	SPC/1 ML.
RAW		34	14
FINISHED	1.2 FREE	1	16
DIST. #1	0.8 FREE	14	13
DIST. #2	0.4 FREE	7	10
DIST. #3	0.3 FREE	73	9

Follow up samples the next day showed no contamination in either the finished water or in the distribution system. The standard plate count was not unusually high.

During the period, no other major contamination was noted. If this set of results were dropped from the data, a mean coliform density in the distribution system would have been 0.1/100 ml., with one sample having a coliform density greater than 4/100 ml.

Standard plate counts at this water system showed a definite corelation to chlorine residual. For example, in January, 1977, the chlorinator became inoperative and this resulted in a dramatic increase in the standard plate count one week (1-12-77). Standard plate counts were as follows: Raw, 13/ 1 ml, finished, 330/1 ml., and distribution average 205/1 ml.

The previous week (1/5/77), when the chlorinator was working properly, counts were: raw, 40/1 ml., finished 26/1 ml., and distribution average 14/1 ml. This example was true in most instances when low or no chlorine residuals were present in the distribution system.

Finished water bacteriological counts were often only slightly below the raw water bacteriological counts. This is explained by the fact that finished water was sampled directly from the unbaffled hydropneumatic tank immediately after chlorination. Very short contact times occurred here. Thus, the chlorine, which needs between 20 minutes and 3 hours for adequate disinfection did not have sufficient contact time.

When an adequate chlorine residual was detected in the distribution system, standard plate counts were generally low. A study conducted at the onset of the project before any alternate disinfection equipment had been installed generally showed a logrithmatically inverse relationship between standard plate count and chlorine residual in the systems under observation.

COLIFORM CONTAMINATION-ANALYSIS

Absence of coliform organisms in the distribution system using ozone or ultraviolet radiation disinfection could not always be assured, even when these systems appeared to be operating properly. This was especially true during the summer months. At the Grand Isle Water Supply Company, ozonation was discontinued after July, 1977, because contamination could not be eliminated from the distribution system. This occurred despite the fact that the disinfection system appeared to be operating properly and that finished water samples had no coliform contamination.

At South Hero Fire District #2, coliform organisms were seldom noticed in the distribution system. However, in the summer of 1977, coliform contamination occurred several times, despite the fact that the ultraviolet intensity monitoring device supplied with the unit showed an adequate ultraviolet dosage. This observation can be interpreted that either the intensity monitoring device did not measure the intensity precisely or that UV did not provide satisfactory disinfection.

These instances of contamination emphasize the fact that when there is no residual disinfectant, the only sure way to ascertain that no problems exist in the distribution system is with bacteriological testing. Except for the one instance at Grand Isle West Shore system, when coliform contamination was found despite an adequate chlorine residual, a free residual chlorine provided a ready indicator of no coliform contamination.

We found that proper operation and maintenance of the disinfection system is the most important aspect in assuring proper disinfection, regardless of what kind of disinfectant is used. This was clearly indicated while monitoring the chlorinated Grand Isle West Shore System for the period January, 1976, to January, 1977. As will be discussed, similar problems would probably occur with ozone and ultraviolet disinfection systems.

STANDARD PLATE COUNT-ANALYSIS

From the data, it is evident that there was a significant rise in the standard plate count in the ozonated systems in the distribution system samples. This was not the case when the systems were properly chlorinated. Several factors could have caused this.

Regrowth of Bacteria Past the Point of Disinfection

With rising temperatures beginning in late May, accelerated regrowth of bacteria may have occurred. There would be no disinfecting residual to counteract this. Additionally, recent studies have shown that organics in water which have been ozonated actually provide more usable "nutrients" to bacteria than the unozonated organics and thus encourage regrowth.[25]

Inadequately Disinfected Repairs to the Distribution System

During the months of April and May, 1977, several repairs to the distribution systems of Grand Isle Water Supply Company and South Hero Fire District #1 were made. Disinfection is not usually practiced in the transmission line where these repairs occur. Without any disinfectant residual, growth of any organisms introduced could not be controlled.

Low or Negative Pressure in the Transmission Lines

This is a frequent problem in these water systems. Storage of water is accomplished by using small pressure tanks. Power outages are frequent. The combination of these two factors cause loss of water pressure in the lines after only a short length of time during power failure. Additionally, there is a further problem in that many transmission lines are inadequately sized and old.

Backsiphonage and/or entrance of contamination through leaks could occur at many points in the system. With no residual disinfectant, control of growth of any bacteriological contamination would be nonexistant.

At the South Hero Fire District #2, we did not note the levels of regrowth that were observed at the ozonated water systems. However, it is important to state that there was a significant difference in the distribution system. As mentioned, it is quite limited with only a 1/2 mile length of galvanized iron pipe. There were no repairs to this pipe during the time period in which results are displayed.

At Grand Isle Water Supply and South Hero Fire District #1, the distribution systems are much more extensive, with several miles of various types of pipe. Several repairs were made on these systems during the time period. This is significant in that it points out that bacteriological results at the five water systems cannot be compared to one another without taking into account the differences in their distribution networks. For a more exact comparison, all the disinfection systems would have to be used on the same water system on a rotating basis.

ULTRAVIOLET RADIATION DISINFECTION - EQUIPMENT PERFORMANCE

In obtaining UV radiation disinfection equipment we found six firms offering units ranging in capacity of .19 l/s (3 gpm) to 3155 l/s (50,000 gpm). Most, but not all, of the firms made claims that their equipment could be used to disinfect potable water. Present commercial application of UV radiation units range from the treatment of water used to manufacture drugs and cosmetics to the disinfection of potable water on ships.

The equipment was relatively easy to install in the existing water systems' buildings. The units were compact 91x30x30 cm (36"x12"x12") for the 3.2 l/s (50 gpm) unit and 169x42x42 cm (66½"x 16½" x 16½") for the 10 l/s (160 gpm) unit. A local plumber and electrician installed the units in approximately 24 man hours per unit for a total installation cost of $400 for the 3.2 l/s (50 gpm) unit and $800 for the 10 l/s (160 gpm) unit.

The major problems noted with the units used in the study can be grouped into the following categories.

Performance Standards

We have failed to find any nationally recognized governmental or industry standard(s) for UV radiation units for the disinfection of community water systems.

UV Radiation Intensity Measuring Device

On the disinfection units studied consistent problems were noted with the UV radiation intensity measuring device. This device consists of a UV transparent quartz window in the side of the disinfection chamber with an attached photoelectric cell and a meter on the control panel. The photoelectric cell, according to the manufacturer, responds only to UV radiation in the germicidal range of 253.7 nm.

Problems noted include failure to obtain "on-scale" readings, photoelectric cells response to visible light, constant response to varying UV and visible light, and variations in intensity readings when photoelectric cells were interchanged.

Leakage

Water leakage problems have ranged from small leaks around the compression gaskets of the quartz tube to flooding of the Grand Isle Fire District Number 4 Water Treatment Plant.

OZONE DISINFECTION - EQUIPMENT PERFORMANCE

In obtaining ozone disinfection equipment, generator and contactor, we found five firms offering ozone generator units capable of producing .68 kg/d (1.5 lbs/d) which was required for the needed water flow rates of 3.2 l/s (50 gpm). Most of the ozone generators in this range were normally used for research purposes. Of the three firms responding to our bids for ozone generating and contact units, only one firm had standard contactors available as well as generators.

The equipment was difficult to install in the existing water systems' buildings. The units were large and heavy: generator 168x91x76 cm (66"x36"x 30"), approximately 386 kg (850 lbs.); contactor 69 cm dia-193 cm h (27" dia x 76" h), 68 kg (150 lbs.). Extensive modifications were required in the piping and electrical systems at each site. The average installation cost was $1,600 including materials for each site. Approximately 80 man hours were required for installation at each site.

While no national standards are available, at least there are no confusing claims of standards. Based upon existing studies and consultations, ozone disinfection equipment capable of supplying a maximum of 2.5 mg/l ozone with a contact time of three minutes was obtained. Generally, an ozone residual of from 0.3 to 0.5 mg/l at the outlet of the contact chamber was obtained.

The most significant problem with ozone is operation and maintenance. The ozone system was found to be far more complicated than either chlorine or UV. In addition to the ozone generator and contactor with their auxiliary equipment, a second pump has to be used in the system, since the contactor must operate at atmospheric pressure.

In less than a year of operation we had to repair much of the auxiliary equipment. Two flow control solenoid valve coils were replaced due to overheating. Check valve o-rings in the driers cracked, causing drier failure. Shock mounts on the air compressors check valve burned out and had to be replaced. Various ozone leaks, broken hoses, and loose or burned out wiring had to be repaired.

At Grand Isle Water Supply Company we lost cooling water flow to the ozone tubes when the ozone system was inadvertently shut down by the local plant operator. The dielectric shells froze which subsequently led to the cracking of all three dielectrics.

When using air feed to produce ozone, air compressors are necessary and these compressors and air driers must be operated on a continual basis. This is necessary in order to maintain a constant dry air environment in the ozone generating tubes. We estimate that the compressors and driers would have to be overhauled at least on a yearly basis for proper operation. The fact that the air compressor must run continually also adds significantly to the electrical costs. The compressor which we used drew approximately nine amps continually.

Alternatives are available to using air feed and operating the compressors on a continual basis. It would be possible to bring bottled or liquid oxygen into the plant and thus eliminate the need for compressors or driers. However, this brings about a new item of maintenance and cost. Bottled or liquid oxygen is more difficult to supply and store than calcium or sodium hypochlorite. During the winter, delivery of bottled oxygen to the small plants would be difficult.

CHLORINE DISINFECTION - EQUIPMENT PERFORMANCE

We encountered no major problems with the chlorine disinfection equipment studied. However, contamination in the system resulted when the chlorinator's solution feed tank was allowed to be pumped dry, so that no chlorine was injected into the water. Additionally, the chlorinator pump lost its prime when there was no solution in the tank to be pumped. If the chlorinator was not re-primed when the solution feed tank was refilled (after having been pumped dry), it would not pump.

Operating failures occurred at least five times during the period when we were monitoring the Grand Isle Water Supply Company system. In all cases, coliform contamination, ranging from 1/100 ml. to 97/100 ml., was detected in the distribution system.

Operation and Maintenance Requirements

One of the main purposes of the disinfection demonstration project was to determine if an alternate disinfectant to chlorine could be found which would substantially reduce operation and maintenance requirements. We have found that neither ozone nor ultraviolet light meet this requirement.

The following is a comparison of routine maintenance for the distribution systems.

Daily

Ozone

- Check ozone residual at outlet of contact chamber, adjust ozonator as necessary.
- Check air pressure and flow from compressor and after drier.
- Check for proper operation of drier.
- Check cooling water flow.
- Check solenoid valves for proper operation.
- Check for proper operation of all accessory controls, time delay relays, and level controls.

Ultraviolet Light

- Check ultraviolet monitoring device for ultraviolet intensity.
- Check lamps for proper operation.

Chlorine

- Check chlorine residual in distribution system.
- Check solution feed tank level.

Weekly

Ozone

- Check for leakage in ozone gas piping.
- Clean air intake filters.

Ultraviolet

- Check for leakage around quartz tubes
- Calibrate ultraviolet intensity measuring device for proper sensitivity.

Chlorine

- Fill chlorine solution feed tank.

Every 2-6 months (depending on conditions)

Ozone

- Clean dielectric tubes.
- Check tube seals for leakage.
- Check drier seals for cracks.
- Check solenoid valve coils for heat damage.

Ultraviolet

- Clean interior of ultraviolet chamber
- Clean contacts on bulbs.
- Check fail safe devices for proper operation.

Chlorine

- Clean out chlorine injection line.

Yearly

Ozone

- Rebuild air compressor.
- Rebuild drier.
- Replace rubber air compressor lines.

Ultraviolet Light

- Replace bulbs.

Examine seals, replace if necessary.
Have UV intensity meter calibrated.
Chlorine
Examine diaphragm for wear.
Clean chlorine solution feed tank.

Extraordinary maintenance must also be considered. Probability of equipment failure becomes more common with increasing complexity of equipment. With equipment failures, comes the additional problem of availability of equipment. Disinfection systems must be reliable, and if they do break down, replacement parts must be easily obtainable. Generally, replacement parts for chlorinators are much more readily available than either parts for ozonators or ultraviolet light disinfection systems.

The consideration of safety of operation must also be taken into account. Ozone gas is toxic, and may cause respiratory difficulty with only slight exposure. The possibility for an ozone gas leak would always be present. Persons who were not aware of the dangers of the gas could take in harmful quantities. This situation would be likely in a small rural water system.

Ultraviolet light can cause radiation burns which can become infected and cause conjunctivitis with only slight exposure to the eyes. Precaution must be taken to avoid this. The fragility of the seals and quartz tubes in use on most ultraviolet light disinfection units may also be a problem. The accidental rupture of a seal, or breaking of a quartz tube could cause water to be released from the unit at high pressure. Consequences could range from the soaking of a person present to flooding of the water treatment plant. This could be especially hazardous during the winter months.

Chlorine when used as 12% sodium hypochlorite solution must be handled with care, and skin contact must be avoided.

COSTS

The following are approximate capital costs encountered during the project (labor costs not included), for a 3.2 l/s (50 gpm) system.

	Initial Capital Costs
-Hypochlorination:	$ 550.
-Ultraviolet light water purifier:	1,995.
-Ozonation:	13,735.

Operational costs for the above system pumping 75,758 l/day (20,000 gpd) are as follows.

Chlorination

Assume dosage at 2 mg/l
Cost of chlorine $5.00 for 5 gallons of 12% NaOCL
Cost of Electricity - $.05/KWH
Chlorine .31 gallons/day 13% NaOCL = $.31 = $113/year
Electricity chlorinator on for 6.67 hrs./day draws 230 watts = 1.5 KWH/day = 550 KWH/year = $28

TOTAL $141.00

Ultraviolet Radiation Purification

Assume unit to run continuously regardless of whether water is flowing or not.
UV bulbs-one new set per year.
9 bulbs at $30 per bulb - $270
Electricity draws 360 watts - 8.6 KWH/day - 3154 KWH/year at $.05 - $158
Cleaning - citric acid at $2.50/lb., 3 lbs/cleaning 4 cleanings/year $30

TOTAL $458.00

Ozonation

Assume Welsbach compressor runs continually to maintain dry air environment in ozone producing tubes.
Electricity - compressor draws 1 KW - 24 KWH/day - 8760 KWH/year =$438.
Ozonator draws 150 watts at 6.67 hrs/day - 1 KWH/day - 365 KWH/year-$18.
Parts for rebuilding air compressors and driers $75/year

TOTAL $531.00

From this evaluation it is obvious that applying ozone or ultraviolet light disinfection in place of chlorination in an existing rural water system using small pressure storage tanks is significantly more expensive than disinfecting with comparable chlorination equipment.

It must be stressed that these were costs incurred by the project as the systems were operated.

Obviously modification could be made in each system to change both capital and operation and maintenance costs. Since the systems involved are all automatic in operation with limited pressure storage, UV and ozone systems had to be designed to fit the particular pumphouse. Thus, the UV unit had to be run all of the time since water is called for frequently and it would be impractical to turn the unit on and off and to warm it up for three minutes each time. With design modifications in the treatment plant, it would be possible to have the unit on only when the pumps are running. This might save both on electricity and bulb life. The same is true for ozone equipment.

Capital costs could be reduced in the ozone system by designing and building a contactor. The Welsbach unit was used by us only because it fit well into the existing pumphouse. Additionally, if an inexpensive source of oxygen were obtained, the ozone generator size could be reduced. Savings on air compressors and driers could also be realized.

It must be mentioned that it is also possible to reduce chlorination costs, most likely by finding a more inexpensive source of chlorine such as gas chlorination.

CHLOROFORM CONTENT ANALYSIS

During 1977, four series of samples from each water system were submitted to the Lawrence Experiment Station in Lawrence, Massachusetts for chloroform analysis. Results are as follows. (Table 15)

TABLE 15. CHLOROFORM CONTENT OF WATER

SAMPLE LOCATION		MICROGRAMS/LITRE $CHCl_3$ FOUND				
		1/31/77	3/9/77	6/8/77	6/29/77	8/4/77
SOUTH HERO F.D.#1	RAW	0.1	0.6	ND	ND	ND
	FINISHED	ND		5.9	ND	ND
	DIST.		1.3	23.0	ND	ND
SOUTH HERO F.D.#2	RAW		1.2	ND	ND	ND
	FINISHED		0.4	ND	ND	ND
	DIST.		3.3	ND	ND	ND
GRAND ISLE WATER SUPPLY	RAW		1.2	ND	ND	ND
	FINISHED		1.5	ND	15.8	0.1
	DIST.		1.7	ND	40.1	>0.1
GRAND ISLE WEST SHORE	RAW	0.7	1.8	ND	15.2	ND
	FINISHED			1.5	27.8	30.3
	DIST.	29.5	20.8	27.0	56.4	71.0

As expected, only chlorinated systems showed significant chloroform formation. In all cases, Grand Isle West Shore was chlorinated. On June 8, 1977, South Hero Fire District #1 was chlorinated and on June 29, 1977, Grand Isle Water Supply Company was chlorinated.

SECTION 6

DISCUSSION

PROTECTION OF FINISHED WATER IN THE DISTRIBUTION SYSTEM

The process of disinfection, if it is to adequately protect the consumer's drinking water, must extend beyond the treatment plant into and throughout the distribution system. A disinfectant residual is required in the distribution system to protect the bacteriological quality of the drinking water. For this reason chlorine has been extensively used in the United States because, when properly applied, it provides effective initial disinfection and residual disinfection in the distribution system.

The relationship between chlorine residual and protection of the bacteriological quality in the distribution system is well documented. In a study by Buelow and Walton[26] it was found that the probability of finding coliform bacteria in a distribution system sample decreases as the residual chlorine concentration of the water increases. Baylis[27] found that maintenance of residual chlorine in the water throughout the system is generally the only safeguard that may be used under existing conditions in many cities. A substantial free chlorine residual may correct damage created by undetected cross connections, except in instances of major contamination. Even in those instances of major contamination the loss of residual chlorine in a localized area can serve as an indicator that foreign material has entered the system and as a monitor to detect contamination.[28]

Regardless of the degree of effectiveness of initial disinfection, neither ozone nor UV provide any appreciable residual disinfectant to protect the distribution system. A residual disinfectant, such as chlorine, is required after either ozone or UV disinfection to protect the distribution systems. The need to maintain a residual disinfectant in the distribution systems after ozonation has been recognized on large systems in France.[1]

It is impractical to use ozone or UV for initial disinfection and then add chlorine to maintain a residual in the distribution system in small community systems. On most community water systems, especially the small systems that we studied, we have found that chlorination alone, when properly practiced, provided initial disinfection equal to or better than ozone or UV and in addition provided a residual to protect the distribution system. Proper chlorination was less costly both in terms of initial and operating costs and presented few operation or maintenance difficulties.

The use of ozone or UV without a supplemental chlorine residual would necessitate extreme care in construction of the distribution system and connected plumbing. It would have to be absolutely free of cross connections and low water pressure situations. Increased maintenance of the distribution lines by use of regular flushing, frequent enough to eliminate deposits that could harbor bacterial growth, would also be necessary.

UV DISINFECTION

On a theoretical basis, UV radiation should be a satisfactory method of initial disinfection. The potential problems resulting from subsequent contamination by photo reactivation and/or dark field repair have not been researched and assessed for the disinfection of drinking water. Even if it is found that photoreactivation and/or dark field repair present no problems, we have determined that UV disinfection is not adequate for small community water systems because of the lack of a residual disinfectant and the resulting hazard of contamination in the distribution system. However, adequate UV disinfection of water of suitable quality at the point of use appears to be theoretically possible. UV disinfection of drinking water at the consumer's tap would eliminate the known hazards of distribution system contamination.

Even this limited role of UV disinfection of drinking water at the tap would not be possible until several problems noted with the UV disinfection units are corrected. These problems are with performance standards, UV radiation intensity measuring devices, leakage, and bacteriological contamination breakthrough.

Performance Standards

At present, there are no reliable performance standards for UV disinfection units for drinking water. There is a Department of Health, Education and Welfare (DHEW) "Policy Statement on Use of the Ultraviolet Process for Disinfection of Water"[24] that is ambiguous and inadequate for multi-tube units. It cannot be considered to be a performance standard.

During the course of obtaining a UV radiation unit for the study, we were referred to a "new standard."[30] We found that this "new standard" was an excerpt from the potable water maintenance section of the DHEW "Recommendations of Vessel Sanitation" issued in 1974.[31] This "new standard" is not a performance standard and contains unknown disinfection parameters. We have been unable to obtain technical justification for these "new standards" or an explanation of the disinfection parameters used. Even within the UV disinfection equipment supply industry there is sentiment that the "new standard" is, from a scientific point of view, completely without basis.

No known reliable performance standards for UV disinfection units exist today. Until standards are developed concerning reliability of performance in addition to biological effectiveness, and UV disinfection units meeting the performance standards are available, reliance cannot be placed on this method of disinfection.

UV Radiation Intensity Measuring Devices

In addition to our findings, a study conducted by the DHEW, Center for Disease Control, during November and December, 1976, of UV disinfection equipment in actual use on seven passenger cruise vessels found similar problems with UV radiation intensity measuring devices. These findings point out another reason why UV disinfection of drinking water is not acceptable at this time.[32]

With UV disinfection there is no residual either in the contact chamber, immediately after the contact chamber, or in the distribution system. Therefore, the only on site method of determining adequacy of disinfection is by measuring UV radiation intensity in the contact chamber. The UV radiation intensity measuring devices which were supplied with the units used in our study have not provided adequate monitoring of disinfection dosage.

From a public health standpoint, our experience with the UV radiation intensity measuring devices used on the disinfection units used in this project indicates UV radiation disinfection is not acceptable. The monitoring of UV radiation intensity within the contact chamber is the only method readily available for a water system operator to determine if the required amount of UV radiation is being applied to the water to be disinfected. Without a reliable method of determining UV penetration through the contact chamber there is a significant health hazard.

However, there does not appear to be any scientific reason why a reliable intensity measuring device capable of detecting UV radiation in the germicidal range cannot be developed for widescale use. Such a device would eliminate the problems noted.

Leakage

Leakage as experienced with the UV disinfection units studied is not acceptable. Again, however, this appears to be a problem that should be easily corrected.

Bacteriological Contamination

In addition to bacteriological contamination being detected in the distribution systems studied, there were instances when contamination was noted directly after the disinfection chamber. Contaminated water was also detected after a UV disinfection chamber by a DHEW, Center for Disease Control, study of a disease outbreak aboard a passenger ship.[33] These findings are in conflict with laboratory studies concerning the adequacy of UV disinfection of water. This problem should be resolved by a study of UV disinfection of drinking water including consideration of photoreactivation and/or dark field repair and the development of reliable performance standards.

OZONE DISINFECTION

The lack of a reliable residual disinfectant to protect the water in the distribution system makes ozone disinfection not acceptable for a small community water system. In addition, it has been our experience that ozone disinfection requires far more equipment and resultant operation and maintenance input than either chlorination or UV disinfection. There does not appear to be a technically feasible method, at this time, of significantly reducing the complexity of ozone disinfection.

CHLORINE DISINFECTION

Our experience indicates that when proper chlorination is practiced and a chlorine residual is maintained in the distribution system, chlorination provides reliable disinfection. The equipment is inexpensive, dependable, and easy to operate. On the average, a fifteen minute per day period at the treatment plant was all that was required for operation and maintenance of the hypochlorination system studied.

The time necessary to service the hypochlorination equipment was little more than that required for a daily inspection visit to the plant which is recommended as good operation and maintenance procedure. However, we did find that daily inspection visits on small water systems are often neglected. It is now apparent that those problems which were felt to be associated only with chlorine disinfection are in fact merely indicators of the much larger problem of general poor operation and maintenance of small water systems.

Since we had, in the past, monitored mainly those parameters associated with disinfection this had appeared to be the only problem. We have found that along with disinfection, all other aspects such as maintenance of pressure, monitoring, repair of distribution system anomalies, etc., often are neglected on small water systems. When proper operation and maintenance is practiced, chlorination presents no problems.

Recent studies[34,35,36,37] have found that chlorination results in the production of chlorinated organic compounds which have been detected in drinking water. In a study of New Orleans drinking water, the existence of certain chlorinated organic compounds in the water has been associated with elevated cancer rates.[38,39] However, the association between chlorinated organics in drinking water and cancer has been challenged.[40] The health hazard, if any, resulting from the presence of chlorinated organic compounds in drinking water has not, at present, been completely determined. Further studies are being conducted to determine the health hazard, if any, of chlorinated organic compounds in drinking water and, if necessary, to establish maximum safe limits of these compounds.

If it is determined that chlorinated organic compounds do present a real health hazard and present levels of these compounds in drinking water exceed maximum safe limits, action will be required. It is known that by simply modifying current treatment techniques the levels of chlorinated organic compounds can be greatly reduced on chlorinated systems.[41] Additional treatment or different disinfectants may be required.

While there are many unanswered questions at this time, one thing is certain; a residual disinfectant is required to protect the water in the distribution system. Also, from our experience, ozone or UV disinfection cannot provide adequate disinfection on small community water systems. In addition, the health hazards resulting from the products of ozone or UV disinfection have not been determined and, in fact, studies in these areas are only just beginning.

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-79-060

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Ozone and Ultraviolet Radiation Disinfection for Small Community Water Systems

5. REPORT DATE
July 1979 (Issuing Date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Linden E. Witherell, Ray L. Solomon, Kenneth M. Stone

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Vermont State Health Department
Burlington, Vermont 05401

10. PROGRAM ELEMENT NO.
1CC614, SOS #2, Task 6

11. CONTRACT/GRANT NO.
Contract No. 68-03-2182

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory--Cin.,OH
Office of Research & Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer: Ralph W. Buelow (513-684-7236)

16. ABSTRACT

Ozone and ultraviolet radiation were used as alternatives to chlorine for disinfection in several small existing community water systems. Both ozone and ultraviolet light were found to be inferior to chlorination from the standpoint of operation and maintenance requirements and maintaining disinfection in the distribution system. A disinfectant residual was found to be necessary even in the small water distribution systems studied. Neither ozone or ultraviolet provide a residual disinfectant. The main problem with chlorination in small community water systems is inadequate operation and maintenance. Inadequate operation and maintenance is a general problem of small community water systems, not limited to the disinfection aspect. Methods for improving operation and maintenance of small water systems need to be established.

Recent studies have shown that chlorination can lead to chlorinated organic compounds production. However the association with cancer and the health hazard have not been completely determined [illegible] by modifying current treatment techniques, Level of haloforms can be greatly reduced [illegible] other disinfectants can play a role

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Water treatment, Disinfection, Ultraviolet radiation, Ozonization, Chlorination, Water supply	Ozonation Small community water systems	13B

18. DISTRIBUTION STATEMENT
Release to Public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
48

22. PRICE

U.S. GOVERNMENT PRINTING OFFICE 1979-657-060/5431

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Environmental Research Information Center
Cincinnati, Ohio 45268

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