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WATER SYSTEM INTAKE FEASIBILITY STUDY
PROJECT NO. 92-00894

APRIL, 1993

PREPARED FOR:

SENECA ARMY DEPOT
DEPARTMENT OF THE ARMY
NEW YORK DISTRICT CORPS OF ENGINEERS
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1.0 INTRODUCTION

1.1 Authorization

On September 30, 1992, the Army District Engineer authorized a feasibility study to be performed by C.T. Male Associates, P.C. The feasibility study included research relative to currently available means to control the spread of zebra mussels and avoidance criteria available to satisfy the Surface water Treatment Rule (SWTR) provisions of the 1986 amendments to the Safe Drinking Water Act. This authorization was provided as zebra mussel infestation of the Great Lakes and Finger Lakes continues and as the official deadline for SWTR compliance, June 29, 1993, approaches. The authorization was specifically for study of the water intake currently in service as a potable water supply to the Seneca Army Depot near the Village of Romulus on Seneca Lake.

1.2 Purpose of Report

It is the purpose of this report to identify the results of research regarding zebra mussel control and SWTR. The report provides effectiveness comparisons of alternative technologies available to address these two issues. The study also defines system improvement costs required to implement the chosen alternative and define operational costs. Finally, the study recommends a program to address the current concerns along with a timetable for implementation. The guidance provided in this report considers and focuses upon the following elements of concern expressed by the project participants:

1. New intake piping must not be subject to zebra mussel infestation. The existing intake is exposed to infestation and should be replaced.

2. No mechanical equipment should be placed in the lake along the intake pipeline. The Depot does not have manpower available to maintain difficult to access equipment.

3. Existing pumping station and appurtenant facilities should be used within the final system to the extent possible.

4. A treatment technology to meet the filtration requirements or avoidance criteria of the Surface Water Treatment Rule shall be used in the recommended alternative.

5. Economical cost of the recommended alternative is essential. The Seneca Army Depot is in the process of down sizing and, as a result must justify expenditures based on a residency smaller than currently in place.

1.3 Project Background

The Seneca Army Depot was established as an army munitions base along the east shore of Seneca Lake in 1943. The base generally employs military personnel with on base residence along with some civilian personnel residing off-base. The Depot was most active in the 1960's but has since down sized as Federal Defense budgets have decreased over the past few years. A site location map and intake location map are provided as Figure 1 and Figure 2, respectively.

The facility was developed with a water supply using Seneca Lake water without any treatment except chlorination and fluoridation. Three factors have led to the decision to authorize this study. First, following efforts to televise the existing 20" cast iron intake, it was realized that the intake pipe interior had experienced encrustation and siltation which is thought to be severely restricting flow. In fact, the entire length of pipe could not be televised due to localized

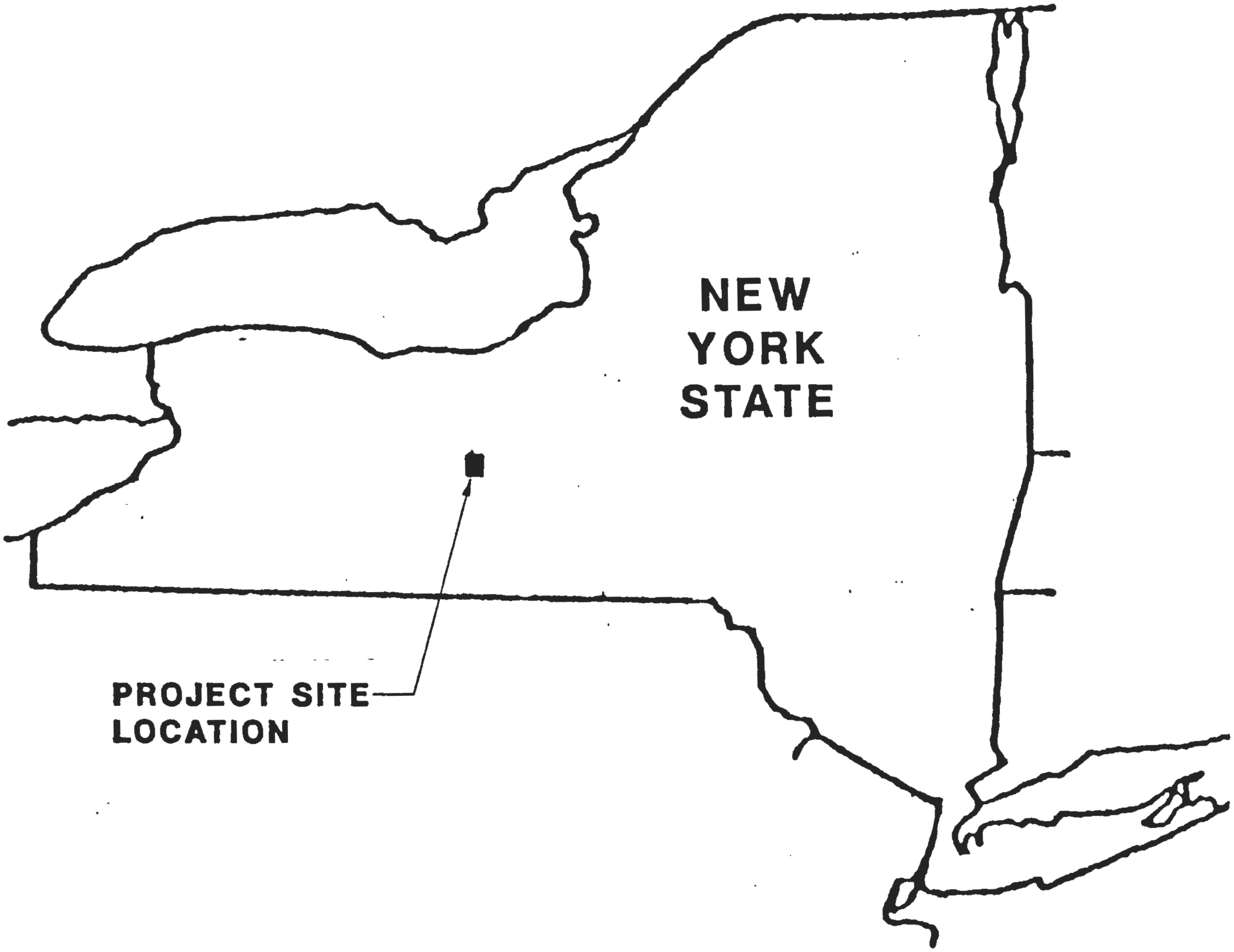

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FIGURE 1
SITE LOCATION MAP

rafter: LPN
DATE: 2/17/93
SCALE: NTS
Proj No. 92.894

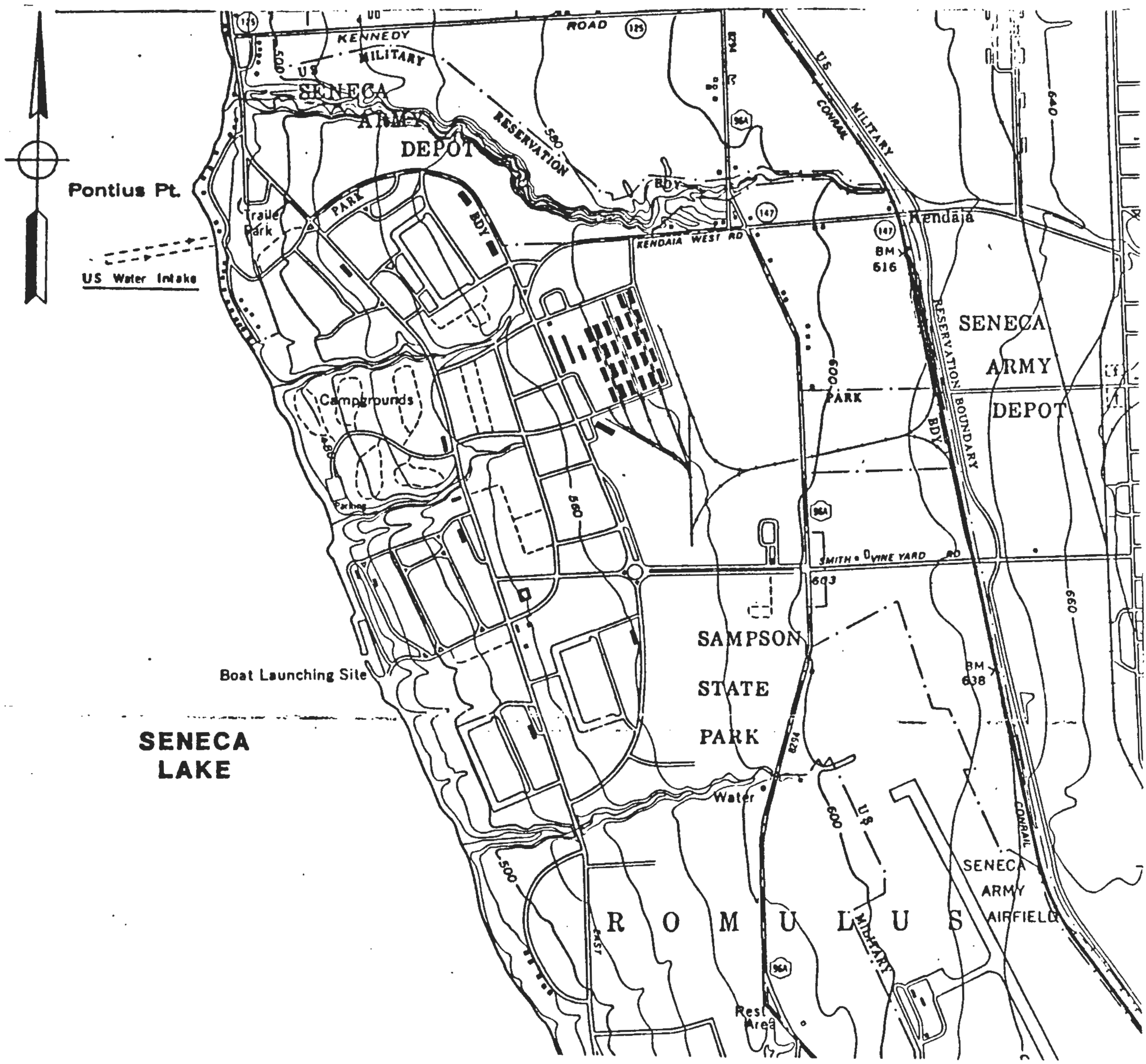

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FIGURE 2
INTAKE LOCATION MAP

Drafter: LPN	DATE: 2/17/93	SCALE: 1" = 2000'	Proj No. 92.894

restrictions. Second, zebra mussels have been discovered within Seneca Lake and pose a threat to infestation of virtually all intake pipelines along the lake shore. The Seneca Army Depot intake is fully exposed to infestation. Finally, the 1986 amendments to the Safe Drinking Water Act call for all surface waters providing community water supply to provide treatment by filtration or meet a variety of criteria suitable to substantiate exemption (avoidance) of the filtration requirement.

1.4 Information Sources

In the conduct of this study, C.T. Male Associates, P.C. has completed a literature search to fully document the current status of technology to control zebra mussel infestation and avoidance of the Surface Water Treatment Rule (filtration). The search included investigation of written resources, water system operators, regulatory officials and personnel of the Sea Grants research program. In addition, contacts in the Netherlands, Switzerland and England have been consulted relative to operation of high velocity intake systems. A complete list of references and contacts is given in Appendix A.

2.0 EXISTING CONDITIONS

Site visits were conducted on July 14, 1992 by Bill Simcoe and Gary McCollum of C.T. Male Associates, P.C.; and on October 6, 1992, December 10, 1992 and February 1, 1993 by Gary McCollum. Site visit notes are provided in Appendix B.

2.1 Intake

The existing water intake pipeline delivering water from Seneca Lake to the Seneca Army Depot consists of a 20 inch cast iron pipeline which was installed on the lake bottom and is now partially exposed and partially buried along its route (see Figure 3). The terminus of the intake is located about 1,150 ft. from the shoreline in water 85 to 90 ft. deep. The end of the intake is configured in a vertical orientation with a screening device and elevated point of entry to discourage intake of lake bottom silts into the pipeline under normal withdrawal conditions. At the shoreline the intake is buried approximately 10 ft. below water level and 17 ft. below grade as it approaches a small valve vault prior to its entry into the main wet well in the facility's pumping station. The valve building contains one valve for the purpose of shutoff of flow.

2.2 Pumping Station

The existing pumping station operates continually to serve the Seneca Army Depot and Village of Romulus. A layout is given in Figure 4. In prior years there were additional services to local installations. With the removal of these services the required capacity of the pumping station has been decreased.

The flow routing through the pumping station includes a chlorination well into which the 20 inch intake pipeline terminates, a 20 inch steel pipe transfer to the main wet well and a circular concrete baffle and port structure to convey water radially to the vertical turbine pump suctions. The station has space available for installation of up to seven (7) vertical turbine pumps. The original capacities of the seven units were listed as follows:

PUMP NO.	MAKE	USE	H.P.	RPM	GPM	DRIVE
1	Peerless	Emergency-High	100	1,600	1,000	Gear
2	Fairbanks	Low Pressure	60	1,800	700	Direct
3	Fairbanks	Low Pressure	60	1,800	700	Direct
4	Fairbanks	High Pressure	75	1,800	700	Direct
5	Fairbanks	High pressure	75	1,800	700	Direct
6	Fairbanks	High Pressure	75	1,765	700	Direct
7	Peerless	Emergency-High	130	1,825	1,000	Gear

Today, only units 4, 5 and 6 remain in service in as much as the low pressure service zone (abandoned services) no longer is required and the emergency service units have been replaced with a generator to provide power to the normal duty pumps. Delivery needs of the system average 0.5 MGD (350 gpm). Therefore, the use of three (3) 700 gpm (1 MGD) pumps provides suitable capacity to cover maximum day flows which may be around 1 MGD with a generous standby capacity.

Water levels in the main well vary from elevation 443.28 to 448.18. This provides a minimum depth of 14.10 ft. in the well and a minimum free board of 5.0 ft. to the pump room operating floor. Any revisions to this pumping station must allow continued operation over this range of levels to maintain pump submergence.

The pumping station is fully functional including the main pump control room, generator room, office, furnace room, lavatory and chlorination room. The chlorination system utilizes gas chlorine delivered in 150 lb. cylinders and is stationed in a room which appears to meet the requirements set forth by the New York State Department of Health. Chlorine is put into solution and added to the flow at the chlorination well. In addition to chlorine, fluorides are added at the chlorination well through a liquid feed system located within the chlorination room.

2.3 Water Supply Network

The original water supply system included individual discharges from each pump which were headered in the yard area east of the pumping station structure. The piping was split into low pressure service and high pressure service. The yard contained two pressure reducing vaults for connection between the systems. These vaults have since been removed from service along with the discharge piping from the four removed pumping units.

The current water supply system includes individual 8 inch discharges from the three (3) active pumps. Each discharge is protected with a check valve and gate valve. The discharges are combined into one common pipe on the west side of East Lake Road. A 6 inch water service is connected to the main header and runs north and south to serve lake shore services. The water directed to the lake shore uses is unmetered by the system. A main 12 inch feeder crosses East Lake Road and passes through a meter vault on the east side of the road. After metering the 12 inch pipeline is reduced to 10 inch size and continues east toward the Depot. (See Figure 5 for configuration). Along the transmission main route, services are fed through sideline pressure reducing valves. The mainline flow is delivered to the main reservoir at the top of the system. The reservoir, at elevation 740 ft., is roughly 300 ft. above lake level (130 psi±). Under peak flow conditions, when water towers need filling, the main flow is re-pumped at West Depot Road inside the Depot security fence line.

2.4 Water Usage

The demands on the Seneca Army Depot water system currently average less than 0.5 MGD. Maximum day flow experienced in recent years is 1.0 MGD, or less. The system is capable of pumping up to 3.0 MGD with all three (3) pumps operating. However, the current transmission and distribution system will not allow conveyance of that full quantity. With one unit out of service the system delivery capacity is much less than 2.0 MGD.

The Depot is in the process of down sizing due to Federal budget cutbacks of military spending. The down sizing is expected to considerably reduce water demands on this system. The extent of reduction cannot be accurately determined at this time. Therefore, it is proposed that any system improvements required for treatment will be sized at a 700 gpm rate with standby available to assure a continuous 700 gpm production.

2.5 Water Quality

Seneca Lake water quality is excellent. The Depot has never had any problems meeting regulatory requirements for turbidity, color, odor or other primary contaminants. The only real concern in the system is the presence of some organics which, upon prechlorination, could lead to formation of trihalomethanes (THM). Chemical addition provided in the renovated facility must consider that free chlorine should not be fed as a molluscicide or cystidal agent unless some removal of organics has been completed prior to chlorine feed. Free chlorine can be used without significant THM threat for final disinfection and residual maintenance.

3.0 SYSTEM CONCERNS

3.1 Zebra Mussels

3.1.1 POTENTIAL FOR INFESTATION

Zebra mussels were first detected in the Great Lakes Basin in 1988. In the past five years they have spread extensively throughout the five lakes as well as along many tributary waterways and into other surrounding lakes. Although the Seneca Army Depot has not yet experienced any infestation, zebra mussels have already been detected in regions of Seneca Lake (Carrol). The impending spread of zebra mussels presents an obvious concern for the potential of future infestation.

3.1.2 CHARACTERISTICS OF THE ZEBRA MUSSEL

Zebra mussels (dreissenia polymorpha) inhabit lakes and rivers where they attach and colonize on solid surfaces. They grow to approximately 2 in during their four (4) to five (5) year life span and will typically reach population densities well above 500/ft^2. They are found primarily in freshwater but can adapt to low concentration brackish waters. They prefer temperatures between 68 and 77°F, and hence are commonly found at depths between 6.5 and 30 ft. (O'Neil etal) Because zebra mussels are stationary for most of their lives, they favor water currents between 0.5 to 1.6 ft/s which provides a continuous supply of food and oxygen (O'Neil etal). Because the zebra mussel prefers moderate water currents, they tend to concentrate in shallow waters where wave action and thermal inversions are likely to occur. Habitation in deep water is less likely however may be induced by deep water intakes which would provide suitable living conditions.

Environments considered inhospitable to zebra mussels are those with temperatures below 45°F or above 90°F, and those with water currents in excess of 6.5 ft/s (O'Neil etal). In adverse conditions, no water, low oxygen, chemical treatment, etc., zebra mussels are capable of closing up their shells and surviving, in some cases, for days.

Zebra mussels are dioecious and reproduce by releasing both the eggs and sperm into the water column where fertilization must take place within several hours. Reproduction is restricted to temperatures between approximately 57°F and 75°F. Hence, zebra mussel populations reach a peak around the late summer months. Mature females can produce 30,000 to 40,000 eggs per year (Turner etal).

The fertilized eggs, 40 to 70 microns long, are free floating and travel with water currents. Within two (2) or three (3) days they develop cilia which provides temporary motility. The now free swimming organism, or veliger, remains on or near the surface of the water. Within three (3) weeks the veliger will gradually replace its cilia with a single foot. Once the zebra mussel loses its motility it must find a suitable substrate for attachment. Surfaces are reached either by water currents or by sinking which is promoted by development of the shell. During this settling stage, zebra mussels experience an extremely high mortality rate due to thermal shock, oxygen depletion, or the inability to locate a substrate. Once attached to a hard substrate material the mussel will spend the rest of its life in that location and will rely on water currents for delivery of air and food. Typically, dead zebra mussels will remain firmly attached to their substrate for a considerable time.

3.1.3 THREAT TO WATER TREATMENT PLANTS

Due to their presence around intake structures and potential population densities, zebra mussels pose a serious biofouling threat to water treatment plants. Any locations prior to the first point of filtration or chemical application are susceptible to zebra mussel infestation. With continuous water flow and hard surfaces, intakes make a perfect environment for zebra mussels. When the mussels are healthy, their presence will quite often improve the water quality. Conversely, as mussels die off the quality is fouled by their decomposition . Once the zebra mussels become attached to screens and pipes, they will populate, settle in, and restrict waterways, affecting the raw water quality and increasing the head loss of pipelines. Often the intake pipe becomes too clogged to operate properly. The goal of the water system operation then, is to prevent the zebra mussels from colonizing the intakes and wet wells. This may be done through biological, chemical, mechanical, or physical methods. Further discussion on the various control methodologies is given in Section 4.1.

3.2 Surface Water Treatment Rule

The federal government,through the US Environmental Protection Agency, in 1986 enacted the Surface Water Treatment Rule (SWTR) within overall legislation to amend the Safe Drinking Water Act (SWDA). The rule, being implemented by the States through primacy agreements, is given in the New York State Sanitary Code Subpart 5-1, and applies to all public water systems which serve greater than fifteen (15) connections and greater than twenty-five (25) people. With respect to the Seneca Army Depot, which utilizes an unfiltered surface water source, the following section applies:

"Section 5-1.30(b) Minimum treatment for surface water sources (or groundwater sources directly influenced by surface water) shall be filtration and disinfection techniques, approved by the State in accordance with section 5-1.22 of this Subpart, capable of 99.9 percent removal and/or inactivation of Giardia lamblia cysts and 99.99 percent removal and/or inactivation of viruses, between a point where the raw water is no longer subject to recontamination by surface water runoff and a point downstream before or at the first customer. Compliance with this treatment technique requirement shall be no later than June 29, 1993 for surface water sources (or within eighteen (18) months for groundwater sources determined to be directly influenced by surface water sources), unless the department determines that the supplier of water can meet specific avoidance criteria as defined in subdivision (c) of this section. Required performance monitoring shall be conducted in accordance with Section 5-1.52 Table 10A of this Subpart."

Qualifying for avoidance of filtration involves demonstration of superior past performance, watershed and shoreline controls, raw water quality, disinfection technique and residuals, and final water quality. For further details, a description of the Surface Water Treatment Rule avoidance criteria is included in Appendix C.

4.0 ALTERNATIVES FOR REMEDIATION

4.1 Zebra Mussels

There have been many questions regarding the extent of infestation that may occur at the Seneca Army Depot. The intake is at a depth of 85 to 90 feet where average influent temperatures of 47°F are experienced in the summer and 40°F in the winter. As stated earlier, zebra mussels prefer temperature above 45°F, and therefore may not readily populate below the thermocline (Claudi). This may or may not be significant since there have been recent reports of similar more durable species of mussels which thrive in deeper/colder waters. Therefore, the alternative remediations have been provided on the basis that extensive infestation of the intake is likely.

4.1.1 BIOLOGICAL METHODS

Zebra mussel populations may be reduced by an increase in the population of their natural predators such as crayfish, waterfowl, and certain fish. In natural settings however, it has been shown that large predator populations cannot be sustained at levels to assure effectiveness. Another potential control method is the introduction of preselected microorganisms that could either increase the zebra mussels death rate or decrease their rate of reproduction. Development of microorganism colonies of this nature has not been successful to this date. Both of these methods will require further research and development into reliable controls. Currently, they are uneconomical to implement especially with respect to an individual treatment plant drawing water from a large lake.

4.1.2 CHEMICAL METHODS

Zebra mussels can be killed off with chemical treatments. This is done either by direct treatment from liquid or gas, or by paints and coatings that resist mussel attachment. Successful, nontoxic paints have not yet become economical for water treatment plants (Mackie, Mussalli etal), but several oxidants are discussed below. The liquid and gas treatments are usually applied at the raw water point of entry through a chemical feed line inside or parallel to the intake pipe. Because Zebra mussels are capable of isolating themselves from the environment for several days by closing their shells, low dosages for long periods of time have shown more effective than short term high concentrations. Veliger populations tend to be more vulnerable to chemical control than adult mussels. Concerns with this type of feed system have been voiced by regulatory agencies due to the potential for leakage of chemical into the source water. A real risk is perceived since the chemical application point is extremely close to the water source. Many regulatory agencies have approved chemical application only as a temporary measure of zebra mussel control until other methods can be advanced. However, system operators who show competence and responsible action relative to this type of system may be more likely to obtain permission to utilize such a system permanently.

Free chlorine has been shown highly effective against zebra mussels. A continuous feed of 2.5 mg/L Cl_2 will produce a 100% kill within forty-two (42) days (1.0 mg/L Cl_2 gave 94% kill) (Klerks etal). Currently, chlorine is a very popular option because it is highly effective and most water treatment systems use chlorine as a disinfectant. There is often concern regarding prechlorination and the formation of trihalomethanes (THMs), where a system's raw water contains some organic constituents. The THM issue is a valid concern at the Seneca Army Depot.

Chlorine dioxide has also been shown highly effective against zebra mussels. Chlorine dioxide is most popular with treatment plants that have THM problems because it reduces the risk of their formation in comparison to free chlorine. The water treatment plant at Brockport, NY, averages a chlorine dioxide dose of 0.8 mg/L. Five (5) minutes after the influent enters the plant, a 100% veliger kill has been verified (Preston). The Brockport source is Lake Ontario. The intake draws from 2,650 ft. off shore at a depth of 27 ft. below surface.

As an oxidant, ozone is also an excellent choice for zebra mussel control. At the present time, the exact ozone concentration required to control zebra mussels is undetermined. Ozone, used as an oxidant, is unstable and very reactive. As a result, ozone dosages may be more variable than other chemicals contingent upon incoming water chemistry. Experience at Monroe Water Treatment Plant, Monroe, MI, suggests that an average ozone application of 1.5 mg/L (estimated to be 0.26 mg/L dissolved ozone at 65°F) is sufficient to inactivate both the veligers and adults. This is based on the 1989 zebra mussel infestation in which colonies were found upstream of, but not within , the ozone contact chamber (Le Page etal). The Monroe Water Treatment Plant currently chlorinates at the point of entry and ozonates at the end of the transmission line (Le Page). Equipment required to generate ozone on site and feed it to its application point is relatively expensive and will be a significant consideration in selection of a zebra mussel control system.

Potassium permanganate has been shown to control zebra mussels but not as effectively as the previous listed chemicals. Mortality rates are much lower than chlorine, fifty-two (52) days for 100% kill at 2.5 mg/L $KMnO_4$ (Klerks etal). Concentrations above 4 mg/L $KMnO_4$ may be more effective (Imlay).

Unfortunately, high doses of potassium permanganate risk the formation of pink water. Potassium permanganate is currently being used in the City of Cohoes, NY which draws its water from the Mohawk River. Although zebra mussel infestation has not been documented (only a few sitings to date), the chemical application is producing some desirable side effects. Among the benefits of potassium permanganate are, improved turbidity, taste and odor improvement and less sludge disposal required in the existing filtration plant.

Polymer treatments have been used successfully as zebra mussel control in Ashtabula, Ohio (Adams). Because the Seneca Army Depot does not include a conventional treatment plant, it does not lend itself to this treatment method.

4.1.3 PHYSICAL METHODS

Physical methods involve environmental factors such as thermal shock, oxygen depletion, or inability to locate a substrate, all identified in the previous section.

Zebra mussels can not tolerate temperatures above 90°F. Existing populations, adults and veligers, can be killed by thermal shock by contacting them with water temperatures above 100°F for one half hour to an hour (O'Neil etal, Turner etal). This is a popular method for power plants. Such plants typically have access to high temperature waters which can be recirculated without discharge to the environment. This method is difficult to implement in water treatment plants since it would require multiple intakes and a method to flush out the pipe. Hot water would have to discharge through the intake into the source water, or be supplied at the point of intake and discharge through the plant. The environmental impact of a hot discharge into source waters presents serious problems. In addition to being uneconomical, this method is reactive and does not provide continuous control.

As an aerobic creature, zebra mussels are susceptible to oxygen deprivation. An existing population, adults and veligers, can be killed by shutting down intake pipes and sealing them off to create an anoxic environment. This requires that the plant have more than one intake because the pipe must be sealed off for several days. After the procedure, the pipe must be flushed out either into the source water or through the plant. This method is reactive and does not provide continuous control.

At water velocities above 6.5 ft/s zebra mussels are unable to attach to their usual hard surface substrates. By operating a high velocity intake at or above 6.5 ft/s the adults will be unable to attach and they will be swept along the pipe with any veligers. To prevent population development within the plant, zebra mussel control (chemical or mechanical methods) must then take place immediately before the velocity drops below 6.5 ft/s. Some European power plants currently use this method. Their transmission lines are typically only 5 to 10 meters in length and the average water velocity is 5 ft/s (Jenner). Design of a high velocity intake is very critical. Pipe bends and other points of added turbulence must be minimized because they may subject the pipe to localized mussel attachment. Once a population has established itself in one locality the flow patterns within the line may induce colonization in adjacent areas when turbulent zones adjust. The high velocities will not detach these mussels. Therefore, the pipes may ultimately require other cleaning methods such as hand scraping or pigging. High velocity does not necessarily provide continuous control but it is proactive and tends to significantly reduce the amount of fouling. (Mackie etal, Turner etal). The major impediment to use of high velocity intake for the Seneca Army Depot is the length of the intake line and associated head loss.

Exposure to high voltage electrostatic filters will kill zebra mussels. With an exposure time of 0.1 seconds, 570 to 635 volts per inch will kill open mussels. However, if the zebra mussel shell is closed, 965 to 1,015 volts per inch is needed (O'Neil etal). Again, this alternative is impractical and uneconomical for the Seneca System.

4.1.4 MECHANICAL METHODS

Mechanical methods involve manual removal of adult mussels by scraping them from the surface. Small diameter pipes which cannot be reached by hand can be cleared using polyurethane pigs. Following the pigging procedure, the system would require flushing to remove mechanically cleaned materials either into the source water or through the system. This method is reactive and does not provide continuous control but may be coupled with any of the above methods to increase effectiveness of the overall control system.

Another mechanical method of zebra mussel removal is via infiltration beds or sand filters. Due to the nature of the media provided for such systems, a system placed on the lake bottom discourages colonization of mussels (improper substrate) and strains veligers and adults from the intake water. Complications in this type of remedy include a) difficulties in underwater construction and quality control associated there with and b) the necessity to periodically clean infiltration beds. These methods are not very commonly used due to these complications.

4.2 Treatment

4.2.1 AVOIDANCE CRITERIA

Avoidance of the surface water treatment rule is granted by the New York State Department of Health for water sources of the most pristine nature and most reliable history. Once avoidance is achieved by the Seneca Army Depot, the system will require the following intensive quality monitoring:

1. Raw water fecal or total coliform - minimum number of three (3) grab samples per week.

2. Raw water turbidity - grab sample every four hours or continuous monitoring.

3. a. Temperature of disinfected water - minimum once per day at each residual disinfection concentration sampling point.

   b. pH of disinfected water - minimum once per day at each residual disinfection concentration sampling point.

   c. Disinfectant contact time - determined daily during peak hourly flow.

   d. Residual disinfection concentration - measured daily during peak hour flow.

4. For systems with chlorine disinfection - continuous residual monitoring.

5. Total coliform - minimum number of five (5) samples per month.

For further details, see Appendix C which provides an interpretation of the State Sanitary Code relative to avoidance.

4.2.2 CHEMICAL CONSIDERATIONS

The Surface Water Treatment Rule (SWTR) allows a potable water supply system to avoid installation of water filtration technologies when using a surface water source, if 1) its source water has a history of excellent quality with no previous record of Giardia Cysts and the giariasis disease which results in humans, from the consumption of waterborne Giardia, 2) the system intensively monitors to assure that there are no lapses in water quality, and 3) the system has control of it's source watershed or has a reasonable opportunity to affect land uses within its watershed area. A system risks losing its avoidance status with its first sampling evidence showing a compromise of quality beyond the parameters set forth for avoidance.

The Surface Water Treatment Rule was implemented for the purpose of reducing the incidence of Giardiasis and other waterborne viral diseases. The rule stipulates that 3-log removal/inactivation of Giardia lamblia cysts (99.9%) and 4-log removal/inactivation of viruses (99.99%) must be completed for compliance. Disinfection of the water supply must be included as a minimum. In order to chemically meet these parameters, two chemical applications (redundant) in the process would normally be required at an installation such as Seneca Army Depot. Initially a chemical should be added as a cystidal disinfectant. Based on previous discussion, chlorination should be avoided due to the potential formation of trihalomethanes. Chlorine dioxide and ozone are two chemicals which could be used with a much lower risk of formation of THM's or other disinfection byproducts. In addition, these chemicals are excellent disinfectants and can be administered to the water supply with relative ease.

A system using chemical application alone to meet the avoidance criteria of SWTR will need to monitor water quality as identified in the previous section.

4.2.3 FILTRATION CONSIDERATIONS

Many water systems have elected to employ water filtration technology to meet the terms of the SWTR. A significant benefit of filtration is the relaxation of intensive monitoring required with maintaining avoidance status. Complete filtration processes which use chemical coagulation, flocculation, sedimentation, rapid sand filtration and disinfection easily satisfy the 3-log and 4-log removal criteria of the rule. Simpler filtration methods such as direct filtration, pressure filtration and others which do not employ chemical addition can expect to remove 2.5-logs of Giardia cysts and 2-logs of viruses as long as turbidity values are controlled within 0.5 NTU. Provision of residual disinfection following filtration will elevate removal/inactivation levels to an appropriate degree. Newer technologies including membrane filtration can provide superior results for removal/inactivation of cysts. Removals are directly related to porosity of the membranes. A micro filtration membrane (particle removal of 0.5 - 1.0 micron size) has been shown to achieve 3-log removal of Giardia and 2-log removal of viruses without chemical addition.

Filtration would require the following monitoring:

1. Raw water turbidity - grab sample every four hours or continuous monitoring.

2. Finished water turbidity-grab sample every four hours or continuous monitoring.

3. For systems with chlorine disinfection - continuous residual monitoring.

4. Residual Aluminum - where alum is used for coagulation.

5. Particle Counting - for micro organisms.

6. Color.

4.3 Alternative Selection Rationale

4.3.1 RATIONALE FOR INTAKE CONCEPT AND ZEBRA MUSSEL CONTROL

The water intake at Seneca Army Depot needs to be replaced due to age, deterioration and its vulnerability to zebra mussel infestation. Most of the alternative means available to discourage colonization or kill zebra mussels in water intakes were discussed in Section 3. A review of the methods was undertaken and selection of chlorine dioxide was made considering the several following factors:

- Biological methods including predator or micro organism addition to control mussels at the intake are not feasible in a system whose intake is nearly 90 ft. under water.

- Virtually all chemical feed options which rely upon addition of chemical into an intake stream at the mouth of the intake risk chemical contamination of Seneca Lake and resulting regulatory fines. In connection with systems operating under the State's avoidance criteria, chemical feed systems tend to be very affordable. Chemical means to date have largely been considered only for temporary control. However, as chemical application experience is gained and its effectiveness against zebra mussels is documented it is felt that acceptance of chemical feed methods on a permanent basis will be possible.

- Thermal kill methods are not feasible in public water supplies since the public will not tolerate heated drinking water and a source of heated water is not readily available.

- Oxygen deprivation is not feasible since the byproduct of anoxic poor quality water will be a problem to dispose.

- Electrical shock methods will be expensive and may be dangerous to fish.

- Mechanical removal by scraping or pigging will be extremely difficult if an intake pipeline proved to be ideal for mussel colonization. Zebra mussels, in ideal conditions, can accumulate too quickly to effectively remove by mechanical methods. For light buildup of mussels, scraping and pigging are effective.

- Infiltration beds and sand filters are excellent means of mussel removal but can be employed effectively only in shallow waters where under water construction and operation pose minor problems. At Seneca Army Depot's 90 ft. deep intake these methods are not feasible.

- High velocity intake would effectively discourage colonization of zebra mussels on the pipe walls as long as 1) water velocity is sustained, 2) a means of periodically cleaning those mussels which do manage to attach to the pipe is provided, and 3) if and when water flow is stopped the line can be back flushed with finished water. The disadvantages of high velocity intake include 1) large suction head loss, 2) pumping energy cost, and 3) increased potential to draw fish and other marine life into the intake.

The most viable alternatives for zebra mussel control would appear to be those which allow for multiple intake pipes, a means of scraping or pigging and administering control chemicals such as ozone, chlorine or chlorine dioxide.

4.3.2 RATIONALE FOR TREATMENT CONCEPTS

Seneca Lake water has a history of excellent quality. The primary focus of new treatment in this system must be on filtration of the water supply or disinfection suitable to meet the avoidance criteria of the Surface Water Treatment Rule. Those methods of treatment which do not negatively impact quality but provide mussel killing and disinfection qualities include application of chlorine dioxide, ozone and micro-filtration. Because each of these methods have mussel killing and disinfection qualities these technologies were selected for further comparison for selection of final concept for implementation.

4.3.3 DETERMINATION OF SCHEMATIC DESIGN CONCEPT

Considering that ozone feed equipment tends to be expensive, microfiltration is required only if avoidance of the Surface Water Treatment Rule cannot be obtained, chlorination can elevate THM levels and a chlorine gas system is available on-site for use in a chlorine dioxide feed system, chlorine dioxide addition to multiple intakes with provision for mechanical cleaning of pipelines was selected as the final concept for design.

4.4 Schematic Design Overview

4.4.1 SCHEMATIC DESIGN FOR CHLORINE DIOXIDE

A chlorine dioxide feed system for the intake has been selected for use based on the above rationale and the generally good acceptance of the method by experts in the zebra mussel control field. Because the system risk to the lake ecosystem and zebra mussels have proven to be a problem in other installations, it is proposed that the system be provided with some added features to minimize negative effects.

The intake elbows, shown in Figure 7, should be protected to discourage zebra mussel veliger and adult access to the interior of the pipeline. The intake end will be set upon a screened foundation (soil maintenance fabric) laid on the lake bottom so that silt lifting into the intakes will be minimized. The intakes will be approximately five feet above the lake bottom and pointed upwards at 45° to horizontal.

The intakes will consist of three (3) twelve-inch polyethylene pipelines with holddowns and yokes as shown in Figure 3. It is proposed that the pipelines be provided so that 1) infestation of a single pipeline will not cause complete shutdown of the water delivery system, 2) multiple pipelines can be used as required to reduce pumping energy costs, and 3) pipelines can be taken out of service individually for cleaning or inspection without interruption to the water system operation. The system provides for two lines used on an alternating basis with one line in reserve. Each pipeline intake will be covered with a slotted spring loaded cap constructed of lightweight plastic to keep fish and debris out.

The intakes will be provided with the ability to clean lines by reverse pigging. This would involve periodic launching of a polyurethane pipe cleaning pig from the pumping station. The pig would traverse the length of the desired intake line, emerge from the intake bell and be released from the slotted cap to float to the lake surface for retrieval. Pigging is expected to be successful in this application for cleaning of any attached mussels since mussels will be reduced in number by the chemical addition. The ability of the chemical feed system to discourage settlement of mussels should result in a very sparse colonization of the intake which can be easily pigged.

The intakes will also be provided with back flush capability so that finished water with a slight chlorine dioxide residual can be back fed into the pipeline upon shutdown of any one of the pipelines. This action will allow the water in the line to remain "fresh" and will tend to kill any surviving mussels.

The primary regulatory concern on this system is expected to be the risk of chemical contamination near the intake. To protect the lake waters, it is proposed that the chlorine dioxide be fed in a water solution to keep the chemical dilute and that the feed line to the mouth of the intake be installed within a larger conduit throughout its length. Any leaking chemical can be trapped within the conduit. It is further proposed that the facility's raw water sampling be taken by drawing sample through the annular space on a continual basis. This will provide the raw water sample as well as allowing the Depot to detect any chlorine dioxide which enters the annular space. Provision of a means to locate the end of the intake by routing a compressed air pipeline to the end of the intake lines is also envisioned. The intake lines will be assembled together to maintain a constant separation distance and rigidly affix the smaller lines to the larger intake pipes.

The intake should be placed without an indicator buoy. Zebra mussels have been known to attach to buoys and accumulate to an extent sufficient to sink the buoy. A sunk buoy could, in this case, deliver zebra mussels to the mouth of the intakes.

Under this alternative, chlorine dioxide would serve as the chemical agent to achieve cysticidal and viricidal disinfection. Chlorine dioxide dosage is anticipated to be less than 1 ppm for Giardia cyst control. Capacity should be provided to feed a maximum of 5 ppm.

The chlorine dioxide feed system would include duplicate feed systems for chlorine, sodium chlorite, and hypochlorous acid, and a residual analyzer. This system should be installed in the existing chlorination room since it requires special housing due to the hazards associated with storing sodium chlorite.

Chlorine dioxide will have multiple benefits of oxidation of color and odor, and reduction of trihalomethane precursors as well as its ability as a mulluscicide and disinfectant.

In accordance with the Safe Drinking Water Act, addition of disinfectants to finished water requires maintenance of a CT value (residual concentration x contact time). This CT value can be achieved by provision of a contact tank or a long length of pipeline. The Depot currently has a long pipeline to its reservoir which supplies most of the water demands required of the system. Adequate CT values should be easy to maintain for the main facility. Special protection will be needed to provide adequate CT values for water services which branch from the system mainline prior to the reservoir. specifically, the Lake Housing and New Residential Housing areas are affected. In order to provide redundant protection of the Lake Housing and New Housing residents adjacent to the pumping station, it will be necessary to add chlorine gas or chlorine dioxide at the high lift pump station and construct a new transmission main parallel to the existing, which would serve as a plug flow contact reactor.

For chlorine dioxide use of a CT value of 63 is required. Considering a maximum desired residual of 1.0 mg/l, the Depot would require contact of 63 minutes on the portion of flow directed to the shore users. It is convenient with the current layout of facilities to parallel the existing pipeline for a length of approximately 1,000 feet. With usage of approximately 32,000 gpd on a Maximum Day Demand basis to the affected users a reactor size of 10″ diameter would be projected. If an increase in line size to 20″ were provided, the facility would have the capacity to use chlorine gas as a disinfectant since a CT value for chlorine in cold water is approximately 250. Provision of a parallel pipeline 20″ in size will be recommended so that flexibility in use of disinfectant can be preserved.

5.0 PROJECT DESIGN

5.1 Basis of Design

Based on the 1) project objectives for zebra mussel control and surface water treatment rule avoidance, 2) physical site restraints, 3) regulatory requirements and 4) the needs of the down sizing Seneca Army Depot, a preliminary project design has been formulated suitable upon which to proceed into final system design. The preliminary design has been summarized into the Basis of Design shown in Table 1. The basis of design provides the key elements of design and sizing for all the new facilities to be incorporated into the project.

TABLE 1
SENECA ARMY DEPOT
ZEBRA MUSSEL CONTROL INTAKE
BASIS OF SCHEMATIC DESIGN

INTAKE CAPS	
Number required	3
Size (length and width)	12″ dia. nominal
Construction	PVC
Pig Release Feature	Hinged and spring loaded
INTAKE PIPELINES	
Number required	3
Size	12″
Material	Polyethylene with holddowns
Jointing	Heat fused
Velocity using 1 pipe (700 gpm)	1.99 fps
Velocity using 2 pipes (700 gpm)	0.99 fps
Operating philosophy	2 for alternating use 1 for standby
Chemical contact time 1 pipe	9.6 minutes
Chemical contact time 2 pipes	19.4 minutes
WET WELL (EXISTING)	
Well diameter	8.0 ft.
Depth min.	12.72 ft.
Wet well capacity	4,780 gals.

TABLE 1
SENECA ARMY DEPOT
ZEBRA MUSSEL CONTROL INTAKE
BASIS OF SCHEMATIC DESIGN
(continued)

Chemical contact time	6.8 minutes
CONTACT PIPELINE - SHORE SERVICES	
Size	20″
Length	1,000 ft.
Max. flow	32,000 gpd
Peak hour flow	86,400 gpd
Velocity	0.061 fps
Chemical contact time	273 minutes
CT for chlorine	250
CT for chlorine dioxide	63
CHLORINE DIOXIDE FEED SYSTEM	
Feed pipeline	2″ PVC
Feed location	At intake
Required design dosage (max.)	5 ppm 41.7 ppd
CT value for 3 log Giardia	63
Feed provisions - primary	At intake
- secondary	Wet well
CHLORINE DIOXIDE FEED EQUIPMENT	
Chlorine gas capacity	21.7 ppd
System components	150 lb. cylinders Cl_2 injector, water feed rotameters
Sodium chlorite capacity	20.9 ppd
System components	Concentrate tank Metering pumps ClO_2 generator Associated piping and controls
AIR LOCATOR SYSTEM	
Feed pipeline	1/2″ PVC
Feed location	At intake
Required design rate	0.5 cfm
Blower type	Positive displacement
Pressure rating	100 psi
RAW WATER SAMPLING SYSTEM	
Feed pipeline	4″ PVC
Sample pump capacity	5 gpm at 25 ft. TDH
Annular space capacity	0.65 gal/ft.

TABLE 1
SENECA ARMY DEPOT
ZEBRA MUSSEL CONTROL INTAKE
BASIS OF SCHEMATIC DESIGN
(continued)

Delay time intake to sample	160 sec. 2.7 minutes
PRESSURE REDUCING VALVE	
Manufacturer (existing)	Empire
Model	Figure 470
Size	6″
Capacity - sustained	60 - 1,000 gpm

5.2 Site Plans

The preliminary design site plans are shown on drawings provided in Figure 3 through 5 at the back of this report.

5.3 Equipment Layouts

Equipment layouts and schematic flow diagrams are shown on drawings provided as Figures 6 and 7 at the back of this report.

5.4 Project Cost Estimate

The preliminary design, basis of design and figures have been used to develop a preliminary project cost estimate. The estimate is presented in Table 2 and provides for contingency as well as engineering, legal and miscellaneous costs expected to be incurred within the project.

TABLE 2
SENECA ARMY DEPOT
ZEBRA MUSSEL CONTROL INTAKE
PROJECT COST ESTIMATE

INTAKE PIPELINE

Fabric Silt Control Blanket	$300
CMU Block Holddowns	$300
Special Intake Caps	$1,000
12″ Polyethylene Pipe - In Place	$32,000
4″ PVC Raw Water Sample Pipe - In Place	$6,000
2″ PVC Chemical Feed Line - In Place	$4,000
1/2″ PVC Air Pipeline - In Place	1,300
Air Blower System	$1,500
Excavation In Lake	$34,500
Excavation On Shore	$12,300
Dewatering	$66,000
Pig Launch System	$20,000
SUBTOTAL	$179,200
CONTINGENCY - 15%	$26,900
ENGINEERING, LEGAL, MISC. - 15%	$26,900
ESTIMATED PROJECT COST - INTAKE	$233,000

CHLORINE DIOXIDE FEED SYSTEM

Chlorine Dioxide Feed Equipment	$90,000
PVC Feed Piping	$6,000
Turbidimeter and Control Systems	$5,000
SUBTOTAL	$101,000
CONTINGENCY - 20%	$20,200
ENGINEERING, LEGAL, MISC. - 20%	$20,200
ESTIMATED PROJECT COST - CHLORINE DIOXIDE	$141,400

TABLE 2
SENECA ARMY DEPOT
ZEBRA MUSSEL CONTROL INTAKE
PROJECT COST ESTIMATE
(continued)

PLUG FLOW/PRESSURE REDUCTION

20" Ductile Iron Pipe - In Place	
1,000 ft. at $90/ft.	$90,000
Valves	$8,000
Connections	$5,000
Pressure Reducing Valve	$3,000
Pressure Reducing Vault	$2,500
SUBTOTAL	$108,500
CONTINGENCY - 20%	21,700
ENGINEERING, LEGAL, MISC. - 20%	$21,700
ESTIMATED PROJECT COST - PLUG FLOW	$151,900

OVERALL PROJECT

SUBTOTAL	$388,700
CONTINGENCY	$68,800
ENGINEER, LEGAL, MISC. - 20%	$68,800
ESTIMATED PROJECT COST	$526,300

OPERATIONAL COST INCREASES

Power - 5 HP connected = 32,800 KWH/yr	$2,600/yr.
Chlorine Dioxide - 10 lbs/day x $1.5/lb.	$5,500/yr.
Labor - 600 hrs/yr x $15/hr	$9,000/yr.
Parts/Maintenance 2% construction cost	$10,000/yr
ESTIMATED TOTAL INCREASE OPERATING EXPENSES	$27,100/yr.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Chlorine dioxide represents a reasonable solution to Seneca Army Depot's concerns regarding future zebra mussel intake infestation and disinfection requirements associated with the New York State (USEPA) Surface Water Treatment Rule. Chlorine dioxide applied at the intake and again at the wet well of the existing pumping station provides redundant feed suitable to satisfy the regulatory requirements. CT (concentration x time) values for water served to the Lake Housing and New Housing must be lengthened by plug flow detention of water in an oversized pipeline to the point of connection of the New Housing to accommodate CT values for chlorine dioxide or chlorine gas.

6.2 Recommendations

To implement the development of the proposed zebra mussel control and water treatment program, it is recommended that the U.S. Army Corps of Engineers and Seneca Army Depot take the following actions.

1. Approve this report.

2. Have the report issued to the local Health Department Office to gain conceptual endorsement of the Department.

3. Authorize the engineer to proceed into the design phase of the project.

4. Budget the project based on the project cost estimates provided within this report.

GM/ps

APPENDIX A

REFERENCES AND CONTACTS

APPENDIX A

REFERENCES AND CONTACTS

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APPENDIX B

SITE VISIT NOTES

C.T. MALE ASSOCIATES, P.C.

MEMORANDUM
Tue, Jul 14, 1992

TO : Sy Katzman ,COE
Steve Absolom ,SAD
Thomas Enroth ,SAD
Gary McCollum,CTM
Neal Gruber,CTM

FROM : Bill Simcoe

RE : Meeting at Seneca Army Depot, 7/14/92

1. Seneca Army Depot (SAD) has been informed that water quality will be poor close to shore where depth will be most practical (20-25 ft.) for an infiltration gallery. This will preclude consideration of avoidance of filtration. Therefore, rather than continue to pursue the infiltration gallery approach that appears to be at an impractical location, Seneca Army Depot would prefer to keep the present intake location with a high-velocity pipeline approach.

2. The literature indicates that the zebra mussel is capable of attaching to firm substrates at water flow velocities below 2.5 meters/second (8.2 feet/second) on horizontal surfaces and 2.0 meters/ second(6.6 feet/second) on vertical surfaces. One method of control is to maintain intake and pipeline velocities above these velocities.

3. Steve Absolom indicates that SAD has envisioned dual intakes,the use of a suction bell turned vertically downward at the end of the intake, and provisions to cap the end of the intake that is not in service.

4. Part of the revised scope of this project will be to design facilities required by the new State Sanitary Code Part 5 for community water systems operating under the "avoidance" criteria.

5. Military housing is very close to the intake pumping station. In order to meet required "Ct" values for inactivation of cysts and virus, Steve proposes to construct a new pipeline from the pump station toward the Depot to act as a plug flow reactor for disinfectant contact.

6. Ozone was suggested by SAD as a disinfectant, to greatly reduce required contact time for "Ct" and not increase THM formation.SAD is already operating close to the THM mcl. CTM indicated that ozone is a very complex technology, with high capital and operating costs. CTM suggested consideration of chlorine dioxide as another chemical that would serve as a disinfectant without formation of THM's.

7. CTM also discussed the possibility of using one of the new technologies currently under investigation by the NYSDOH for small water systems : 1. 3-M Bag Filters; and 2. Memcor microfilters with automatic backwash. These technologies do not require chemical pretreatment , are simple to

operate , and remove particles that are the size of microorganisms (<1.0 microns). Use of these technologies could reduce required contact time to achieve the overall objective of 3-log giardia and 4-log virus inactivation.

8. Bill Simcoe said that CTM preliminary calculations indicate that to develop a high velocity intake at the present location it will be necessary to install pumps at the inlet in the lake. Head loss through the pipeline will exceed 50 feet, making a long suction intake to shore pumps impractical. Centrifugal pumps can only develop 29 feet of suction lift under ideal conditions. The only way to develop a suction intake would be by constructing a deep shore well . The existing shore well has its floor only 16 feet below mean lake level.

9. Intake pipe material was discussed. CTM suggested either Usiflex-type river crossing pipe or fusion-welded polyethelene. Steve Absolom indicated that SAD had envisioned the use of polyethylene pipe.

10. Steve Absolom wants the engineering study to clearly identify labor requirements for all considered alternatives . The facility should require minimum staffing on the part of the SAD. Possibly complex systems such as ozone would be maintained by a contract operator.

11. CTM is to develop a scope of services including the following tasks:

Literature search on high-velocity intake

Outline facility requirements to meet "avoidance" of filtration

Bathymetric and topographic surveys at the intake site

Research capital and operating costs for ozone and chlorine dioxide

Research capital and operating costs of bag filters and microfilters, and reduced disinfection " Ct" required using this technology.

Develop schematic designs for the lake intake, disinfection facilities, new disinfection contact pipeline

Calculate and determine pump, pipe, and treatment equipment sizing.

Investigate construction aspects and maintenance aspects of intake pipeline and pump installation.

Evaluate alternatives on a life-cycle basis, outline labor requirements and review aspects of reliability and uninterrupted service during construction and future maintenance.

Recommend a plan for implementation.

Meet with SAD to review the recommended plan.

Prepare preliminary drawings, a project cost estimate, and a preliminary schedule for selected alternative. Construction is desired by March of 1993.

12. CTM obtained from SAD :

    Topographic Maps 5,7 in the area of the intake

    Water Maps 5,7

    Upgrade of Pumphouse PR 60-88, 10 Drawings

    Pump Station Layout 1963 1 Drawing

    Replace Intake 1973

    Fluoridation 1970

    Original Pump House Drawings 1942-44 22 Drawings

13. Lake Housing in the area of the Pump Station includes :

    180 seat restaurant
    56 housing units, 2 and 4 bedrooms
    14 trailers

14. CTM can arrange with SAD for a boat for the bathymetric survey.

15. To facilitate the schedule a mid-September completion date for the study is desired.

16. CTM to FAX new scope to SAD and COE as soon as possible, with cost proposal to follow week of July 20, 1992.

17. Certain ground rules were established for the study of alternatives:

    a. Any mechanical equipment in the Lake must be easy to retrieve for maintenance or replacement.

    b. Intake of high velocity design is considered necessary, unless our literature search shows disadvantages.

    c. No alternative shall increase formation potential of THM's.

/sm

C.T. MALE ASSOCIATES, P.C.

MEMORANDUM

DATE: December 15, 1992

TO: Sy Katzman, COE
Steve Absolom, SAD
Thomas Enroth, SAD
Bill Simcoe, CTM

FROM: Gary McCollom

RE: Meeting at Seneca Army Depot, 12/10/92

On December 10, 1992 a meeting was held at the Seneca Army Depot to review the development of the study and preliminary report concerning the Seneca Army Depot Water Supply Intake. Steve Absolom, Thomas Enroth and Gary McCollum were in attendance. The primary topics of the meeting included the following:

1. C. T. Male provided the Depot attendees with three (3) sets of draft report, preliminary cost estimates, contact list, survey prints and schematic diagram. Also transmitted was one (1) copy of a proposed schedule for project completion. Two (2) copies of the information provided in the meeting were transmitted on December 11, 1992 to Mr. Katzman.

2. Meeting attendees "walked through" the report by section. C.T. Male requested the Depot to closely review the Introduction and Existing Conditions sections of the report. C.T. Male had somewhat limited written resources available upon which to develop these sections. The Seneca Army Depot has recently released some general information to public sources. Depot reviewers will check the report statements in the context of their recent release.

3. C.T. Male indicated that the purpose of Section 3, "System Concerns" was to provide persons without direct input into the project, the opportunity to understand why the high velocity zebra mussel control intake was selected and why there is a need to meet the Surface Water Treatment Rule requirements or substantiate an ability to avoid the rules and maintain cyst free and virus free finished water.

4. C.T. Male noted that the following problems were found relative to high velocity intakes:

    a. Most systems need to slow velocity down at some point - makes system vulnerable to veliger attachment.

    b. Some attachment of mussels probably will occur over time regardless of operating conditions, due to localized velocity profiles.

    c. Generally involves high headloss, high energy cost.

    d. Could serve to draw fish or debris into intake pipe.

    e. Could be a potential to develop Frazil Ice under the coldest of conditions.

5. In the preliminary system proposal, remedies have been provided to safeguard the system against the potential problems identified in #4 above with the exception of the Frazil Ice issue. Seneca Army Depot recommended we contact Navel Barge in Dresden to determine likelihood of ice formation. Naval Barge tracks thermoclines and all sorts of data on the Lake. Contact operator Loren Cornish or manager Lynn Carlton at (315) 536-4280 to get information.

6. The attendees reviewed the schematic design alternatives and the cost estimates provided. Among the questions raised were the following which should be answered by letter as soon as possible so that Depot can review before December 18, 1992.

    a. Ozonation energy costs appear to be light. Review energy usage and confirm the annual cost.

    b. Depot showed some surprise that on-site "atmospheric" ozone/chlorine dioxide contact tanks were less cost then "pressurized" plug flow (oversize pipe) reactor. Depot would like to have some backup information to show C.T. value calculations and some construction cost estimate detail. Make sure we use 32°F as the base temperature.

c. The ozone and chlorine dioxide option looked very favorable. Depot asked C.T. Male to review possibility that excess ozone contacted water retaining a residual could be backfed through the pigging system and into any idle intakes. This would help keep the inactive intakes free of zebra mussels.

7. C.T. Male asked if there is a necessity to reduce pressures to lake shore services. Depot noted that all pressure reduction required is already in effect. There are several individual unit PRV's and one larger "community" PRV.

8. C.T. Male showed print of previous design which showed a 12" pipeline to be installed within the existing 20" intake. The print also showed the 12" insert to be only 800 ft. long as opposed to 1,200 ft. Depot does not believe that this 1970 work was ever completed.

9. Seneca Army Depot asked whether the new 8" intakes could be threaded through the 20" intake and whether the end anchorage could in some way be used as anchorage for the new intakes. It is recognized that there was difficulty televising this line previously due to encrustation/silt etc. This option can only be evaluated if the main intake valve on shore could be removed so that the primary run of 20" pipe could be inspected. Depot suggested that we may want to have a bid item in the final design package for inspection of the line and removal of the valve.

Gary R. McCollum

/sm

MEMORANDUM

DATE: February 3, 1992

TO: Sy Katzman, COE
Steve Absolom, SAD
Thomas Enroth, SAD
Bill Simcoe, CTMA
Neal Gruber, CTMA

FROM: Gary McCollum

RE: Meeting at Seneca Army Depot, 2/1/93

A. REPORT FINALIZATION

1. Army District Engineer (New York) and Seneca Army Depot have reviewed the draft report which was distributed in our meeting of December 10, 1992 and by transmittal letters dated December 10, 1992 and December 31, 1992. Although the report was received favorably in the December 10, 1992 meeting, considerable discussion among the personnel at Seneca Army Depot has resulted in a proposed change in recommendation for water system improvements.

   a. The report recommended 1) high velocity intake with strainers, 2) new raw water pumping station, 3) ozone or chlorine dioxide treatment, 4) contact vessel, 5) residual chlorination of the pumped flow and 6) reverse flow pigging.

   b. Latest concept includes provision of 1) three normal velocity intake lines, 2) chlorine dioxide addition at each intake entry, 3) removable intake crib, 4) air line locator pipe at intake entry, 5) raw water sampling capability, 6) conversion of chlorination room into one which will be suitable to produce and feed chlorine dioxide, 7) pressure reduction facility for lake housing and new housing 8) plug flow chlorine contact vessel (pipeline) with chlorination booster system and 9) ability to reverse pig the pipelines.

c. The change was primarily a result of the Depot's concerns that high velocity intake may need considerable maintenance and may become subject to plugging or restriction by Frazil Ice.

2. In completing the feasibility report, it should be C.T. Male Associates' goal to produce a product similar to a 35% design submittal generally received by the Army. A full description of the system with Basis of Design and space requirements identified should be provided.

3. Vendor information shall be contained in the final report, especially relative to chlorine dioxide feed system.

4. Calculations will be provided for contact time using two stage chlorine dioxide injection and to determine whether existing PRV is large enough to serve new housing as well as lake housing. Plug flow reactor calculations will be provided along with booster chlorination system sizing if required.

5. Provide for placement of a turbidmeter, continuously reading, in the improvements. Verification of extreme lake levels must also be completed. Contact of Barge Canal operators was recommended. Depot confirmed that the greatest pumping rate would be one pump at a time (650-700 gpm). These factors will be used to determine chlorine contact time available in intake, wetwell and discharge pipeline and determine whether there is a need for additional contact chamber.

6. An estimated construction cost should be provided in detail and should be structured into three main areas reflecting potential segmentation of project in construction phase.

   a. Intake, chemical feed line and air line (i.e., all underwater elements subject to Corps permit).
   b. Chlorine Dioxide system.
   c. Pressure Reduction, Plug Flow pipe line and booster chlorination as necessary.

7. All parties felt that the report submitted to date could be salvaged with some wording changes to direct the reader to the selected conclusions and recommendations and addition of a section to report on the recommendation.

8. Depot noted two report corrections to be made to draft report. On page 7 change "laboratory" to "lavatory" and on page 8 change text on booster station to reflect periodic operation during peak use times and to fill the towers on the Depot. In addition, all parties would like to know actual composition of chlorine dioxide (chem. formula).

B. DESIGN SCOPE/PROPOSAL

9. Design should proceed, upon authorization by delivery order, in a manner to allow great flexibility in separation of the three segments noted in Item 6 above. Each item could be awarded individually. Primary reason: permit time may be excessive on the lake construction aspects of the project and Depot may have ability to undertake some aspect of project on their own.

10. In design of the intake crib it would be best to provide three different cribs, each handleable by a diver and each easily attached and detached from its mounts on the lake bottom. An exit hatch of some type should be provided for the pig to escape. Depot noted that research is finding that finer mesh and smaller openings tend to collect more zebra mussels. We should keep the mesh at a size to limit collection of mussels on the cribs, yet small enough to keep fish and debris out of the intake. To prevent entry of smaller debris and fish each pump should be equipped with strainer basket.

11. All parties agreed that scope of design phase should be developed as soon as possible and submitted for review by Army District and Seneca Army Depot. Scope will consider that the design will be at 35% level going into Agreement. Design cost proposal can be developed following scope concurrence. At 65% design completion, both

parties should get another shot at review of documents. The review will be undertaken by several personnel followed by major meeting to discuss design and comments. The 65% review documents will include all functional and technical aspects of project along with detailed construction cost estimate.

12. A biddable document review (90% phase) will be completed by both parties with comment period and revision period to follow. The 100% documents used for bidding will include resolution of all comments previously offered by reviewers.

13. C.T. Male Associates should assist and coordinate regulatory agency submittals on behalf of the Depot. In every case the materials to be submitted to regulatory agencies shall be previewed by the Depot.

14. For design information Depot indicated the original 1942 contract drawings are the most accurate dimensionally. The 1991 drawings depict the station in the way it should be when a contractor arrives to perform the construction work of this contract.

15. Permit options - Depot could make preliminary application on Army Corps permit or the contractor could be required to make application by contract.

16. Soil information was available from Depot. Mr. Absolom provided Geotechnical Report Contract DACA65-87-C-0042. This is Depot's only copy; return to Steve when finished extracting information.

17. Pressure reducing valve information was provided to C.T. Male.

18. Survey and Bathymetric information is complete.

19. Schedule for receipt of report and scope of design is February 19,1993.

If any recipient of this meeting memo should identify any inaccuracies in the above documentation, contact the undersigned as soon as possible.

Gary R. McCollum

Gary R. McCollum, P.E.

GRM/sm

APPENDIX C

SURFACE WATER TREATMENT - CHAPTER 3

3

Requirements for Systems to Avoid Filtration

As of 1989, approximately 3000 public water systems in the United States used surface water sources without filtration. In order for these systems to continue to avoid filtration, they must operate stringent programs of maintaining source water quality and site-specific conditions (see below). In addition, much more monitoring will be required: monitoring will be more frequent, covering more parameters, and under more specific conditions than are currently required. Systems that initially fail to meet these new requirements, or fail to meet them in the future, will have to filter.

The specific requirements that must be met by a system to be eligible for continued operation without the use of filtration are divided into the following categories:

- Source water quality conditions
  —source water coliform contamination level and
  —source water turbidity level.
- Site-specific conditions
  —adequacy of the disinfection treatment process,
  —reliability of disinfection treatment equipment,
  —maintenance of disinfectant residual in water entering the distribution system,
  —maintenance of an adequate disinfectant residual in the distribution system,
  —maintenance of a watershed control program,

—annual on-site inspection,
—no identified waterborne disease outbreaks,
—compliance with the MCL for total coliforms, and
—compliance with the MCL for TTHMs.

DETAILS OF SPECIFIC REQUIREMENTS

Source Water Coliform Level

References:* §141.71(a)(1)
§141.74(a)(1) and (a)(2)
§141.74(b)

- Representative samples of the source water must be regularly collected at a point immediately prior to the first, or only, point of disinfection application.
- The minimum number of samples that must be collected each week the system serves water to the public is shown in Table 3-1.
- If a system is required to collect more than one sample per week, the samples must be collected on separate days.
- The analytical methods to be used are detailed in §141.74(a)(1) and (2) of the regulation.
- A system may have analyses performed for either fecal coliforms or total coliforms or both. If both are measured, the limit on fecal coliform must be met.
- At least 90 percent of the source water samples analyzed during the previous six months that the system served water to the public on an ongoing basis must have coliform concentrations equal to or less than 20/100 mL for fecal coliforms and 100/100 mL for total coliforms.
- Each day the raw water turbidity exceeds 1 NTU, an additional raw water sample must be collected for coliform analysis (see source water turbidity level requirements). These samples may be counted as part of the total weekly samples.

Source Water Turbidity

References: §141.71(a)(2)
§141.74(a)(4) and (b)(2)

- Turbidity measurements must be made regularly on representative grab samples of source water immediately prior to the first or only point of disinfection application.
- Samples must be collected at least once every four hours that the system serves water to the public.
- A system may substitute continuous turbidity monitoring for grab sampling if the monitoring equipment is calibrated on a regular basis, using a procedure approved by the state.
- The analytical method to be used is detailed in §141.74(a)(4) of the regulation.

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*All references in this chapter are to Title 40, *Code of Federal Regulations* (40 CFR). See also *Federal Register*, June 29, 1989 (54:124:27486–27541).

Table 3-1 Number of Samples to Be Collected for Coliform Analysis

Population Served	Samples per Week*
<500	1
501–3300	2
3301–10,000	3
10,001–25,000	4
>25,000	5

Source: Federal Register, *June 29, 1989.*

*Must be collected only during weeks in which the system serves water to the public.

- Each day the system serves water to the public and the turbidity of the source water exceeds 1 NTU, one raw water sample must be collected for fecal coliform or total coliform analysis. These samples may be used to count toward the weekly raw water sampling requirement.

The state may waive the requirement for this sample if it determines that, for reasons outside the system's control, the coliform sample could not be analyzed within 30 h after collection.

- Generally speaking, the raw water turbidity level can at no time exceed 5 NTU. However, the state may allow a system to exceed this level if *both* of the following conditions are met:

—the state determines the excess turbidity was caused by circumstances that were unusual and unpredictable and

—counting the current instance of excess turbidity, there have been not more than the following number of "events" in which the source water turbidity exceeded 5 NTU while the system served water to the public:

–not more than two in the past 12 months or

–not more than five in the past 120 months.

NOTE: An event occurs when, on "a series of consecutive days," at least one turbidity reading each day exceeds 5 NTU. The SWTR defines a series of consecutive days as one day or more than one consecutive days.

Disinfection Treatment Process

References: §141.71(b)(1)(i)
§141.72(a)(1)
§141.74(b)(3)(i)–(v)

- The disinfection treatment process used by a nonfiltering surface water system must ensure 99.9 percent (3-log) inactivation of *Giardia* cysts and 99.99 percent (4-log) inactivation of viruses. This is done by maintaining disinfectant residuals and contact times prescribed by the SWTR.
- A system must calculate the *CT* value(s) each day water is served to the public to determine whether the value is sufficient to meet the specified inactivation levels. The procedure for calculating the *CT* value is summarized in chapter 2.
- The inactivation levels must be met *every day* the system serves water to the public, except any one day each month.
- The system must, on a continuing basis, meet these conditions at least *11 of every 12 months* that the system served water to the public. The only exception is if a system fails to meet the requirements during 2 of the 12 months and the

state determines that at least one of the failures was caused by unusual or unpredictable circumstances.

Disinfection Treatment Equipment

References: §141.71(b)(1)(ii)
§141.72(a)(2)

- To ensure reliability, the disinfection system used by a public water system must have either:

—redundant components, including an auxiliary power supply with automatic startup and alarm, to ensure that disinfectant is applied continuously while water is being delivered to the distribution system; or

—a component that will automatically shut off delivery of water to the distribution system whenever there is less than a 0.2 mg/L disinfectant residual in the water. This alternative cannot be used if the state determines that automatic shutoff would pose an unreasonable risk to health or would interfere with fire protection.

Disinfectant Residual in Water Entering the Distribution System

References: §141.71(b)(1)(iii)
§141.72(a)(3)
§141.74(a)(5) and (b)(5)

- The disinfectant residual of water entering the distribution system must be monitored continuously by systems serving a population of more than 3300.
- If the continuous monitoring equipment fails, grab samples may be collected every four hours, but for no more than five working days following the equipment failure.
- Systems serving 3300 or less may take grab samples on an ongoing basis, in place of continuous monitoring. Samples must be collected at the frequencies given in Table 3-2.
- If at any time the disinfectant residual falls below 0.2 mg/L in a system using grab samples, the system must take additional grab samples every four hours until the residual is equal to or greater than 0.2 mg/L.

All systems. The disinfectant residual in water entering the distribution system cannot be less than 0.2 mg/L for more than four hours during periods when the system serves water to the public. The only exception is if the state determines that a failure was caused by unusual or unpredictable circumstances.

Table 3-2 Sampling Frequency for Disinfectant Residual in Water Entering the Distribution System

Population Served	Samples per Day*
<500	1
501–1000	2
1001–2500	3
2501–3300	4

Source: Federal Register, *June 29, 1989*

*Samples must be taken at intervals prescribed by the state.

- Any time the disinfectant residual concentration falls below 0.2 mg/L, the system must notify the state.
- Methods of analysis to be used for various disinfectants are detailed in §141.74(a)(5) of the SWTR.

Disinfectant Residual in the Distribution System

References: §141.71(b)(1)(iv)
§141.72(a)(4)
§141.74(a)(3), (a)(5), and (b)(6)

- The disinfectant residual must be measured at least at the same points in the distribution system and at the same time as total coliforms are sampled. Details of coliform monitoring frequencies are included in appendix B.
- A state may allow a system that uses both surface water and groundwater to take disinfectant residual samples at points other than the coliform sampling points if those points are more representative of the quality of the disinfected water within the system.
- The disinfectant residual in the distribution system must be measured as total chlorine, combined chlorine, or chlorine dioxide.
- Methods of analysis to be used for disinfectant residual are detailed in §141.74(a)(5) in the regulation.
- Disinfectant residuals in the distribution system cannot be undetectable in more than 5 percent of the samples each month, for any two consecutive months that water is served to the public.
- A system may substitute heterotrophic plate count (HPC) analyses for some required distribution system residual disinfectant measurements. An HPC concentration less than or equal to 500/mL means the water can be considered to have a "detectable disinfectant residual" for the purposes of determining compliance with this requirement.
- The number of HPC analyses a system may use in place of disinfectant residual measurements can be computed by use of the following formula:

$$V = \frac{A + B + C}{\text{number of residual measurements} + \text{number of HPC substitutions analyzed}} \times 100 \qquad \text{(Eq 3-1)}$$

Where:

A = the number of samples with no disinfectant residual and no HPCs measured

B = the number of samples with no disinfectant residual and HPC >500/mL

C = the number of samples with disinfectant residual not measured and HPC >500/mL

- The value of V in the formula cannot exceed 5 percent in one month, for any two consecutive months.
- The method to be used for HPC analysis is referenced in §141.74(a)(3) of the regulation.

- For determining whether a system meets the criteria to avoid filtration, the state may waive this requirement (for monitoring the residual in the distribution system) if the failure to comply was not caused by a deficiency in treatment of the source water. In such cases, the system would still be in violation of a treatment technique requirement but would not be required to filter.
- The state may waive the requirements for monitoring the residual in the distribution system if the state

—determines, based on site-specific conditions, that a system has no means of having a sample transported and analyzed for HPC by a certified laboratory under the specified time and temperature conditions, and

—determines that the system is providing adequate disinfectant residual in the distribution system.

Watershed Control Program

Reference: §141.71(b)(2)

- Each nonfiltering surface water system must maintain a watershed control program that minimizes the potential for contamination by *Giardia* cysts and viruses in the source water.
- At a minimum, the program must

—characterize the watershed hydrology and land ownership,

—identify watershed characteristics and activities that may threaten or harm source water quality, and

—monitor activities that may threaten or harm source water quality.

- The system must demonstrate through ownership and/or written agreements with landowners within the watershed that it can control all human activities that may threaten or harm the microbiological quality of the water.
- The system must submit an annual report to the state describing its watershed control program (see Monitoring and Reporting Requirements, page 21).

Annual On-Site Inspection

Reference: §141.71(b)(3)

- The system's watershed control program and disinfection treatment process must be inspected on-site annually.
- The on-site inspection must be conducted by the state or a party approved by the state.
- The on-site inspection must

—review the effectiveness of the watershed control program,

—review the physical condition of the source intake and how well it is protected,

—review the system's equipment maintenance program to ensure there is little likelihood that the disinfection process will fail,

—inspect the disinfection equipment for physical deterioration,

—review operating procedures,

—review records to ensure that all required tests are being conducted and recorded and disinfection is effectively practiced, and

—identify improvements needed in equipment, system maintenance and operation, or data collection.

- A report of the on-site inspection must be prepared every year.
- The on-site inspection must show that the watershed control program and disinfection treatment process are adequately designed and maintained.

No Identified Disease Outbreaks

Reference: §141.71(b)(4)

- The system must not have been identified as a source of a waterborne disease outbreak. If the system has been identified as a source, the system must have been modified to prevent another occurrence. The required modifications are determined by the state.

Compliance With the MCL for Total Coliforms

References: §141.71(b)(5)
§141.63

- The public water system must comply, on an ongoing basis, with the MCL for total coliforms in at least 11 of the previous 12 months that water was served to the public. The state may make an exception if it determines that failure to meet the requirement was not caused by a deficiency in treatment.
- Total coliform monitoring and compliance details are detailed in §141.63 of the regulation.

Compliance With the MCL for Total Trihalomethanes

References: §141.12
§141.30
§141.71(b)(6)

- The system must comply with the requirements for THMs as detailed in §141.12 and §141.30 of the regulation.

MONITORING AND REPORTING REQUIREMENTS

Reference: §141.75

Surface water systems that do not filter must begin complying with new monitoring and reporting requirements by Dec. 30, 1990. The only exception is if the state has determined by Dec. 30, 1990, that the system must add filtration. In that case, the state may specify alternate monitoring requirements until filtration is in place.

Monthly Reports

Nonfiltering surface water systems file reports with the state each month. These reports must be filed within 10 days after the end of each month water is served to the public.* The information to be included on the reports is extensive; it is summarized in the following paragraphs.

Source water quality conditions. The report must give the name of the month or months covered by the report and the cumulative number of reports (the total number of monthly reports that have been submitted).

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*If the state has determined that filtration is required, it may specify alternative reporting until filtration is in place.

Fecal coliform and/or total coliform samples. Information regarding fecal coliform and total coliform analyses must include

- dates of sample collection,
- dates when turbidity exceeded 1 NTU,
- number of fecal coliform samples equal to or less than 20/100 mL, and
- number of total coliform samples equal to or less than 100/100 mL.

Previous samples. Information on samples collected during the previous six months water was served to the public must include

- total number of fecal coliform analysis samples,
- total number of total coliform analysis samples,
- total number of fecal coliform samples that were equal to or less than 20/100 mL,
- total number of total coliform samples that were equal to or less than 100/100 mL,
- percentage of fecal coliform samples that were equal to or less than 20/100 mL, and
- percentage of total coliform samples that were equal to or less than 100/100 mL.

Turbidity levels. The report must include the following information on turbidity levels measured during the month:

- maximum level measured during the month,
- date(s) for any measurements exceeding 5 NTU, and
- date(s) the measurements exceeding 5 NTU were reported to the state.

Number of events during which turbidity exceeded 5 NTU. If any turbidity measurement is greater than 5 NTU, more information must be given. This additional information relates to turbidity "events." Remember, an "event" occurs when, on one or more consecutive days, at least one turbidity reading each day exceeds 5 NTU.

During the first year of record keeping, information must include the total number of events and the date of each event. After the first year of record keeping, information must include the total number of events in the previous 12 months and the dates of each event in the previous 12 months. For the first 10 years of record keeping, the report must include the total number of events to date and the date of each event. After 10 years of record keeping, the report must show the total number of events in the previous 10 years and the date of each event during the previous 10 years.

Disinfection information. The report must give the residual disinfectant concentration in water entering the distribution system, including

- the lowest measurement for each day of the month,*
- the date and duration of each period when residual was below 0.2 mg/L, and

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*The state may waive the need for reporting this information. See Exceptions, page 23.

Special Reports

A system must report the following events to the state as soon as possible, but no later than by the end of the next business day:

- discovery that a waterborne disease outbreak may be traced to the water system,
- any turbidity measurement greater than 5 NTU, and
- any time the disinfectant residual of water entering the distribution system falls below 0.2 mg/L.

PUBLIC NOTIFICATION

The general public notification requirements may be found in §141.32 of the Primary Drinking Water Regulations (40 CFR). They include specific requirements for the frequency, manner, and content of notices and require the inclusion of USEPA-specified health effects information in each notice.

The regulation divides violations into two tiers, based on the seriousness of the violation.

Tier 1 violations that apply to nonfiltering systems include

- violations of an MCL, a treatment technique requirement, or a variance or exemption schedule;
- failure to meet requirements to avoid filtration, and filtration is not installed;
- failure to be operated by qualified personnel;
- failure to comply with the requirement that the turbidity level immediately prior to chlorination must not exceed 5 NTU; and
- the system is identified as a source of an outbreak of a waterborne disease.

Tier 2 violations that apply to nonfiltering systems include

- failure to comply with a testing procedure and operating under a variance or exemption and
- failure to comply with all of the analytical and monitoring requirements in §141.74.

The public notification requirements of §141.32 describe in detail the manner and frequency of notification and require the use of certain words (mandatory language) in the notice. The states may be more stringent, or consider special situations, so systems that must provide public notification should do it as directed by the state.

DEADLINES

Reference: §141.71(c)

By Dec. 30, 1991, states must determine which unfiltered surface water systems will be required to filter. If a state fails to meet this deadline, systems must still comply with the "objective" or "self-implementing" criteria (that is, the requirements that are clear and do not require state input), beginning Dec. 30, 1991.

When a state determines that an unfiltered system must add filtration, the filtration system must be installed within 18 months of that decision, or by June 29, 1993, whichever is later.

Beginning Dec. 30, 1991, if a nonfiltering system fails to meet *any one* of the source water quality or site-specific conditions, even if the system met all the conditions up to that point, it must install filtration and comply with the requirements for filtered systems within 18 months of the failure.

When a state determines that filtration is required for a particular system, it may specify source water or site-specific requirements for the period prior to installation of the filtration system.

IMPLEMENTATION DATES

The principal implementation dates for nonfiltering systems under the SWTR are

Dec. 30, 1990: Nonfiltering surface water systems must begin meeting new monitoring and reporting requirements.

Dec. 30, 1991: Nonfiltering systems must begin meeting all requirements to avoid filtration, unless the state has determined that they must add filtration. Whenever the state determines that filtration is required, it may specify interim requirements for the period prior to installation of filtration treatment.

June 29, 1993: Nonfiltering systems that are directed to add filtration must have filtration installed. The system may have filtration installed within 18 months of state determination or by June 29, 1993, whichever is later.

SUGGESTIONS FOR NONFILTERING SYSTEMS

Some suggestions for nonfiltering systems have been provided by USEPA and AWWA experts.

Start Early

The USEPA estimates that about 85 percent of the current unfiltered systems will not be able to meet the new requirements. About 50 percent of the systems currently not filtering are expected to add filtration to achieve compliance. The other 35 percent will probably either change to a groundwater source or will connect to another water system that is in compliance. Systems should start using the new monitoring methods on their own as soon as possible to see if they will be able to meet the new criteria. Those that wait and find in December 1991 that filtration is required may find it very difficult to progress through all the stages of design, approval, financing, and construction before the final deadline of June 1993.

Review Source Water Conditions

Systems should carefully review their water source to see if any improvements can be made to obtain the best possible water quality. Improvements that could be considered include tighter restrictions on human activity within the watershed; change of intake location; and construction of dams, reservoirs, or other control structures to reduce both turbidity and microorganisms.

Consider Disinfection Changes Carefully

If any changes in disinfectant type, feed rate, or application point will be necessary to meet the new requirements, consider the effect on disinfection by-products. The USEPA limits on disinfection by-products are almost certain to become more stringent, so a system that just meets the current TTHM requirements now may exceed the new requirements in a few years. Methods of improving disinfection without increasing disinfection by-products may include increased removal of precursors before the first disinfectant application, change in type of disinfectant, and improved disinfectant contact time (rather than increased dosage) in key sections of the treatment process.

Consider Improving Contact Time

Systems having trouble meeting the new *CT* values will generally have the choice of increasing the disinfectant concentration *C* or increasing the contact time *T*. In many cases, tanks and reservoirs were not originally designed with disinfectant contact time in mind, so they have very little, if any, baffling. The addition of baffles in such reservoirs may result in a significant reduction in chemical costs, improved plant operation, and, possibly, reduced levels of disinfection by-products. Even the construction of additional contact chambers might prove more cost-effective in the long run than increasing disinfectant feed.

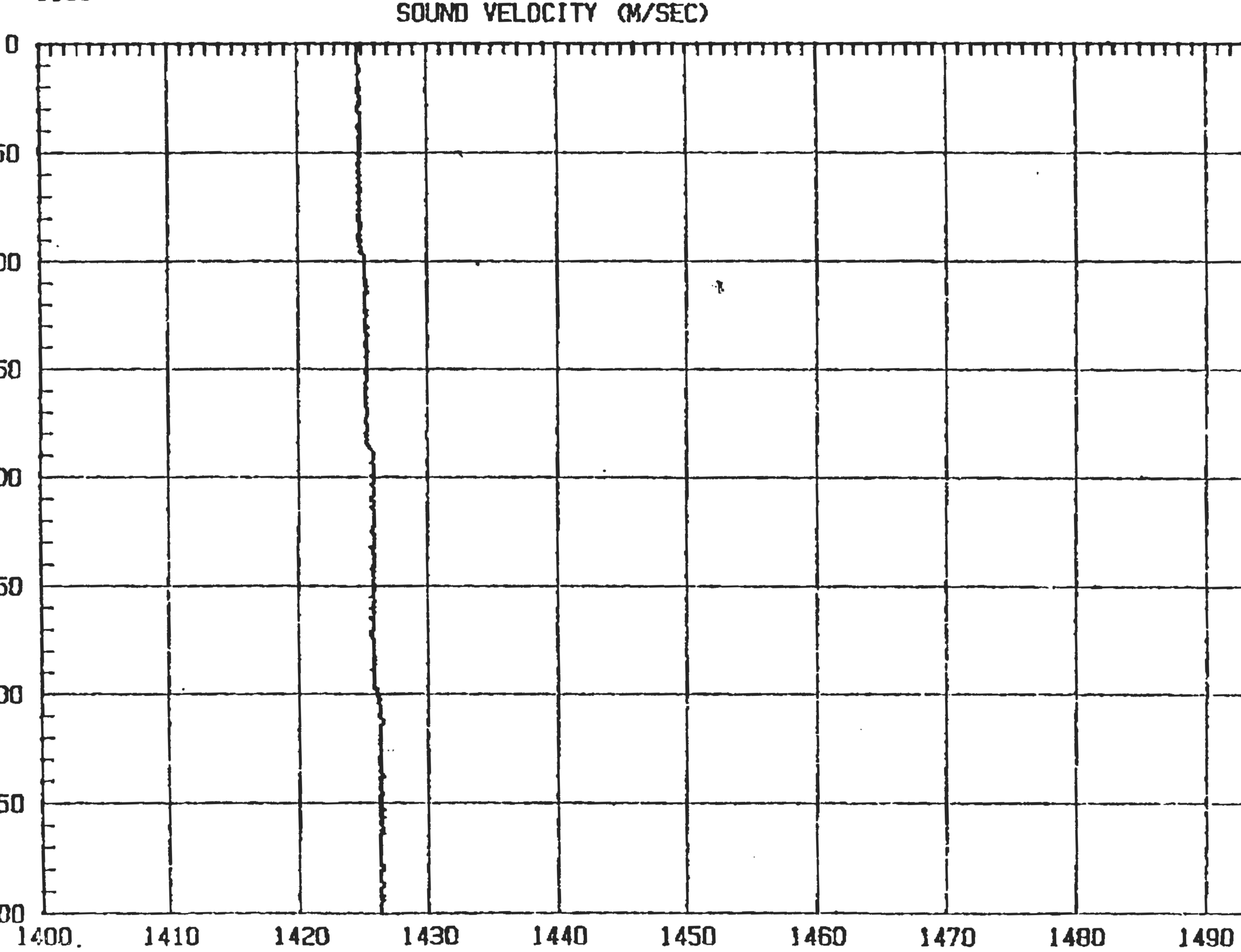
APPENDIX D

SENECA LAKE THERMAL PROFILES

SENECA LAKE SOUND SPEED PROFILE

19-DEC-89

1130



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SENECA LAKE SOUND SPEED TEMP PROFILE
APPLIED MICROSYSTEMS SVP-16 ser 3043
   19-DEC-89      1130

   DEPTH     SPEED      DEG     SPEED     DEG
    FT       M/SEC       C      FT/SEC    F
   -----     ------     ---     ------    ----
       .7    1424.9     4.5     4674.9    40.1
      7.2    1424.7     4.5     4674.2    40.1
     17.1    1424.7     4.5     4674.2    40.1
     24.0    1424.9     4.4     4674.9    39.9
     32.4    1424.7     4.5     4674.2    40.1
     48.2    1424.9     4.4     4674.9    39.9
     55.1    1424.7     4.5     4674.2    40.1
     65.5    1424.7     4.5     4674.2    40.1
     75.9    1424.9     4.5     4674.9    40.1
     81.0    1424.7     4.4     4674.2    39.9
     90.2    1424.7     4.4     4674.2    39.9
    101.4    1425.2     4.4     4675.9    39.9
    111.5    1425.4     4.5     4676.5    40.1
    120.4    1425.2     4.5     4675.9    40.3
    130.2    1425.4     4.5     4676.5    40.1
    138.1    1425.4     4.5     4676.5    40.1
    144.4    1425.2     4.4     4675.9    39.9
    152.6    1425.4     4.4     4676.5    39.9
    162.4    1425.2     4.5     4675.9    40.1
    170.3    1425.4     4.5     4676.5    40.1
    178.5    1425.4     4.5     4676.5    40.1
    185.7    1425.6     4.5     4677.2    40.1
    197.2    1425.9     4.5     4678.1    40.1
    204.7    1425.9     4.5     4678.1    40.1
    212.9    1425.9     4.4     4678.1    39.9
    222.4    1425.9     4.5     4678.1    40.1
    228.3    1425.9     4.5     4678.1    40.1
    237.2    1425.9     4.4     4678.1    39.9
    245.1    1425.9     4.5     4678.1    40.1
    253.5    1425.9     4.5     4678.1    40.1
    261.8    1425.9     4.5     4678.1    40.1
    269.7    1425.9     4.5     4678.1    40.1
    275.6    1425.9     4.5     4678.1    40.1
    283.5    1425.9     4.5     4678.1    40.1
    291.7    1425.9     4.5     4678.1    40.1
    297.2    1426.1     4.5     4678.8    40.1
    305.1    1426.3     4.4     4679.5    39.9
    313.3    1426.6     4.5     4680.4    40.1
    320.9    1426.3     4.5     4679.5    40.1
    326.8    1426.3     4.4     4679.5    39.9
    335.6    1426.3     4.4     4679.5    39.9
    344.2    1426.3     4.5     4679.5    40.1
    351.7    1426.3     4.5     4679.5    40.1
    358.3    1426.3     4.5     4679.5    40.1
    365.5    1426.3     4.4     4679.5    39.9
    373.4    1426.3     4.4     4679.5    39.9
    380.2    1426.3     4.5     4679.5    40.1
    387.8    1426.6     4.4     4680.4    39.9
    393.4    1426.3     4.4     4679.5    39.9
    401.2    1426.3     4.4     4679.5    39.9
    406.5    1425.9     4.4     4678.1    39.9
    415.4    1425.9     4.4     4678.1    39.9
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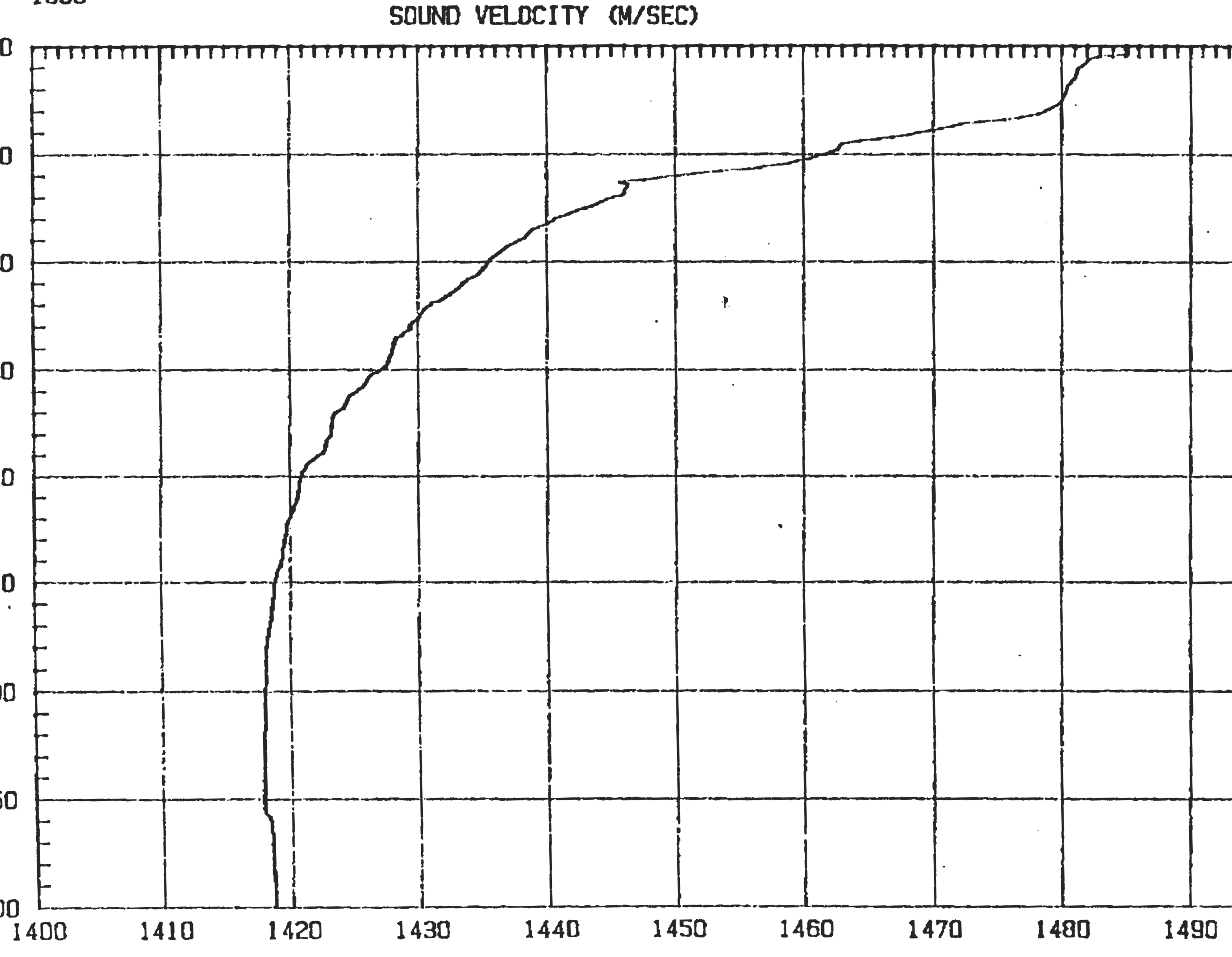
SENECA LAKE SOUND SPEED PROFILE

8-27-90

1000



SENECA LAKE SOUND SPEED TEMP PROFILE
8-27-90 1000

DEPTH FT	SPEED M/SEC	DEG C	SPEED FT/SEC	DEG F
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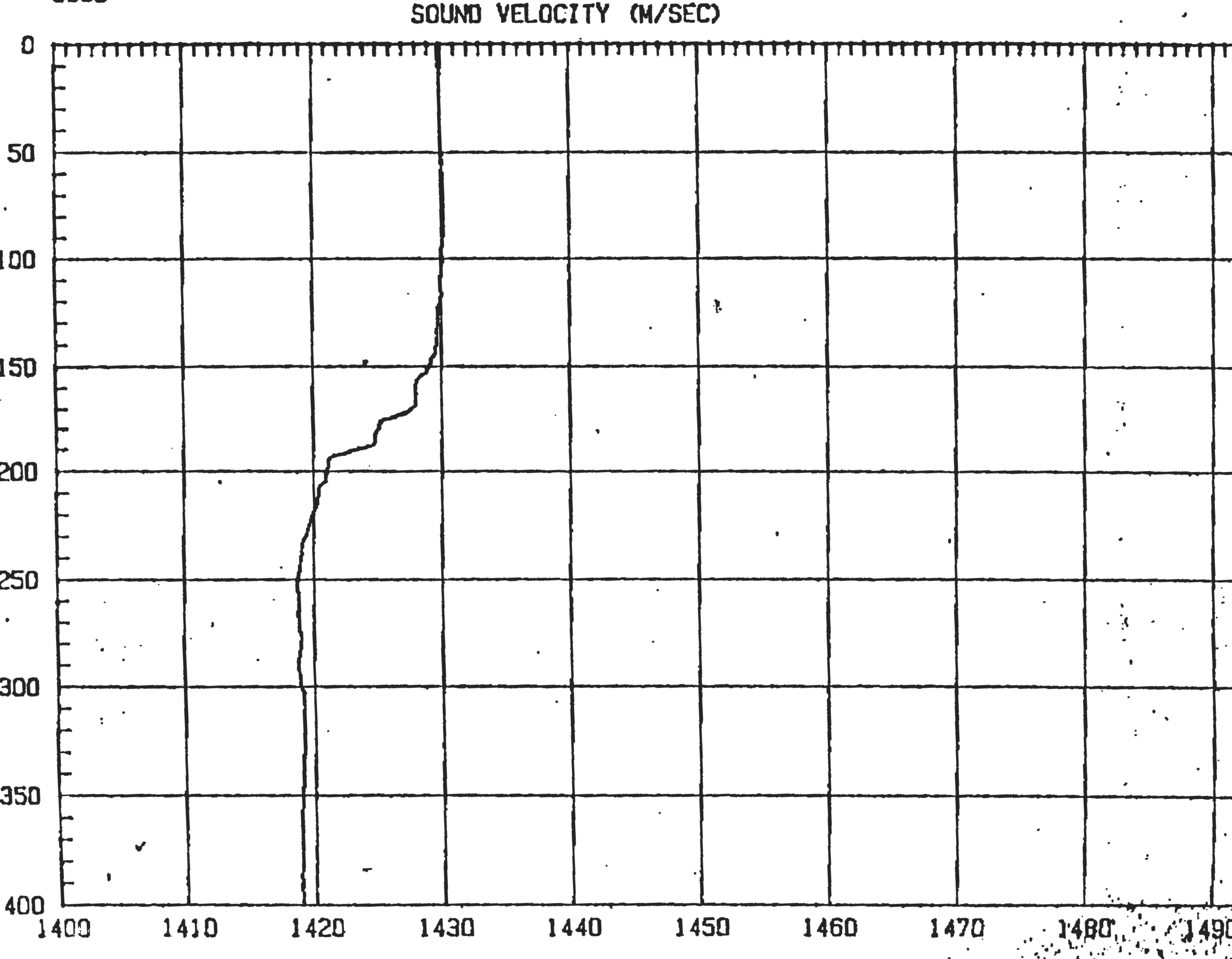
10	1481.3	19.6	4860.0	67.2
20	1480.3	19.3	4856.8	66.8
30	1478.7	19.0	4851.3	66.2
40	1468.9	16.5	4819.1	61.7
50	1461.7	14.5	4795.5	58.1
60	1450.2	11.4	4757.9	52.5
70	1445.1	10.0	4741.2	50.1
80	1440.6	9.0	4726.4	48.1
90	1437.9	8.3	4717.4	47.0
100	1435.4	7.7	4709.4	45.9
110	1433.4	7.3	4702.9	45.1
120	1430.9	6.7	4694.7	44.0
130	1429.4	6.3	4689.6	43.4
140	1428.0	6.0	4684.9	42.8
150	1427.1	5.8	4681.9	42.4
160	1425.2	5.4	4675.8	41.7
170	1423.5	5.0	4670.4	41.0
180	1423.2	4.9	4669.2	40.9
190	1422.2	4.7	4665.9	40.5
200	1420.8	4.4	4661.6	39.9
210	1420.5	4.3	4660.5	39.8
220	1419.9	4.2	4658.6	39.6
230	1419.5	4.1	4657.2	39.4
240	1419.3	4.1	4656.4	39.3
250	1418.7	3.9	4654.6	39.1
260	1418.6	3.9	4654.1	39.0
270	1418.4	3.9	4653.4	39.0
280	1418.1	3.8	4652.6	38.9
290	1418.0	3.8	4652.3	38.8
300	1418.0	3.8	4652.2	38.8
310	1418.0	3.8	4652.2	38.8
320	1417.9	3.8	4651.8	38.8
330	1417.9	3.8	4651.8	38.8
340	1417.8	3.8	4651.7	38.8
350	1417.8	3.8	4651.7	38.6
360	1418.4	3.9	4653.6	39.0
370	1418.5	3.9	4653.8	39.0
380	1418.6	3.9	4654.1	39.0
390	1418.6	3.9	4654.2	39.1
400	1418.5	3.9	4654.1	39.0
410	1418.8	4.0	4654.9	39.1

SENECA LAKE SOUND SPEED PROFILE

12-DEC-80

0830



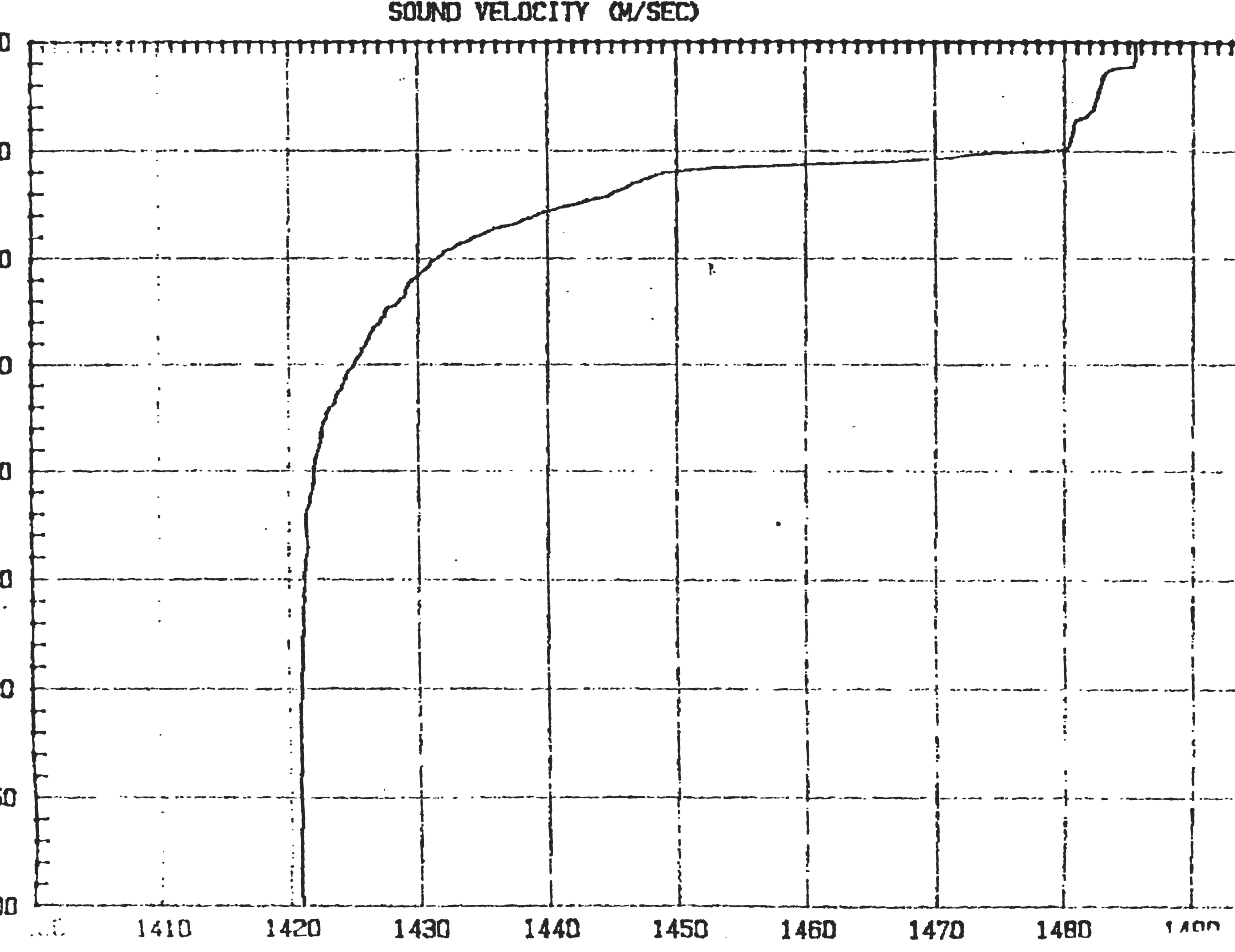
SENECA LAKE SOUND SPEED TEMP PROFILE

12-DEC-90 0830

DEPTH FT	SPEED M/SEC	DEG C	SPEED FT/SEC	DEG F
0	1429.8	6.4	4691.0	43.6
10	1429.9	6.4	4691.2	43.6
20	1430.0	6.5	4691.5	43.6
30	1430.0	6.5	4691.6	43.6
40	1430.0	6.5	4691.7	43.7
50	1430.1	6.5	4692.0	43.7
60	1430.1	6.5	4692.0	43.7
70	1430.2	6.5	4692.3	43.7
80	1430.2	6.5	4692.4	43.8
90	1430.2	6.5	4692.1	43.7
100	1430.1	6.5	4692.0	43.7
110	1429.9	6.5	4691.3	43.6
120	1430.0	6.5	4691.5	43.6
130	1429.7	6.4	4690.8	43.5
140	1429.6	6.4	4690.4	43.5
150	1429.1	6.3	4688.6	43.3
160	1428.1	6.0	4685.2	42.8
170	1427.6	5.9	4683.9	42.7
180	1425.2	5.4	4675.8	41.7
190	1423.6	5.0	4670.5	41.0
200	1421.1	4.5	4662.4	40.0
210	1420.4	4.3	4660.2	39.8
220	1419.9	4.2	4658.6	39.6
230	1419.4	4.1	4656.8	39.4
240	1419.1	4.0	4655.7	39.2
250	1418.7	3.9	4654.6	39.1
260	1418.9	4.0	4655.1	39.1
270	1418.9	4.0	4655.2	39.2
280	1419.1	4.0	4655.7	39.2
290	1418.8	4.0	4654.9	39.1
300	1419.1	4.0	4655.7	39.2
310	1419.3	4.1	4656.4	39.3
320	1419.2	4.0	4656.1	39.3
330	1419.2	4.1	4656.3	39.3
340	1419.1	4.0	4655.9	39.2
350	1419.0	4.0	4655.5	39.2
360	1418.9	4.0	4655.3	39.2
370	1418.9	4.0	4655.3	39.2
380	1418.9	4.0	4655.3	39.2
390	1419.0	4.0	4655.5	39.2
400	1419.0	4.0	4655.6	39.2

SENECA LAKE SOUND SPEED PROFILE

8-30-81
0830



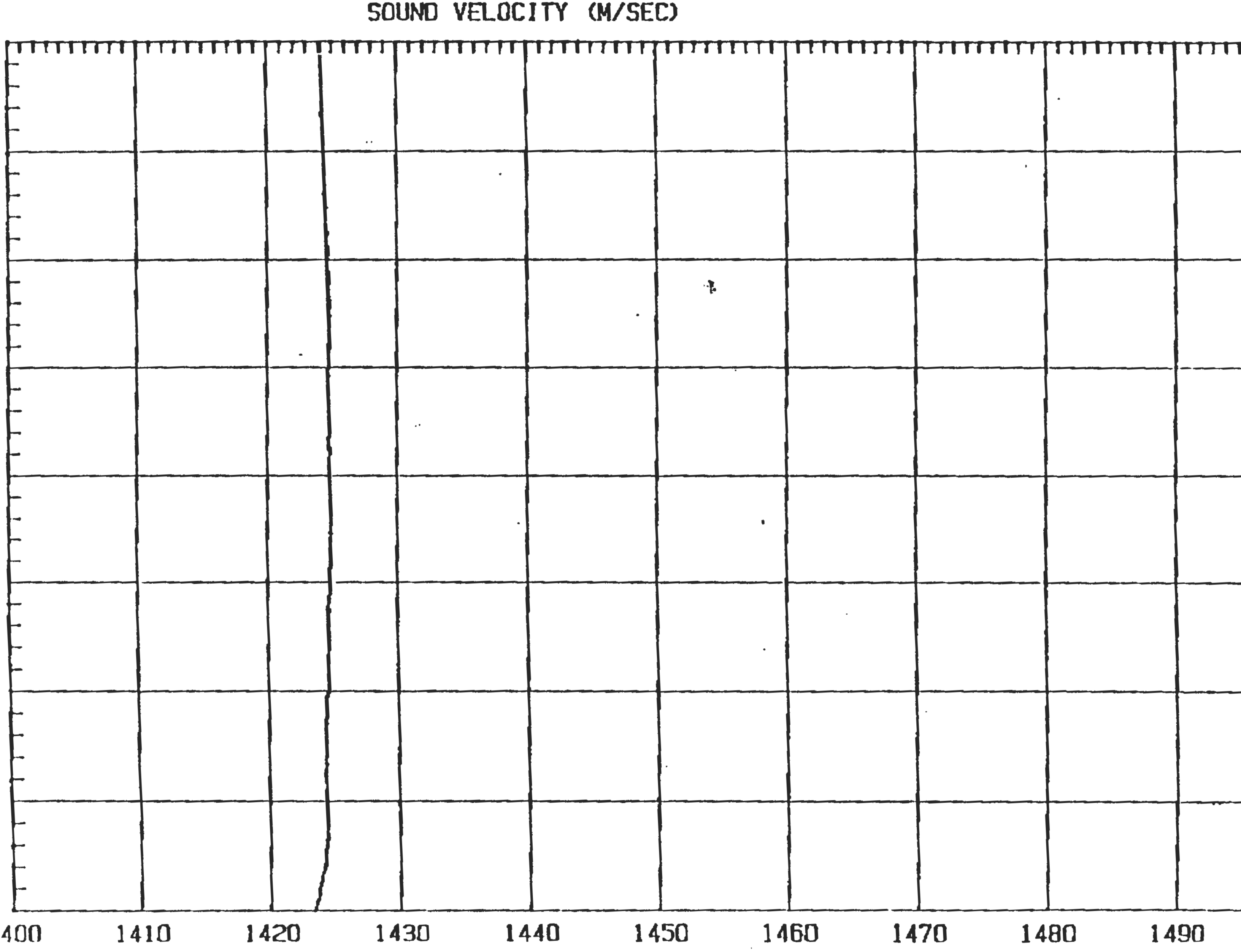
ENECA LAKE SOUND SPEED TEMP PROFILE
8-30-91 0830

DEPTH FT	SPEED M/SEC	DEG C	SPEED FT/SEC	DEG F
0	1485.6	20.4	4873.9	68.8
10	1485.4	20.4	4873.5	68.8
20	1482.8	19.9	4864.9	67.8
30	1482.3	19.8	4863.3	67.6
40	1480.8	19.4	4856.1	67.0
50	1478.8	19.0	4851.7	66.2
60	1449.0	11.1	4754.1	51.9
70	1444.9	10.0	4740.4	49.9
80	1439.1	8.6	4721.5	47.5
90	1434.4	7.5	4706.0	45.5
100	1431.4	6.8	4696.2	44.2
110	1429.5	6.4	4690.1	43.5
120	1428.6	6.1	4687.0	43.0
30	1427.1	5.8	4682.1	42.4
140	1426.0	5.6	4678.4	42.0
150	1425.1	5.3	4675.4	41.6
60	1424.2	5.1	4672.4	41.3
70	1423.2	4.9	4669.3	40.9
180	1422.6	4.8	4667.3	40.6
190	1422.3	4.7	4666.3	40.5
00	1422.0	4.7	4665.2	40.4
210	1421.8	4.6	4664.7	40.3
220	1421.3	4.5	4663.2	40.1
30	1421.4	4.5	4663.3	40.2
240	1421.3	4.5	4653.1	40.1
250	1421.2	4.5	4662.7	40.1
260	1421.1	4.5	4662.5	40.1
270	1421.1	4.5	4662.4	40.0
280	1421.0	4.4	4662.1	40.0
290	1421.0	4.4	4662.0	40.0
300	1420.9	4.4	4661.7	40.0
310	1420.8	4.4	4661.4	39.9
320	1420.8	4.4	4661.6	39.9
330	1420.8	4.4	4661.6	39.9
340	1420.8	4.4	4661.6	39.9
350	1420.8	4.4	4661.6	39.9
360	1420.8	4.4	4661.4	39.9
370	1420.7	4.4	4661.2	39.9
380	1420.8	4.4	4661.3	39.9
390	1420.8	4.4	4661.6	39.9
400	1420.9	4.4	4661.8	40.0
410	1421.1	4.5	4662.3	40.0

SENECA LAKE SOUND SPEED PROFILE

6-JAN-92

0830



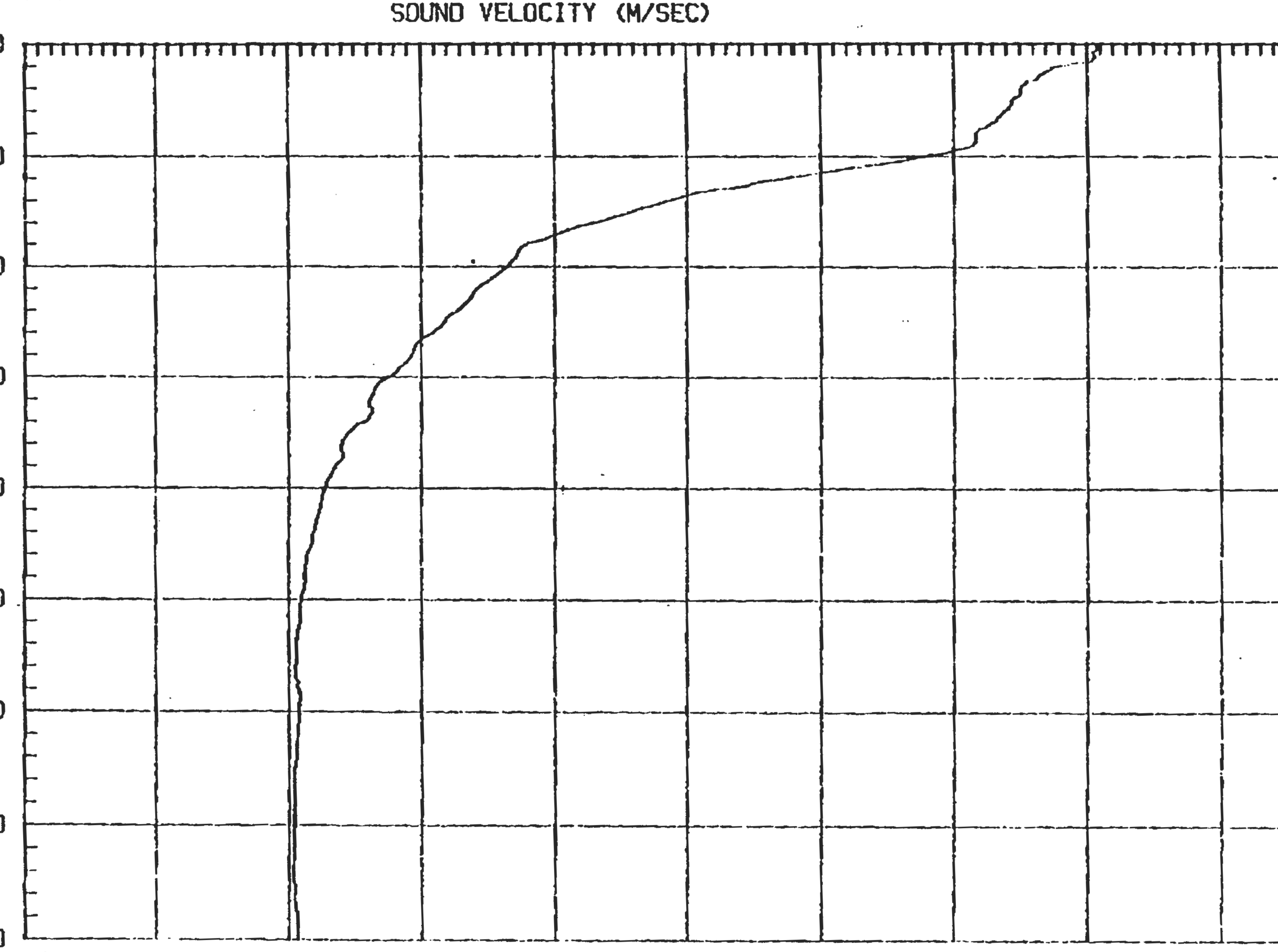
SENECA LAKE SOUND SPEED TEMP PROFILE
6-JAN-92 0830

DEPTH FT	SPEED M/SEC	DEG C	SPEED FT/SEC	DEG F
0	1424.0	5.1	4671.9	41.2
10	1424.2	5.2	4672.6	41.3
20	1424.2	5.2	4672.7	41.3
30	1424.3	5.2	4672.8	41.3
40	1424.3	5.2	4673.0	41.3
50	1424.4	5.2	4673.1	41.3
60	1424.4	5.2	4673.4	41.4
70	1424.4	5.2	4673.4	41.4
80	1424.5	5.2	4673.7	41.4
90	1424.6	5.2	4673.9	41.4
100	1424.7	5.3	4674.1	41.5
110	1424.7	5.3	4674.3	41.5
120	1424.8	5.3	4674.5	41.5
130	1424.8	5.3	4674.6	41.5
140	1424.7	5.3	4674.3	41.5
150	1424.7	5.3	4674.2	41.5
160	1424.7	5.3	4674.2	41.5
170	1424.7	5.3	4674.3	41.5
180	1424.8	5.3	4674.5	41.5
190	1424.8	5.3	4674.6	41.5
200	1424.8	5.3	4674.5	41.5
210	1424.8	5.3	4674.6	41.5
220	1424.9	5.3	4674.9	41.6
230	1424.9	5.3	4674.8	41.5
240	1424.9	5.3	4674.8	41.5
250	1424.8	5.3	4674.5	41.5
260	1424.7	5.3	4674.1	41.5
270	1424.7	5.3	4674.2	41.5
280	1424.7	5.3	4674.1	41.5
290	1424.6	5.2	4673.9	41.4
300	1424.7	5.3	4674.1	41.5
310	1424.4	5.2	4673.3	41.4
320	1424.3	5.2	4673.0	41.3
330	1424.4	5.2	4673.1	41.3
340	1424.4	5.2	4673.1	41.3
350	1424.4	5.2	4673.3	41.4
360	1424.4	5.2	4673.3	41.4
370	1424.3	5.2	4672.8	41.3
380	1424.2	5.1	4672.4	41.3
390	1423.7	5.0	4670.9	41.1
400	1423.4	5.0	4669.9	40.9

SENECA LAKE SOUND SPEED PROFILE

8-27-92

0830



SENECA LAKE SOUND SPEED TEMP PROFILE
8-27-92 0830

DEPTH FT	SPEED M/SEC	DEG C	SPEED FT/SEC	DEG F
0	1481.1	19.5	4859.2	67.1
10	1478.1	18.9	4849.4	66.0
20	1475.1	18.2	4839.6	64.8
30	1473.9	18.0	4835.6	64.3
40	1471.6	17.3	4828.2	63.2
50	1467.8	16.2	4815.5	61.1
60	1457.1	13.2	4780.6	55.8
70	1448.5	10.9	4752.2	51.7
80	1443.0	9.5	4734.1	49.1
90	1437.9	8.3	4717.4	47.0
100	1436.5	8.0	4712.9	46.4
110	1434.2	7.5	4705.4	45.4
120	1432.7	7.1	4700.6	44.8
130	1430.9	6.7	4694.6	44.0
140	1429.3	6.3	4689.4	43.4
150	1427.6	5.9	4683.7	42.6
160	1426.2	5.6	4679.2	42.1
170	1425.8	5.5	4677.7	41.9
180	1424.1	5.1	4672.2	41.2
190	1423.6	5.0	4670.5	41.0
200	1422.8	4.8	4668.0	40.7
210	1422.4	4.8	4666.7	40.6
220	1422.0	4.7	4665.2	40.4
230	1421.5	4.5	4663.6	40.2
240	1421.3	4.5	4662.9	40.1
250	1421.0	4.4	4662.0	40.0
260	1420.9	4.4	4661.7	40.0
270	1420.6	4.4	4660.9	39.9
280	1420.5	4.3	4660.4	39.8
290	1420.8	4.4	4661.3	39.9
300	1420.8	4.4	4661.4	39.9
310	1420.7	4.4	4661.2	39.9
320	1420.6	4.4	4660.9	39.9
330	1420.4	4.3	4660.2	39.8
340	1420.5	4.3	4660.5	39.8
350	1420.5	4.3	4660.4	39.8
360	1420.4	4.3	4660.2	39.8
370	1420.4	4.3	4660.2	39.8
380	1420.5	4.3	4660.5	39.8
390	1420.7	4.4	4661.2	39.9
400	1420.7	4.4	4661.2	39.9

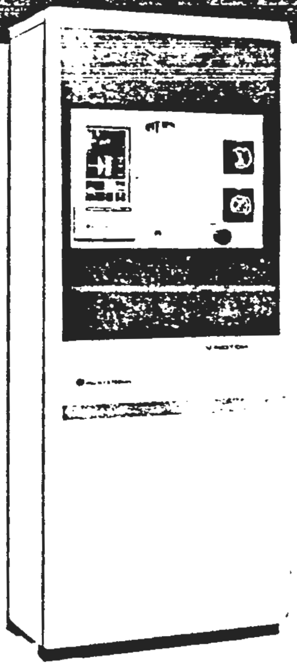
APPENDIX E

VENDOR DATA - CHLORINE DIOXIDE FEED

WALLACE & TIERNAN

CHLORINE DIOXIDE SYSTEMS

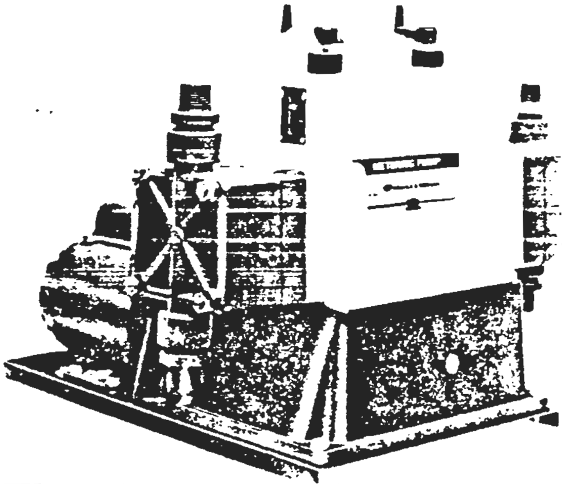
Series 85-200



These Wallace & Tiernan Systems generate chlorine dioxide from chlorine, sodium chlorite, and diluted hydrochloric acid. They are designed to produce chlorine dioxide with optimum efficiency and to meter the solution directly to the process.

CHLORINE DIOXIDE AND WATER TREATMENT

Chlorine dioxide has been used for many years in water treatment systems for the elimination of chlorophenols; the oxidation of iron and manganese; and in the control of taste, odor, and color. The oxidation-reduction potential of chlorine dioxide is approximately that of chlorine. It has strong bactericidal and viricidal properties; and these properties remain essentially undiminished in the presence of ammonia and most other nitrogen compounds. In applications with high ammonia content, chlorine dioxide will react rapidly with the oxidizable material without combining with the ammonia. The EPA recognizes chlorine dioxide as an acceptable alternative to chlorine for use as a primary disinfectant. It is especially suited to those situations where the formation of trihalomethanes (THM's) is a critical consideration.



APPLICATIONS

- Primary disinfectant for water treatment.
- Pre-treatment for oxidation and removal of iron and manganese.
- Post-treatment for destruction of phenol and chlorophenol compounds that produce odors and affect taste.
- Control of contaminant bacteria and organics in situations where significant ammonia is present.
- Control of slime, bacteria, and viruses in applications where chlorine is unacceptable.

CAT. FILE 85.200
Revised 9-99

FEATURES

WIDE RANGE OF FEED RATE CAPACITIES

- Model 85-200L low capacity systems with supplemental acid feed are available in ten standard capacities: 17, 34, 51, 85, 127, and 170 lb of chlorine dioxide per day with single-tower generator; 255 and 340 lb chlorine dioxide per day with two-tower generator; 425 and 510 lb per day with three-tower generator. All standard capacity arrangements are adjustable over a 10 to 1 range. Higher capacity arrangements, Model 85-200H, have custom-sized, single-tower generator units.

CHOICE OF CONTROLS, AUTOMATIC OPERATION

- Wallace & Tiernan Chlorine Dioxide Systems can be controlled on a manual, automatic start-stop, or automatic proportional basis.

EFFICIENT COST-CONTROLLED OPERATION

- Chlorine dioxide's strong bactericidal and viricidal properties make it an effective disinfectant for water treatment applications. Unlike chlorine, it is unstable as a gas and cannot be stored or transported. For efficiency and economy, W&T Chlorine Dioxide Systems generate chlorine dioxide solution on-site and apply it immediately to the process stream.

PRE-ENGINEERED SYSTEMS

- Standard-capacity systems are pre-engineered and designed for capacities up to 510 lb of chlorine dioxide per day. Three main components, the chlorinator, metering pump, and generating unit, are compact entities easily adapted to limited space. These components and all the complementing system hardware, including booster pump, pressure switch, gauge, calibration chambers, and all process line valves, are furnished by W&T. Custom designed, single-reactor towers are supplied for systems with capacities greater than 510 lb per day.

MINIMIZES THM FORMATION

- Trihalomethanes are formed when organic compounds react with free chlorine in the process stream. The EPA has established regulations limiting the maximum contaminant level of THM's to 0.1 mg/L. The Series 85-200 System with supplemental acid feed generates chlorine dioxide containing an amount of unreacted chlorine which has no significant effect on THM levels.

SYSTEM INTERLOCKS

- A water pressure switch in the water line will interrupt operation if a low pressure condition develops. A chlorinator vacuum switch will stop operation if the operating vacuum is lost. Both switches are electrically interlocked with the pump SCR drive to stop system operation when water flow or operating vacuum is interrupted.

CHLORINE DIOXIDE

Chlorine dioxide is a red-yellow gas formed by sodium chlorite solution and chlorine at a pH of 4 or less. Though more expensive than chlorine, it it used as a primary disinfectant because of some unique properties. Chlorine dioxide does not disassociate in water or enter into reactions to form amines or trihalomethanes. Chlorine dioxide will maintain a residual longer than chlorine and is less subject to the influence of pH.

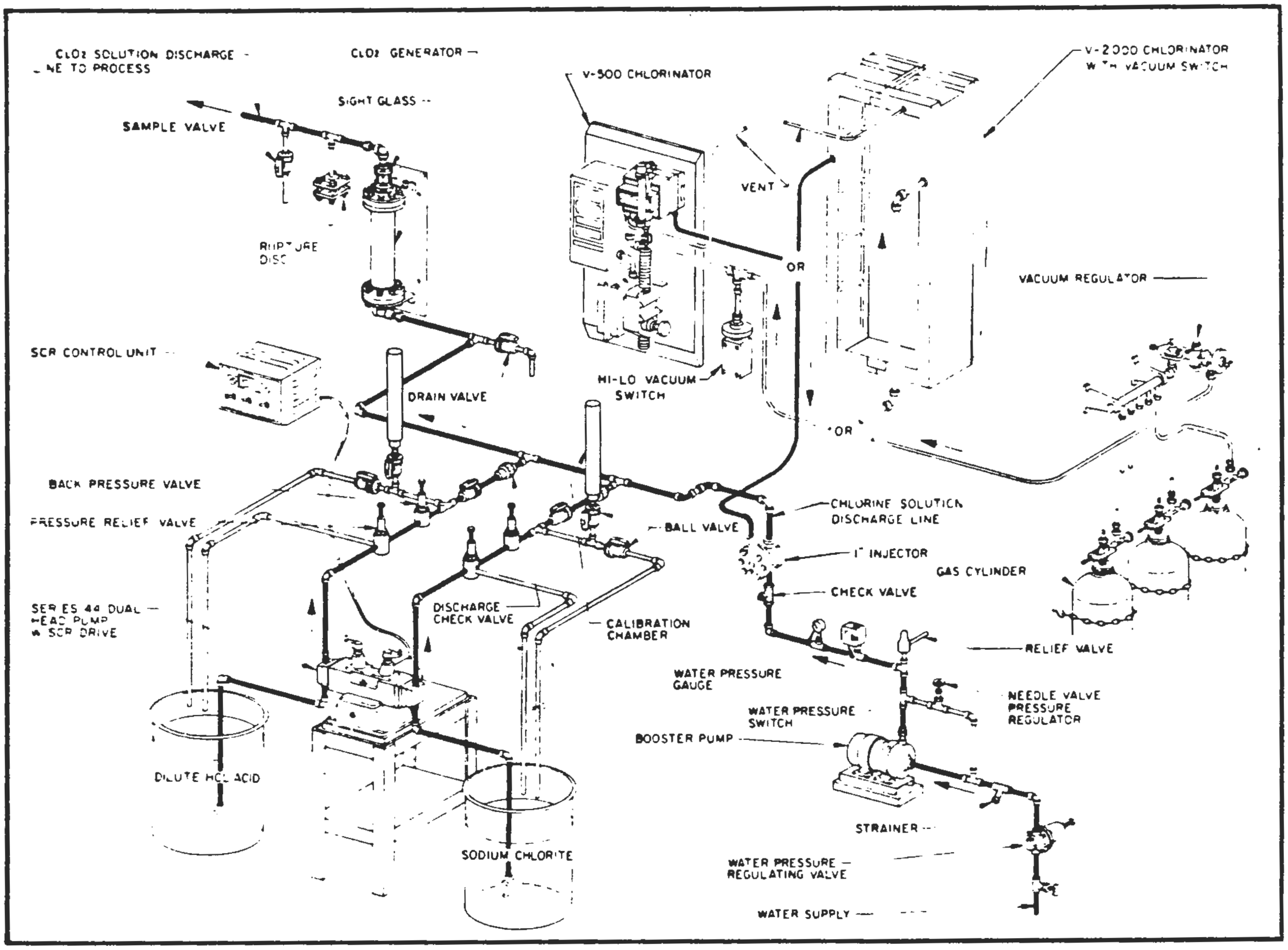
CHLORINE DIOXIDE SYSTEMS WITH SUPPLEMENTAL ACID FEED

Wallace & Tiernan's Series 85-200 System generates chlorine dioxide from solutions of chlorine, sodium chlorite, and weak hydrochloric acid. The dilute acid solution serves in lieu of excess chlorine to lower the pH. This chlorine/chlorite/acid process produces chlorine dioxide with a minimum of unreacted chemicals that could react with precursors in the product stream and form trihalomethanes. Trihalomethanes are formed when free residual chlorination is practiced in water containing precursors (organic compounds). Free residual chlorine is common where chlorine is used as a disinfectant. Measurable amounts of unreacted chlorine also occur in some chlorine dioxide systems in which an excess of chlorine is used to lower the pH. The Series 85-200 System with supplemental acid feed is especially suited to applications where THM formation is a concern. For applications where some unreacted chlorine can be tolerated, a generating system without supplemental acid feed is available from Wallace & Tiernan.

DESIGN AND OPERATION

Chlorine solution is fed from a W&T Series V 500 or Series V 2000 Chlorinator. A 44 Series Dual-head Metering Pump feeds a solution of sodium chlorite and a solution of

DESIGN and OPERATION



hydrochloric acid simultaneously. Both solutions are fed into the chlorine solution line. Discharge check valves, in the solution pump feed lines, protect against back syphoning. The solutions, after combining, are then fed to the inlet of the chlorine dioxide generator.

This system produces chlorine dioxide continuously by merging solutions of chlorine, sodium chlorite, and hydrochloric acid. The chemical reaction takes place in a W&T generator designed for a specific, minimum retention time. Chlorine dioxide is produced as the solutions mix and flow through the generator. The chlorine dioxide solution is then discharged to the point of application.

The basic generating unit in the Series 85-200 System is a flanged reactor tower, glass or PVC, filled with porcelain Raschig rings. The Raschig rings provide contact surface for mixing as the solutions flow upward. The yellow color of chlorine dioxide is evident through the glass reactor tower. If a PVC chamber is used, a separate sight glass is provided for this visual check. The discharge connection is located at the top of the generator.

SHORT DESCRIPTION

The system is a Wallace & Tiernan Series 85-200 Chlorine Dioxide System which generates chlorine dioxide from sodium chlorite, chlorine, and hydrochloric acid. Model 85-200L provides capacities to 510 pounds of chlorine dioxide per day. Model 85-200H provides higher capacities. The standard system includes a chlorine dioxide generator, a V-notch Chlorinator, and a 44 Series Dual-head Metering Pump with SCR drive. System hardware including booster pump, calibration chambers, valves, strainer, water gauge, and pressure switch are supplied for on-site piping and wiring. Optional automatic control of the chlorinator and metering pump is available. Solution tanks for 24-hour supplies of hydrochloric acid and sodium chlorite solution can be supplied.

The chlorinator can be a Series V-500 (wall mounted) or a Series V-2000 (in free standing cabinet). A switch for high or low chlorinator operating vacuum is included. *The pump* is a 44 Series Diaphragm Metering Pump with dual heads. The pump includes manual stroke adjuster, 3-digit stroke-length indicator, and SCR drive with speed readout.

The generator can be one or a combination of two or three chlorine dioxide reactor towers.

Standard system hardware includes: booster pump with by-pass piping; water pressure switch; water pressure gauge; water line check valve; spring relief valve; water pressure regulating valve and strainer; all to be installed in water line piping. Also included are 2 each, (one for sodium chlorite line and one for hydrochloric acid line) discharge check valves, pressure relief valves, back pressure valves, and calibration chambers with isolating valves. A drain valve is provided for installation prior to generator inlet; a sampling valve and a pressure relief unit are supplied for installation in generator discharge line.

Wallace & Tiernan Chlorine Dioxide Generating System without acid feed includes the same equipment and hardware as above except for valves and calibration chamber that are part of hydrochloric acid line. A 44 Series Single-head Metering Pump is furnished in place of the dual-head pump.

TECHNICAL DATA

capacities

Model 85-200L with supplemental acid feed: one-generator arrangement, 17, 34, 51, 85, 127, and 170 ppd; two-generator arrangement, 225 and 340 ppd; three-generator arrangement, 425 and 510 ppd.

Model 85-200L without acid feed: one-generator arrangement, 15, 30, 45, 75, 112, and 150 ppd; two-generator arrangement, 225 and 300 ppd; three-generator arrangement, 375 and 450 ppd.

NOTE: Series 85-200 Chlorine Dioxide Systems without acid feed generate chlorine dioxide with as much as 10% (as a weight percentage of chlorine dioxide) excess chlorine.

Excess chlorine can react with certain precursors to produce trihalomethanes. Systems without acid feed are not to be used in potable water applications where trihalomethane control is critical.

Model 85-200H for capacities greater than 510 ppd with acid feed and 450 ppd without acid feed, includes custom sized, single-tower generator unit.

operating range

10:1 for standard systems with acid feed; 5:1 for model 85-200L without acid feed.

backpressure

35 psig maximum with glass generator tower; 75 psig maximum with PVC tower.

water requirements

2.5 gpm for 170 ppd capacity; 5.0 gpm for 340 ppd capacity; 7.5 gpm for 510 ppd capacity.

electrical requirements

115 volt; 60 Hz; 9 amps (manual), 10 amps (automatic). Booster pump not included.

methods of control

Manual: manual operation of chlorinator and pump dosage. *Automatic Start-stop:* responds to interruption of injector water supply. System is electrically interlocked to shut down in the event of water failure. *Automatic Proportional:* chlorinator and pump are paced to common mA (typically 4-20 mA) signal.

chemical solution strength

These systems are capable of generating chlorine dioxide with solutions prepared from commercially available concentrations of sodium chlorite and hydrochloric acid.

REVENTIVE MAINTENANCE KITS
Vallace & Tiernan has preventive maintenance kits that contain standard replacements for the parts of this equipment most susceptible to wear. Using these kits in a scheduled program for replacing worn parts can minimize the incidence of downtime. These kits can also facilitate minor emergency repairs.

chemical requirements

Varies with concentration of chemicals used. Typically, 10 lb of chlorine, 15.2 gallons of 16.7% sodium chlorite solution and 15.2 gallons of 0.8% hydrochloric acid solution* for each 17 pounds of chlorine dioxide. (*Acid concentration not to exceed 1.3%.)

equipment furnished

W&T Systems with supplemental acid feed have three main components: one V-500 or V-2000 Chlorinator with vacuum switch; one dual-head Series 44-100 Metering Pump with SCR drive; and a chlorine dioxide generator (glass or PVC chamber with sight glass). Standard system also includes, 2 calibration chambers with isolating valves, 2 discharge check valves, 2 back pressure valves, 2 pressure relief valves, a sampling valve, drain valve, strainer, water pressure switch, water pressure regulating valve, water pressure gauge, water line check valve, a system pressure relief unit, and a booster pump with by-pass piping. If optional automatic mA control is ordered, a V-notch actuator and controller for the chlorinator and a milliamp-compatible SCR drive for the metering pump are furnished.

W&T Chlorine Dioxide Systems without acid feed include same hardware as above except for parts specific to acid line. A single-head 44 Series Pump is furnished in place of the dual head pump.

options and accessories

Solution tanks for 24-hour supply of acid or sodium chlorite solutions: 55-gallon tank, (for 50 ppd chlorine dioxide), 105-gallon tank (for 100 ppd), 210-gallon tank (for 200 ppd); larger tanks are available.

Wall mounting brackets, pump table, main connections, and other standard pump and chlorinator line accessories are available. Piping, wiring and other elective features will be included only as specifically listed in a quotation.

installation

Pump, chlorinator, generating unit, and all system hardware are shipped as individual components. Piping, wiring, and assembly are done on location.

shipping weights

V-500, 85 lb; V-2000, 120 lb; 44 Series Pump, 95 lb; generator, 60 lb (1 chamber), 120 lb (2 chambers), 180 lb (3 chambers); system hardware less booster pumps, 80 lb.

All unattended chlorine containers and chlorination equipment should be continuously monitored for leaks. Sensitive chlorine detectors, which will respond quickly to the presence of chlorine in the ambient air, should be installed at each site. See W&T Cat. File 50.135

SERVICE AND REFERENCES

Prompt service on Wallace & Tiernan equipment is available from branch offices in principal cities. Publications on other equipment, dimension and typical arrangement drawings, water requirements, and other data are available on request.

Progressive changes in design may be made without prior announcement.

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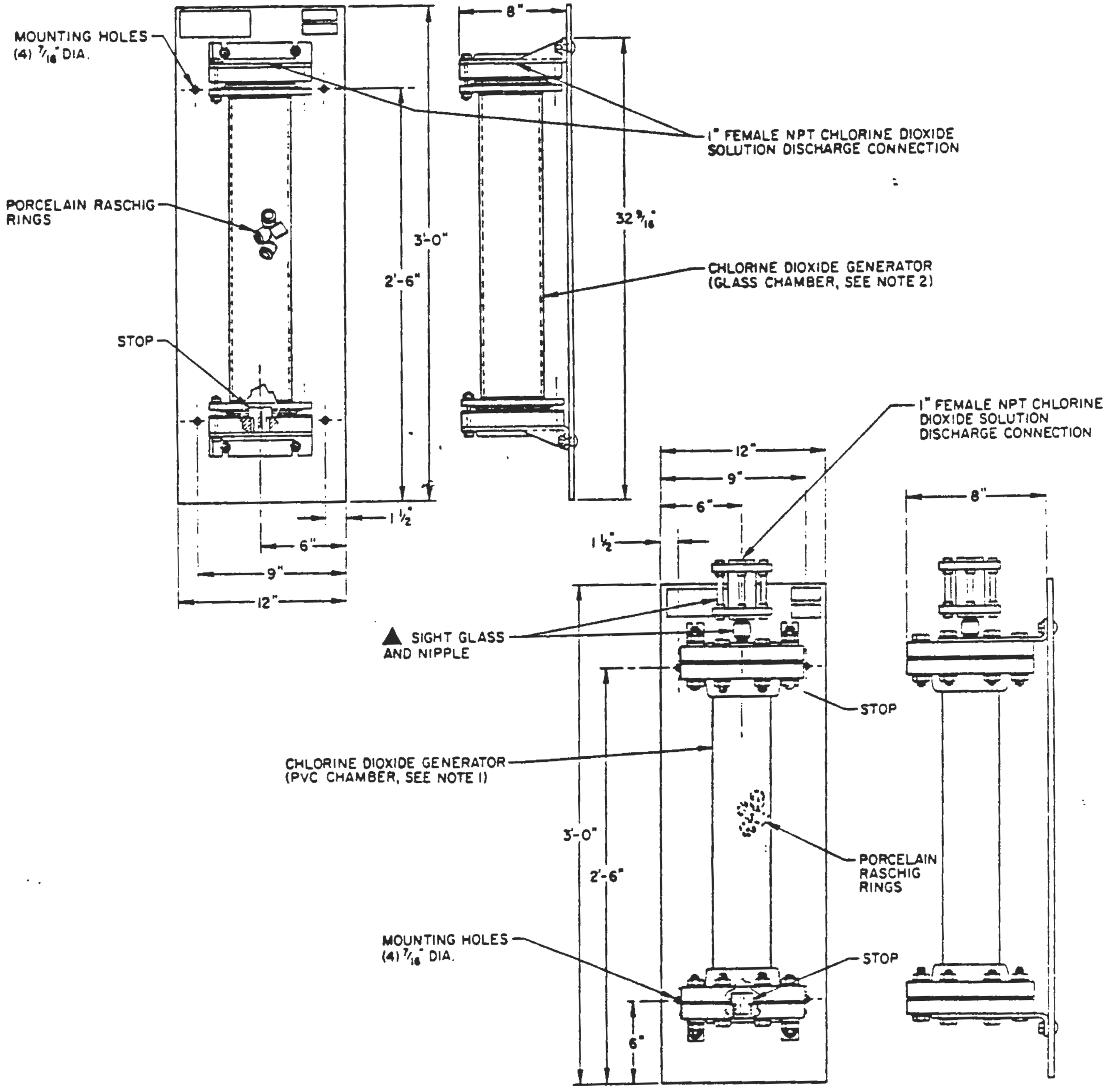
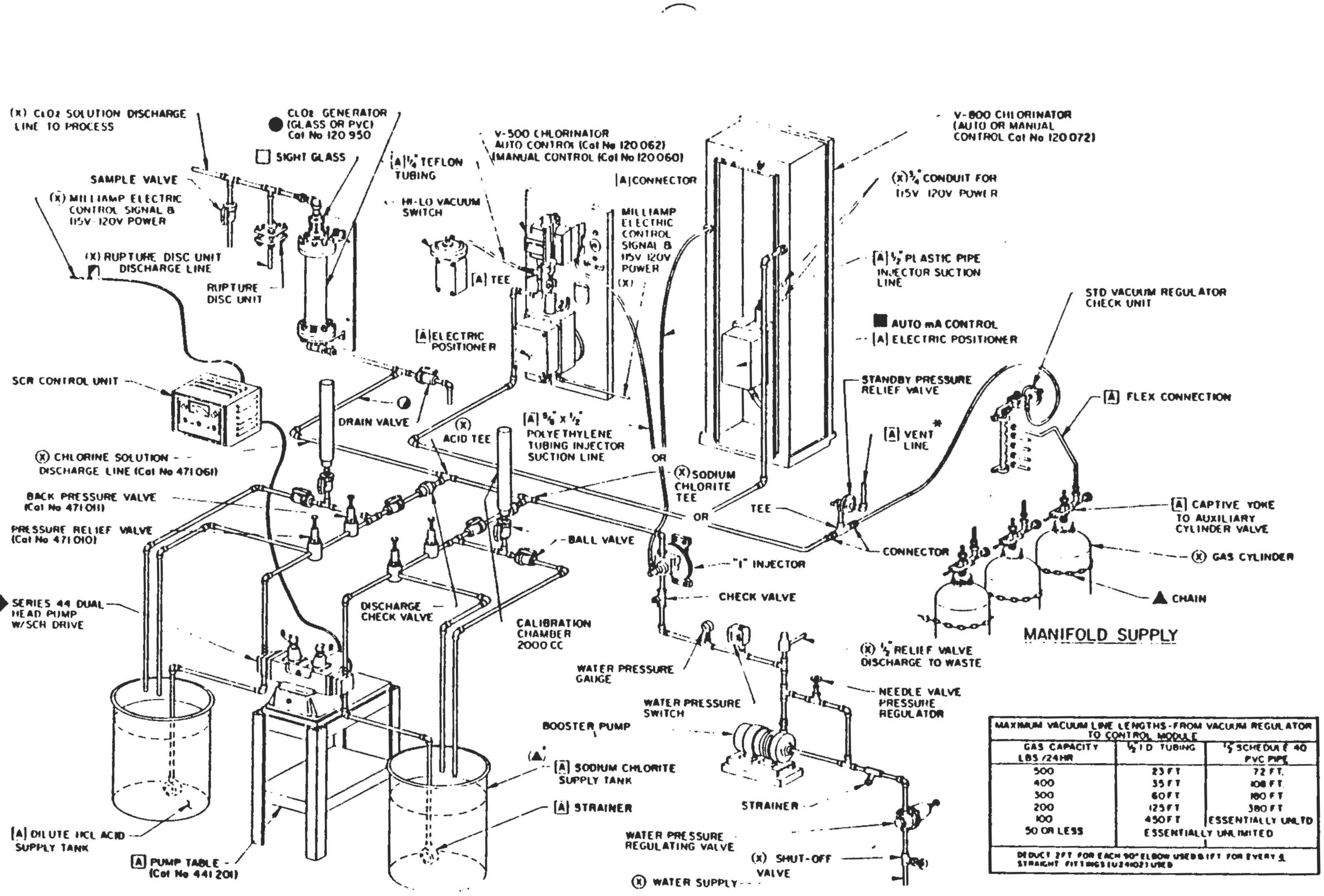


NOTE:

1. MAXIMUM BACKPRESSURE -75 PSI W/PVC CHAMBER.
2. MAXIMUM BACKPRESSURE -35 PSI W/GLASS CHAMBER.

▲ SIGHT GLASS AND NIPPLE FURNISHED AS INDIVIDUAL UNITS.



MAXIMUM VACUUM LINE LENGTHS - FROM VACUUM REGULATOR TO CONTROL MODULE		
GAS CAPACITY LBS /24HR	1/2" I D TUBING	1/2" SCHEDULE 40 PVC PIPE
500	23 FT	72 FT.
400	35 FT	108 FT.
300	60 FT	180 FT
200	125 FT	380 FT
100	450 FT	ESSENTIALLY UNLTD
50 OR LESS	ESSENTIALLY UNLIMITED	
DEDUCT 2FT FOR EACH 90° ELBOW USED & 1FT FOR EVERY 2 STRAIGHT FITTINGS (U24102) USED		

NOTE:

1 CHLORINE DIOXIDE W/ACID FEED AS SHOWN

2 CHLORINE DIOXIDE W/O ACID FEED DOES NOT REQUIRE ACID SUPPLY TANK, ACID PUMP HEAD, OR ACID RELATED HARDWARE

3 ALL INTERCONNECTING PIPING AND WIRING BY OTHERS

4 TO DETERMINE MAXIUM VACUUM LINE LENGTH WHEN TUBING AND PIPE ARE USED IN COMBINATION, EACH FOOT OF 1/2" I D TUBING CAN BE REPLACED WITH.

(A) 3 1' OF SCHEDULE 40 1/2" PVC PIPE (B) 9 5' OF SCHEDULE 40 3/4" PVC PIPE

(X) NOT FURNISHED BY WBT

[illegible] NOT USED WITH MANUAL CONTROL ARRANGEMENT.

[illegible] 2' RUN BETWEEN GENERATOR INLET AND ACID TEE.

[illegible] WARNING THE RUPTURE DISC DISCHARGE LINE MUST TERMINATE IN AN AREA WHERE [illegible] DIOXIDE SOLUTION AND FUMES CAN NOT CAUSE DAMAGE OR INJURY TO PER- [illegible] DO NOT TERMINATE THE DISCHARGE LINE AT A LOCATION ROUTINELY USED BY [illegible] SUCH AS WORK AREAS OR PATHWAYS NOR NEAR WINDOWS OR VENTILATION SYSTEM INTAKE

(.) CAUTION STORAGE AND HANDLING OF SODIUM CHLORITE REQUIRES SPECIFIC PRECAUTIONARY MEASURES PRIOR TO THE DESIGN OF STORAGE AND HANDLING FACILITIES, CONSULT THE CHEMICAL MANUFACTURER OR SUPPLIER FOR DETAILED INFORMATION AND RECOMMENDATIONS

[A] ACCESSORY ITEM FURNISHED ONLY IF SPECIFICALLY LISTED IN QUOTATION AND AS CHECKED ON THIS DRAWING.

* WARNING THE VENT LINE MUST TERMINATE IN AN AREA WHERE GAS FUMES CAN NOT CAUSE DAMAGE OR INJURY TO PERSONNEL DO NOT TERMINATE THE VENT LINE AT A LOCATION ROUTINELY USED BY PERSONNEL SUCH AS WORK AREAS OR PATHWAYS NOR NEAR WINDOWS OR VENTILATION SYSTEM INTAKES

▲ GAS CYLINDERS MUST BE SECURED IN SUCH A MANNER (e g CHAIN) AS TO PREVENT THEIR BEING KNOCKED OVER.

●

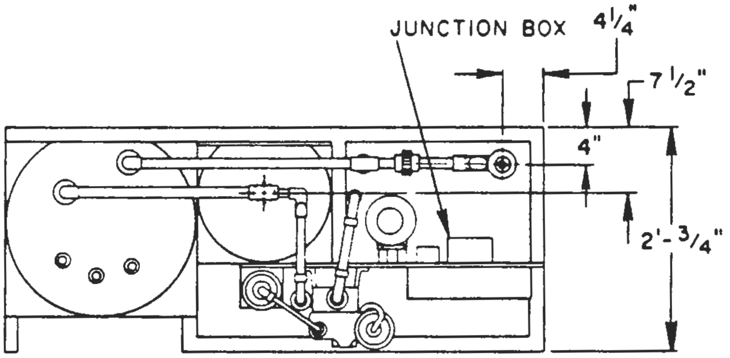
NUMBER OF GENERATORS	CAPACITY	
	W/ACID	W/O ACID
1	170PPD	150PPD
2	340PPD	300PPD
3	510PPD	450 PPD

◆ THE PUMP DISCHARGE LINES MUST TEE INTO THE CHLORITE SOLUTION LINE IN THE FOLLOWING ORDER; SODIUM CHLORITE THEN HCL, AS SHOWN ABOVE.

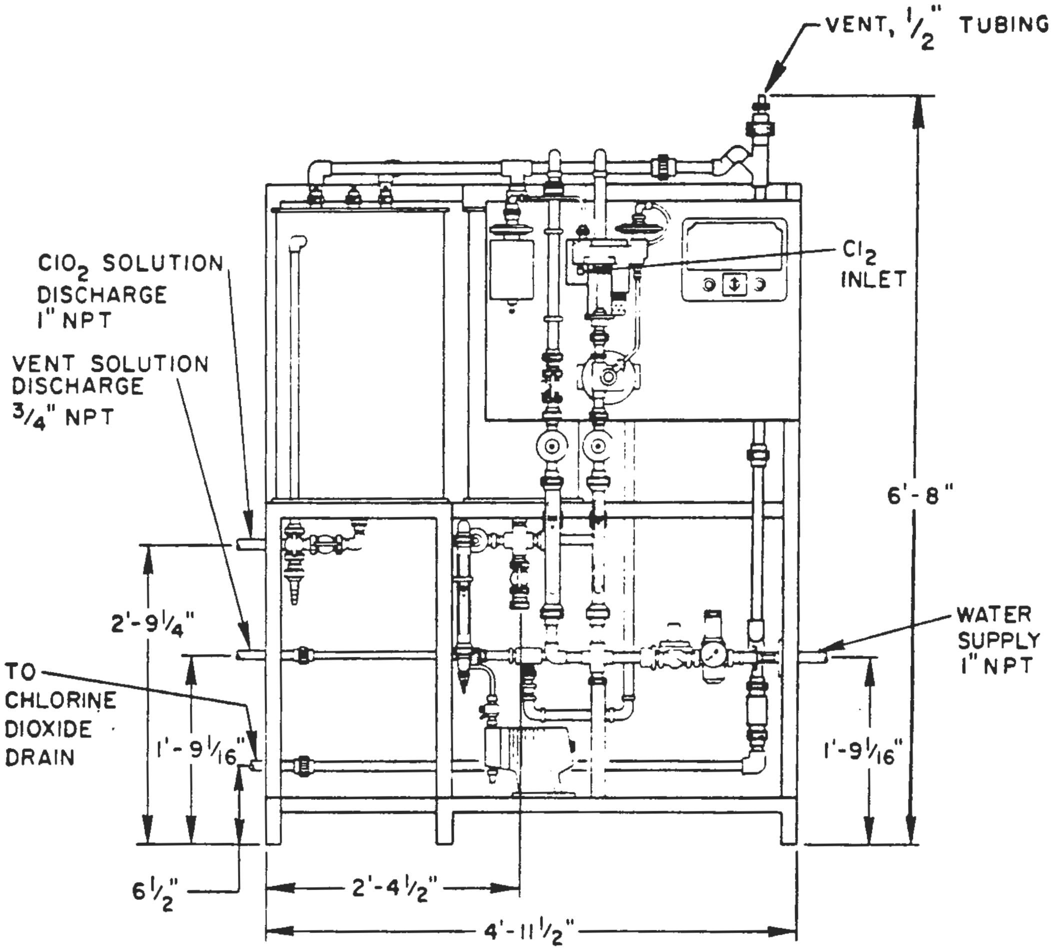
☐ SIGHT GLASS FURNISHED WITH PVC GENERATOR ONLY.

SERIES 85-250 CHLORINE DIOXIDE SYSTEM — DIMENSIONS

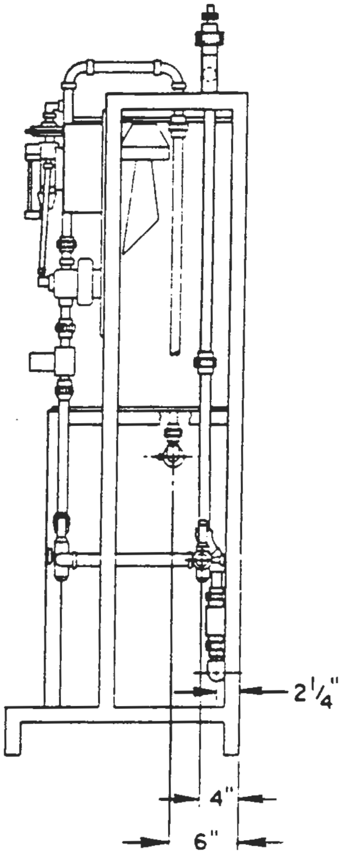
80 PPD And 240 PPD Capacity — 150.700



TOP VIEW



FRONT VIEW



SIDE VIEW

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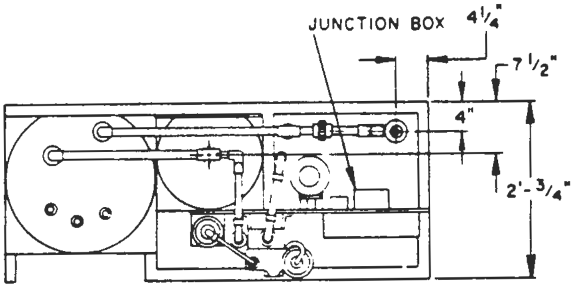
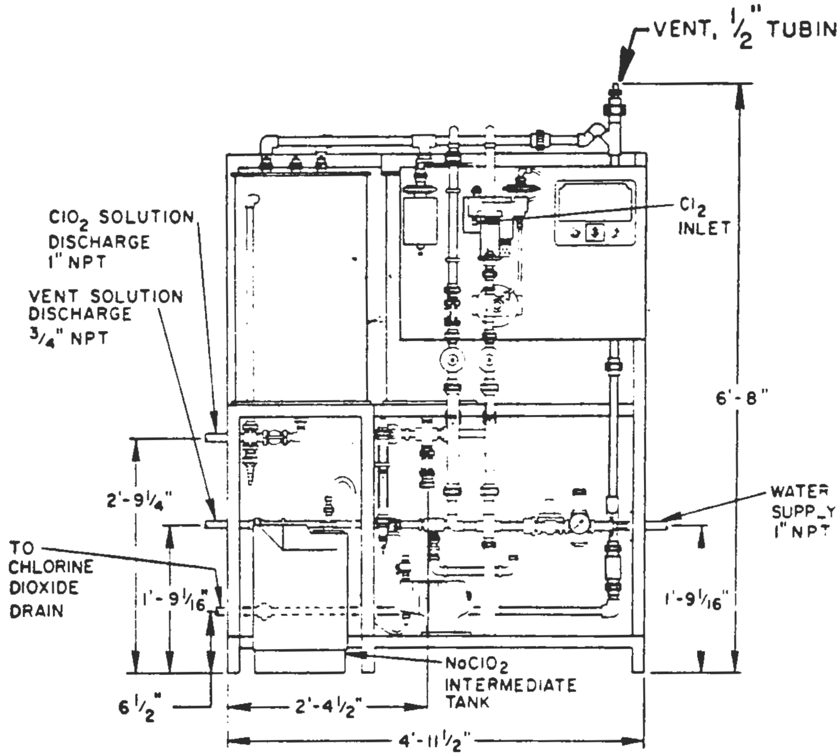
SERIES 85-250 CHLORINE DIOXIDE SYSTEM DIMENSIONS

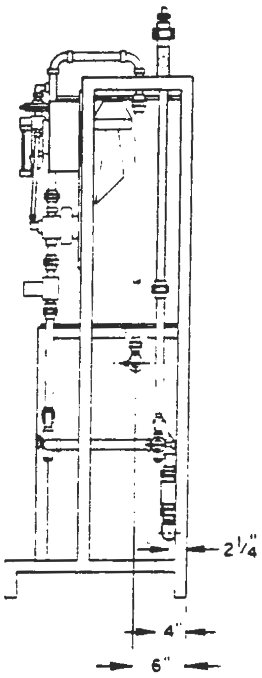
With $NaClO_2$ Intermediate Tank And Transfer Pump 150.701



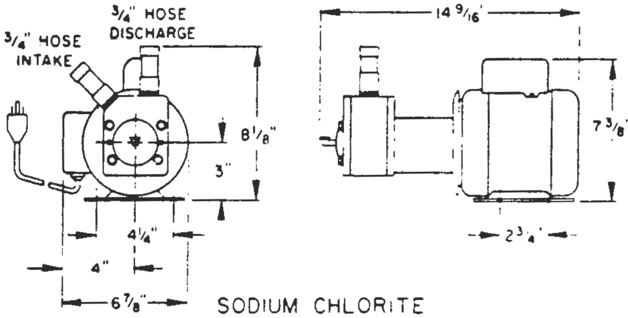
TOP VIEW



FRONT VIEW



SIDE VIEW



SODIUM CHLORITE TRANSFER PUMP

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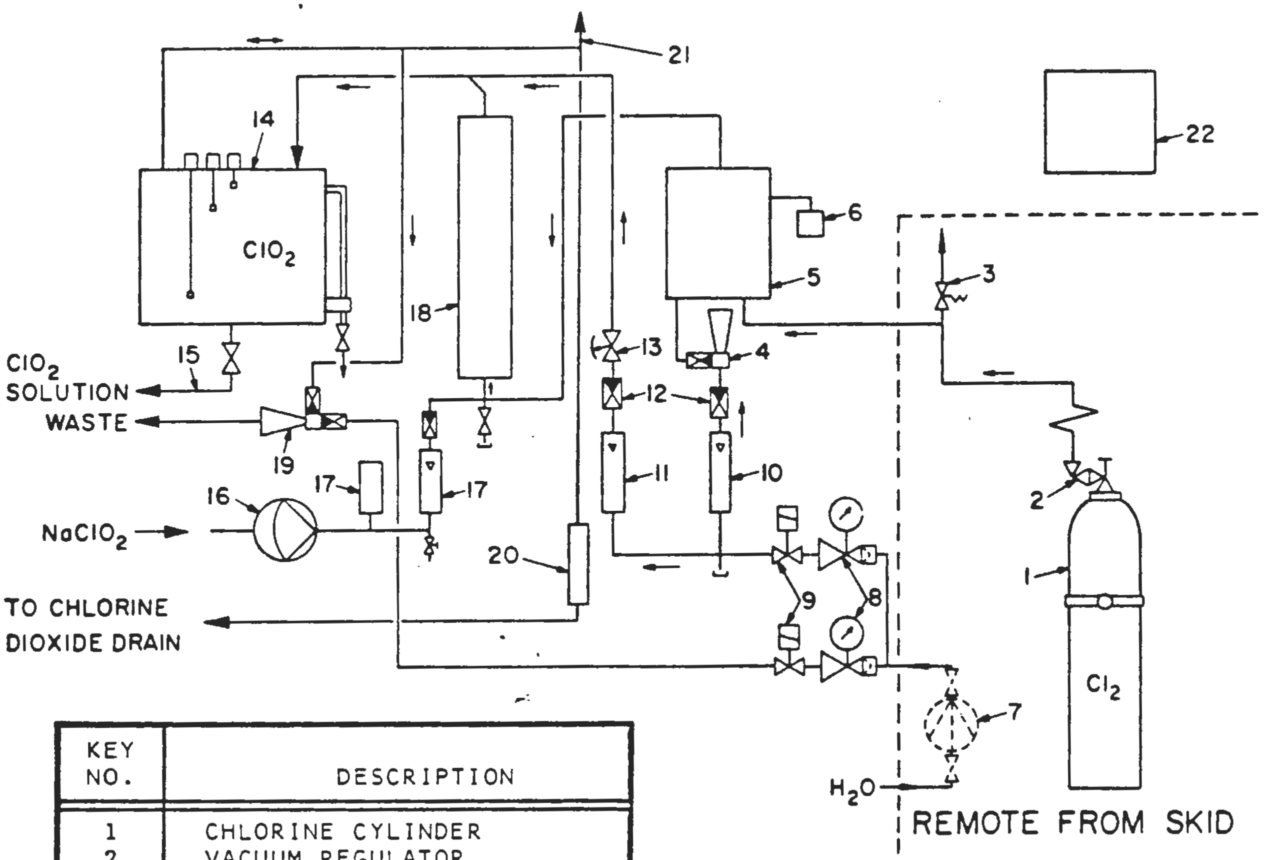
SERIES 85-250 CHLORINE DIOXIDE SYSTEM

FLOW DIAGRAM

150.702



KEY NO.	DESCRIPTION
1	CHLORINE CYLINDER
2	VACUUM REGULATOR
3	PRESSURE RELIEF VALVE
4	INJECTOR
5	REMOTE VACUUM CHLORINATOR
6	VACUUM SWITCH
7	BOOSTER PUMP (OPTIONAL)
8	PRESSURE REDUCING VALVE
9	SOLENOID VALVE
10	FLOWMETER FOR INJECTOR OPERATING WATER
11	FLOWMETER FOR DILUTION WATER
12	CONSTANT LOAD/CHECK VALVE
13	CONTROL VALVE
14	ClO_2 STORAGE TANK WITH LEVEL PROBES
15	ClO_2 SOLUTION OUTLET LINE
16	$NaClO_2$ METERING PUMP
17	$NaClO_2$ FLOWMETER AND PULSATION DAMPENER
18	REACTION TOWER
19	CHLORINE DIOXIDE FUME EVACUATION INJECTOR
20	OVERFLOW RELIEF VALVE
21	VENT LINE
22	CONTROL PANEL

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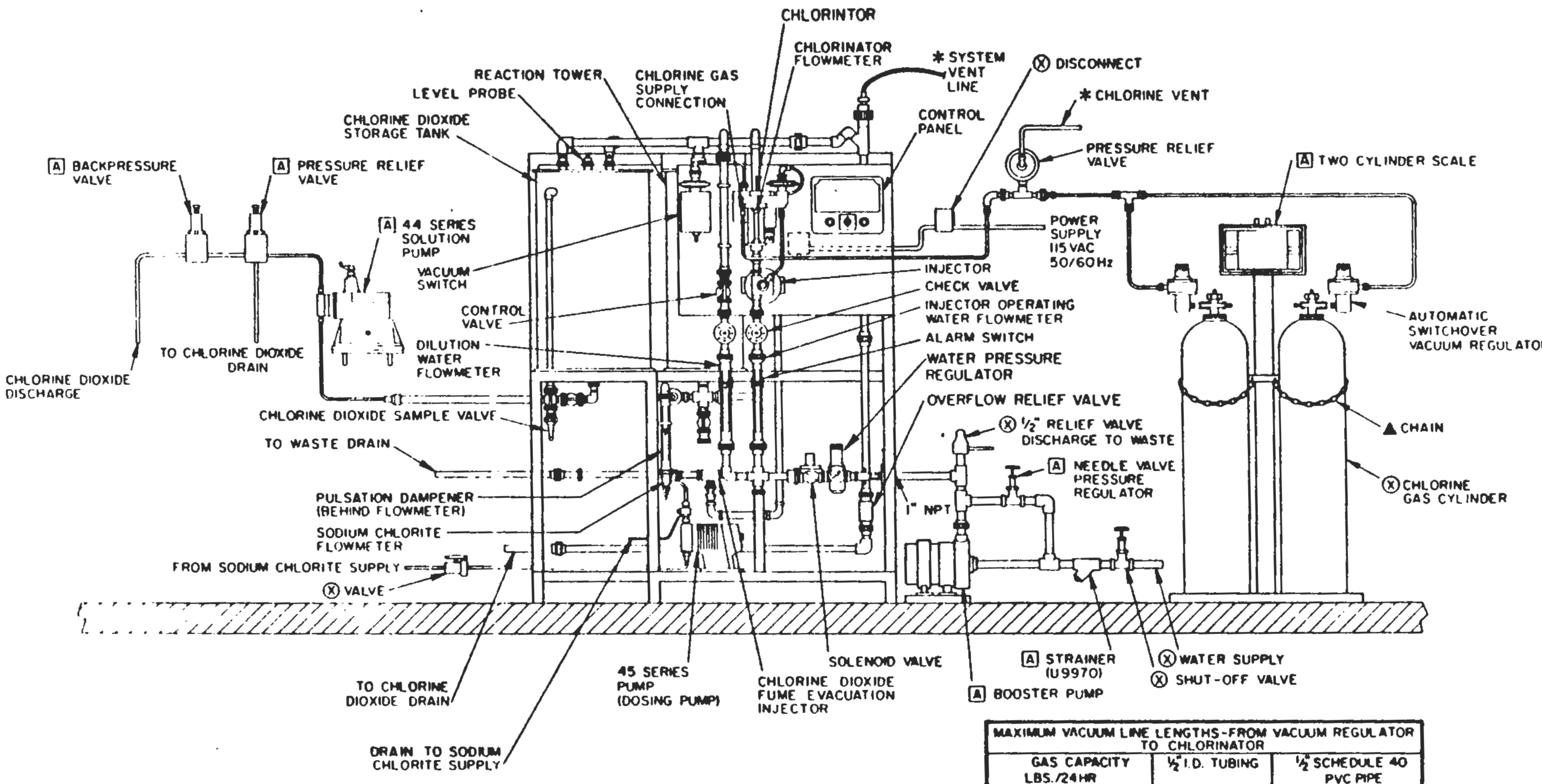

MAXIMUM VACUUM LINE LENGTHS-FROM VACUUM REGULATOR TO CHLORINATOR		
GAS CAPACITY LBS./24HR	1/2" I.D. TUBING	1/2" SCHEDULE 40 PVC PIPE
200	125 FT.	380 FT
100	450 FT.	ESSENTIALLY UNLTD
50 OR LESS	ESSENTIALLY UNLIMITED	
DEDUCT 2 FT. FOR EACH 90° ELBOW USED & 1 FT FOR EVERY 4 STRAIGHT FITTINGS (U24102) USED.		

WARNING: ▲ GAS CYLINDERS MUST BE SECURED IN SUCH A MANNER (e.g. CHAIN) AS TO PREVENT THEIR BEING KNOCKED OVER.

* THE VENT LINE MUST TERMINATE IN AN AREA WHERE GAS FUMES CANNOT CAUSE DAMAGE OR INJURY TO PERSONNEL. DO NOT TERMINATE THE VENT LINE AT A LOCATION ROUTINELY USED BY PERSONNEL SUCH AS WORK AREAS OR PATHWAYS NOR NEAR WINDOWS OR VENTILATION SYSTEM INTAKES.

NOTE: Ⓧ NOT FURNISHED BY W&T.

A ACCESSORY ITEMS FURNISHED ONLY IF SPECIFICALLY LISTED IN QUOTATION AND AS CHECKED ON THIS DRAWIN

en and Sawyer, 1992, Disinfection
ernatives for Safe Drinking Water,
es 171-195.

6

Chlorine Dioxide

with contributions by
W. J. Masschelein
Brussels Intercommunal
Water Board, Belgium

Alex J. Varas
Hazen and Sawyer
on *Design Concepts*

Chlorine dioxide is an alternative disinfecting form of chlorine that is quite different in character from either free chlorine or chloramines. Unlike free chlorine and chloramines, in which chlorine occurs in the +1 oxidation state, chlorine in chlorine dioxide is in the +4 oxidation state. This is a significant difference that sets chlorine dioxide apart chemically, yielding different reaction pathways for both disinfection and the formation of byproducts. One advantageous consequence of this difference is a limited tendency for the formation of trihalomethanes. Furthermore, many other chlorinated byproducts of concern that occur with both free chlorine and chloramines are also not formed. Therefore, much of the recent interest in the use of chlorine dioxide is largely a result of its possible role for achieving disinfection while minimizing the formation of certain unwanted byproducts.

While use of chlorine dioxide can greatly reduce formation of many of the principal free chlorine byproducts of concern, other byproducts must be considered. These can include the inorganic degradation products of chlorine dioxide, chlorate (ClO_3^-), and chlorite (ClO_2^-), as well as nonchlorinated organic end products. A degree of chlorinated organic formation can also occur, partially as a result of the presence of free chlorine as an impurity in many chlorine dioxide feed solutions. As a consequence of these phenomena, it is more appropriate to characterize chlorine dioxide

sinfectant that alters the types of byproducts formed, as opposed to
ering it to be an alternative for reducing the formation of by-
cts that occur with the use of free chlorine. In other words, the
of the byproducts of chlorine dioxide must also be considered,
gh they may be of much less concern based on prevailing informa-

jor concerns about the use of chlorine dioxide have been raised with
t to possible health consequences resulting from the ingestion of
ne dioxide and its two inorganic reaction byproducts, chlorate and
te. Because of these concerns, it may become necessary to limit the
num chlorine dioxide level in water distribution systems. This limi-
could make it difficult to maintain an adequate residual at all loca-
in the distribution system and could restrict its role in secondary
ection applications under approaches normally applied in the United
. Because of this potential limitation, much of the current U.S.
st in chlorine dioxide centers on its potential for use as a primary
ectant that could replace free chlorine within a water treatment
Other disinfecting chemicals might then be required for meeting
stream or distribution system criteria for secondary disinfection.
ine dioxide is successfully used, however, for maintaining second-
isinfection in several European applications where stringent limita-
have not been placed on maximum residual levels.
key factor in the application of chlorine dioxide is that it normally
s as a relatively unstable gas that cannot be compressed to a lique-
orm without danger of explosion. Because of this inherent instabil-
hlorine dioxide cannot be conveniently delivered from off-site loca-
and, therefore, is normally generated on-site on an as-needed basis.
cally, for the quantities encountered in water treatment, such genera-
employs chlorine and sodium chlorite as reactant chemicals. A need
gorously control this generation reaction occurs as a result of both the
y and the product quality considerations. This represents a signifi-
change in the nature of operations as compared with free chlorine.
in chloramination, in which chloramines are formed within the pro-
stream by reaction between chlorine and ammonia, the need for such
of reaction control is much less.

TORY OF THE USE OF CHLORINE DIOXIDE

rine dioxide was discovered in 1814 by Sir Humphrey Davy as a
uct of a reaction between potassium chlorate and sulfuric acid. How-
, it was not extensively commercialized until 1940. Much of its early

application developed around use in pulp and paper manufactur
could serve as a bleaching agent that was not as susceptible as
loss by unproductive reactions (1).

Chlorine dioxide was initially used in water treatment becau
as an effective oxidant for eliminating taste and odor problems
when free chlorine is contacted with a water that contains phe
pounds. Free chlorine tends to react with these compounds to
rinated phenols, which produce an offensive chlorinous taste
chlorine dioxide destroys these compounds.

While chlorine dioxide has been applied to a limited ex
United States, it has been more commonly considered in Eur
industrial discharge of phenols has been a greater concern in c
ing surface water supplies (2). However, interest in chlorine c
recently increased, both in the United States and internatio
result of its possible role as an alternative that can reduce the fo
trihalomethanes and other disinfection byproducts that are
with the use of free chlorine.

COMMERCIAL CHEMICALS USED TO FORM CHLORINE DIOXIDE

Generation of chlorine dioxide generally results from reaction
either sodium chlorite ($NaClO_2$) or sodium chlorate (NaClO
chlorate is employed in a process that generates chlorine diox
reduction of the chlorate component by sulfur dioxide. This p
been extensively applied to produce the larger volumes of chl
ide required in pulp and paper-bleaching operations. However
ter treatment applications have used generation techniques t
sodium chlorite. These techniques involve reactions with chlo
adjustment with acids. A typical reaction sequence using chlo
represented by the following general expression:

$$2NaClO_2 + Cl_2 = 2ClO_2 + 2NaCl$$

Commercial sources of chlorine have been discussed in Cha
cussions in this chapter will, therefore, focus on sodium chlo

Sodium chlorite solutions are normally made up to a conce
approximately 25 percent. This concentration achieves the lo
ing point and is therefore less susceptible to handling difficul
weather. Chlorate can occur as an impurity in commercial sodi
at levels of 2 to 3 percent by weight of chlorite. A degree of
sometimes introduced to stabilize these solutions since sodi

degrade prematurely under acidic conditions. However, a low solution (less than 10 mg/l as $CaCO_3$) is desirable for many of ation methods used for water treatment (3). The equipment supld be consulted to determine the appropriate solution conditions n generation system.

n chlorite solutions are highly corrosive, and consideration e given to proper material selection for storage, pumping, and ven at the optimum concentration of 25 percent, these solutions ubject to freezing at temperatures of −15°C (5°F) (3), and the heated storage should be considered for facilities that are located . Upper limits also need to be placed on temperature in order to plosion. With this in mind, temperatures should be maintained at 40°C (104°F), and conditions should not be allowed that could temperatures above 80°C (176°F).

form, sodium chlorite occurs as a flaked salt at a concentration imately 80 percent. It is naturally white in color, although other n may occur with impurities. For example, partial formation of dioxide in the solid form can lead to an orange color, which can rous.

odium chlorite can be highly reactive, having a capability for eaction (explosion) when it contacts with organic substances lothing, gloves, cotton waste, sawdust, mops, brooms, and oils. factors such as heat, friction, or impact can also lead to reaction. e reasons, the liquid form is normally preferred for water treathen a dry form is used, it should be dissolved into solution as possible. Because of possible hazards, care should be taken to y spills of the liquid form before evaporation can lead to a deposit lt. To avoid potential explosions, provisions for spill containment nup are an important consideration for design and operation. turers of chlorine dioxide equipment and sodium chlorite suppli-ld be consulted for more detailed information on the appropriate rovisions.

STRY OF CHLORINE DIOXIDE

dioxide chemistry is often presented in terms of oxidation chares (30). These characteristics define the tendency to accept elec- oxidize other chemical constituents. Its role as an oxidizing l in water involves two steps.

rine dioxide gains one electron to form chlorite (ClO_2^-):

$$ClO_2 + 1e^- = ClO_2^- \qquad (6\text{-}2)$$

2. Chlorite gains four electrons to form chloride (Cl^-):

$$ClO_2^- + 2H_2O + 4e^- = Cl^- + 4OH$$

The first step to form chlorite can usually proceed in the pH rang mally encountered in water treatment practice. However, the ch form is less reactive for many constituents found in water, and the s step does not proceed as readily. The predominant oxidizing capabi chlorine dioxide for organic matter as well as many inorganic consti is characterized by the oxidation potential of the one-electron tr that occurs in the first reaction step. As a consequence, the overal electron total transfer capability for complete reaction through th steps is often not available.

The oxidation potential of the first reaction step is 0.95 V at sta conditions and 25°C. This compares with a greater oxidation po 1.49 V for the common free chlorine specie, hypochlorous acid, d by the following reaction:

$$HOCl + H^+ + 2e^- = Cl^- + H_2O$$

This simple numerical comparison would seem to indicate that free rine has a stronger oxidizing potential for organic compounds. How other factors must be considered for chlorine dioxide reactions. In p ular, the oxidation effectiveness depends on the availability of re pathways that allow the oxidation potential to be exerted under a set of circumstances. Chlorine dioxide and free chlorine cannot, fore, be compared on a simple oxidation potential basis for a given tion reaction. Observations indicate that free chlorine may be mor cient for general removal of total organic carbon due to a wider ra reaction pathways (4), while chlorine dioxide can be more effecti oxidizing specific organic groups as illustrated by a reactivity phenols.

Although some features of reactions between chlorine dioxide a ganic constituents are understood, many specific aspects are still tain. In general, it is known that chlorine dioxide has an unpaired el in its molecular structure. This is a less stable and therefore more re chemical condition that is termed a *free radical condition*. This char istic can affect the nature of disinfection reactions as well as reactio produce the first oxidation step that results from a one-electron tran produce chlorite. Some research suggests, however, that mecha other than free radical reactions may be important for certain con (5). Other types of mechanisms are also involved if the second s reaction occurs in which chlorite loses four electrons to form chl

rine dioxide reactions with inorganic compounds can follow differ-
ction pathways than those encountered with organic compounds.
mple, chlorine dioxide can react with some inorganic constituents
a complete five-electron transfer (5) that involves both oxidation
Equations 6–2 and 6–3). Specific inorganic constituents that can
such reactions include hydrogen sulfide and the +2 oxidation
iron (i.e., the ferrous, or Fe^{+2}, form).

respect to general reaction properties, the +4 oxidation state of
found in chlorine dioxide does not readily substitute into other
l structures to form compounds such as chlorinated organics or
mines. Chlorine dioxide also does not readily oxidize ammonia.
re, ammonia, a constituent that can represent a significant de-
or free chlorine, does not exert a demand for chlorine dioxide.
other sources of chlorine dioxide demand are low, this factor may
n lower dose requirements relative to free chlorine, especially
significant levels of background ammonia are present in a raw

rine dioxide is relatively stable in neutral and mildly acidic solu-
However, under alkaline conditions, chlorine dioxide can more
degrade to form both chlorate (ClO_3^-) and chlorite (ClO_2^-) accord-
he following reaction (7):

$$2ClO_2 + 2OH^- = H_2O + ClO_2^- + ClO_3^- \qquad (6\text{–}5)$$

reaction does not proceed to an appreciable extent at a pH less
However, it can be a consideration where highly alkaline condi-
re encountered, such as those where high pH softening processes
ployed (6). The rate of degradation is also influenced by the chlo-
xide concentration. Degradation proceeds at higher rates at higher
trations of chlorine dioxide. Phosphate and carbonate ions reduce
of degradation.

ldition to these reactions, chlorine dioxide is susceptible to photo-
al breakdown when exposed to light. These degradation reactions
d to the formation of hydrogen peroxide, chlorite, chlorate, oxy-
d chlorine (9). To minimize this form of degradation, care should
en to shield chlorine dioxide feed streams from light.

ther important degradation reaction involves the breakdown of
, where chlorite degradation to chloride, shown in Equation 6–3,
ds in the acid pH range. This reaction can ultimately lead to com-
egradation to the inert chloride form. Chlorite can also undergo
ant degradation in other ways if sufficient time is available. For
le, studies by Noack and Doerr (10) suggested that, with ade-
eaction time, chlorite could react with chlorine to form chlorate as

---

an end product at pH 7. These findings were based on observed
ratios and the fact that little chlorine dioxide was observed in
This hypothesis was not confirmed by analyses of chlorate le
though varying results for this type of reaction have been report
dependent on time of reaction, reactant concentrations, and pH

The total effect of reactions involving chlorine dioxide is a co
of all of the reaction pathways. In one study involving fulvic
tracted from natural water sources, approximately 70 percent o
acted chlorine dioxide was converted to chlorite at pH 7 (11). In a
reactions with phenol (12), approximately 50 percent of chlorine
reacted was converted to chlorite.

A further indication of the variability of chlorite formation was
tered in a recent study at the Orange Water and Sewer Authori
treatment plant in Carrboro, North Carolina (13). It was observ
study that conversion to chlorite shifted from a range of betwee
66 percent in raw water to 76 percent in settled water treated wi
sium permanganate.

The ultimate effect of all of these reactions is varied and ap
result in a range of chlorite production of between 50 and 75
(6, 13). Chloride typically accounts for most of the remainde
reacted chlorine dioxide in many laboratory solutions. However,
can also be produced at significant levels under some field cond

DISINFECTION BYPRODUCT FORMATION

Significantly, the +4 oxidation state of chlorine that occurs in
dioxide does not readily substitute into organic matter to form ch
byproducts such as trihalomethanes. Other halogenated orga
pounds can be formed but much lower levels are observed t
chlorine (22). A number of nonhalogenated organic byprod
formed, predominantly as a result of oxidation reactions. Some s
in reaction pathways appears to occur for these oxidation reacti
example, it is reported that chlorine dioxide is most reactive wit
organic amines and phenols. Its reactivity with secondary amine
and it is relatively unreactive with primary amines. Chlorine d
also reported to react with aldehydes and with alcohols under ac
tions. It is moderately reactive with alkenes that contain unsat
double bond configurations between carbon atoms, and unreac
saturated aliphatic hydrocarbon groups, saturated carboxylic a
amino acids under conditions normally found in water treatmen

In spite of these observations of selectivity in reaction pathwa
rine dioxide can engage in some reactions with the humic mate

lly occur in drinking water. End products are predominantly non-
nated organics that are formed as a result of oxidation. Many of
reactions are thought to involve phenolic groups—i.e., groups that
t of a basic benzene ring–type structure to which hydroxyl groups
) are attached (see Figure 3–2). Chlorine dioxide has been shown to
with these types of compounds in a manner that opens the benzene
o yield products such as di- and tricarboxylic acids, glyoxalic acid,
dehydes. Formation of quinones, a group of compounds that con-
a benzene ring structure to which two oxygen groups (=O) are
ed, is also observed with some phenolic reactions (7). The outcome
se reactions depends on the character of the phenolic compound,
being more susceptible to reaction than others. Reactions with hu-
cids at conventional doses have produced many similar byproducts,
ing carboxylic acids and glyoxal and other aldehydes. High doses
so produce monochloroacetic acid and traces of monochlorsuccinic
nd di- and trichloroacetic acids.

e extent to which ring opening occurs in reactions with phenolic
ounds can depend on the ratio of chlorine dioxide to organic carbon.
v chlorine dioxide ratios, the ring structure may be retained and the
on can lead to formation of quinones. Some chlorine substitution
also occur at lower ratios, leading to the formation of chlorinated
ls and chlorinated quinones (7), both halogenated organic bypro-
This substitution may actually result from alternative chlorine di-
degradation pathways in which hypochlorous acid becomes an in-
diate product. This type of reaction has been proposed for reaction
phenolic and other ring-type organics according to the following
al reaction in which R represents a benzene ring–type compound:

$$R{-}H + ClO_2 \longrightarrow R{=}O + HOCl \qquad (6\text{–}6)$$

ner reaction sequences leading to the formation of free chlorine have
proposed. Free chlorine also frequently occurs as an impurity, espe-
in cases where it is used for the generation of chlorine dioxide.
fore, there is a potential for free chlorine to be present in chlorine
le reactions, irrespective of mechanism. Consequently, some halo-
ed organic byproducts can be formed as a result of side reactions
chlorine. Because of this potential, consideration can be given to
aining a background level of ammonia to convert any free chlorine
oramines, thereby limiting the potential for these side reactions.
other significant feature of chlorine dioxide chemistry is the fact that
ide is not readily oxidized to hypobromous acid in dark solution.
is not the case with ozone, where some formation of halogenated

organic compounds is thought to occur as a result of hypobr
formation due to bromide oxidation in ozonated waters. A
quence, formation of brominated byproducts may be reduced
ride dioxide is used in place of ozone. However, it should be
photosensitized oxidation of bromide is possible with chlori
Therefore, the extent to which bromide-related reactions ca
mized may depend on the exposure to light.

Some research has indicated that chlorine dioxide can react
lomethane precursors to reduce the formation of trihalometh
percent of reduction in such trihalomethane formation potentia
as the ratio of chlorine dioxide to total organic carbon is incr
One study indicated that in the treatment of Ohio River water
mg/l of chlorine dioxide, a 50 percent reduction in the formatio
for trihalomethane resulted (14). However, such extensive re
the potential for THM formation may not always be possibl
actual extent of such reductions should be confirmed based on
tal evaluation. For example, in other research, chlorine dioxide
to increase the chloroform formation potential of certain labor
pounds, which were predominantly in the benzoic acid gro
other instances, where high levels of organic material are enco
may be difficult to achieve appreciable reductions in the forma
tial without producing excessive residual levels of chlorine dio
rite, and chlorate.

Although it is clear from available research that chlorine d
react to form some byproducts of potential health concern,
significance of these byproducts is not as apparent. Glyoxal an
acid are among classes of compounds that have exhibited muta
erties. Quinones are also a class of compounds of possible healt
However, other than chlorite and chlorate, the health effect
byproducts have not, as yet, been specifically evaluated in de
ies. Some indication of possible reduced health concern relati
ucts of free chlorine is offered in several studies that indicate r
in mutagenic activity in solutions subsequent to chlorine dioxi
tion. However, these types of studies, as discussed in Chapter
conclusive in nature.

DISINFECTION

Chlorine dioxide is regarded as a strong primary disinfectant th
tive for bacterial, viral, and protozoan pathogens. This is refle
EPA CT criteria for *Giardia* and enteric viruses. To achieve c
specified log removal of *Giardia*, these criteria can be met b

t CT levels that are usually less than half of the required free
CT. Under most pH conditions, the reduction in required CT, as
d with that for free chlorine, is even greater. However, in the
emoval of virus, free chlorine is given a higher credit for disinfec-
eby reversing the situation for this category of pathogens. How-
us removal is still reasonably achieved with chlorine dioxide.
most cases, CT criteria for *Giardia* will dictate the disinfecting
onditions.

e free chlorine, the disinfecting effectiveness of chlorine dioxide
dia is not affected by pH over a range of 6 to 9 (8). Therefore, it
e a further disinfecting advantage over chlorine as pH is in-
Care may still have to be taken to avoid excessive alkalinity,
an accelerate degradation of chlorine dioxide, as shown in Equa-

ne dioxide does not readily react with ammonia. As a result,
nmonia is present, the demand for chlorine dioxide may be re-
compared with chlorine, a disinfectant for which ammonia can
appreciable demand. However, many waters can exert a consid-
lorine dioxide demand through other pathways that result from
ence of background organic matter or inorganic substances such
manganese, and sulfides. In some of these cases, chlorine dioxide
can be difficult to maintain, and disinfection results can become
atic as a consequence. Furthermore, concerns for excess finished
sidual levels of chlorine dioxide, chlorite, and chlorate may re-
latitude for increasing the chlorine dioxide dose to more consis-
hieve the desired disinfecting residual. As an example of the
f certain types of demand, investigations in a water treatment
Lexington, Kentucky, disclosed a deterioration in certain aspects
cteriological quality of filtered water at functional pretreatment
of chlorine dioxide as compared with previous plant experience
chlorine (16). While coliform criteria were maintained with chlo-
xide, capability for broader disinfection was a concern. In this
observed deterioration was associated with high levels of back-
olonies of a noncoliform nature.

pproaches may be considered to resolve problems that occur
rine dioxide demand. In the first, the point of chlorine dioxide
on can be moved to a location in the treatment train that is
eam of the pretreatment process, allowing for maximum removal
ic and inorganic demand prior to chlorine dioxide addition. If
y, alternative oxidants such as potassium permanganate can
dered to achieve both preoxidation and reduction of demand.
al removal of demand-causing substances can be achieved in fil-

tration so that consideration can be given to locating the chlorine
addition to points downstream of this particulate removal pro
well.

The second approach for achieving more consistent chlorine
disinfection involves the addition of an adequate chlorine dioxide
achieve primary disinfection goals under all demand conditions.
ing the period of contact necessary to meet primary disinfection
tives, consideration can be given to removal of any excess chlori
ide residuals in a manner similar to the dechlorination processes
water and wastewater treatment. Under this approach, another d
tant, such as free chlorine or chloramines, would subsequently b
at dosages appropriate for meeting downstream secondary disi
criteria.

It is important to note that, while methods are available for re
chlorine dioxide and chlorite, chlorate is not easily removed or
formed. Therefore, reaction conditions for chloride dioxide ger
and within the process stream, prior to adding the reducing agent,
such that little chlorate is formed. In general, chlorate formation
able and may initially occur in limited quantities as long as the c
dioxide generation process is properly controlled to minimize such
tion. Subsequently, chlorate can form as a degradation product ov
with formation being catalyzed in the presence of sunlight. It c
occur as a result of reactions between excess chlorine and chlorite
range of 6 to 10 (32). As a consequence of these phenomena, steps
be considered to (1) limit chlorate formation during chlorine dioxi
eration and (2) select conditions for removing chlorine dioxide ar
rite that do not produce chlorate.

Granular activated carbon (GAC) and sulfur dioxide were or
thought to show promise as agents for removing chlorine dioxi
chlorite residuals. However, under some conditions, chlorate app
be a major end product when activated carbon is used and pot
negates benefits from this approach unless appropriate contacting
tions are employed. In the case of sulfur dioxide, both chlorine
and chlorite can be removed at a pH less than 6 (17). Howev
process also has been found to lead to the formation of chlorate
reducing agents that have been evaluated include sodium metab
sodium thiosulfate, and ferrous iron (Fe^{2+}) salts. Like sulfur diox
GAC, sodium metabisulfite has produced chlorate as an undesira
product. However, sodium thiosulfate does not produce apprecia
els of chlorate. This agent was particularly effective in a pH rang
to 6.5. Ferrous iron has been highly effective in achieving remov
pH range of 6.0 to 7.0 without producing chlorate (33).

there are some health concerns regarding chlorine dioxide resid-
orine dioxide has been effectively used to provide a disinfecting
for meeting secondary disinfection goals in some water distribu-
ems; several applications of this type exist in Europe (6). In this
application chlorine dioxide can often be more stable than free
by virtue of the fact that it does not readily react with water,
a, bromide ions, or most organic nitrogen compounds (8). The
f this advantage depends upon the presence of additional oxidant
ng constituents that might react with chlorine dioxide. Therefore,
ive stability of chlorine dioxide may be site specific. Where chlo-
xide is applied as a secondary disinfectant, attempts should be
remove these oxidant demanding substances prior to its addition.
as been discussed, the use of chlorine dioxide in a secondary
ion role may be limited by criteria that restrict residual levels of
dioxide, chlorite, and chlorate due to health concerns. Such
ons would constrain the allowable chlorine dioxide dosage. As a
ence, sufficient latitude for adding an adequate dosage might not
r many water systems.

ISINFECTION USES OF CHLORINE DIOXIDE

f the nondisinfection uses of chlorine dioxide result from its oxi-
roperties. This allows it to serve as a potential replacement for
orine in certain applications in which oxidative removal of target
ces such as iron and manganese, sulfide, color, and some taste and
mpounds can be achieved. Chlorine dioxide can also be effective
cide for the control of biological growths in water treatment sys-
his latter feature can result in improved filter performance and
dewaterability (18).

ome cases, goals for control of target substances can be more
ely achieved by using chlorine dioxide rather than free chlorine.
er, some caution should be exercised before arriving at such a
ion. For example, the demand exerted for free chlorine compared
for a chlorine dioxide alternative may have a significant influence
relative effectiveness of these two chemicals for meeting nondisin-
goals.

l of Biological Growths

e dioxide has not been widely cited as a biocide for control of
e biological growths. However, it appears to have a potential role

in this area. For example, chlorine dioxide has been used in so
trial applications for control of biofilms (6). Chlorine dioxide m
effective as a biocide for the control of Asiatic clams in raw w
lines (19). Another evaluation in Philadelphia reported chlorine
be an effective algicide for an open reservoir (20). Chlorite a
degree of biocidal capability, although it is not as strong as re
acceptable levels of pathogenic reduction (31).

Control of Tastes and Odors

One of the early applications of chlorine dioxide in water tre
related to its effectiveness for controlling certain types of t
odors. For instance, phenolic compounds can react with free c
form odorous chlorinated phenols. This phenomenon has been
some cases by using chlorine dioxide, which degrades both ph
chlorophenolic compounds by oxidation (2). Other common
odor compounds such as geosmin, 2,3,6-trichloroanisole, 2-i
3-methoxy pyrazine, and 2-methylisoborneol (MIB) have been
removed by chlorine dioxide (21). Geosmin and MIB are typ
most difficult of these compounds to remove.

Chlorine dioxide also appears to be useful in eliminating sulf
sulfide is rapidly oxidized by chlorine dioxide (6). This reaction
take advantage of the full oxidizing capability of chlorine dio
five-electron gain to form chloride. The total end product of thi
is not entirely clear, although it appears that sulfate is predom

While these experiences indicate a role for chlorine dioxide f
ling many taste and odor problems, a number of water utilities
the opposite experience in the actual creation of a significant
lem associated with the use of chlorine dioxide. These partic
have been observed to occur sporadically throughout service
certain homes and businesses reporting odors that range fr
sene" to "cat urine." It has been discovered that these od
produced by reactions between chlorine dioxide vapor esca
water at taps and showers and organic vapors found in the atm
some homes (23). Water temperature is probably a factor sinc
bility of chlorine dioxide in water decreases as temperature is
(30). A common source of reactive organic vapors is new carp
search (23) has indicated that, even in systems in which th
dioxide residual was very low in finished water leaving a water
plant, chlorine dioxide could be reformed to some extent in th
tion system by a reaction of its major degradation product, ch
the free chlorine species, hypochlorous acid (HOCl). The level

luced by this reaction was found to be capable of yielding the
chlorine dioxide off-gassing necessary for producing odors.
niation to convert free chlorine to chloramines was recom-
as one means for eliminating the reformation reaction. This ap-
vas reported to be effective by one utility (16). However, while
be effective where there is only a limited chlorine dioxide resid-
e finished water, such an approach may not be effective where
ntly larger chlorine dioxide residuals leave the plant. In such
moval of chlorine dioxide from finished water may be required.

of Iron and Manganese

dioxide has been demonstrated to be effective for the oxidation
le forms of iron (Fe^{2+}) and manganese (Mn^{2+}) to the higher oxida-
es (Fe^{3+} and Mn^{4+}) that are readily precipitated as hydroxides or
nd subsequently removed. Notably, the iron oxidation reactions
advantage of the full oxidation capability of chlorine dioxide to
electrons and form chloride (see Equations 6–2 and 6–3). How-
e manganese reaction appears to involve only a single electron
to form chlorite. These reactions result in theoretical dosages
ng of chlorine dioxide per mg of manganese (25) and 0.24 mg of
dioxide per mg of iron (assuming full five-electron transfer to
loride). Higher doses will actually be required due to the presence
demand-causing substances.
e generally improved manganese removal has often been reported
onverting to preoxidation with chlorine dioxide (18), the actual
eness for manganese control may depend on several key factors.
e dioxide can be extremely effective in achieving initial oxidation,
h it may not achieve effective manganese control if its residual is
iently dissipated in the treatment plant, a condition that allows
ese to return to its reduced form and redissolve. Capability for
ning a residual varies depending on the presence of demand-
substances. In particular, naturally occurring organic material
resent a significant competing demand (25).
cifically, redissolution phenomena are most likely to occur both in
ntation basins that do not continuously withdraw sludge as well as
urface of filter media where the manganese precipitate can attach.
phenomena can also occur in supernatant recycle streams from
handling and dewatering processes and in sedimentation basins
actice mechanical cleaning, especially at low cleaning frequencies.
olution has proved to be a problem in some plants upon conversion
rine dioxide. Conversely, previous use of free chlorine achieved a

more continuous level of oxidation throughout the treatment t
The problem might be alleviated either by the use of a higher
dioxide dosage or by multiple points of addition. Care may n
exercised, however, to avoid excess residuals of chlorine diox
rite, and chlorate that could exceed health-related criteria.
Water chemistry can significantly influence the effect of chlor
ide on both iron and manganese. Iron can be complexed with h
fulvic acids to form organic compounds that retard its rate of c
While manganese is not as readily complexed by the same h
fulvic matter (25), competitive oxidant demand is exerted. It als
reported that the chlorine dioxide oxidation rate of mangane
dependent (25); removal rates increase with increased pH, alth
in excess of 4.5 is adequate for most situations.

Removal of Color

Chlorine dioxide is widely recognized for its decoloring capa
industrial applications such as pulp- and paper-bleaching o
However, its effectiveness as a decoloring agent for drinking
not been as widely cited (2). A major consideration for use o
dioxide in this role is the dose requirement, especially in ca
health concerns for chlorine dioxide, chlorite, and chlorate resi
limit the applied dosage to a certain level.

ALTERNATIVE METHODS FOR APPLYING CHLORINE D

As has been discussed, two major issues limit the acceptable
chlorine dioxide residuals that can be maintained in finished w

- Health-related criteria that limit the exposure to chlorine diox
  degradation products, chlorate and chlorite.
- Odor problems related to chlorine dioxide off-gassing and s
  reaction with organic compounds emitted by household sourc
  carpets (discussed in the section Control of Tastes and Odo

The major questions related to these concerns are where and h
apply chlorine dioxide to achieve the maximum benefit within t
ated limitations on residual levels. The predominant factor that
izes the application of chlorine dioxide is the point of appli
general, chlorine dioxide can be used either for a pretreatment a
to raw water or for a posttreatment application to settled or filte
Each type of application has its particular advantages and li
In a pretreatment application, chlorine dioxide can be used for

ch as improved coagulation, oxidation of iron, manganese, and
control of certain tastes and odors, control of biological growth,
of color, and reduction of the trihalomethane formation poten-
night also be used for achieving disinfection goals in this type of
on, depending on the residual level available after demand. How-
major disadvantage of using a pretreatment location for disinfec-
hat the raw water demand may be high, making it difficult to
a consistent disinfecting residual. Also, high demand conditions
ate problems for maintaining a consistent oxidizing residual to
problems with downstream release of manganese. As discussed
receding section, previously oxidized manganese precipitates in
r on the surface of filter media can become exposed to periodic
conditions upon intermittent loss of a chlorine dioxide residual,
in a potential for resolubilization.

sttreatment location for chlorine dioxide application can reduce
s associated with maintaining a disinfecting residual under high-
raw water conditions. With this approach, upstream processes
coagulation and sedimentation are used to reduce the demand.
xidants, such as potassium permanganate, might also be applied
sedimentation and filtration to achieve the removal of iron, man-
sulfides, color, and taste- and odor-causing substances. Problems
nganese redissolution may occur, however, with these oxidants as
ternative biocides may also be necessary to control nuisance bio-
in settling tanks and filters.

tion of the type of application will depend on water quality factors
the level of chlorine dioxide demand in raw water, capability for
demand by treatment, the amount of downstream contact time
e at posttreatment locations for meeting primary disinfection cri-
e possible need for pretreatment oxidation for iron and manganese
and the availability of alternative oxidants for pretreatment when
l. These features will vary with location, and the best combination
oaches will necessarily be specific for a given set of water quality
ons and treatment goals.

dition to the location of the chlorine dioxide feedpoint, compati-
ith other water treatment conditions is another consideration in
a feedpoint. Powdered and granular activated carbon can re-
hlorine dioxide residuals and may, therefore, be incompatible.
lorine and potassium permanganate can also react with chlorine
so that simultaneous addition may need to be avoided. Excessive
ping and other gas transfer operations such as recarbonation can
eduction in chlorine dioxide levels due to its volatility. Alkaline pH
reater than 8 should be avoided due to a more rapid degradation to

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chlorite and chlorate as shown in Equation 6–5. Therefore, hi
cesses such as lime softening may present a problem for chlori
application unless the pH can be adjusted downward prior to it

Processes for removing chlorine dioxide after the necessary
fection and primary disinfection goals have been achieved m
more significant if restrictions on residual levels excessivel
permissable dosage range. These methods have been discus
section Disinfection.

GENERATION OF CHLORINE DIOXIDE

For the quantities usually required in water treatment, chlori
generation systems have typically relied on one of several re
volving sodium chlorite ($NaClO_2$). Alternative methods involvi
chlorate in place of sodium chlorite are more commonly us
larger quantities of chlorine dioxide that are applied in pulp
manufacture.

Chlorine dioxide formation from sodium chlorite typically
result of one of the following general reactions: (1) reaction wit

$$Cl_2 + 2NaClO_2 = 2ClO_2 + 2NaCl$$

or (2) an acidification reaction,

$$5NaClO_2 + 4HCl = 4ClO_2 + 5NaCl + 2H_2O$$

The reaction with chlorine gives a 1-to-1 yield of chlorine di
sodium chlorite compared to the 4-to-5 yield with acidification.
the chlorine reaction methodologies have the advantage of mor
utilization of sodium chlorite. This advantage has favored the u
rine reaction–based methodologies, and there are few plants w
used in water treatment.

Although extreme acidity is not desirable, a moderate leve
(pH 2 to 3) enhances the chlorine reaction and is commonly us
enhancement results from two phenomena that occur with a
(17, 26):

1. Conversion of free chlorine from hypochlorous acid (HOC
   ular chlorine (Cl_2):

$$2H^+ + 2HOCl = Cl_2 + 2H_2O$$

reaction can begin to occur in the pH 2 to 3 range and can be
ortant for the formation of chlorine dioxide since molecular chlo-
reacts more rapidly with chlorite to form chlorine dioxide.
version of chlorite ion (ClO_2^-) to chlorous acid ($HClO_2$).

$$H^+ + ClO_2^- = HClO_2 \qquad (6\text{–}10)$$

reaction also begins to occur in the region of pH 2 to 3. Chlorous
is more reactive with hypochlorous acid (HOCl), which may still
resent in this region.

e older-generation systems do not apply the appropriate acid con-
to fully form chlorine dioxide so that partial conversions occur as a
Under partial conversion, an undesirable excess of hypochlorite
orite can persist. These conditions can also lead to formation of
e as an undesirable byproduct (17).
tively precise control of pH is important since extremely low pH
an cause the onset of the less efficient acidification reaction (Equa-
8). Conversely, inadequate acidity does not allow sufficiently rapid
on of chlorine dioxide. Reactant ratios must also be controlled to
e nearly complete conversion of chlorite while avoiding undesir-
cess levels of chlorine.
edures used for the generation of chlorine dioxide include control
tant ratios and other conditions such as pH. Direct monitoring of
n products as a control measure, however, has been complicated
cumbersome techniques used for analyzing chlorine dioxide, chlo-
d chlorate. Methods for analyzing chlorate have been particularly
. These complications have inhibited development of convenient
ls for direct field analysis and control. Reactant ratio and pH con-
e typically relied upon for process control and are confirmed by
c laboratory results that use the more cumbersome methods avail-
r analysis (27). Newer direct analysis techniques under develop-
nclude a recent method for assessing chlorate and chlorite by ion
atography (28) and a flow injection analysis method (17). While
nay eventually simplify laboratory methods, improved methods for
field analysis would still be helpful for process control decisions.

ation Methods

enerating systems that rely primarily on the acidification of sodium
e (Equation 6–8) have been used in the past and may still have a
However, as has been discussed, these systems are generally less

efficient than those that rely on reaction of chlorine with sodi
(Equation 6–7) and are not widely used. Basic alternative
methods using chlorine and sodium chlorite are shown in Figu
are summarized below.

Chlorine/Chlorite System

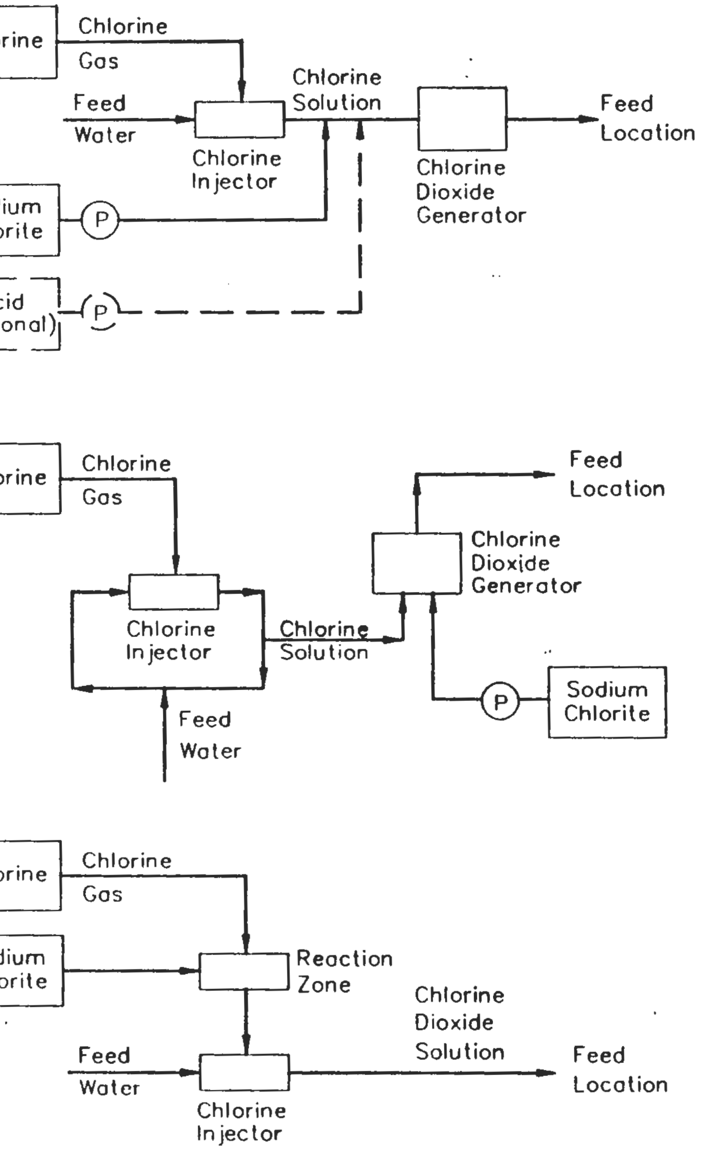
This system involves the dissolution of chlorine into a feed w
followed by subsequent contact with a sodium chlorite stream
tor or reactor. The two streams are mixed for reaction eithe
reactor or in the reactor influent pipeline, as shown in Figur
can be added if necessary for controlling the reaction within t
pH range for chlorine dioxide generation. In some systems, t
feed stream can provide much of the necessary acidity. Add
requirements will depend on the system provided and the p
with chlorine addition. In general, the chlorine/chlorite syst
require proper pH control. A slight excess of chlorine is usu
for complete conversion of sodium chlorite. However, the e
tity should be limited to avoid unnecessary levels of free chl
feed stream and to minimize undesirable side reactions in wh
reacts to form chlorate (29) or where excess chlorine may for
downstream points of application.

Chlorine Recycle System

With this approach, chlorine is applied to a recycle loop, all
rine levels to build up to higher levels than can be achieved
pass systems. These high chlorine concentrations have flexib
vide a pH down to less than 2 by virtue of the acid properties
A feed stream is drawn off of this recycle loop to mix with sod
in the generation reaction and a feed water stream is added to
loop to make up the volume difference. As in the case of t
chlorite system, the chlorine feed must be maintained in a pre
with the sodium chlorite feed to provide nearly complete co
sodium chlorite while avoiding excess chlorine levels. H
problems that can occur in maintaining optimum chlorine/ch
in the absence of separate acid addition are reduced by the
recycle loop is used for controlling pH. This allows the chlori
at a proper pH, to be withdrawn to the chlorine dioxide gener
on an as-needed basis for achieving the optimum ratio.

Gaseous Chlorine System

The gaseous chlorine system involves direct addition of a ga
rine stream to a liquid sodium chlorite stream, as shown in



1. Basic chlorine dioxide systems using chlorine and sodium chlorite: (a)
rite system; (b) chlorine recycle system; (c) gaseous chlorine system.

Both streams are drawn by the vacuum created by the feed w
through a chlorine injector. They are combined in the injector f
in a reaction zone. This method of contacting allows for a rea
tween molecular chlorine, directly available from the gas stre
chlorite in the liquid stream. A significant attribute of this sys
reduced need for rigorous pH control due to the fact that, as
sorbed, molecular chlorine tends to react rapidly with the ch
solution before it can react with water to form hypochlorous acid
However, chlorine feed must still be maintained in proper bal
sodium chlorite feed. It is claimed that this fast reaction metho
less acidic condition produces a high chlorine dioxide yield that m
contamination with chlorine and chlorate.

EQUIPMENT AND PIPING

Generation of chlorine dioxide requires handling of reactant an
streams that can include sodium chlorite, chlorine, acid, and
dioxide. All of these chemicals are extremely corrosive and re
propriate material selection for equipment and piping. They are
ardous, and appropriate safety measures need to be included i
Containment barriers should be placed around all liquid storag
the event of spill or rupture.

The basic components of chlorine dioxide generation syste
follows:

- Sodium chlorite storage and feed system
- Acid storage and feed system (acid use depends on generation
- Chlorine storage and feed system (chlorine use depends on g
  method)
- Chlorine dioxide generator
- Chlorine dioxide feed piping and dispersion equipment

Chlorine storage and feed equipment have already been des
Chapter 4. Acid and sodium chlorite storage and feed systems
cally liquid systems that consist of a storage tank(s) and solu
pumps. In some cases, storage might be separated into bulk
smaller operational or day tanks that are filled periodically.
tanks are most often used for such storage. Diaphragm meteri
are commonly used for control of liquid feed rate. The diaphr
partment of the feed pumps is normally made of PVC, and
resistant diaphragms such as Teflon membranes are used. Sodiu
flows are frequently measured with magnetic flow meters or r

se control. Piping is of PVC, rubber, or Tygon materials. Provi-
uld always be made for back-flow prevention. Sodium chlorite is
y reactive, especially in the dry form, and care should be taken to
gainst potentially explosive conditions.
ne dioxide generators are relatively simple mixing chambers that
tructed of Pyrex or PVC. The reactors are frequently filled with
ch as Raschig rings or PVC rings in order to generate hydraulic
ce for mixing. In many cases, glass is better than porcelain for
rings since a small manganese content in dilution water can lead
ipitate formation that clogs porcelain. A sample valve is desirable
scharge end to allow for monitoring of the generation process.
ation systems are available in sizes from 10 to more than 1,000 lb/
ases where a wide range of feed rates is encountered, it may be
to intermittently operate a chlorine dioxide generation system to
termediate equalization tank as opposed to trying to maintain
generation for various reactant streams under varying condi-
ariable flows can then be withdrawn from the tank as required
owing conditions in the generation system to remain constant.
of system is described by Masschelein (29). Care must be taken
sign of these tanks to protect against the potential for toxic off-
he maximum acceptable concentration for chlorine dioxide in
areas is 1 ppm by volume in air; a gas phase containing more than
nt by volume is explosive. As in the case of chlorine, chlorine
s denser than air.
suppliers of gaseous chlorine dioxide generation systems have
d equipment that can provide a high level of feed control of
feed streams under varying chlorine dioxide demand conditions.
stems can eliminate the need for intermediate chlorine dioxide

stem Design Considerations

wing basic features should be considered in the design of chlo-
xide systems:

t material should be used in contact with the strong oxidizing and/
cid solutions involved in chlorine dioxide systems.
arate containment should be provided for each liquid chemical.
age tanks should be provided with vents to outside.
quate ventilation and air monitoring should be ensured.
masks and first aid kits should be provided outside of the chemi-
areas.

6. A washdown capability should be provided in chemical stor
ing areas.
7. The reactor should be equipped with glass view ports if it is r
of transparent material.
8. Flow monitoring should be provided on all chemical feed lin
tion water lines, and chlorine dioxide solution lines.
9. Dilution water should not be excessively hard in order to a
cium deposits and should be near neutral pH.
10. On-site and frequent testing of chemical solution strengths s
practiced to achieve efficient process control.
11. Air contact with chlorine dioxide solutions should be cont
limit the potential for explosive concentrations. Chlorine
concentrations in air higher than 8 to 10 percent volume
avoided. Two methods can be applied: operation under va
under higher positive pressure (45 to 75 psi) to prevent b
excess chlorine dioxide.

TYPICAL PLANT REQUIREMENTS

Commercially available sodium chlorite solution is usually 2
sodium chlorite by weight or 300 to 310 g/l (a tropical version
strength exists) and weighs 10.53 lb/gal. It takes 0.52 gallons of
tion and 0.5 pounds of chlorine to produce 1 pound of chlorine d
10 mgd plant feeding 0.5 mg/l of chlorine dioxide would require
gallons a day of sodium chlorite and 20 pounds of chlorine. Prop
changes in feed quantities would be required for variations in
and dosage, respectively. For small capacity plants, sodium chlo
tion comes in many sizes of bulk packs and is pumped directly f
storage units. In larger plants, a 30-day storage tank should be
with a transfer pump. Two chemical feed pumps would be re
each chemical for duplication of facilities as required by the EP
Water Treatment Rule. It may be appropriate to install two chlo
ide generators or to provide the capability to substitute free c
short periods of time.

Some small communities have arranged for the supplier to f
service the generator. The service could include regular testing
uals of chlorite, chlorate, and chlorine dioxide in the treated w
service could double or triple the cost of sodium chlorite but n
expensive than arranging for the equipment, servicing, and te
rately. Since the chemicals for generating a pound of chlorine d
be more expensive than per pound of chlorine, depending on l
local chemical suppliers' prices for various size deliveries shou
for estimating the operating costs.

nces

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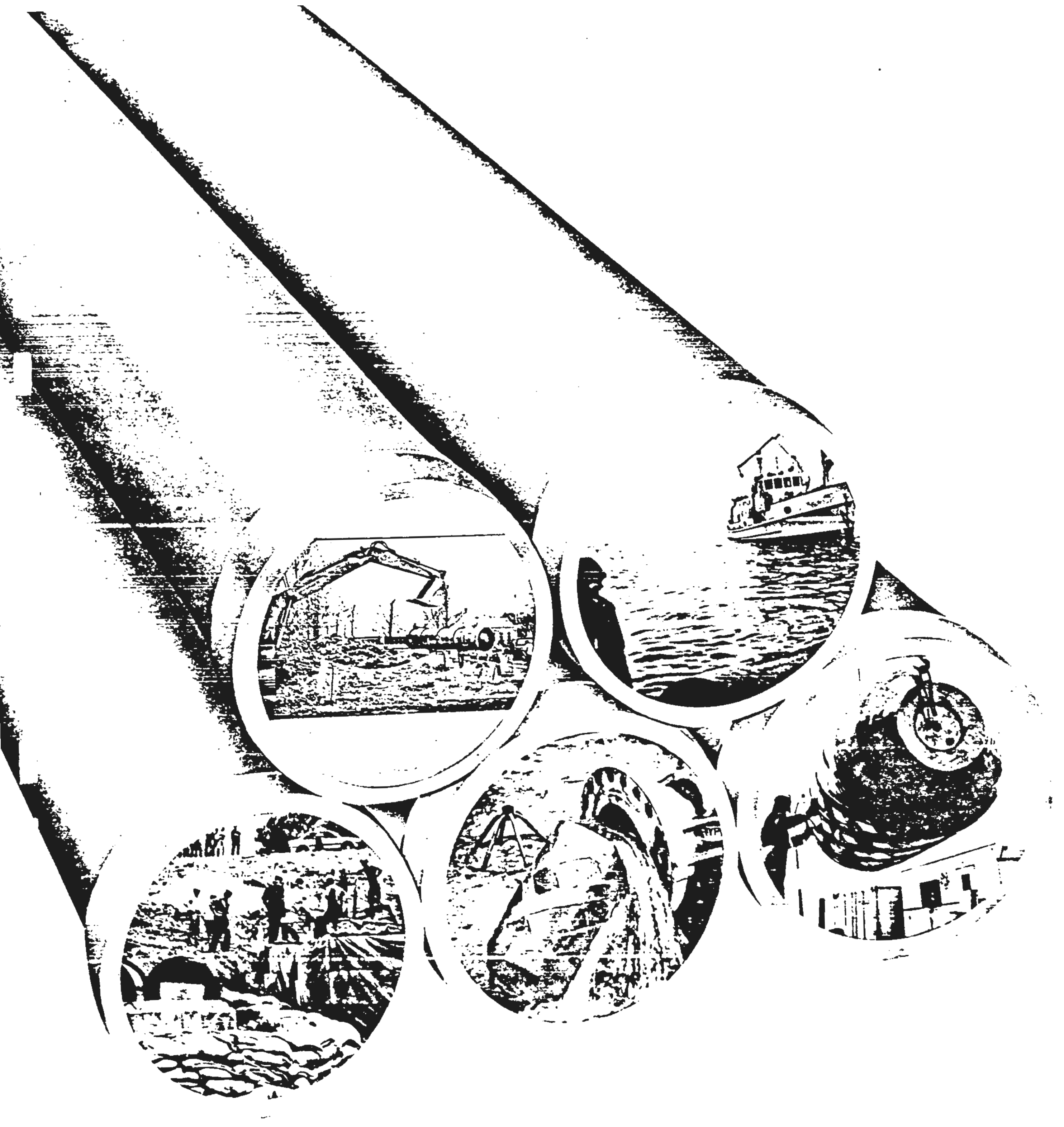
APPENDIX F

VENDOR DATA - PIPELINE PIGS



PIPELINE CLEANING – Industrial and Municipal

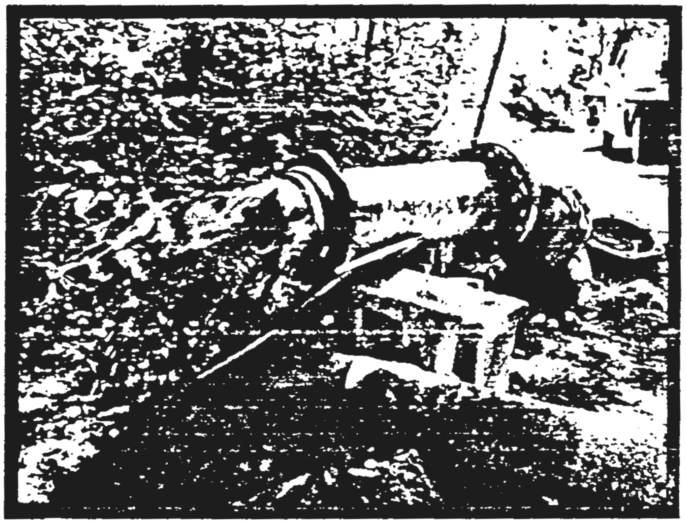
MONTAUK SERVICES, INC.

STATE OF THE ART HY

When Montauk Services is on the job, pipeline networks are cleane crews, clean thousands of feet in one run, navigating 90 degree short ra

MUNICIPAL PIPELINE CLEANING

Montauk Services solves restricted flow problems in a variety of pipelines through the use of poly-pigs.



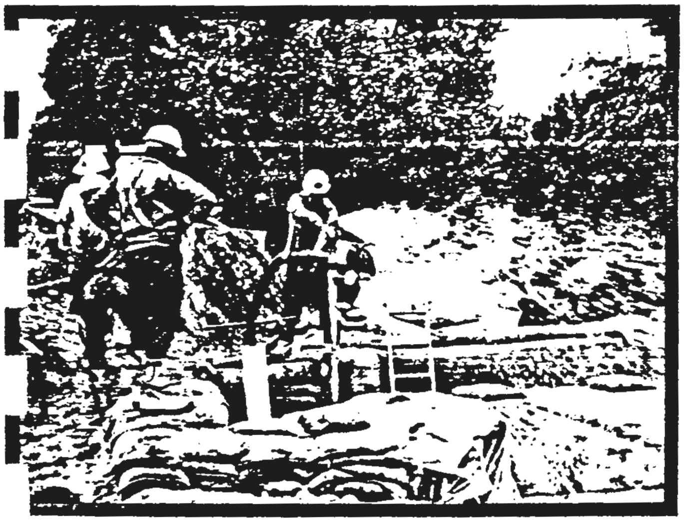
Pig exiting 8" cast iron water main.

DISTRIBUTION LINES

Montauk Services cleans and restores thousands of feet of pipeline in towns across the nation with a minimum of disruption and downtime. Our poly-pigs are propelled through 90 degree turns, valves and multi-dimensional pipes to break loose and clean out rust, iron deposits, tuberculation and calcium deposits. This unique flexibility and strength eliminates many of the expensive excavations and repairs normally associated with pipeline cleaning.

TRANSMISSION WATER MAINS

Miles of transmission water mains are cleaned with poly-pigs without the expense of temporary by-pass water service. Specified flow is restored to municipal pipelines without the damage to inner pipe wall or joints hat can be experienced when using other cleaning systems.



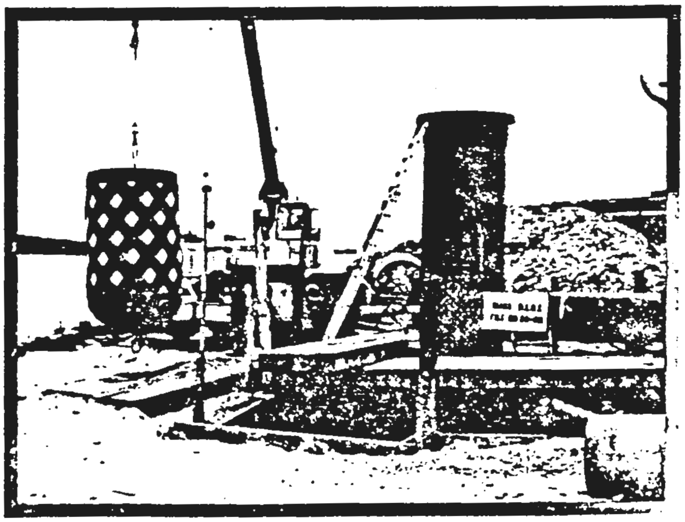
48" Transmission main retrieval site.

WASTE WATER FORCE MAINS

Waste water force mains are cleaned by launching igs at the pumping station and retrieving them at an existing manhole. This system is the most cost effective and efficient method available to esolve force main capacity problems and to educe pumping costs.

OUTFALL PIPELINES

Large diameter underwater outfall pipelines can be cleared of the construction debris found in new lines or cleaned of the debris and silt that accumulate over the years in existing lines. Montauk Services' custom made outfall pig is fitted with a special underwater transmitter so that the pig's location can be constantly monitored by our technicians.

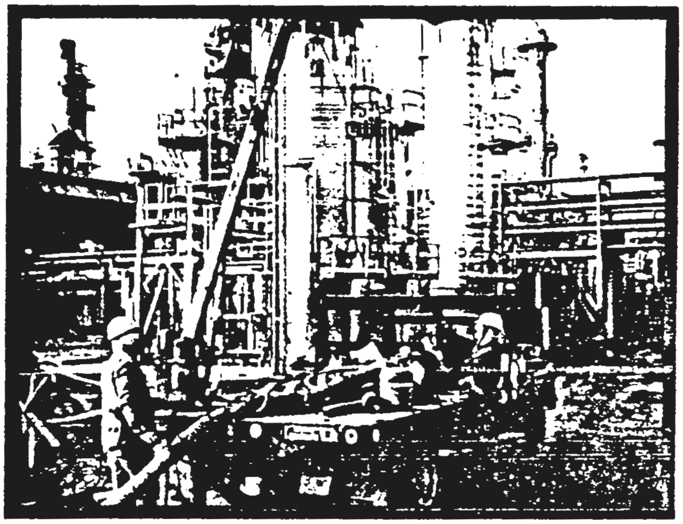


60" outfall pig and launcher.

and flow is restored. Poly-pigs, the mainstay of Montauk's field us elbows, crossing tees and passing through full opening valves.

INDUSTRIAL PIPELINE CLEANING

Montauk's services and pigs clean underground and in-plant pipeline networks throughout the world.



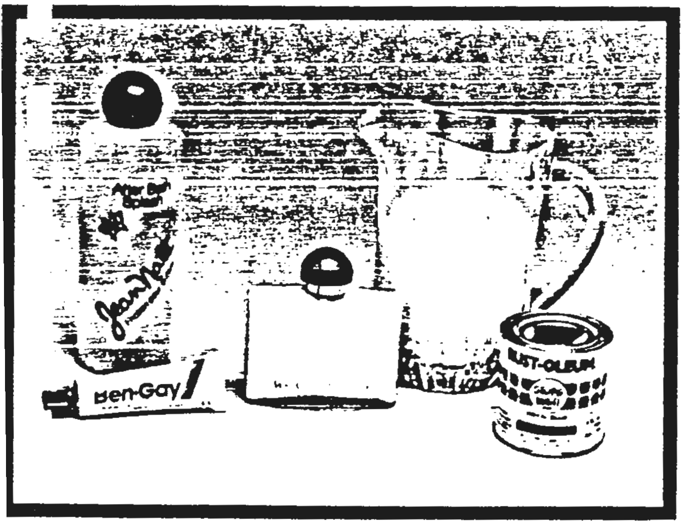
Cleaning of refinery fire lines.

FIRE SYSTEMS

Miles of underground fire mains are "pigged" by Montauk Services every year to meet underwriters' flow requirements. This is achieved at a fraction of the cost of alternatives such as cement lining or pipeline replacement.

PROCESS WATER LINES

Process water lines need to be kept free of contaminants and scale to insure the quality of finished water. Montauk's pigs, launchers, and receivers accomplish these goals and reduce pumping costs.



A few of the products reclaimed by Montauk Services.

INTAKE AND DISCHARGE LINES

Large diameter intake and effluent lines are restored to maximum flow with Montauk Services' pigging process.

IN-PLANT PRODUCT LINES

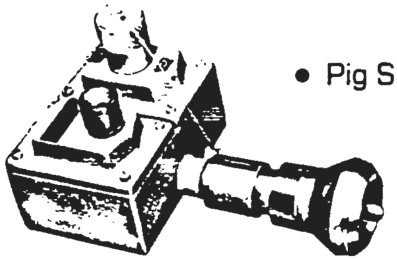
Montauk Services' pigs save industry tens of thousands of dollars annually by reclaiming tons of usable product from their in-plant product lines. Perfumes, paints, oil, precious metal slurry, toothpaste, solvents, silicone, chemicals, pharmaceuticals and fruit juices are among the many products salvaged at enormous profit to our clients.

Removal of 36" pig from in-ground trap.

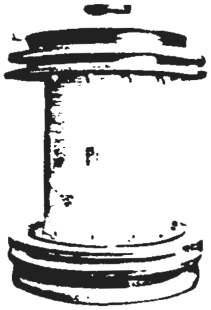
PRODUCTS and SERVICES

Companies and cities throughout America have found cleaning and rehabilitating their pipes the reasonable and cost effective alternative to replacement. To maximize the dollar saving advantages of the poly-pig method, they have bought pipeline products from Montauk Services for their own use.

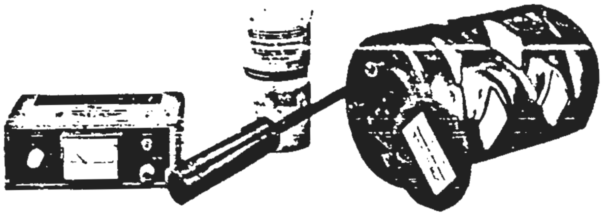
PRODUCTS AVAILABLE



- Pig Signals

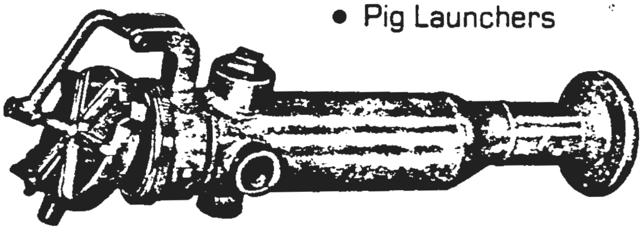


- De-watering Pigs



- Transmitters & Receivers

- Polyurethane Pigs



- Pig Launchers

SERVICES

- Turnkey Cleaning
- Consulting
- Hydrostatic Testing
- Leak Detection

THE NEEDS OF EVERY INDUSTRY AND CITY ARE DIFFERENT. AS AMERICA'S FOREMOST FULL SERVICE PIPE CLEANING COMPANY, MONTAUK SERVICES IS ABLE TO MEET YOUR SPECIAL REQUIREMENTS.

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Rex Murphey

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