

GUIDANCE MANUAL FOR THE DISPOSAL OF CHLORINATED WATER

Maria W. Tikkanen, Ph.D., East Bay Municipal Utility District, Oakland, CA

John H. Schroeter, P.E., East Bay Municipal Utility District, Oakland, CA

Lawrence Y.C. Leong, Ph.D., QEP., Kennedy/Jenks Consultants, Irvine, CA

Rajagopalan Ganesh, Ph.D., Kennedy/Jenks Consultants, Irvine, CA

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GUIDANCE MANUAL FOR THE DISPOSAL OF CHLORINATED WATER**Maria W. Tikkanen, Ph.D., East Bay Municipal Utility District, Oakland, CA****John H. Schroeter, P.E., East Bay Municipal Utility District, Oakland, CA****Lawrence Y.C. Leong, Ph.D., QEP., Kennedy/Jenks Consultants, Irvine, CA****Rajagopalan Ganesh, Ph.D., Kennedy/Jenks Consultants, Irvine, CA****ABSTRACT**

Periodically, water utilities discharge finished water containing residual chlorine during emergency and planned activities that may end up in receiving streams. Chlorine is toxic to aquatic life, however, even at concentrations that cannot be detected by field measurements. In addition, the Endangered Species Act may be listing more aquatic species in the near future. Hence, preventing chlorinated water releases from reaching receiving streams is becoming an increasingly important issue for water utilities.

East Bay Municipal Utility District (EBMUD) has recently undertaken an AWWARF project to prepare a guidance manual for dechlorination of potable water releases. The objective of the project is to summarize applicable federal and state regulations, summarize planned and unplanned sources of chlorinated water, summarize dechlorination methods currently in use, and develop standard operation guidelines for disposal. Ten participating utilities located throughout North America provided information concerning dechlorination, as well as overall technical review during the project. Field test data were also developed by several water utilities concerning the use of dechlorination chemicals.

The AWWARF guidance manual summarizes the state of the art of dechlorination, provides a sample 'Fly Sheet' for quick reference for operationally focused management staff and operators, and recommends future work required to develop Best Management Practices (BMPs) for each dechlorination activity.

INTRODUCTION

Chlorine is widely used as a disinfectant by water utilities. Chlorinated waters from potable water systems are released to the environment through activities such as water main flushing, disinfection of new mains, distribution system maintenance, water main breaks, filter backwash and other utility operations. Although chlorine protects humans from pathogens in water, it is highly toxic to aquatic species in the receiving streams. In particular, chlorine may be toxic to many species protected under the Endangered Species Act, even at very low concentrations.

Dechlorination is practiced by some water utilities during releases of chlorinated water. Several chemical and non-chemical methods are used for chlorine neutralization during such releases. However, dechlorination is still an evolving practice in the water industry. Impacts of dechlorination chemicals on the water quality of receiving streams are not well documented. For example, over-application of chemicals such as sodium metabisulfite and sulfur dioxide, which are commonly used

for dechlorination, may deplete the dissolved oxygen concentration or alter the pH of receiving streams. Currently, there is no industry guidance or AWWA standards for dechlorination of potable water releases. Recent changes in regulatory approach, that includes a more ecological and watershed perspective, have caused an increased level of scrutiny concerning current dechlorination practices. The regulatory review can become more significant as some of the secondary impacts of the dechlorinated discharges are more completely understood.

Currently, most written materials that are available to water utilities concerning dechlorination practices are summarized in utility reports. The reports are not readily available to other utilities that have to deal with dechlorination issues.

East Bay Municipal Utility District, Oakland, CA, has undertaken an American Water Works Association Research Foundation (AWWARF) project to develop a guidance manual for the disposal of chlorinated water from potable water sources. This guidance manual summarizes available information on current dechlorination regulations and disposal practices in a centralized, easily available manner. The manual, which addresses dechlorination issues in the United States and Canada has been prepared through the active participation of ten utilities in geographically diverse locations throughout the U.S. and Canada. The utilities differ significantly in their use of disinfectant, source waters and in the population served (Table 1). These variations in utility activities have an impact on the water management practices and hence, in the approach to dechlorination. The manual addresses dechlorination of free and combined chlorine (chloramine) disinfectants.

Table 1. Participating Utility Information

Utility	Location	Population Served	Water Source (% Annual Basis)	Disinfection Residual
East Bay Municipal Utility District	Oakland, CA	1,200,000	100% Surface	Combined
Bureau of Water Works	Portland, OR	800,000	Primarily Surface	Combined
City of Mesa	Mesa, AZ	360,000	80% Surface, 20% Ground	Free
Department of Public Utilities	Naperville, IL	110,000	100% Surface	Free
South Central Connecticut Regional Water Authority	New Haven, CT	379,000	Surface & Ground	Free
Environmental Operations Division, Broward County	Pompano Beach, FL	250,000	100% Ground	Combined
Tacoma Public Utilities	Tacoma, WA	300,000	90% Surface, 10% Ground	Free

El Paso Water Service	El Paso, TX	1,060,000	45% Surface, 55% Ground	Free
Department of Water Works	Cincinnati, OH	810,000	88% Surface, 12% Ground	Free
Regional Municipality of Ottawa-Carleton	Ottawa, Ontario, Canada	650,000	100% Surface	Combined

SCOPE OF WORK: GUIDANCE MANUAL FOR THE DISPOSAL OF CHLORINATED WATER

The objective of this project is to develop a guidance manual that summarizes the state of the art of dechlorination. The following tasks were performed to accomplish this.

1) Identification of existing regulatory requirement and agencies. Federal, State and Provincial regulations related to the disposal of chlorinated water were identified. The permit programs used by state/provincial regulatory agencies for disposal of chlorinated waters were also summarized.

2) Identification of sources of chlorinated water releases. Data on various sources of chlorinated potable water release were obtained from the participating utilities. The sources were then categorized based on the volume of flow, nature of release and amount of chlorine present, in order to assist in the development of Best Management Practices (BMPs).

3) Identification and evaluation of existing disposal and treatment practices and technologies. Non-chemical and chemical dechlorination methods currently practiced in the industry, their benefits and limitations were identified. In addition, dechlorination chemical feed techniques, chlorinated water flow control measures, and analytical techniques for measuring residual chlorine concentrations were briefly summarized.

4) Field test selected candidate technologies. Subsequently, field tests were conducted using six dechlorination chemicals to obtain data on dechlorination efficiency. Rates of dechlorination, effect of over-application of chemicals, impacts on water quality, impact of dechlorination chemical forms and impacts of the type of chlorine present were evaluated.

5) Develop Guidance for chlorinated water disposal. The final task of the project was to assist in the development of BMPs for disposal of chlorinated water. Based on the available data, a sample 'Fly Sheet' was prepared to provide a state of the art, quick summary for operationally focused management staff and operators for disposal of chlorinated water from hydrants. In addition, future work required to facilitate development of BMPs for each dechlorination scenario were identified.

STATE OF THE PRACTICE OF DECHLORINATION

Current Dechlorination Regulations

U.S. Regulations

Regulations For Residual Chlorine Concentration. The United States Environmental Protection Agency (USEPA) has established Water Quality Criteria (WQC) for ‘total residual chlorine’ (TRC) concentrations permissible in receiving waters, to protect aquatic life and water quality. These concentrations are based on acute and chronic toxicity effects for aquatic life. Under the acute toxicity criterion, the 1-hour average chlorine concentration of the stream should not exceed 19 µg/L more than once every three years, on the average. Under the chronic toxicity criterion, the 4-day average concentrations should not exceed 11 µg/L more than once every three years, on the average.

Most states in the U.S. use 19 and 11 µg/L as the acute and chronic criteria for TRC for receiving streams. Some states have adopted a toxicity-based criterion as the water quality criterion for TRC. The state regulatory agencies require water utilities to abide by the receiving water quality criterion while discharging chlorinated waters. In addition, the regulatory agencies use WQC to develop maximum allowable chlorine concentrations while issuing general/individual permits for discharge of chlorinated water into streams.

The permit processes used by state regulatory agencies to regulate chlorinated water discharge vary significantly from state to state. California, Oregon, Washington, Nevada, Maryland and West Virginia have stringent regulatory discharge limits for chlorinated waters. Chlorine discharge limits in all water releases into receiving streams must not exceed 0.1 mg/L (or a more stringent limit) in these states. Other states have more than one general permit to regulate various chlorinated water releases. However, these permits do not include all potable water discharges. Nebraska and Texas regulate hydrotesting waters through a general permit or an administrative rule. Utah has administrative guidelines for chlorinated water discharges. In many states, no general or individual permit program is in place for potable water releases. Although permits are not required, utilities in these states are required to meet the water quality criteria of receiving streams while discharging potable waters. Table 2 highlights selected states based on the severity of permit processes for chlorinated water disposal.

Table 2. Status of permit program for chlorinated water release in the U.S.

Permit Requirement	States
States regulating all chlorinated water discharges through general permit, BMPs or individual permits.	California, Oregon, Nevada, Washington, Maryland and West Virginia
States having multiple general permits.	Colorado, Connecticut, Tennessee, Kentucky, South Carolina, Wisconsin and Wyoming
States regulating hydrostatic test waters only.	Hawaii, Nebraska, North Dakota and Texas
States with no general permits that may or may not require individual permits for select discharges	Idaho, Iowa, Kansas, Illinois, Indiana, Michigan, Arkansas, Georgia, Louisiana, Maine, New Jersey, New Mexico, New York, South Dakota, Utah, Virginia and Vermont

Associated Regulations to Chlorinated Water Releases in the U.S. In addition to residual chlorine concentrations, some other water quality parameters must be monitored during disposal of chlorinated

waters. For example, dechlorination of chloramine residuals may result in the release of ammonia. USEPA has determined the maximum allowable acute and chronic concentrations of ammonia based on the pH, temperature and the type of aquatic habitat present (warm vs. cold water species) in receiving waters. Under the most stringent conditions, (cold water, pH of 9 at 30° C), a one-day average total ammonia concentration must not exceed 0.58 mg/L as NH₃ and the four-day average must not exceed 0.08 mg/L as NH₃.

Most states have adopted the EPA criteria as the water quality standards for ammonia. Water utilities using combined chlorine often maintain a residual chlorine concentration of less than 1.5 mg/L in potable waters, with a chlorine to ammonia ratio of 4:1 to 5:1 by mass. This will result in a total ammonia concentration of approximately 0.4 to 0.5 mg/L, which is less than the acute criterion of 0.58 mg/L for total ammonia under the worst-case scenario. A ten-fold dilution of chloraminated water in the receiving stream will result in compliance with the chronic ammonia concentration criterion (0.08 mg/L) under the most stringent conditions.

Hence, for the majority of dechlorination operations, ammonia released from chloramines is likely to be within the regulatory requirements. However, some states may have regulations more stringent than the EPA criteria for selected waters. Caution must be exercised in releasing dechloraminated water into receiving streams under such conditions.

Dechlorination using reducing agents such as sodium bisulfite and sodium metabisulfite may deplete oxygen concentrations in receiving waters. Water quality standards for minimum dissolved oxygen (DO) concentrations may vary from state to state and by the type of water use. The minimum dissolved oxygen concentration for certain fresh waters in Oregon that provide for salmonid spawning, is as high as 11 mg/L. In contrast, DO concentrations as low as 2.5 mg/L are permitted for certain waters in Arizona. However, in most cases, the minimum required DO concentrations for warm and cold water streams, respectively, vary from about 5.0 to 6.0 mg/L and 6.0 to 9.0 mg/L.

Many dechlorinating agents produce hydrochloric and sulfuric acids while neutralizing chlorine. In most states, receiving water pH standards vary with the use classification of the receiving streams. Most of the state water quality standards require a receiving water pH between 6.0 and 8.5. In addition, many regulatory agencies require that the release of chlorinated waters should not alter the pH of the receiving stream by more than 0.2 to 0.5 units.

Caution must be exercised in complying with ammonia, pH and DO regulations during dechlorination activities.

Canadian Regulations

Regulations For Residual Chlorine Concentration. Canadian Environmental Quality Guidelines (1987) propose a water quality criterion of 2 µg/L of total residual chlorine for receiving streams. Many provincial regulatory agencies have adopted this chlorine concentration as the WQC. However, the criteria for chlorine and chloramine concentrations are currently being reviewed under the 1999 water quality guidelines.

The provinces of British Columbia and Ontario require all water releases to contain less than 2 µg/L of chlorine. In British Columbia, the regulatory discharge limit for intermittent flows is a function of the duration of the release as given by the following equation:

$$\text{TRC} = [1074 (\text{duration})^{-0.74}] \mu\text{g/L},$$

Where, 'duration' is the uninterrupted exposure period in minutes. The maximum concentration of total residual chlorine should not exceed 100 µg/L (0.1 mg/L) regardless of the exposure period.

Nova Scotia requires all new facilities to dechlorinate completely prior to discharge into receiving streams. Existing water utilities must meet water quality criteria for receiving streams while discharging chlorinated waters. Saskatchewan has a general permit for hydrostatic test water releases. Permissible chlorine concentrations are decided on a case-by-case basis. Permit programs are not in place for other chlorinated water releases. New Brunswick recommends release of chlorinated water into sanitary sewers. An individual permit is issued for chlorinated water releases to receiving streams or storm sewers. Prince Edward Island uses groundwater with no chlorination for potable water supply. Hence, the majority of the potable water releases do not have residual chlorine. Individual permits are issued when chlorinated water is released after disinfection of new or repaired mains. Alberta, Manitoba and Quebec do not have a general permit for potable water releases, but require all utilities to meet the discharge limit of 2 µg/L through water treatment plant operating permits. In Newfoundland, the residual chlorine concentration in released water should not exceed 1 mg/L.

Associated Regulations for Disposal of Chlorinated Water in Canada: In general, the water quality criteria for ammonia, dissolved oxygen and pH in Canada are similar to those in the United States. In Newfoundland, the pH of the released water should be between 5.5 and 9.0. In Saskatchewan, total ammonia concentrations in the receiving water can be as high as 2.6 mg/L at pH 6.0 and 0° C to as low as 0.06 mg/L at pH 9.0 and 30° C.

Sources of Chlorinated Waters

Potential sources of chlorinated water releases were obtained from the participating utilities. Chlorine is present in these waters as a result of disinfection of system components (water mains, storage facilities, etc.) or disinfection of potable water. The concentration of chlorine present, and the amount of water released, depend on the source of the water release. The releases can generally be classified into planned, unplanned and emergency releases.

Planned releases of chlorinated waters result from operation and maintenance activities such as disinfection of mains, testing of hydrants, and routine flushing of distribution systems for maintenance. The volume, duration and chlorine concentrations vary with the type of activity. For example, following repairs, water mains are disinfected with highly chlorinated waters (50-300 mg/L). However, waters released from flushing activities generally contains less than 4 mg/L. Although planned sources sometimes may contain high concentrations of chlorine, their discharges are generally easier to control and hence, easier to dechlorinate.

Unplanned releases occur from activities such as main breaks, leaks and overflows. Unplanned releases in most cases have lower chlorine concentrations (reflective of chlorine concentrations in the distribution system) than those in most planned releases. Unplanned releases are harder to neutralize due to limitations in response time, staff availability and the difficulty in containing these discharges.

Activities such as water main flushing in response to higher than allowable coliform counts, taste and odor complaints from the public, and releases during fire fighting are examples of emergency releases of chlorinated waters. Emergency sources of chlorinated waters are the most difficult types to dechlorinate, because of the extremely low predictability of these events and limitations in the response time.

Table 3 categorizes sources that generate chlorinated waters according to varying TRC concentrations, durations and flow rates. In developing these categories, low chlorine releases are defined as those containing less than 4 mg/L chlorine. Flows greater than 500 gpm and lasting for more than a day are defined as high flows, and flows smaller than 50 gpm and lasting for less than 2 hours are classified as low flow releases. Remaining flows are considered moderate flow releases.

Table 3. Sources of chlorinated water release

Characteristic of the release	Source Activity
Planned, low chlorine, high flow sources	Main dewatering (> 24" diameter pipe inspection); Pumping plant and reservoir maintenance (reservoir draining for maintenance); Standpipe cleaning; Aqueduct dewatering; High pressure aqueduct releases; Treatment plant modifications (draining of plants and clearwells).
Planned, low chlorine, moderate flow sources	Main dewatering (< 24" diameter new construction & maintenance); Pumping plant/reservoir operation & maintenance (O&M) (new construction disinfection, drain valve testing, dead end pumping to relieve excess pressure, reservoir rehabilitation pipe flushing); Main flushing (due to taste and odor concerns, due to Coliform Rule, preventative - to avoid water quality concerns, emergency flushing, new cement lined pipes flushing); Temporary by-pass line flushing; Hydrant testing; Planned distribution system maintenance (trench dewatering); Treatment plant operational releases (filter to waste, filter backwash, sludge/water from sedimentation basins).
Planned, low chlorine, low flow sources	Pumping plant and reservoir O&M activities (maintenance or construction related, tank freshening).
Planned, high chlorine, moderate flow sources	Pumping plant and reservoir O&M activities (new construction disinfection); Main flushing (following disinfection); Treatment plant new construction/modification (plant disinfection).
Unplanned, low chlorine, high flow releases	Pumping plant, reservoir activities (underground emergency scenarios); Water main breaks.
Unplanned, low chlorine, moderate flow releases	Pumping plant, reservoir O&M activities (reservoir overflow); Water main breaks (smaller branches); Unauthorized hydrant opening.
Unplanned low chlorine, low flow sources	Leakages (from reservoir altitude valves, underdrains, treatment plant basins and temporary by-pass lines).

Passive Non-Chemical Methods for the Disposal of Chlorinated Water

Chlorine is a relatively unstable, moderately reactive element. In the environment, chlorine is neutralized upon reaction with air, sunlight and other contacting surfaces. Furthermore, chlorine readily reacts with organic and inorganic impurities in soil, paved surfaces, water and wastewater. Many utilities take advantage of these properties and dispose chlorinated water passively by discharge into sanitary sewers, retention in holding tanks, or release to soil surfaces.

The advantage of dissipating chlorine passively is that such a process does not involve chemical addition. Hence, utilities do not have to be concerned with the effects of neutralizing chemicals in receiving streams. Also, costs are minimized, as well as health and safety concerns related to storage, transportation and handling of these chemicals are avoided. A discussion of the effectiveness of various passive non-chemical methods for disposal of chlorinated water follows.

Discharge of Chlorinated Waters in Sanitary Sewers

The release of chlorinated water into sanitary sewers is a very safe and effective means of disposing chlorinated waters, in most cases. Most of the water utilities prefer this method as their first option for releasing chlorinated potable waters. A very high demand exerted by sulfide and other inorganic/organic pollutants in sewage rapidly neutralizes chlorine. In addition, since the water is not directly released to receiving streams, utilities do not have to be concerned with meeting receiving water quality standards and discharge limits.

The availability of a sanitary sewer near the point of chlorinated water release, and the capacities of the sanitary sewer/wastewater treatment plant to handle the additional load are the primary limitations associated with this method. Potential upset of treatment plant operations due to the presence of chlorine must also be evaluated. Coordination with sanitary system officials and caution to avoid potential cross-connection are required.

Discharge to Storm Sewers

Discharging chlorinated water into storm sewers may be an effective way to dissipate chlorine from some potable water releases. However, storm waters are usually discharged into receiving streams or waters leading to streams. Also, the impurities in storm water may not be sufficient to completely dechlorinate the water released.

Retention in Holding Tanks

The chlorine concentration in stored water gradually decreases with time due to aeration, reaction with sunlight/surfaces of holding tanks. Some utilities in the United States and Canada store filter backwash water and main disinfection water in holding tanks to allow for residual chlorine decay prior to discharge. Since dechlorination of super-chlorinated water requires a large amount of chemicals, some utilities reduce the chlorine concentration by retention in holding tanks, prior to adding dechlorination chemicals.

There are several limitations to this method. First, chlorine decay through natural reactions is extremely slow. Decay of chlorine to meet regulatory discharge limits may take several hours to a few days. Second, activities such as reservoir cleaning and large main dewatering produce a large volume of chlorinated water, requiring very large tanks for storage. Also, it may be difficult and expensive to transport holding tanks to various dechlorination sites in the service area.

Land Application of Chlorinated Water

Organic and inorganic impurities in soil and pavements exert a significant amount of chlorine demand and rapidly neutralize chlorine in waters. Hence, spraying chlorinated waters onto soils or pavements can be a very effective method for disposing of chlorine-containing waters.

However, potential drainage of waters applied to land, particularly from recently cleaned roads and pavements, into storm drains and receiving waters is a matter of concern. Land application of large volumes of water may lead to soil erosion.

Discharge of Chlorinated Water for Groundwater Recharge

In some cases, chlorinated water, may be discharged to dry streambeds or to land for groundwater recharge. This is an acceptable dechlorination practice if the water percolates before it reaches another body of water. Currently, no standard practices have been developed for this activity. However, prior to any discharge, the area and the distance where the discharge might travel must always be properly assessed. Efforts must also be coordinated with the local flood control entity, where appropriate. During disposal of chlorinated water for groundwater recharge, dechlorination equipment should be available for use, if necessary.

Discharging Through Hay Bales and Other Natural Obstructions

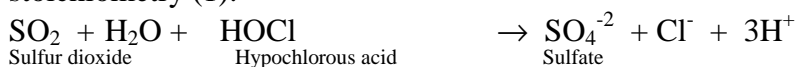
Backwash and planned water releases from the distribution system may be allowed to flow through hay bales or other obstructions to dissipate chlorine prior to discharging into storm sewers and receiving waters. While the chlorine demand exerted by these obstructions can be reasonably high, it may be difficult to achieve regulatory discharge limits in some cases. Also, elaborate arrangements required to construct such barriers, practical difficulties in construction of such barriers at various field discharge points, and potential soil erosion are some of the additional concerns in using this technique.

Chemical Dechlorination

Whenever it is not possible to dispose of chlorinated waters safely by non-chemical methods, chlorine may be neutralized using chemicals. Several solid, liquid and gaseous dechlorination chemicals are commercially available and are widely used by water and wastewater utilities. This section describes the reactions of various chemicals with free and combined chlorine, related water quality, health & safety issues, ease of use, cost and other issues related to the application of the chemicals commonly used for dechlorination.

Sulfur Dioxide (SO₂)

Sulfur dioxide is a colorless gas with a suffocating pungent odor. It is widely used in water and wastewater treatment plants for dechlorinating backwash water and wastewater disinfected with chlorine. Sulfur dioxide reacts instantaneously with free chlorine according to the following stoichiometry (1):



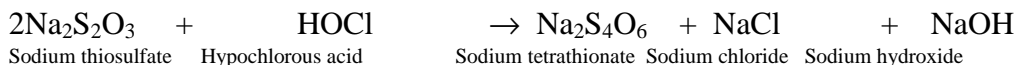
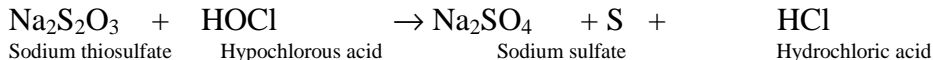
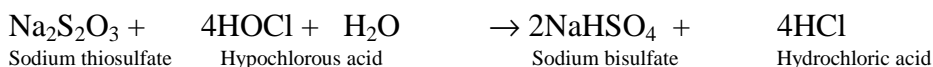
In the field, nearly 1.1 parts of SO₂ are required to neutralize 1 part of chlorine (2). SO₂ is an oxygen scavenger. It can deplete dissolved oxygen in the discharge water and receiving stream. SO₂

can also reduce pH of water significantly. Approximately 2.8 mg of alkalinity as CaCO₃ is consumed per milligram of chlorine reduced.

Sulfur dioxide is a toxic chemical subject to reporting requirements of the Superfund Amendments and Reauthorization Act (SARA). It has a National Fire Protection Association (NFPA) rating of 2, 0 and 0 for health, fire and reactivity, respectively. (Hazard ratings range from 0 to 4, with 0 indicating no hazard and 4 indicating extremely hazardous). It is an extremely irritating gas. While it is suitable for use in facilities such as treatment plants and pumping stations, it is not best suited for field applications.

Sodium Thiosulfate (Na₂S₂O₃)

Sodium thiosulfate is a colorless, transparent monoclinic crystal widely used by municipalities for dechlorination. It undergoes multiple reactions with free and combined chlorine, depending on solution pH (1,3). Reaction with chlorine yields the following:



The amount of thiosulfate required for dechlorination may vary with solution pH (3). Sodium thiosulfate is a reducing agent. However, it scavenges less oxygen than sodium sulfite, bisulfite or metabisulfite.

Sodium thiosulfate is a skin, eye, nose and throat irritant. It has a NFPA Rating of 1,0, 0 for health, fire and reactivity, respectively. An EPA toxicity study indicated that sodium thiosulfate is not very toxic to aquatic species. Sodium thiosulfate may react slowly with chlorine under some conditions, and requires more time for dechlorination than most dechlorination chemicals (4). Over-dechlorination with sodium thiosulfate may encourage thiobacillus and some other bacterial growth in receiving streams, particularly during low flow conditions.

Sodium Sulfite (Na₂SO₃)

Sodium sulfite is another dechlorinating agent widely used by utilities. It is available in powder/crystalline and tablet form. It undergoes the following reaction with free chlorine (3):

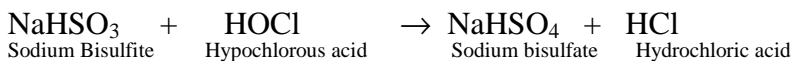


On a weight-to-weight basis, approximately 1.775 parts of sodium sulfite are required to remove one part of chlorine (5). Sodium sulfite is a reducing agent and is reported to scavenge more oxygen than sodium thiosulfate.

The major advantage of using sodium sulfite is that, it is available in tablet form. Many utilities find the tablets easier to store, handle and apply as compared to solutions or powders. In addition, dechlorination tablets are very effective for dechlorinating constant, low flow rate chlorinated releases.

Sodium Bisulfite (NaHSO₃)

Sodium bisulfite is available as a white powder, granule or clear liquid solution. It is highly soluble in water. Currently, many industries and wastewater utilities use sodium bisulfite solution for dechlorination. It undergoes the following reactions with free chlorine:



On a weight-to-weight basis, approximately 1.45 parts of sodium bisulfite are required to dechlorinate 1 part of chlorine. Sodium bisulfite is a good oxygen scavenger. Sodium bisulfite can cause skin, eye and respiratory tract irritation. It is harmful if swallowed or inhaled. Sodium bisulfite may crystallize at room temperatures. It is highly viscous and sometimes difficult to handle. Sodium bisulfite is highly corrosive and caution must be exercised in safely handling this chemical. It has a NFPA rating of 1,0,1.

Sodium Metabisulfite (Na₂S₂O₅)

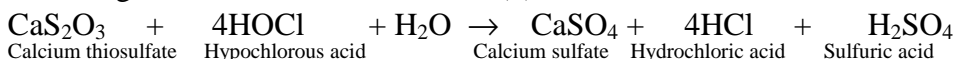
Sodium metabisulfite is available as crystal, powder or solution. It reacts with chlorine as follows.



Scavenging properties of sodium metabisulfite are comparable to that of sodium bisulfite. On a weight-to-weight basis, approximately 1.34 parts of sodium metabisulfite are required to remove 1 part of free chlorine. Sodium metabisulfite is an eye, throat, skin and lung irritant. The hazard ratings for sodium metabisulfite are 3,0,1.

Calcium Thiosulfate (CaS₂O₃)

Calcium thiosulfate is a clear crystalline substance, with little color, a faintly sulfurous odor and near neutral pH. It reacts with free as well as combined chlorine. Calcium thiosulfate undergoes the following reactions with free chlorine (6).

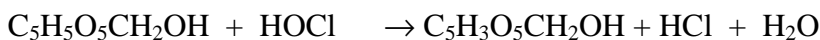


Approximately 0.99 and 0.45 mg of calcium thiosulfate is required to neutralize one mg of residual chlorine at pH 7.35 and 11, respectively. Calcium thiosulfate is not toxic to aquatic species. The 96-hour LC₅₀ for fathead minnows is greater than 750 mg/L. The NFPA hazard rating of calcium thiosulfate is 0,0,0.

One concern with using calcium thiosulfate is that dechlorination reactions using stoichiometric concentrations require nearly five minutes for complete neutralization (6). Over-dosing of calcium thiosulfate may produce milky-colored suspended solids, causing turbidity violations. Also, excess thiosulfate release may promote thiobacillus bacterial growth.

Ascorbic Acid (Vitamin C)

Ascorbic acid has recently been used by several water utilities for dechlorination. The reactions with chlorine are shown below:



Approximately 2.5 parts of ascorbic acid are required to neutralize 1 part of chlorine. Ascorbic acid is not reported to scavenge DO. Since ascorbic acid is weakly acidic, the pH of water may decrease slightly in low alkaline waters. Caution must be exercised to prevent accidental inhalation or contact with the skin, eyes or lungs.

Sodium Ascorbate

In addition to ascorbic acid, sodium ascorbate is also currently under evaluation by several utilities for dechlorination. Sodium ascorbate undergoes the following reaction with free chlorine.



Approximately 2.80 parts of sodium ascorbate are required to neutralize one part of chlorine. Sodium ascorbate is not reported to impact the DO or pH of the receiving streams. The pH of sodium ascorbate is approximately 7.0. The chemical is very stable with a shelf life of at least one year in a dry state, if kept in a cool, dark place. However, once in solution, the chemical degrades within a day or two.

Dechlorination Chemical Summary

Currently, sodium bisulfite, sodium sulfite and sodium thiosulfate are most frequently used by water utilities for dechlorination. The choice of a particular dechlorination chemical is dictated by site-specific issues such as the nature of water release, strength of chlorine, volume of water release, and distance from receiving waters. Sodium bisulfite is used by some utilities due to its lower cost and higher rate of dechlorination. Sodium sulfite tablets are chosen by utilities due to ease of storage and handling, and its ease of use for dechlorinating constant, low flow rate releases. Sodium thiosulfate is used for dechlorination since it is less hazardous and consumes less oxygen than sodium bisulfite and sodium sulfite. Ascorbic acid and sodium ascorbate are used because they do not impact DO concentrations.

Knowledge on dechlorination efficiencies of various chemicals is incomplete. A comprehensive study evaluating all the chemicals for various chlorinated water release scenarios is not currently available.

Field Methods for Residual Chlorine Measurement

Several methods such as water quality test strips, swimming pool test kits and orthotolidine indicator kits can be used to measure TRC in the field. Many of these methods lack sensitivity required for ensuring regulatory compliance.

A colorimetric kit supplied by Hach company is widely used to monitor dechlorination in the field. The kit can measure free or combined chlorine residuals at concentrations of 0 to 4.5 mg/L with a detection limit of 0.1 mg/L. In this method, a pre-measured amount of reagent is added to the water sample, mixed well, and the sample analyzed for chlorine concentration. A liquid crystal detector indicates the chlorine concentration in solution based on the intensity of the color formed.

Field Test Data

Although limited information on the performance of chemicals is available, so far no study was found that compared the efficiencies of dechlorination chemicals under identical conditions to determine the chemical of choice for various dechlorination applications. So, field studies were performed during this project to obtain preliminary data on dechlorination efficiencies of various chemicals. The field tests were conducted at Tacoma Waters, WA, Portland Bureau of Water Works, OR, and EBMUD, CA.

In these studies, dechlorination efficiencies of the chemicals and other water quality impacts were evaluated. In the Tacoma and Portland studies, a 1% solution of the dechlorination chemicals were introduced into water released from a hydrant. In the EBMUD study, bags or dispensers containing tablets or powders of dechlorination chemicals were placed in the flow path of hydrant water. At all three sites, the water used for the test originated from surface water sources rather than from groundwater sources.

Field Dechlorination Tests at Tacoma Waters

Tacoma Waters uses free chlorine for disinfection. The field study evaluated the rate of dechlorination of water released from a hydrant when stoichiometric amount of dechlorination agent was added. In addition, the effects of overdosing and concurrent impact on water quality parameters were evaluated using twice the stoichiometric amount of dechlorination chemicals.

Sodium metabisulfite, sodium thiosulfate, sodium sulfite, calcium thiosulfate, ascorbic acid and sodium ascorbate were used. Water from the hydrant was released through a fire hose 50 feet long and 6 inches in diameter. The flow rate was adjusted to 300 gpm using a valve and a flow meter. The other end of the fire hose was connected to a diffuser to facilitate mixing of chemicals with the flow. A 1% solution of each chemical was prepared in a polyethylene bucket and introduced into the flow at the upstream side of the diffuser using an adjustable rate metering pump. Dechlorination chemicals were fed either at concentrations just sufficient to neutralize all the chlorine in the water (stoichiometric amount) or at concentrations resulting in 100% overdose for chlorine neutralization (twice the stoichiometric amount). Table 4 shows the amount of chemical used in each test. A pre-calibrated metering pump was used to verify rates prior to each dechlorination test. Water released from the hydrant traveled approximately 500 feet and discharged into a storm sewer leading to a holding pond. Results from the Tacoma field test are summarized below.

Table 4. Feed rate of 1% (w/v) dechlorination chemicals during field tests

Chemical	Parts (mg) required per part (mg) of chlorine (@ pH 8.0)	Hydrant flow/ chlorine conc. (mg/L)	Feed rate @ stoichiometric amount (gpm)	Feed rate @ 100% over dechlorination (gpm)
Sodium Thiosulfate	1.86	300 gpm, 1.0 mg/L	0.056	0.112
Sodium Sulfite	1.96	300 gpm, 1.0 mg/L	0.06	0.12

Sodium Bisulfite	1.61	300 gpm, 1 mg/L	0.048	0.096
Sodium Metabisulfite	1.47	300 gpm, 1.0 mg/L	0.066	0.13
Calcium Thiosulfate	1.19	300 gpm, 1.0 mg/L	0.036	0.072
Ascorbic acid	2.48	300 gpm, 1.0 mg/L	0.11	0.22
Sodium Ascorbate	2.78	300 gpm, 1.0 mg/L	0.13	0.26

Residual Chlorine Concentrations. Figure 1 shows the chlorine concentrations at sampling points after the addition of stoichiometric concentrations of dechlorination chemicals. Chlorine concentrations during the flow, when no chemicals were added, are also shown.

The field study indicated that, when no chemical was added, free chlorine concentration in the water did not decrease significantly. Chlorine concentrations decreased from 1.2 mg/L to approximately 1.0 mg/L after a travel of 450 feet (4 minutes, 10 seconds) in the semi-paved, asphalt road. When stoichiometric concentrations of dechlorination chemicals were added, most of the chemicals neutralized chlorine instantaneously. Samples analyzed 2 feet downstream of the diffuser contained less than 0.1 mg/L of chlorine. An exception to this trend was calcium thiosulfate. When calcium thiosulfate was added, chlorine concentrations decreased to 0.2 mg/L within 2 feet and residual chlorine was reduced to less than 0.1 mg/L after a travel of 200 feet.

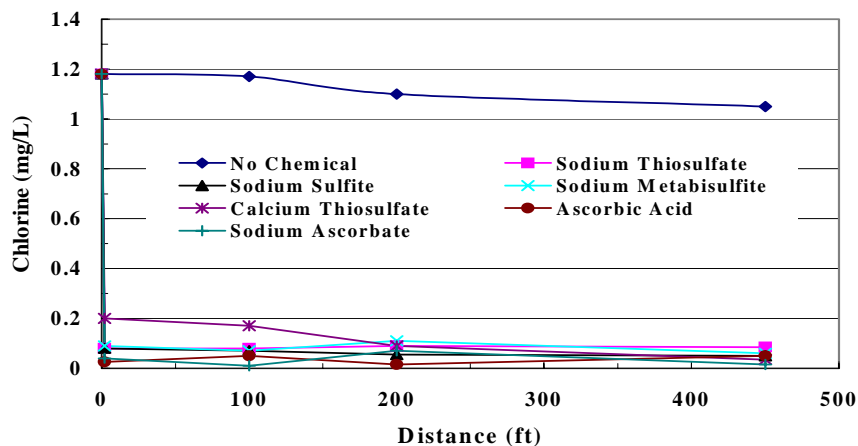


Figure 1. Chlorine concentrations at Tacoma City Water when stoichiometric concentrations of dechlorination chemicals were used to neutralize chlorine in potable water from a hydrant.

When twice the stoichiometric concentration of chemicals was added, residual chlorine in all the tests (including calcium thiosulfate) decreased to below 0.1 mg/L immediately (approximately 2 seconds).

Dissolved Oxygen. When no dechlorination chemical was added, the dissolved oxygen concentration of the released water decreased from 11.08 to 10.81 mg/L (0.27 mg/L) after traveling 450 feet in one test, and from 10.4 to 10.3 (0.1 mg/L) in a second test (data not shown). When stoichiometric amounts of dechlorination chemicals were added, the DO decreased by 1.18, 0.3, 0.55, 0.5 mg/L in the presence of sodium metabisulfite, sodium sulfite, sodium thiosulfate and calcium thiosulfate, respectively. When, twice the stoichiometric amounts of dechlorination chemicals were added, the dissolved oxygen concentration decreased by 1, 0.9, 0.9, 0.7 mg/L in the presence of sodium metabisulfite, sodium sulfite, sodium thiosulfate and calcium thiosulfate, respectively. With the addition of stoichiometric concentrations of ascorbic acid and sodium ascorbate, the DO of the water increased by 0.3 mg/L, after a travel of 450 feet. When twice the stoichiometric concentrations of these chemicals were used, the DO decreased by 0.2 mg/L. The reasons for the trends observed using either concentrations of ascorbic acid and sodium ascorbate are not known.

In summary, results indicated that sodium metabisulfite had a greater impact (1.0 – 1.18 mg/L depletion) on the DO concentrations of the water tested. Sodium sulfite, sodium thiosulfate and calcium thiosulfate decreased the DO concentration by 0.3 to 0.9 mg/L, depending on the amount of dechlorination chemical used. Ascorbic acid and sodium ascorbate had the least impact on the DO of the water tested.

pH. The initial pH of the hydrant water, prior to chemical addition, was between 8.8 and 9.0. Sodium metabisulfite, at either concentration used, decreased the water pH about 0.8 units after a travel of 450 feet. After a travel of 450 feet, ascorbic acid decreased the pH of the water by 0.3 and 0.6 units when stoichiometric and twice the stoichiometric amounts, respectively, were used. The pH decreased by less than 0.1 units when sodium sulfite, calcium thiosulfate or sodium ascorbate was used at stoichiometric or twice the stoichiometric amounts.

Field Dechlorination Studies at Bureau of Water Works, Portland

Portland Bureau of Water Works uses combined chlorine for disinfection. The tests conducted at Portland were similar to those at Tacoma, except in the following aspects: Tests using all the chemicals, except sodium sulfite, were conducted at stoichiometric concentrations only; a 100 feet

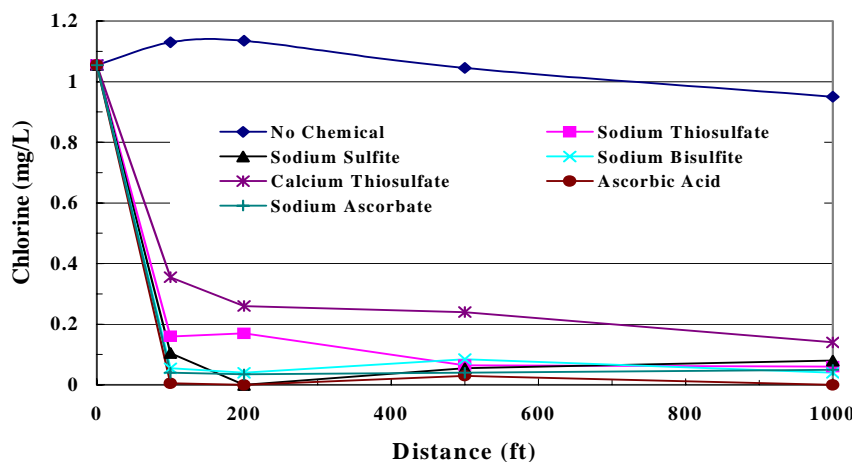


Figure 2. Chlorine concentrations at Portland waters when stoichiometric concentrations of dechlorination chemicals were added to neutralize chlorine in potable water from a hydrant.

hose, rather than a diffuser, was provided for mixing of chemicals with the water; the released water traveled along a well paved surface for 1,000 feet prior to discharging into a storm draining leading to a storage pond; a special feeder developed by the Bureau, rather than a metering pump, was used for feeding the chemicals.

Samples were analyzed for residual chlorine concentrations and pH at the hydrant, and 2, 100, 500 and 1000 feet downstream of the 100-foot long hose. The travel time for the water to reach the sampling points were 0 minutes, 24 seconds (100 feet); 3 minutes, 2 seconds (500 feet); and seven minutes, 10 seconds (1000 feet), respectively.

Residual Chlorine Concentrations. When no dechlorination chemical was added, the chlorine concentration decreased from 1.05 to 0.95 mg/L after 1,000 feet (Figure 2). This indicated that only a small amount (0.1 mg/L) of the chloramines dissipated through chlorine demand of paved surfaces. Sodium bisulfite, sodium sulfite, ascorbic acid and sodium ascorbate neutralized all detectable chlorine to below 0.1 mg/L within 2 feet downstream of the mixing hose (approximately 2 seconds). Sodium thiosulfate neutralized more than 80% of the chlorine within 2 feet. However, chlorine concentrations decreased below 0.1 mg/L (the discharge limit in most states) after about 500 feet (elapsed time 3 minutes, 2 seconds). Calcium thiosulfate neutralized 60 % of the chlorine within 2 feet and neutralized 90 % of the chlorine after 1,000 feet (elapsed time 7 minutes, 10 seconds).

pH. At concentrations used in this study, none of the chemicals appeared to affect the pH of the Portland Water Bureau water appreciably.

Dechlorination Field Studies at EBMUD

EBMUD uses combined chlorine for disinfection. The purpose of the field study at EBMUD was to evaluate dechlorination when chemicals were placed either as tablets or as powder within the path of the chlorinated water. The following dechlorination chemicals were evaluated:

- Exceltech D-Chlor Tablets (91.5% sodium sulfite)
- Ascorbic acid (food grade, free white powder)
- Sodium thiosulfate (photo grade 1/8 inch diameter granules)

Several series of field tests were conducted under different conditions. Only selected results are presented in this report. Flow was discharged from a hydrant on EBMUD's water distribution system, through a fire hose and onto a fairly level paved and curbed street close to the curb. The water flowed down the street, into a drop inlet 160 feet downstream. The drop inlet led to an onsite storm drain system at EBMUD's wastewater treatment plant that flows into the headworks of the plant.

Chlorine residual concentrations of the water upstream and downstream of the dechlorination chemical feed points were measured using a Hach Chlorine Pocket Colorimeter. A Hydrolab Datasonde equipped with temperature, dissolved oxygen (DO), pH and oxidation-reduction potential (ORP) sensors was used to continuously log real time water quality parameters.

Effect of Number of Tablets and Flow Rates. The test procedure consisted of initially placing a single D-chlor tablet, then 2, 4, 16, and 28 tablets in the water flow 10-feet downstream of the flow control valve and meter. The flow rates ranged from 100 gpm up to 500+ gpm. Samples were collected 150 feet downstream of the tablets. As shown in Figure 3, one tablet effectively reduced the chlorine

residual of the flow it came in contact with, to below 0.1 mg/L for 45 minutes at a flow rate of 100 gpm. The tablet was not fully consumed, but became ineffective after approximately one hour.

When 12 tablets were placed across the flow of 100 gpm, the chlorine concentration decreased below detection limit (0.1 mg/L) within five minutes. It remained below the detection limit even after 60 minutes. In the next test, initially a flow rate of 300 gpm was maintained and 16 tablets were placed across the flow. Within five minutes the chlorine concentration decreased to below detection limit. After 10 minutes, the flow rate was increased to 450 gpm. At this increased flow rate, the residual chlorine concentration increased to values of 0.60 to 0.8 mg/L, well above the detection limit of 0.1 mg/L (which is the allowable discharge limit in many locations), within 25 minutes (Figure 3). This indicates that the flow rate of chlorinated waters can significantly impact the efficiency of dechlorination operations. Higher flow rates may not provide sufficient contact time for dissolution of tablets into the stream. After approximately 40 minutes, the number of tablets was increased to 20. This decreased the residual concentration to below detection limit within five minutes. The increase in the number of tablets probably provided an enhanced contact area and better dissolution of the tablets into the flow, resulting in a decrease in the residual chlorine concentrations.

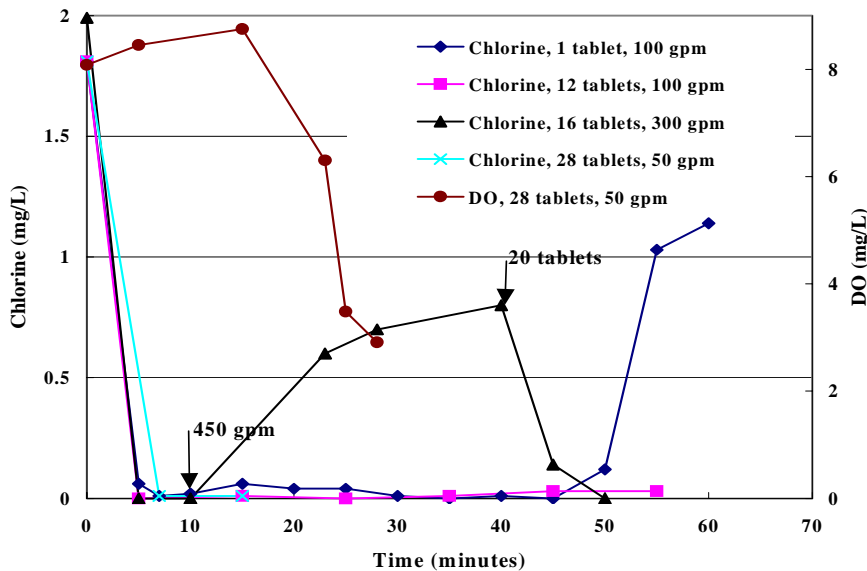


Figure 3. Chlorine and DO concentrations when sodium sulfite tablets were placed across the flow.

No significant impact upon pH was observed in any of the tests. In the test where 1 tablet was placed across the flow, the initial pH was 8.84. The pH after 60 minutes was 8.80. In the presence of 12, 16 or 28 tablets, the initial pH did not change by more than 0.2 units. The average alkalinity of EBMUD water is about 26 mg/L as CaCO₃.

Dissolved oxygen concentrations were not measured when 1 or 12 tablets were placed across the flow. When 16 or 20 tablets were placed across a flow of 300/450 gpm, the initial dissolved

oxygen concentration was 8.59 mg/L. No specific trend was observed in the DO profile. When 28 tablets were placed across a flow of 50 gpm, the DO concentration decreased significantly from 8.08 mg/L to 2.91 mg/L within 25 minutes. The larger number of tablets and a lower flow rate maintained in this test as compared to the previous three tests, probably caused for the enhanced depletion of DO in the water.

In summary, results from the test series indicated that, for a flow rate of up to 100 gpm for EBMUD water, one Dechlor tablet maintained the residual chlorine concentration below the detection limit for 45 minutes. An increase in the number of tablets increased the residual chlorine removal efficiency. However, an increase in flow rate to 450 gpm resulted in an increase in residual chlorine concentrations to above detection (and compliance) limits within 25 minutes, even in the presence of 16 tablets. Results also indicated that, when the flow rate was decreased (50 gpm) and the number of tablets increased (28), the DO concentration decreased significantly.

Chlorine Profile Along the Flow Path. In this test, water quality was analyzed along the flow path, upon contact with dechlorinating chemical. A flow rate of 100 gpm was maintained, and one or four tablets were placed across the flow. samples were collected at the point of release and 40, 80, 120 and 160 feet downstream of the tablets. The residual chlorine concentration in the water decreased with distance (Figure 4). One tablet was sufficient to remove chlorine to below 0.1 mg/L after 120 feet of travel under the test conditions.

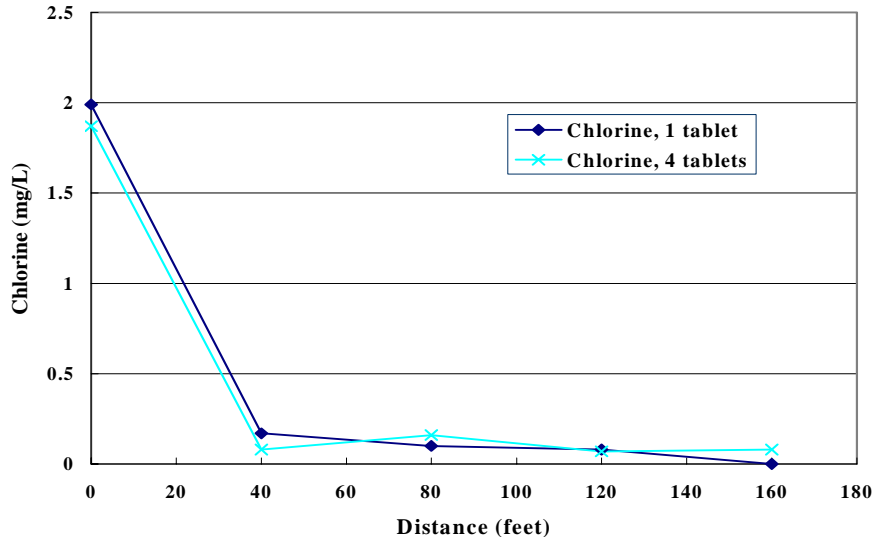


Figure 4. Chlorine concentration when 1 or 4 tablets were placed along the flow path. The flow rate of the EBMUD water was 100 gpm.

The DO concentration decreased from 7.0 mg/L to 6.0 mg/L within 80 feet, when one tablet was placed across the flow. The DO subsequently increased to 9.60 mg/L after traveling 160 feet. The pH decreased from 8.95 to 8.70 units within 80 feet and decreased to 6.67 units after 160 feet. The reasons for the increase in DO concentration, and decrease in pH, after a travel a distance of 80 feet, are not known. However, the trend was less pronounced when four tablets were placed across the flow

path. The DO concentration decreased from 9.26 mg/L to 9.05 mg/L after a travel of 80 feet and increased to 9.66 mg/L after 160 feet. The pH decreased from 8.95 to 8.9 units after a travel of 80 feet and decreased to 8.75 units after 160 feet. In general, the initial decrease in DO may be due to the reaction of sodium sulfite. Subsequent increase may have resulted after the exhaustion of the released sodium sulfite in the water.

Dechlorination Using Ascorbic Acid Powder/Sodium Thiosulfate Crystals. In these tests, 1 lb of the dry chemical in a nylon bag was placed across a flow of 100 gpm. Both of the chemicals decreased the TRC to below 0.1 mg/L. However, in both the cases, the chemical dissolved rapidly and escaped the bag. Excessive dissolution of ascorbic acid decreased the water pH from 8.9 to 5.07. Dissolution of sodium thiosulfate did not significantly affect the pH or DO.

Summary of Tacoma, Portland and EBMUD field test results

The studies yielded the following:

- All of the chemicals tested in solution, tablet or powder form were able to neutralize free and combined chlorine to below 0.1 mg/L.
- Stoichiometric concentrations of dechlorination chemicals in solution removed more than 90% of residual chlorine.
- The DO concentration decreased by 1 mg/L when a stoichiometric amount of sodium metabisulfite was added.
- A decrease in DO concentrations (~1.0 mg/L) was observed when twice the stoichiometric amounts of sodium metabisulfite, sodium sulfite or sodium thiosulfite were used.
- Reactions of sodium/calcium thiosulfate with chloramine were slower than those with free chlorine.
- While ascorbic acid and sodium thiosulfate solutions neutralized chlorine effectively, when used in powder/crystal form, they dissolved rapidly, causing water quality concerns.
- Sodium sulfite tablets were very effective in dose control and dechlorination. One tablet was sufficient to dechlorinate 2.0 mg/L of chloraminated water to below 0.1 mg/L for 45 minutes when water was released at 100 gpm.
- An increase in the number of tablets to 28 decreased the DO concentration by 5 mg/L within 25 minutes at a flow rate of 50 gpm.
- An increase in flow rate from 100 to 450 gpm decreased the length of time that the residual chlorine concentration was below the detection limit (0.1 mg/L) by more than 20 minutes.

Emerging Dechlorination Technologies

EBMUD has developed dechlorination mats/strips to facilitate effective contact between the flow and sodium sulfite tablets during dechlorination. For dechlorination of discharges from trenches during main breaks, the tablets are placed inside synthetic mesh fabric pockets sewn together in a grid

or line. The dechlor mat or strip is laid across the flow path or over the storm drain. As the discharged water flows over and around the tablets, chemical is released, which destroys the chloramines.

Washington Suburban Sanitation Commission, MD has developed techniques such as Tablet/diffuser dechlorinator, tablet/plastic pipe dechlorinator, tablet/hose monster cage to facilitate dechlorination using tablets under various release situations.

The City of Salem, OR and Water and Wastewater Technologies, Inc, WA have developed venturi based dechlorination devices to feed chemical solutions into the chlorinated water flow. These devices can be attached to the downstream end of a hose connected to hydrants to dechlorinate the water released from hydrants. These devices can handle a flow rate of 20 to 1,000 gpm.

Industrial Testing Systems, Inc. at Rock Hill, SC has developed chlorine-monitoring strips for measuring free and combined chlorine at various range of concentrations. The advantages of this strip over the current field monitoring test kits, as reported by the company, are that wide ranges of residual chlorine concentration (0.02 to 750 mg/L) can be measured without any dilution and the strips are sensitive for measuring chlorine concentrations as low as 0.02 mg/L. This method is useful in measuring residual chlorine concentrations in superchlorinated water without having to dilute the samples.

STANDARD OPERATING PROCEDURE AND FLY SHEET EXAMPLE

A primary objective of this project was to develop BMPs / Standard Operating Procedures for various chlorinated water release scenarios. It is also a goal to provide quick summary 'Fly Sheets' to aid operationally focused management staff and operators for disposal of chlorinated water generated by various activities. A sample Draft Flysheet for one such scenario is provided in Figure 5 for one such scenario. As discussed throughout this report, dechlorination is still an evolving practice. More data is required to develop BMPs and Fly Sheets for various dechlorination activities.

SUMMARY

The AWWARF manual summarizes available dechlorination information in a centralized manner. The state/provincial permit processes for release of chlorinated waters vary significantly. However, utilities are required to meet the water quality criterion of the receiving streams during such releases in all of the states and provinces. Several chemicals are available for dechlorination. Chemicals such as sodium metabisulfite, sodium sulfite and sodium thiosulfate may deplete DO of receiving streams under certain circumstances. Sodium metabisulfite and ascorbic acid may decrease the pH of some waters. Field tests were conducted to evaluate the dechlorination efficiencies of various chemicals/forms and the results are summarized in the report. A sample 'Fly Sheet' to serve as a quick reference to operationally focused personnel is attached (Figure 5). Finally, recommendations for further works required to develop BMPs are made in the report.

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FIGURE 5.

DRAFT FLYSHEET INDICATING CURRENT DECHLORINATION PRACTICE FOR CERTAIN PLANNED, LOW CHLORINE, MODERATE FLOW RELEASES

Type of Release Planned Unplanned

Anticipated Residual > 4 mg/L < 4 mg/L

Type of Residual Free Chlorine Combined Chlorine

Source of Water Surface Water Groundwater

Turbidity High (> 10 NTU) Low (< 10 NTU)

Discharge Large Volume (> 500 gpm, > 24 hours) Low Volume (< 500 gpm, < 24 hours)

Type of Release Hydrant Release to trench due to main break Pipe, tank draining

Suggested Dechlorination Methods

1. Dechlorination by Non-chemical Means

Method	Benefits	Concerns/Limitations
Discharge to sanitary sewer	<ul style="list-style-type: none">• Does not involve chemicals.• Hence, no concern due to impact of dechlorination chemicals.• Savings in chemical cost.	<ul style="list-style-type: none">• Sanitary sewer must be available nearby.• Permission may be required from sanitation district.• Cost of discharge to sanitary sewer should be evaluated.• Potential impact of chlorine to microorganisms in wastewater treatment plant should be considered.

2. Dechlorination Using Chemicals.

If disposal by discharge to sanitary sewer is not feasible, dechlorination can be performed using chemicals. The chemicals are listed according to the order of preference, based on the **limited** data currently available.

Chemical	Form	Feed Technique*	Feed Rate of 10 g/L Solution		Comments/concerns
			Water Flow Rate (gpm)	Chemical Feed Rate (l/minute)	
Sodium Ascorbate ψ	Solution	Any feed controlled delivery system such as venturi-based units, metering pumps or carboy on a curb.	50	0.06	<ul style="list-style-type: none"> • No known impact on water quality. • Sodium ascorbate is more expensive than most other dechlorination chemicals. • Sodium ascorbate solution can not be stored for more than a day or two. • Total Organic Carbon (TOC) impact on receiving streams should be evaluated.
			100	0.12	
			200	0.23	
			300	0.35	
			400	0.46	
			500	0.58	

- * - A 10% overdose is included;
- ψ - Ascorbic acid is shown as the chemical of choice since it did not cause any water quality impacts in the field tests.

Water Quality Monitoring

Total Residual Chlorine: A pocket colorimeter (Hach Company) may be used to measure residual chlorine concentration in the water.

Dissolved Oxygen: Some of the chemicals may deplete DO concentrations. The DO concentration should be monitored using a probe.

pH: Overdosing with ascorbic acid and some other chemicals may deplete water pH. The discharge water pH must be monitored to minimize water quality impacts.

Ammonia: None of the dechlorination chemicals have been reported to eliminate ammonia from water. Ammonia liberated from chloramines may exceed allowable ammonia concentrations under certain extreme conditions. Caution must be exercised to avoid water quality impact due to ammonia concentrations.