

FLOWCHARTS FOR THE SELECTION OF LEAD AND COPPER CORROSION CONTROL STRATEGIES

By

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Foreword

In 1996, the Office of Ground Water and Drinking Water of the U. S. Environmental Protection Agency was interested in developing some simple guidance that could be used by regulators, small water systems, and their engineers to aid in initially determining what treatment approaches for lead and copper control would have the best chance of success. The original document was prepared for Peter Lassovszky, U. S. Environmental Protection Agency Office of Ground Water and Drinking Water in January of 1997. The manual was developed under USEPA Contract 68-C4-0007 by Black & Veatch under subcontract to The Cadmus Group. The primary author of the manual was Jonathan Clement (Black & Veatch), with assistance from Michael Schock (U. S. Environmental Protection Agency, National Risk Management Research Laboratory, Water Supply and Water Resources Division) and Wendy Marshall (U. S. Environmental Protection Agency, Region 10).

In the four years since the completion of the manual, many water systems have successfully employed corrosion control treatment to achieve compliance with the Lead and Copper Rule. However, the information in the manual is still timely and relevant, because some systems still have difficulty in sufficiently reducing lead and copper corrosion, and other systems may need to change water treatment approaches because of other

regulatory issues or changes in water sources. Thus, corrosion control for lead and copper will need to be revisited in the context of these changes.

Rather than exactly reproducing the manual as originally printed, it was decided to take advantage of the considerable experience in New England and elsewhere throughout the past four years to refine (or even sometimes correct) the recommendations for treatment selection. Thus, this version of the manual has been slightly revised and edited by a collaboration of many members of the New England Water Works Association Committee on Corrosion and Its Effects on Water Quality, to help provide readers with the best general screening-level guidance current knowledge permits.

Introduction

The objective of this manual is to assist water systems with selecting effective treatment strategies for controlling lead and copper in drinking water. The selection of a treatment strategy for lowering lead and copper levels in drinking water from corrosion of plumbing materials depends on numerous site-specific factors that cannot be addressed in this manual; Therefore, to address these site-specific factors, water systems should seek out the advice of water treatment professionals when selecting a treatment strategy.

Why should we monitor for lead and copper?

The National Primary Drinking Water Regulations for Lead and Copper (also called the Lead and Copper Rule or LCR) became effective in 1991. The LCR requires all community and non-transient non-commu-

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nity water systems to monitor for lead and copper at a specified number of taps within homes and/or buildings served by that water system. It also establishes treatment technique requirements including corrosion control treatment, source water treatment, lead service line replacement, and lead public education. These requirements may be triggered if more than ten percent of tap water samples collected during any monitoring period exceed the lead action level (AL) and/or the copper action level. The action level for lead is 0.015 mg/L. The copper action level is 1.3 mg/L. Lead and copper are being regulated because of the possible negative health effects associated with drinking water containing these two contaminants. Health effects associated with exposure to lead in infants and young children include lower birth weight and a slowing down of normal physical and mental development which may result in lower IQ levels, damaged hearing, reduced attention span and poor classroom performance. Impacts to adults may include kidney damage, slight increases in blood pressure, damage to the reproductive system and high levels of nitrate may magnify these adverse health effects.

While drinking water with high levels of copper should not cause long-term health effects like lead, high copper levels in drinking water can cause very uncomfortable gastrointestinal effects such as nausea and diarrhea, and can magnify adverse effects of nitrate ingestion, especially in children.

Why do we need to sample tap water?

High levels of lead and copper are rarely found in the water that a water system provides to its customers. The main sources of lead and copper in drinking water usually are plumbing materials made from copper; lead service lines and lead solder, commonly used before 1990 to join lengths of copper pipe together; and faucets containing brass or bronze internal parts, which usually contains lead impurities. Under the 1996 Amendments to the Safe Drinking Water Act, "lead free" brass can contain as much as 8% lead by weight, which is enough to contribute significant amounts to lead to tap water samples. If the water provided by your water system is highly or even moderately corrosive, some of the lead and/or copper in the plumbing materials may be released into the drinking water in houses or buildings served by your water system.

A sampling program that measures lead and copper

levels at the tap helps to determine if a water system is providing corrosive water. Those water systems found to be providing corrosive water are required to install corrosion control treatment to lower the corrosivity of the water, which should then result in lower lead and copper levels at the users' taps.

What do we do next?

The Federal Lead and Copper Rule requires all water systems that have exceeded the lead action level, the copper action level, or both action levels to recommend a corrosion control treatment method that will minimize lead levels at users' taps and reduce copper levels to below the 1.3 mg/l AL. In addition, water systems may be required to perform corrosion control studies to evaluate the most effective corrosion control treatment method. The objective of this guidance manual is to assist small water systems with selecting the appropriate treatment strategy.

Background on Corrosion Control for Lead and Copper

Lead and copper entering drinking water from household plumbing materials such as pipes, lead solder and faucets containing brass or bronze, can be controlled by changing water quality characteristics. The water quality factors that have the greatest affect on lead and copper corrosion are pH, dissolved inorganic carbonate (DIC), orthophosphate concentration, alkalinity and buffer intensity. There are many other factors that affect the corrosion of lead and copper, but they cannot be easily altered by a water system and have a lesser effect on corrosion. Alkalinity, which is interrelated with pH and DIC, is often measured by water systems. Buffer intensity, which is also interrelated with pH and DIC, is an additional parameter that is very important in maintaining optimal corrosion control and water quality out in the distribution system.

pH

The pH of a water is a measure of acidity. pH values can range from 0 to 14, and the lower the value the more acidic the water. Most drinking waters range from 6 to 10. One common corrosion control treatment strategy is to raise the pH of the source water. This can be done through chemical or non-chemical means. Any increase in pH within the pH range of 5 - 10 should result in a decrease in lead and copper levels. At the higher pHs, there is less tendency for

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lead and copper to dissolve and enter drinking water. The pH of water can vary significantly as water moves through the distribution system. Although the pH measured at the pump station or treatment facility may appear to be stable, as it passes through the distribution system it may increase or decrease significantly. This will depend on the size of the distribution system, flow rate, age and type of plumbing material. It is important to maintain the target pH throughout the distribution system, so that lead and copper levels can be minimized at the tap.

Dissolved Inorganic Carbonate (DIC)

The level of DIC affects levels of lead and copper and affects the stability of the pH. The amount of DIC relates to the buffering of the water. The buffering of a water is its ability to resist a change in pH. If a water has minimal DIC, then the pH may fluctuate significantly. Because of the high sensitivity of copper and lead to pH, the improved pH control of a minor (3-6 mg C/L) DIC increase to increase buffering offsets potential increases in copper or lead levels. Therefore, balancing the amount of DIC for lead, copper and buffering is important part of corrosion control.

At a constant pH, as the DIC increases copper levels should increase. The effect of DIC is not as strong as the effect of pH until high (> 30 mg/L) levels of DIC are reached, when pH adjustment stops being an effective treatment approach. Increases in DIC of 3-6 mg C/L will typically have minimal impact on copper levels, particularly with respect to the regulatory Action Level. In contrast, for control of lead, as the DIC increases the lead concentration decreases or remains essentially unchanged within the pH range of about 7.0 to 8.0. At higher pHs there will be very little impact of DIC on lead levels or there may be a very slight increase in lead levels with increasing DIC.

Orthophosphate

In the proper pH range, orthophosphate (PO_4) added as a corrosion control treatment chemical can combine with lead and copper in plumbing materials to form several different compounds. These compounds do not have a strong tendency to dissolve. As a result, lead and copper levels in the water will

remain low. The key to ensuring that orthophosphate will reduce lead and copper levels is to maintain the proper pH and orthophosphate residual. Residual orthophosphate is the free amount of orthophosphate measured in the distribution system. It is very important for most water systems to maintain a residual of at least 1 mg PO_4/L . In many cases, water systems maintain a residual that is too low, thus making the orthophosphate treatment ineffective. When using orthophosphate for lead and copper control, the pH should be maintained within the range of 7.2-7.8. If the pH is too low, even high dosages will not work. At high pH, poor corrosion-protecting film stability has often been observed. Much higher concentrations are often needed to resolve copper problems than lead problems. Treatment chemicals containing zinc will help protect cement and cement mortar lined pipes. When copper or zinc concentrations in wastewater discharge or sludge are of concern, then pH/DIC adjustment to control copper corrosion is usually preferable, (when feasible).

Alkalinity

Alkalinity is the capacity of water to neutralize acid. It is the sum of carbonate, bicarbonate and hydroxide anions. Alkalinity is typically reported as "mg/L as calcium carbonate (CaCO_3)." Low alkalinity water will not neutralize acids well, while high alkalinity water does neutralize acid well. Alkalinity is interrelated to the parameters pH and DIC for drinking water. Waters with high alkalinities also tend to have high buffering capacities, or in other words, a strong ability to resist changes in pH brought about by chemical dosing or water quality changes in the distribution system.

Buffer Intensity

Buffer intensity is a measure of the resistance of a water to changes in pH, either up or down. Bicarbonate and carbonate ions are the most important buffering species in almost all drinking waters. At high pH (over 9) silicate ions also supply buffering. Phosphate contributions are normally insignificant as long as DIC is approximately 5 mg/L as C or greater. Buffering is normally greatest at approximately pH 6.3, decreases towards a minimum at a pH of between about pH 8 and 8.5, and then again

gets increasingly higher as pH goes above 9. Thus, treated waters in this very low buffer intensity pH range (8-8.5) tend to have highly variable pH in the distribution network. This is aggravated in waters that have very low amounts of DIC (less than about 10 mg C/L). Waters with low buffer intensity are prone to pH decreases from such sources as uncovered storage or nitrification, and pH increases from contact with cement pipe surfaces. Maintaining sufficient buffering is very important when using orthophosphate addition or pH adjustment, because copper and lead control require particular pH ranges to be effective. Even if the pH of the water leaving the treatment plant is correct, pH changes in the distribution system may nullify the intended corrosion control treatment.

Directions for Making Treatment Determinations

Selecting a viable treatment option for controlling lead and copper is a five-step process:

1. **Examine the lead and copper data.** Because small water systems collect so few samples, it is important to ensure that an action level exceedance is due to corrosive water, rather than some other cause. Water with pHs greater than 8 and with alkalinities between 30 and 100 mg CaCO₃/L would generally not be considered corrosive. Water with an alkalinity greater than 100 mg CaCO₃/L is frequently highly corrosive toward copper. If the water quality data appears to reflect conditions stated above, the water system should provide treatment recommendations to the primacy agent. However, the possibility of resampling or materials replacement should also be discussed with the primacy agent.
2. **Collect accurate and sufficient background chemistry information to characterize the water and anticipate future regulatory requirements.** Although it initially appears to be expensive to collect many water samples and analyze a broad range of water quality constituents, doing so can save tens or hundreds of thousands of dollars of added expenses later in revising treatment plants or adding new processes that were not anticipated. Having very accurate pH, carbon dioxide and alkalinity/DIC data is absolutely necessary to know the feasibility of such simple treatments as aeration or limestone contactors, and also the cost associated with chemical additions and chemical delivery systems. Having good calcium, magnesium, sulfate and other water quality data may help in defining constraints to pH adjustment, phosphate dosing, use of packed tower aerators, membranes or other processes, because of scale buildup issues. Knowing whether or not arsenic or radon are present in the source water will dictate corrosion control treatments which are compatible with the removal processes, and this can be planned and done at once. For example, radon can readily be removed by aeration, which can also be used for substantial pH adjustment for corrosion control, so chemical feeds may not be necessary. However, a complication to both might be iron or manganese, so a combination of a removal process or filtration following oxidation (aeration/disinfection) might be cost-effective and would eliminate the need for sequestration. Similarly, some arsenic removal processes may coincide with iron removal and simplify the corrosion control chemistry treatment. For surface water or blended surface/ground water systems, knowledge of the potential for disinfection by-product formation or microbial concerns could change the corrosion control approach. There are many other possible interactions, and the water system should try to anticipate as many future regulatory water quality requirements and treatment selection influences as possible.
3. **Use one of the three attached sets of treatment recommendation flow charts to select treatment options (see Section 1).** The treatment recommendation flow charts suggest appropriate water quality modifications based on the limited amount of water quality information available to the water system. Treatment strategies not suggested by the flow charts for a particular set of water quality characteristics should be avoided.
4. **Once the treatment option(s) are selected from the treatment recommendation flow charts, use the "Water Treatment Checklist" (see Section 2) to determine if there are other restricting factors.** If all of the condi-

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tions are not met for a particular treatment, then that strategy should be discarded.

5. If there is more than one viable treatment option remaining, examine each option with regard to secondary impacts and the operability of the system (see Section 3).

In some cases, several different treatment options will be available to a particular water supply. As a result, some water systems will be able to select the most appropriate treatment option based on system configuration, economics, simplicity, reliability, operations, and other site-specific factors. Consideration also may be need to be given to impacts of drinking water treatment chemicals on wastewater discharge limits, or concentrations of metals in sludge. These aspects are beyond the scope of this document, but should be thoroughly addressed by all water systems as appropriate.

Section 1 - Flow Chart Treatment Determinations

There are four sets of flow charts which can be used to determine treatment approaches. To start, select the set which corresponds to your system as follows:

- (1) Exceeded lead and copper action level - set A;
- (2) Exceeded lead action level - set B;
- (3) Exceeded copper action level - set C;
- (4) Exceeded either of the action levels and have elevated source water iron and manganese levels - set D.

The selection of a corrosion control treatment option will be dependent on the pH, alkalinity, DIC, and other water quality data such as calcium, iron and manganese levels in the source water and possibly also changes in the water distribution system. Invalid water quality data can result in the misapplication of a treatment strategy. Note that as treatments are applied, particularly pH adjustment, your position and choices may move to another chart. *Before using the flow charts you must read the following information and calculate the DIC as described below.*

pH Measurements - pH is the most critical variable for determining treatment options. Many factors affect pH measurements. The following are some of the most significant.

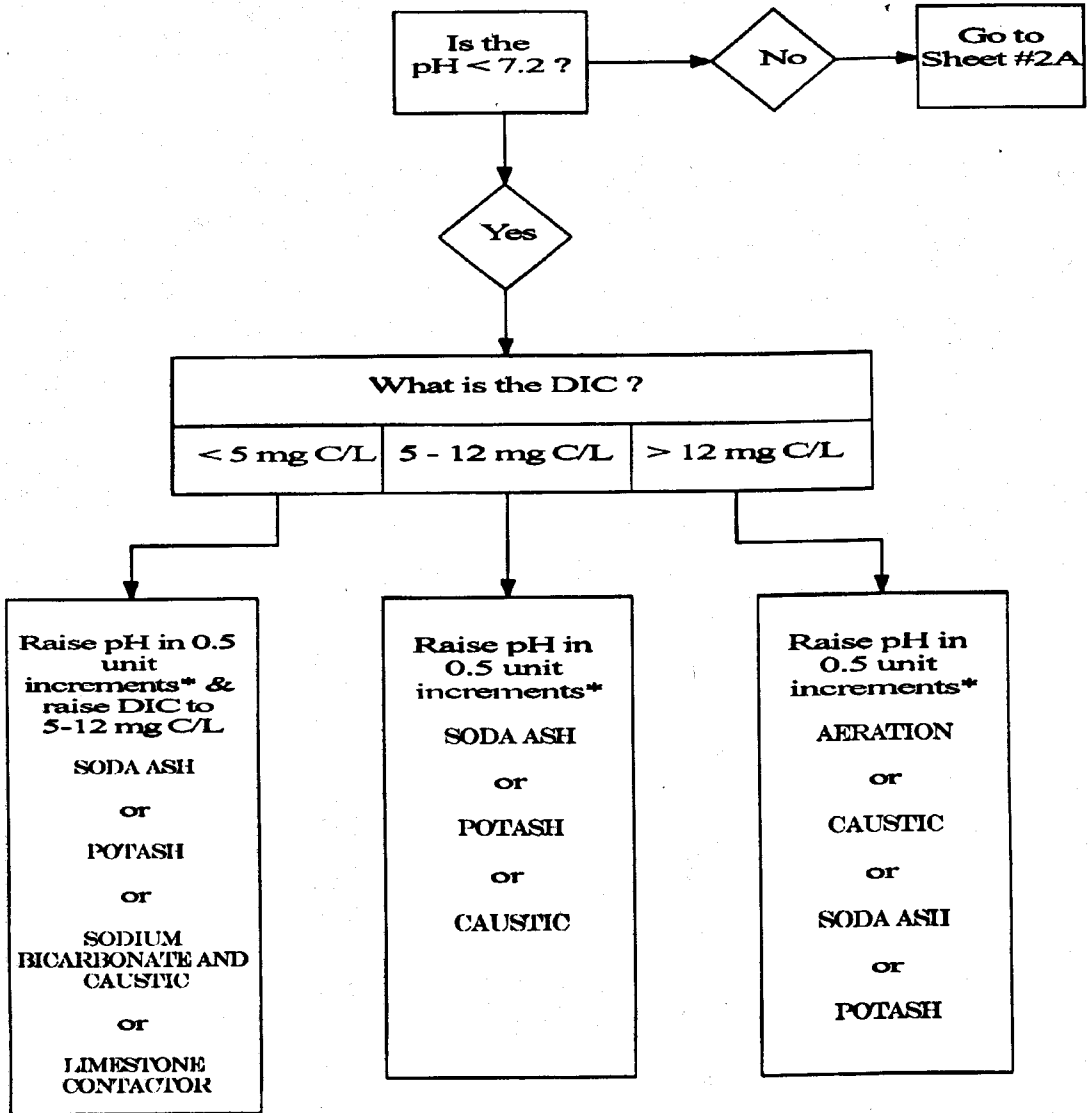
The pH instrumentation and calibration. Many pH measuring devices do not allow for appropriate calibration. Calibration of the pH probe should be performed with 3 standards at pH = 4, pH =7, and pH= 10. Calibration should also be performed prior to each set of analyses.

Aeration of the sample. Loss or introduction of carbon dioxide can greatly affect the pH of the sample, almost immediately. The pH should be measured on-site (in the field) with extreme care being taken not to shake the sample, stir rapidly, or expose the water to the atmosphere if it can be avoided. The use of small flasks and rubber stoppers bored out and fit around electrodes have been found to be very useful for minimizing the substantial errors that can result in the measured pH from only a few minutes of contact of typical New England ground waters or pH adjusted waters with the air. (See: "Laboratory Techniques for Measurement of pH for Corrosion Control Studies and Water not in Equilibrium with the Atmosphere." *Jour. AWWA*, 72:5:304, 1980)

Water Quality Variations. pH may vary depending upon the time of day, the season, or in response to precipitation. For well supplies the pH may vary depending on how long the pump has been running. It is critical to examine when the samples were collected and over what time period. If the water source varies seasonally as a function of precipitation or temperature it would be important to have data over the period of the entire seasonal cycle.

DIC Calculation - Dissolved inorganic carbonate affects levels of lead and copper levels and plays an important role in stabilizing pH. The DIC is calculated by using Table 1, which was developed with good approximations for New England conditions. Determine the DIC by reading corresponding pH and alkalinity values measured by the water system.

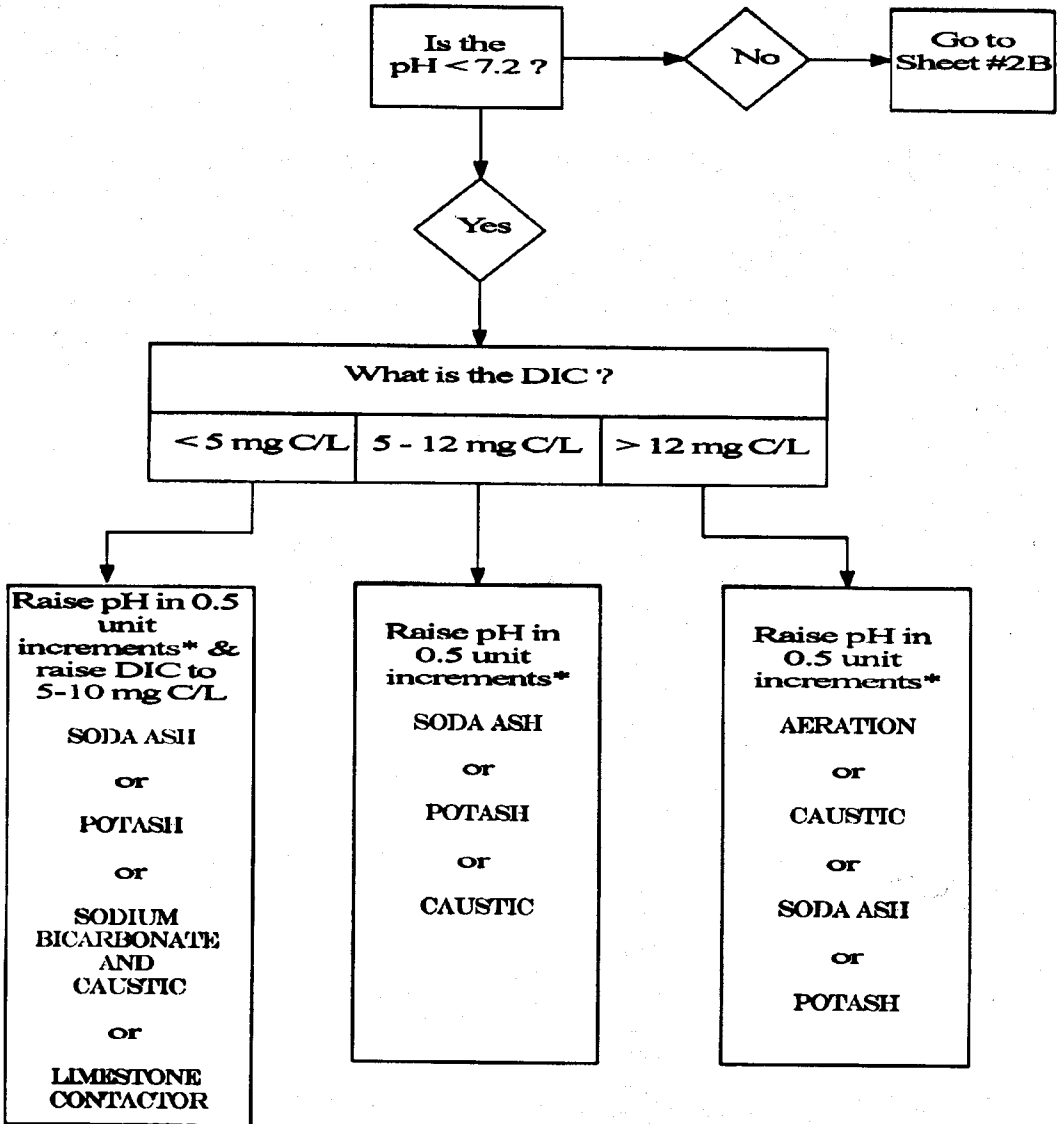
EXCEEDED LEAD AND COPPER ACTION LEVELS Sheet 1A



***See Section 4 describing pH adjustment**

Orthophosphate addition with pH/alkalinity adjustment is a viable treatment too. See Sheet 2A.

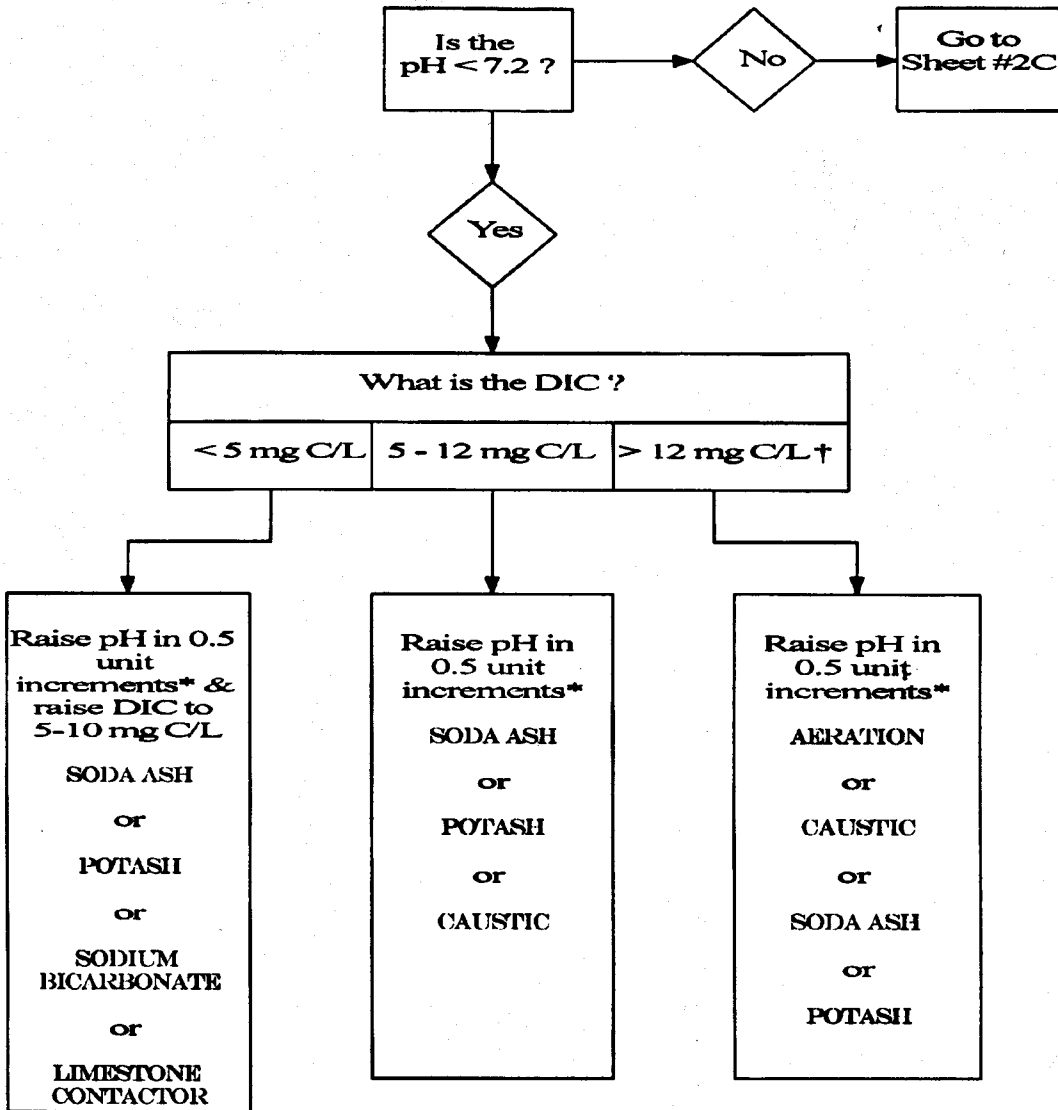
EXCEEDED LEAD ACTION LEVEL
Sheet 1B



***See Section 4 describing pH adjustment**

Orthophosphate addition with pH/alkalinity adjustment is a viable treatment too. See Sheet 2A.

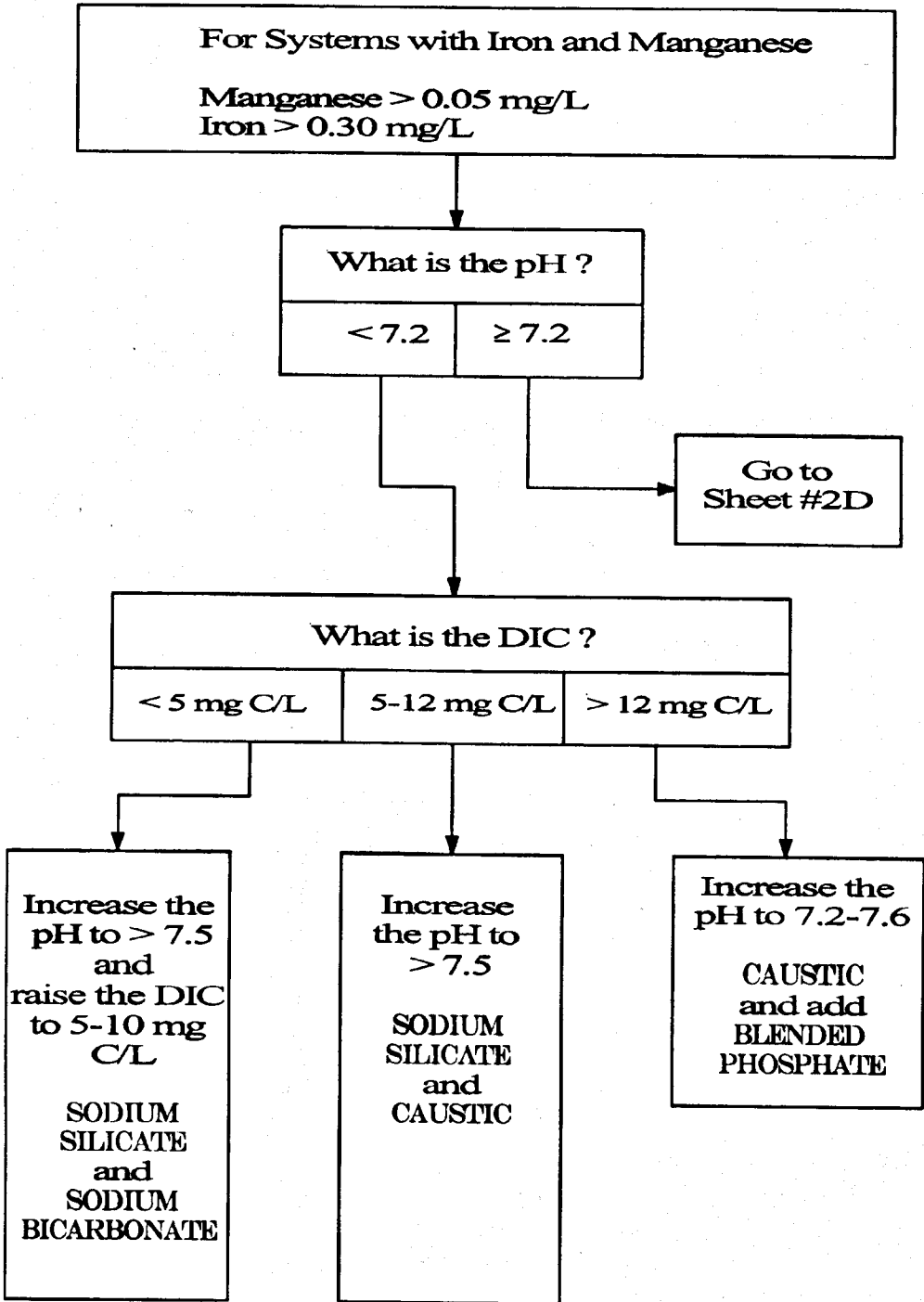
EXCEEDED COPPER ACTION LEVEL
Sheet 1C



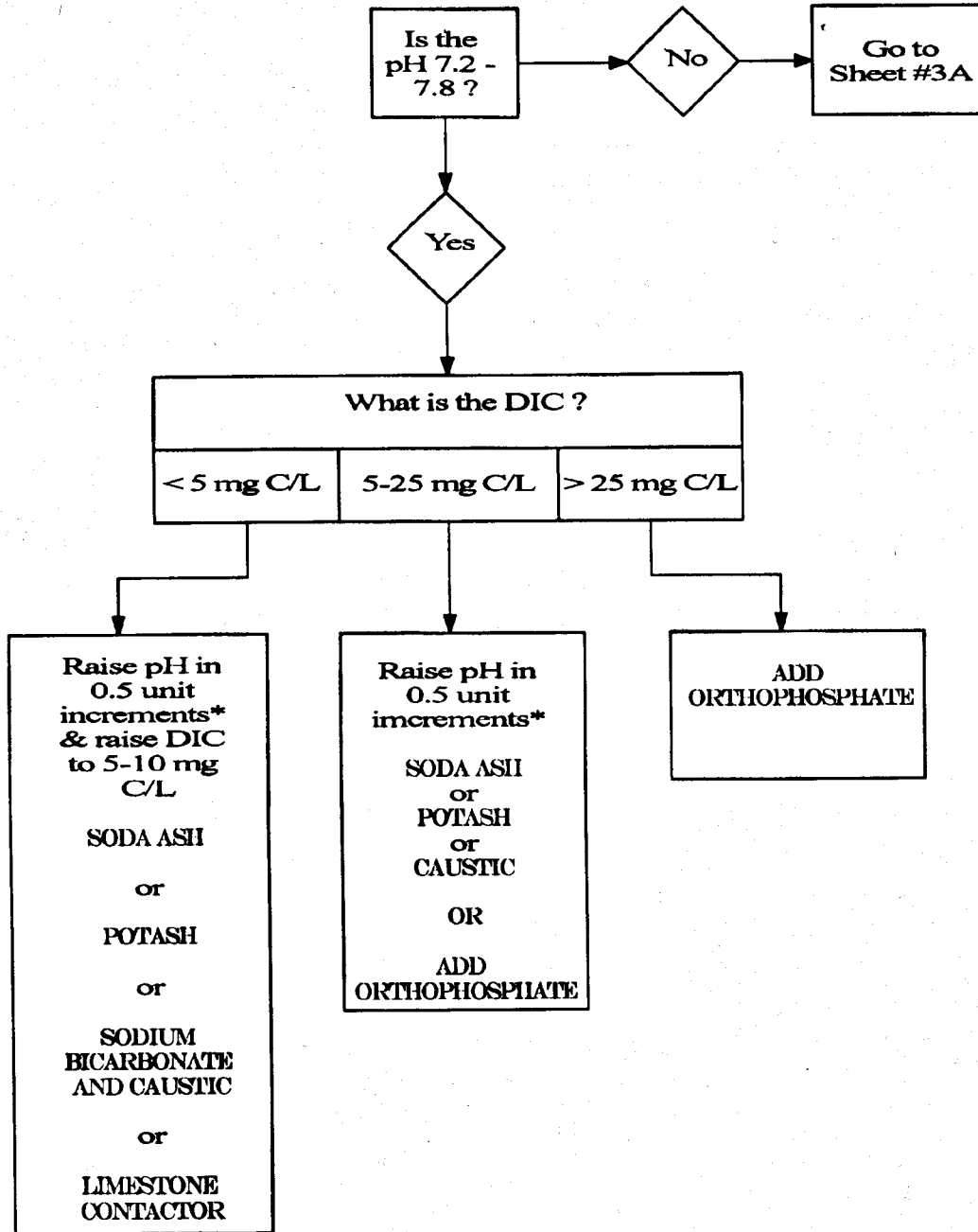
*See Section 4 describing pH adjustment

†Orthophosphate is necessary for new copper if pH > and DIC > 25 mg/L as C. See Sheet 2C.

Sheet 1D

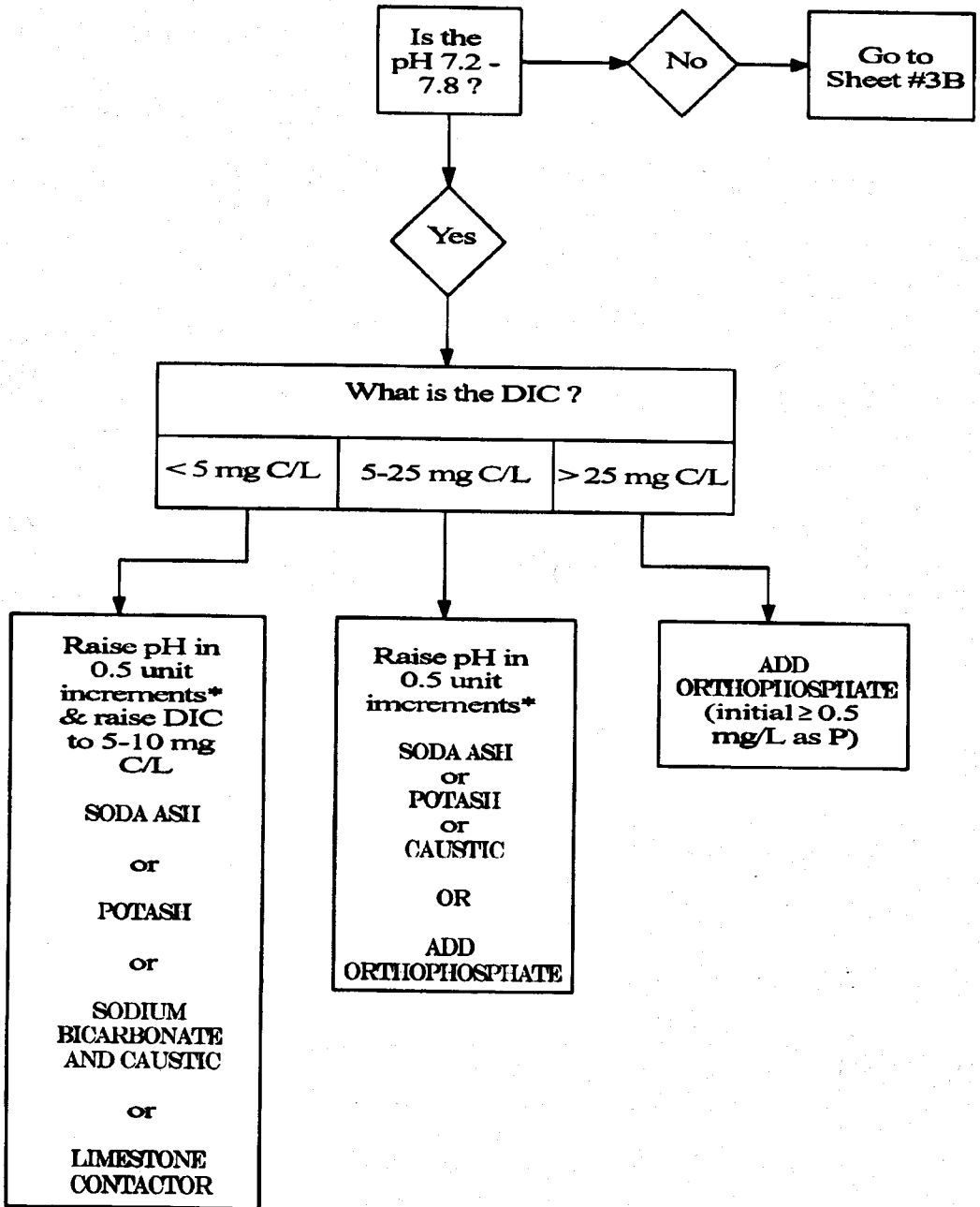


EXCEEDED LEAD AND COPPER ACTION LEVELS Sheet 2A



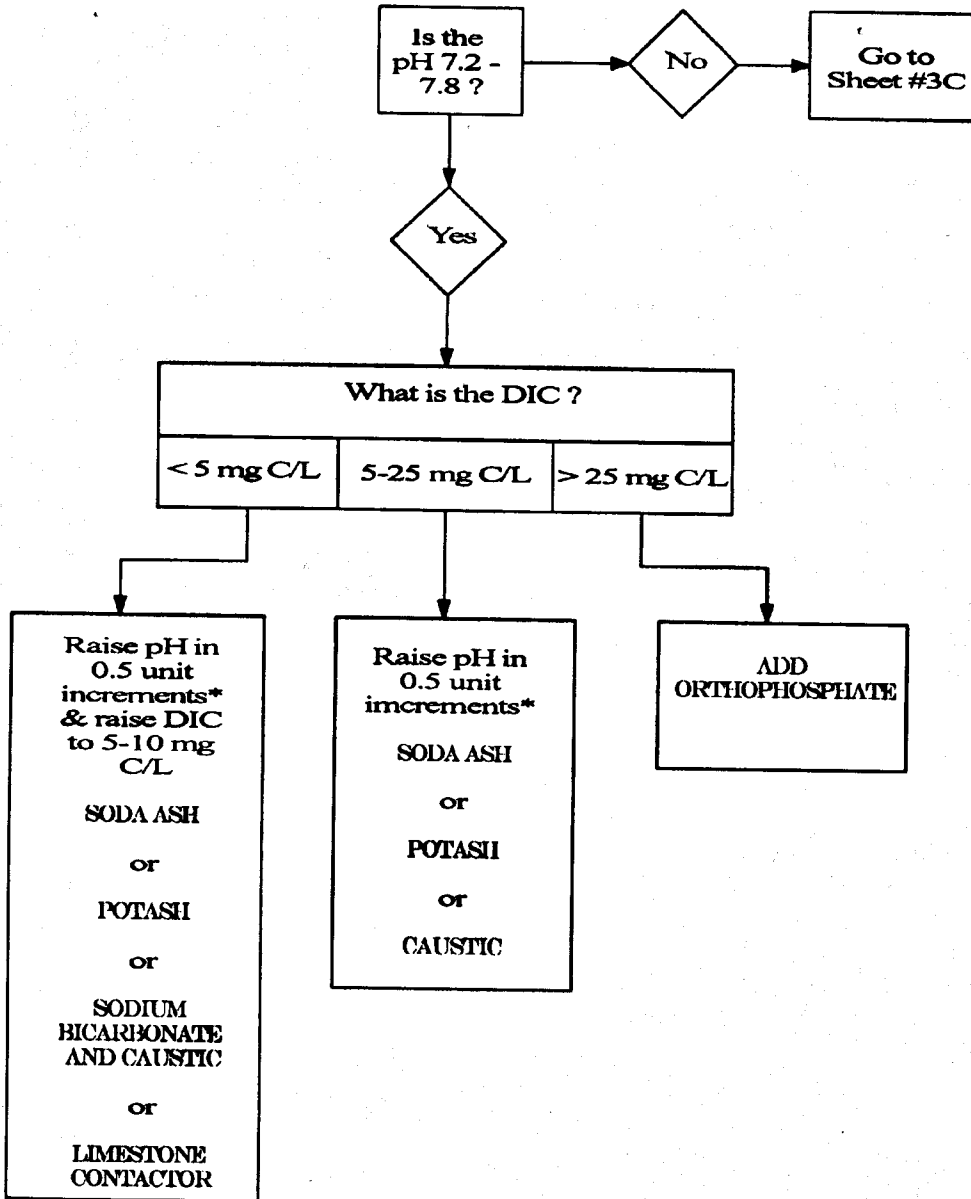
***See Section 4 describing pH adjustment**

EXCEEDED LEAD ACTION LEVEL
Sheet 2B



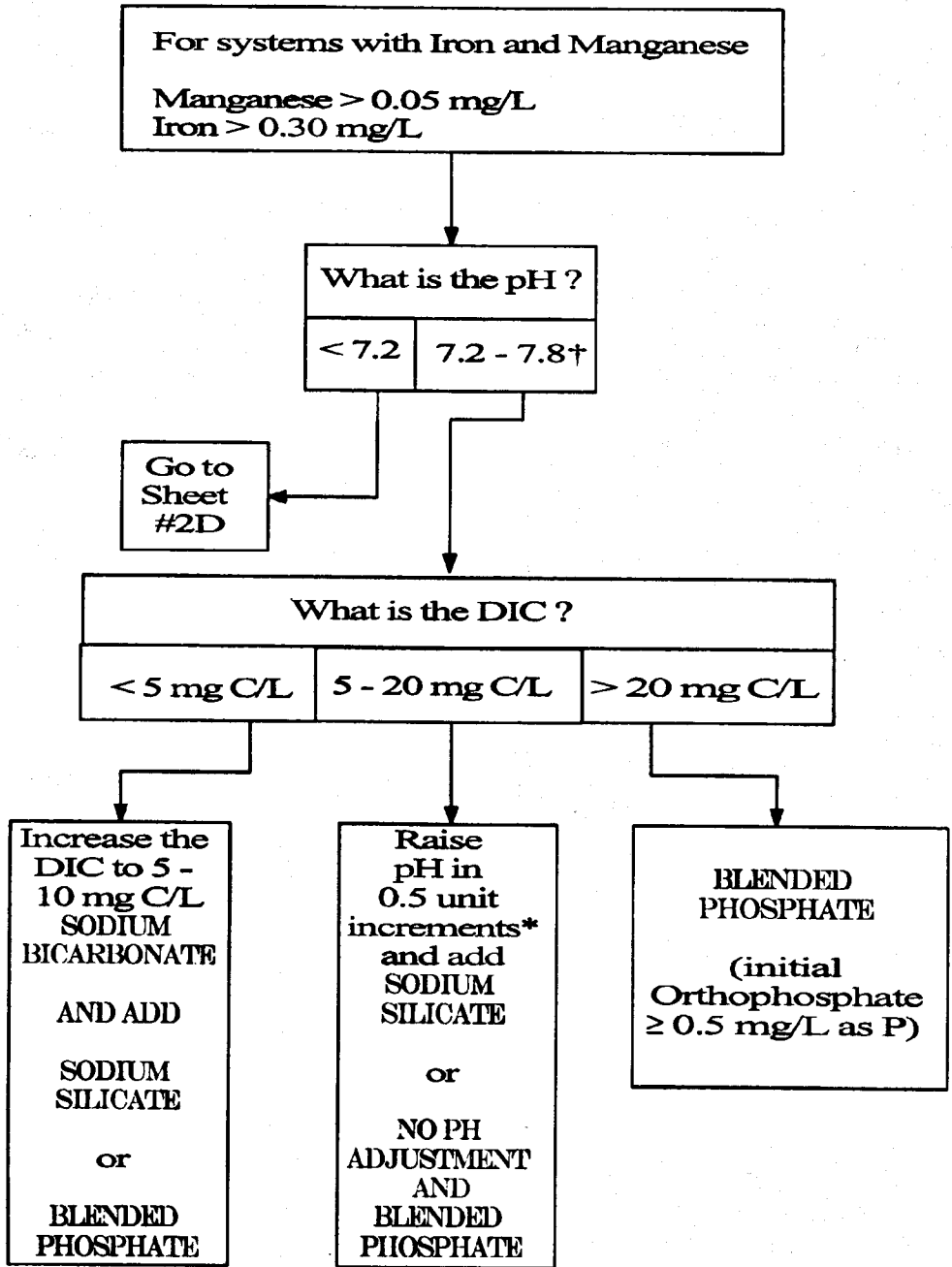
*See Section 4 describing pH adjustment

EXCEEDED COPPER ACTION LEVEL Sheet 2C



*See Section 4 describing pH adjustment

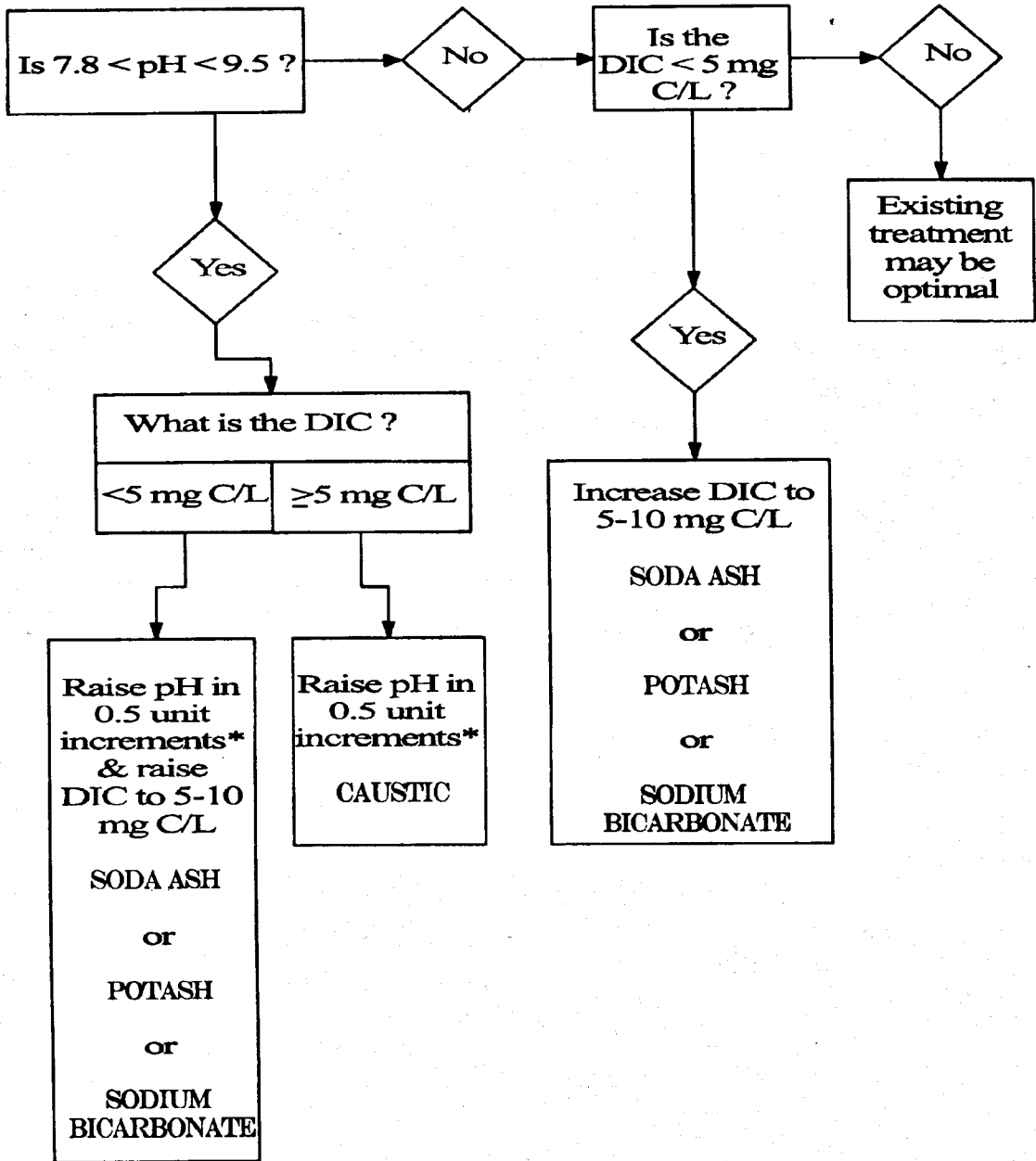
Sheet D



*See Section 4 describing pH adjustment

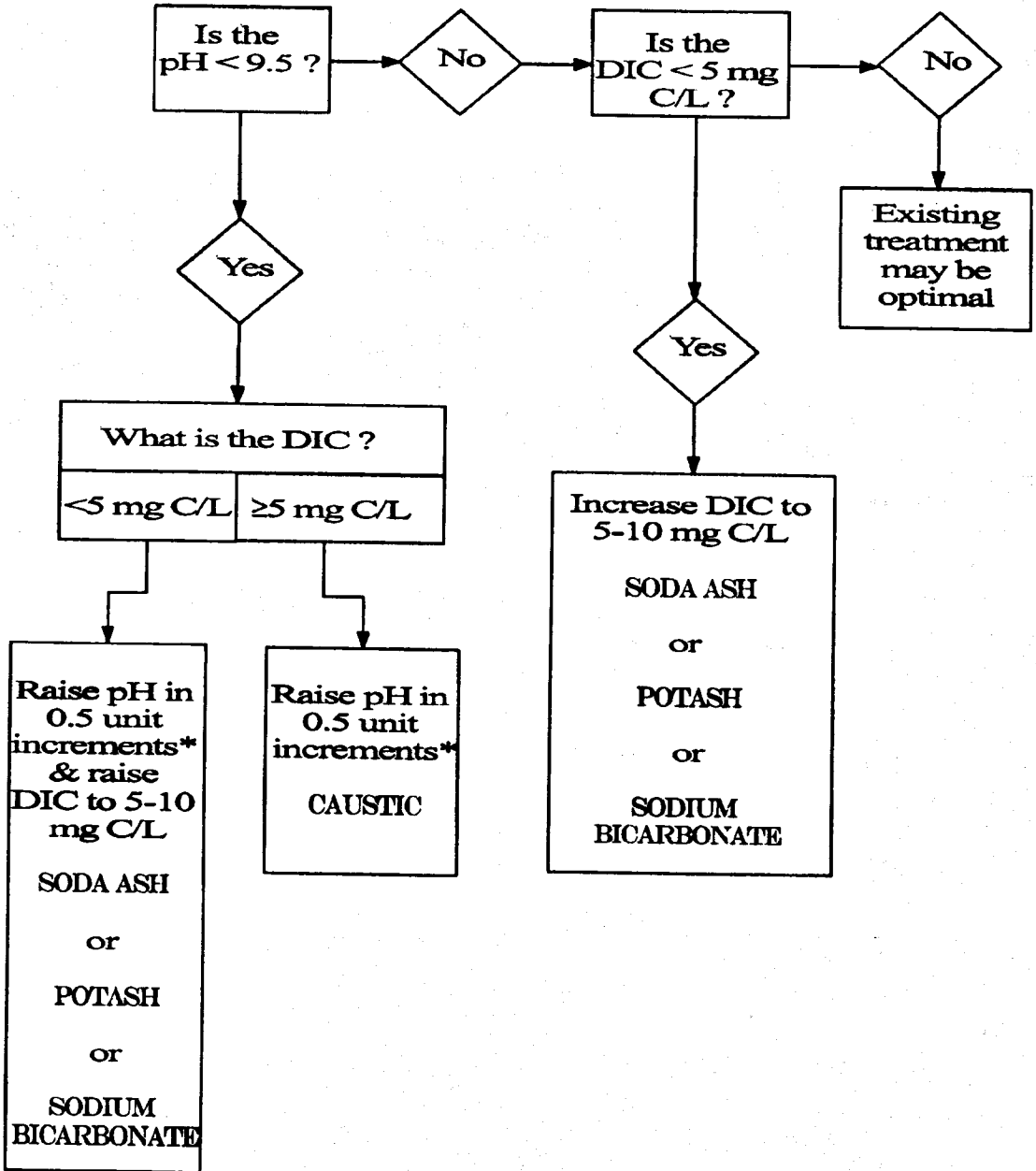
†For pHs > 7.8, use silicate and maintain DIC > 5 mg C/L

EXCEEDED LEAD AND COPPER ACTION LEVELS
Sheet 3A



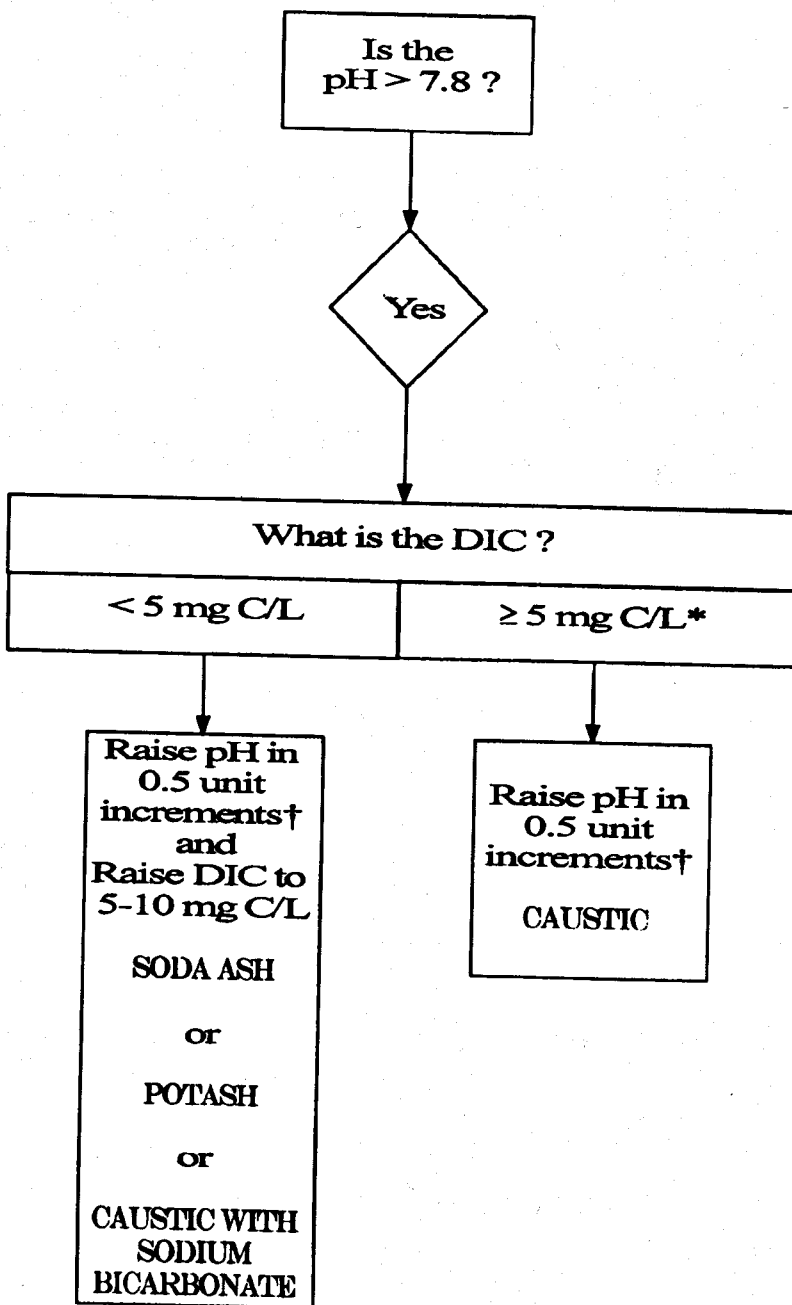
***See Section 4 describing pH adjustment**

EXCEEDED LEAD ACTION LEVEL
Sheet 3B



***See Section 4 describing pH adjustment**

EXCEEDED COPPER ACTION LEVELS Sheet 3C



†See Section 4 describing pH adjustment

*If DIC > 25 mg C/L, add orthophosphate, do not adjust pH

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Section 2 - Water Treatment Checklist

After identifying possible appropriate treatment strategies using the flow charts in Section 1, the following Water Treatment Checklist should be consulted for information on corrosion control treatment chemicals. The criteria listed under a specific treatment method must be met in order for that treatment to be selected.

ORTHOPHOSPHATE

pH in the range of 7.2-7.8

DIC > 5 mg C/L

When substantial cement-lined or asbestos-cement pipe is present, formulations containing zinc are beneficial.

CAUSTIC SODA or POTASSIUM HYDROXIDE ("caustic")

DIC > 5 mg C/L

SODIUM BICARBONATE (baking soda)

DIC < 5 mg C/L

SODIUM CARBONATE (soda ash) or POTASH (potassium carbonate)

3 mg C/L < DIC < 25 mg C/L

BLENDED ORTHOPHOSPHATE/ POLYPHOSPHATE (blended phosphate)

Iron or manganese over secondary limits* or creating water quality problems (red or black water)

Calcium precipitation is a problem

pH 7.2-7.8

DIC > 5 mg C/L

*Federal secondary containment levels for iron and manganese are as follows:

iron = 0.30 mg/L

manganese = 0.05 mg/L

Section 3 - Selection Considerations.

For some water systems more than one corrosion control treatment option may be chemically viable. The purpose of this section is to provide general information regarding the operation, and secondary impacts associated with each treatment option which may further influence which final treatment option should be chosen for your water system.

pH Adjustment Systems - Caustic (sodium or potassium hydroxide), soda ash, limestone contactors (calcite filters) and aeration (air stripping) are the principal methods for increasing the pH.

Caustic (Hydroxide) - Caustic, a liquid chemical, is very hazardous if not handled carefully. It can cause severe burns and damage the eyes. Caustic feed systems at a minimum should include an eye washing system, full shower, eye goggles, protective gloves, boots, aprons, easy-to-handle barrels and chemical containment areas. For very small systems such as schools, trailer parks etc. another option such as soda ash should be used if possible. While caustic traditionally means "sodium hydroxide" solution, potassium hydroxide can always be substituted for sodium hydroxide if a water system prefers, and dosages adjusted accordingly.

Soda Ash/Potash - Soda ash, or sodium carbonate, is a dry compound which is relatively safe to handle compared to caustic. Soda ash will not cause skin irritation. When soda ash is added to a water it also increases the DIC slightly. Because soda ash is safe to handle, it is strongly suggested as the pH adjustment chemical for schools, condominiums, or any facility where technical resources are limited. It dissolves more easily than lime. Potassium carbonate (potash) can be used in lieu of soda ash, since it dissolves more readily than soda ash.

Aeration Systems - Aeration systems can increase the pH without adding chemicals to the water. The exception is that some aeration systems may require intermittent or continuous chlorine disinfection to control bacterial growth. There are a wide variety of pH adjustment systems including diffused bubble systems, packed or tray tower, and venturi systems. Any aeration system selected for pH adjustment should be capable of removing at least 80- 90% of the carbon dioxide. Larger amounts of pH adjustment will require the use of designs that produce higher percentages of carbon dioxide removal. One of the disadvantages associated with aeration is that repumping of the water is required. Some water systems can configure their well, plant and storage locations to maximize the use of gravity in the hydraulics of their distribution networks.

Limestone Contactors - A limestone contactor is usually an enclosed filter containing crushed high-

purity limestone. As the water passes through the limestone the limestone dissolves, raising the pH, calcium, DIC and alkalinity of the water. Since the system does not require any pumps it is very simple and requires very little maintenance. Occasionally the limestone must be replaced. The limestone is not a hazardous material. When selecting a limestone contactor from a supplier it is important to ensure that it is adequately sized to produce sufficiently high pHs for the range of flow rates and temperatures encountered during plant operation.

Secondary Water Quality Impacts - When the pH of a water supply is increased, several unwanted side effects may occur. Water systems with a low pH (~7) and elevated levels of iron and manganese may notice a significant increase in black and red water complaints when the pH is increased. Water systems with this condition should consider using either a silicate or blended phosphate.

Water systems using surface water are subject to a series of regulations under a broad heading of the Surface Water Treatment Rule (SWTR). These systems must meet certain disinfection criteria. This includes maintaining an adequate contact time with chlorine at a specific pH and temperature, by meeting certain "CT" criteria, and other disinfection credits through filtration. A corrosion control strategy that causes an increase in pH may affect your ability to maintain adequate chlorine contact. Increases in finished water pH for surface water supplies should be performed after the chlorine contact chamber.

Disinfection by-product (DBP) formation also varies with pH. There is a tendency for trihalomethanes (THMs) to increase with prolonged exposure to higher pH's, whereas haloacetic acids (HAAs) tend to form or persist less at elevated pHs. Depending on the points of chlorination and the DBP precursor material concentration remaining after initial treatment, corrosion control strategies may be limited by concerns of violating new regulatory levels for DBPs in the distribution system that will become effective in 2004.

The increases in pH, orthophosphate, or silicate concentration necessary for lead and copper control may sometimes result in scaling in distribution system valves, in hot water heaters, or in some industrial chemical processes.

DIC Adjustment Systems - The adjustment systems for DIC include aeration and soda ash/potash (described above), and sodium bicarbonate (baking soda).

Sodium Bicarbonate - Sodium bicarbonate is a dry chemical that substantially increases the DIC, while providing a very minimal increase in pH. This chemical is typically applied to waters with very minimal DIC (< 5 mg C/L). Because it is a dry chemical, it must be dissolved in a tank of water for feeding. It is very safe to handle and will not increase the pH above 8.3.

Phosphate Adjustment - The addition of orthophosphate to a water supply can be achieved by adding any one of several different formulations. These include zinc orthophosphate, potassium or sodium orthophosphate, and phosphoric acid. Various chemical suppliers can furnish orthophosphate chemicals in liquid or dry chemical forms. The goal is to ensure that an adequate dosage of orthophosphate is maintained throughout the distribution system. Phosphoric acid is not recommended for small systems because it is difficult to handle. Orthophosphate may also be added by dosing poly/orthophosphate blends. The ratio of orthophosphate to polyphosphate is very important to assure sufficient orthophosphate residual to control the lead or copper release. Too much polyphosphate will cause instability of protective scales. Some polyphosphate components in blends are more detrimental to copper or lead levels than others, but due to the proprietary nature of the products these effects are difficult or impossible to predict before use.

The addition of orthophosphate or blended phosphates may cause the temporary release of particles (turbidity) from the inside surfaces of pipes. Over time, the conditions will stabilize and turbidity and color levels should return to existing levels.

Orthophosphate compounds that contain zinc may promote problems with receiving wastewater treatment plants. Many wastewater systems have limitations on how much zinc can be discharged to a receiving water body or remain in the sludge. Also because orthophosphate is a nutrient, some wastewater treatment plants will be limited in the amount of orthophosphate they can discharge to the receiving stream. It is important to check with the wastewater treatment plant to ensure that

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zinc or orthophosphate are not a problem. If zinc is a problem, a non-zinc based orthophosphate should be used. However, many water systems may find zinc a very important additive to reduce the pH increases caused by contact with cement and cement-lined pipes.

Section 4 - Optimizing Treatment

Once the best treatment strategy has been identified using the Flow Charts in Section 1, Water Treatment Checklist in Section 2 and the Selection Considerations in Section 3, the appropriate operating pH must be determined. In addition, if orthophosphate is added, an appropriate distribution system orthophosphate concentration must be maintained. No matter what the intended corrosion control strategy is, a comprehensive flushing program should be started at least several months before initiation of treatment changes to remove sediment and loose scale material that could be easily resuspended or destabilized by the new treatment. Disinfection and microbial quality should be carefully monitored during the flushing period. It is also important to continue the frequent and comprehensive flushing while the new treatment program is stabilizing. The flushing will also aid in assuring delivery of the corrosion inhibitor or water of proper pH and DIC levels to the surface of the pipes, which will help promote more rapid and more stable protective film development on the pipes.

pH Adjustments - When using treatment chemicals including caustic (sodium or potassium hydroxide) or soda ash/potash (sodium or potassium carbonate), adjustments of pH should be made in 0.5 unit increments. The pH should never be increased beyond 10. At a minimum, for systems with a pH of less than 7.0, the pH should be increased to at least 7.0. **For other pH increasing systems, either aeration or limestone contactors, the final pH will be established by the specifics of the water chemistry and design of the contactor or aerator.**

Increasing the pH of a water that contains calcium may promote the precipitation of calcium carbonate. In some circumstances, precipitation of calcium carbonate can clog hot water heaters and produce cloudy water. To limit the problems associated with calcium precipitation, the pH at which calcium is likely to precipitate can be estimated by use of Figure 1. The pH of calcium precipitation is estimated by finding the

point on the figure that corresponds to the DIC and calcium level. The calcium must be expressed as calcium (Ca) and not calcium carbonate (CaCO_3). Note that maintaining the pH below the level estimated on the chart should minimize, not eliminate, the potential for precipitating calcium carbonate. In many cases, it will be possible to exceed the estimated pH levels without having a calcium precipitation problem because the precipitation of calcium is affected by many factors, such as temperature and other dissolved metals.

Systems with unlined cast-iron pipe or large amounts of galvanized pipe need to consider the impacts of pH adjustment on iron corrosion. Although, the water quality impacts that impact iron corrosion are poorly understood, it appears that lower buffer intensity may accelerate iron corrosion. Water's minimal buffering intensity occurs approximately in the pH range of 8.0 - 8.5. Water systems that move their pH into this range may experience iron corrosion and red water.

Lead and copper levels should be monitored at representative homes or buildings four to six months after the pH has been adjusted. The state should then be consulted to determine if another pH increase is needed. A decision to increase the pH should not be made before this time because it usually takes at least four to six months for lead and copper levels to stabilize after a pH adjustment.

Orthophosphate Addition - The addition of orthophosphate should be performed by incremental increases in the dosage. Orthophosphate should only be added for lead problems when the pH is in the range of 7.2-7.8. A slightly lower pH may sometimes work for copper problems. Initially a system selecting orthophosphate should add enough of the orthophosphate based chemical to establish at least a 1 mg PO_4/L residual in the system. A close approximation is that 1 mg/L of orthophosphate expressed as P corresponds to 3 mg/L expressed as PO_4 . Systems with high DIC and considerable new copper piping may need to start with 3 mg PO_4/L (1 mg/L as P). To establish this residual, the amount of orthophosphate added will need to be higher than what is measured in the system since some of the orthophosphate will be depleted. After establishing a residual of 1 mg PO_4/L for 6 months, samples from selected homes and buildings should be analyzed for lead and copper. The results should be discussed with the State to determine if increasing the dosage is neces-

sary to satisfy the "orthophosphate demand" of the distribution system. The dosage should be increased in 1 mg PO₄/L increments, with lead and copper monitoring following after 6 months with the same dosage. The increases should continue until the desired metals levels are achieved. Even when lead and copper levels are substantially reduced, dosages should not be lowered until the orthophosphate residual throughout the distribution system is constant and is nearly equal to the concentration leaving the treatment plant.

Section 5 – Example Treatment Determinations

Water System 1

Population Served = 2000
Supply - single well
System failed both lead and copper action level

pH Data: 6.7, 6.9, 6.4, 6.4, 6.7
Alkalinity 56, 45, 44, 57 and 50 mg CaCO₃/L
Calcium: 18, and 18, 19, 20 mg Ca/L

Step 1: Determine the DIC in mg C/L

The median (mid-value pH) is 6.7 and the average alkalinity is 50.

Go to table 1 and determine the DIC. (Because there are no DIC values for a pH 6.7) determine the DIC at a pH of 6.6 and a pH of 6.8 for an alkalinity value of 50, and determine the DIC at pH 6.7 by averaging the values at pH 6.6 and 6.8.

For a pH of 6.6 and alkalinity of 50 the DIC is 19
For a pH of 6.8 and alkalinity of 50 the DIC is 17.
For a pH of 6.7, the DIC would be approximately 18.

Step 2. Determine the maximum pH to minimize calcium precipitation

Using Figure 1 with an average calcium concentration of 19 mg/L and a DIC of 18, the maximum pH is about 8.3.

Step 3. Use flow charts

The sheets for systems that exceeded both the lead and copper (set A) action levels are used. The first sheet is used since the pH is less than 7.2. The DIC is greater than 12 mg C/L, therefore the viable treatment options are: aeration, caustic, or soda ash/potash.

Step 4. Use the Water Treatment checklist

Check the requirements for each of the viable treatment options. Because all the criteria listed under

the three treatment options have been met, any of the three treatment options may be selected.

Water System 2

Population Served = 100
Supply - single well
System failed copper action level

pH Data: 6.9, 7.4, 7.1, 7.0, 7.0
Alkalinity 16, 18 and 20 mg CaCO₃/L
Calcium: 7, 8 and 9 mg Ca/L

Step 1: Determine the DIC in mg C/L

The median (mid-value pH) is 7.0 and the average alkalinity is 18.

Go to table 1 and determine the DIC.

For a pH of 7.0 and alkalinity of 20 (closest value to 18) the DIC is 6 mg C/L.

Step 2. Determine the maximum pH to minimize calcium precipitation

Using Figure 1 with a calcium concentration of 8 mg/L and a DIC of 6 the maximum pH is about 9.3.

Step 3. Use flow charts

The sheets for systems that exceeded the copper action level (set C) are to be used. The first sheet is used since the pH is less than 7.2. The DIC is between 5 - 10 mg C/L, therefore the viable treatment options are: caustic, soda ash, or limestone contactor.

Step 4. Use the Water Treatment checklist

Check the requirements for each of the viable treatment options. Because all the criteria listed under the three treatment options have been met, any of the three treatment options may be selected.

Water System 3

Population Served = 2900
Supply - surface water and groundwater
System failed both lead and copper action level

GROUNDWATER DATA	SURFACE WATER DATA
20 % of supply	80% of Supply-140,000 GPD
pH Data: 7.6 7.4 7.1 7.6 7.6	pH data: 6.8, 6.6, 6.8, 7.0
Alkalinity 50,54,56 and 60 mg CaCO ₃ /L	Alkalinity 6,7,7,8mg/L
Calcium: 29, 30, 28, 32 mg Ca/L	Calcium: 2, 2, 2, 2 mg Ca/L

Multiple Source System

Several factors must be examined when determining treatment for a water system with multiple sources.

SELECTION OF LEAD AND COPPER CORROSION CONTROL STRATEGIES

1. *Amount of Water.* The surface water in this case is where most of the water is derived. It is of greater importance on that basis.

2. *Corrosiveness:* The primary factors here are the pH and alkalinity. The groundwater, having higher pH values, is less corrosive.

Based on these factors, the approach should be to determine a treatment recommendation for the surface water supply.

Step 1: Determine the DIC in mg C/L

The median (mid-value pH) is 6.8 and the average alkalinity is 7.

Go to table 1 and determine the DIC.

For a pH of 6.8 and alkalinity of 5 (closest value to 7) the DIC is 2 mg C/L.

Step 2. Determine the maximum pH to minimize calcium precipitation

Using Figure 1 with a calcium concentration of 2 mg/L and a DIC of 2, the maximum pH is about >9.75.

Step 3. Use flow charts

The sheets for systems that exceeded both the lead and copper action level (Set A) are to be used. The first sheet is used since the pH is less than 7.2. The DIC is < 5 mg C/L, therefore the viable treatment options are: soda ash, sodium bicarbonate or limestone contactor.

Step 4. Use the Water Treatment checklist

Check the requirements for each of the viable treatment option. A limestone contactor cannot be used because the system's flow rate is >50,000 gallons per day. Soda ash cannot be used because system DIC does not fall within the required range of 4 - 24 mg C/L. Because the criterion listed under sodium bicarbonate is met, sodium bicarbonate should be used to optimize corrosion control treatment.

Section 6 - Some Additional Sources of Information

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Spencer, C.M., 1998. Aeration and Limestone Contact for Radon Removal and Corrosion Control. *Jour. NEWWA*, 112:1:60.

Table 1 DIC Determination

Dissolved Inorganic Carbonate (DIC mg C/L) as a Function of pH and Alkalinity (as CaCO₃)
 For a Purely Carbonate+H₂O Closed System at 10 C (50 F); Ionic Strength - 0.005 (TDS @ 200 or Cond @ 312)

Alkalinity	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	
0	18.67	7.50	3.03	1.23	0.51	0.21	0.09	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	92.93	54.80	33.32	20.79	13.29	8.72	5.90	4.15	3.05	2.37	1.93	1.66	1.49	1.36	1.26	1.18	1.11	1.05	1.00	0.95	0.91
10	187.19	102.10	63.60	40.34	26.07	17.23	11.71	8.26	6.09	4.72	3.88	3.32	2.90	2.58	2.32	2.10	1.91	1.75	1.61	1.49	1.38
15	241.46	149.40	93.89	59.89	38.83	25.73	17.52	12.37	9.12	7.08	5.80	4.98	4.47	4.05	3.72	3.44	3.19	2.97	2.76	2.57	2.40
20	315.72	198.70	124.18	79.44	51.63	34.34	23.31	16.47	12.16	9.44	7.73	6.64	5.98	5.46	5.03	4.68	4.37	4.08	3.82	3.58	3.36
25	389.98	244.00	154.48	99.00	64.41	42.74	29.14	20.58	15.19	11.80	9.68	8.30	7.45	6.82	6.30	5.88	5.51	5.18	4.88	4.61	4.36
30	464.24	291.30	184.75	118.55	77.19	51.23	34.95	24.69	18.23	14.15	11.59	9.96	8.94	8.22	7.60	7.07	6.64	6.23	5.85	5.49	5.15
35	538.50	338.59	215.04	138.10	89.96	59.76	40.76	28.60	21.28	16.51	13.52	11.83	10.43	9.52	8.80	8.17	7.64	7.13	6.64	6.17	5.82
40	612.76	385.89	245.32	157.65	102.74	68.26	46.57	32.91	24.30	18.87	15.45	13.29	11.82	10.91	10.18	9.55	9.03	8.53	8.05	7.59	7.15
45	687.03	433.19	275.61	177.20	115.32	78.77	52.38	37.02	27.33	21.23	17.39	14.95	13.41	12.50	11.87	11.34	10.83	10.34	9.87	9.42	8.99
50	761.29	480.49	305.89	196.76	128.30	85.27	58.19	41.12	30.37	23.59	19.31	16.61	14.90	13.99	13.26	12.73	12.22	11.73	11.25	10.78	10.33
55	835.55	527.79	336.18	216.31	141.08	93.76	64.00	45.23	33.40	25.94	21.24	18.27	16.59	15.68	14.95	14.42	13.91	13.41	12.92	12.44	11.97
60	909.81	575.09	366.47	235.96	153.86	102.29	69.81	49.34	36.44	28.30	23.17	19.93	17.88	16.97	16.24	15.71	15.20	14.70	14.21	13.73	13.26
65	984.07	622.39	396.75	255.41	166.64	110.79	75.62	53.45	39.47	30.66	25.10	21.59	19.37	18.46	17.73	17.20	16.69	16.19	15.70	15.22	14.75
70	1058.34	669.69	427.04	274.96	179.42	119.30	81.43	57.56	42.51	33.02	27.03	23.25	20.86	19.95	19.22	18.69	18.18	17.68	17.19	16.70	16.22
75	1132.60	716.99	457.33	294.42	192.20	127.80	87.24	61.67	45.54	35.37	29.96	24.91	22.35	21.44	20.71	20.18	19.67	19.17	18.67	18.18	17.70
80	1206.86	764.28	487.61	314.07	204.98	136.31	93.05	65.77	48.58	37.73	30.89	26.57	23.64	22.73	22.00	21.47	20.96	20.45	19.95	19.45	18.96
85	1281.12	811.58	517.90	333.82	217.76	144.82	98.86	69.89	51.61	40.09	32.82	28.23	25.33	24.42	23.69	23.16	22.65	22.14	21.63	21.13	20.63
90	1355.38	858.88	548.18	353.17	230.54	153.32	104.67	73.99	54.65	42.45	34.75	29.89	26.82	25.91	25.18	24.65	24.14	23.63	23.12	22.61	22.11
95	1429.65	906.18	578.47	372.73	243.32	161.83	110.48	78.10	57.68	44.90	36.68	31.55	28.31	27.40	26.67	26.14	25.63	25.12	24.61	24.10	23.60
100	1503.91	953.48	608.76	392.28	256.10	170.33	116.28	82.21	60.72	47.16	38.61	33.21	29.80	28.89	28.16	27.63	27.12	26.61	26.10	25.59	25.08
110	1652.43	1048.08	689.33	431.36	281.85	187.34	127.90	90.43	68.79	51.88	42.47	36.53	32.78	31.87	31.14	30.61	30.10	29.59	29.08	28.57	28.06
120	1800.95	1142.87	729.90	470.49	307.21	204.36	139.52	98.64	72.86	56.59	45.33	39.85	35.76	34.85	34.12	33.59	33.08	32.57	32.06	31.55	31.04
130	1949.48	1237.27	790.48	509.59	332.77	221.37	151.14	106.86	78.93	61.31	50.19	43.17	38.74	37.83	37.10	36.57	36.06	35.55	35.04	34.53	34.02
140	2098.00	1331.87	851.03	548.69	358.33	238.38	162.76	115.08	85.00	66.02	54.03	46.49	41.72	40.81	40.08	39.55	39.04	38.53	38.02	37.51	37.00
150	2246.53	1426.47	911.62	587.80	383.89	255.39	174.38	123.29	91.07	70.74	57.91	48.81	43.70	42.81	42.08	41.55	41.04	40.53	40.02	39.51	39.00
160	2395.05	1521.07	972.19	626.90	409.45	272.40	186.00	131.51	97.14	75.45	61.77	51.14	45.68	44.79	44.06	43.53	43.02	42.51	42.00	41.49	40.98
170	2543.57	1615.68	1032.77	668.01	435.01	289.42	197.62	139.79	103.21	80.17	65.63	53.40	47.50	46.61	45.88	45.35	44.84	44.33	43.82	43.31	42.80
180	2692.10	1710.28	1093.34	705.11	460.56	308.43	209.24	147.94	109.28	84.88	69.49	55.76	49.10	48.21	47.48	46.95	46.44	45.93	45.42	44.91	44.40
190	2840.62	1804.86	1153.91	744.22	486.12	323.44	220.86	156.16	115.35	89.60	73.35	63.10	56.62	55.73	55.00	54.47	53.96	53.45	52.94	52.43	51.92
200	2989.14	1899.46	1214.48	783.32	511.68	340.45	232.48	164.38	121.42	94.31	77.21	66.42	59.40	58.51	57.78	57.25	56.74	56.23	55.72	55.21	54.70

SELECTION OF LEAD AND COPPER CORROSION CONTROL STRATEGIES

Dissolved Inorganic Carbonate (DIC mg C/L) as a Function of pH and Alkalinity (as CaCO3)
For a Purely Carbonate+H2O Closed System at 10 C (50 F); Ionic Strength - 0.005 (TDS @ 200 or Cond @ 312)

Alkalinity	pH									
	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9	8.0	8.1
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	1.38	1.31	1.27	1.24	1.22	1.20	1.19	1.17	1.15	1.11
10	2.76	2.63	2.54	2.48	2.44	2.41	2.39	2.36	2.32	2.26
15	4.15	3.94	3.81	3.72	3.67	3.62	3.58	3.54	3.49	3.42
20	5.53	5.26	5.08	4.97	4.89	4.83	4.78	4.73	4.68	4.57
25	6.91	6.57	6.35	6.21	6.11	6.04	5.98	5.91	5.83	5.72
30	8.29	7.88	7.62	7.45	7.34	7.25	7.18	7.10	7.00	6.87
35	9.68	9.20	8.89	8.68	8.56	8.46	8.37	8.28	8.17	8.02
40	11.06	10.51	10.16	9.94	9.78	9.67	9.57	9.47	9.35	9.18
45	12.44	11.83	11.43	11.18	11.01	10.88	10.77	10.66	10.52	10.33
50	13.82	13.14	12.70	12.42	12.23	12.09	11.97	11.84	11.69	11.48
55	15.21	14.46	13.98	13.66	13.45	13.30	13.16	13.03	12.86	12.63
60	16.59	15.77	15.23	14.91	14.68	14.51	14.36	14.21	14.03	13.78
65	17.97	17.08	16.52	16.15	15.90	15.72	15.58	15.40	15.20	14.94
70	19.35	18.40	17.79	17.39	17.12	16.93	16.78	16.58	16.37	16.09
75	20.74	19.71	19.06	18.63	18.35	18.14	17.96	17.77	17.54	17.24
80	22.12	21.03	20.33	19.88	19.57	19.34	19.15	18.96	18.72	18.39
85	23.50	22.34	21.60	21.12	20.79	20.55	20.35	20.14	19.88	19.54
90	24.88	23.65	22.87	22.36	22.02	21.76	21.55	21.33	21.06	20.70
95	26.27	24.97	24.14	23.60	23.24	22.97	22.75	22.51	22.23	21.85
100	27.65	26.28	25.41	24.85	24.46	24.18	23.94	23.70	23.40	23.00
110	30.41	28.91	27.93	27.33	26.91	26.60	26.34	26.07	25.74	25.30
120	33.18	31.54	30.49	29.82	29.36	29.02	28.74	28.44	28.08	27.61
130	35.94	34.17	33.04	32.30	31.80	31.44	31.13	30.81	30.43	29.91
140	38.71	36.80	35.58	34.78	34.25	33.86	33.53	33.19	32.77	32.22
150	41.47	39.42	38.12	37.27	36.70	36.28	35.92	35.56	35.12	34.52
160	44.24	42.05	40.66	39.75	39.14	38.70	38.32	37.93	37.46	36.82
170	47.00	44.68	43.20	42.24	41.59	41.12	40.71	40.30	39.80	39.13
180	49.77	47.31	45.74	44.72	44.04	43.53	43.11	42.67	42.14	41.43
190	52.53	49.94	48.28	47.21	46.48	45.95	45.50	45.04	44.49	43.74
200	55.30	52.57	50.82	49.69	48.93	48.37	47.90	47.42	46.83	46.04

Dissolved Inorganic Carbonate (DIC mg C/L) as a Function of pH and Alkalinity (as CaCO3)
 For a Purely Carbonate+H2O Closed System at 10 C (50 F); Ionic Strength - 0.005 (TDS @ 200 or Cond @ 312)

Constants For DIC Calculations at 10 C

Alpha H2CO3*	0.00	0.00	0.00	0.00
Alpha HCO3-	0.77	0.58	0.43	0.46
Alpha CO3=	0.23	0.42	0.57	0.54

Alkalinity	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	
DIC (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
pH	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35	6.35

- TEMP Fahrenheit 49.986
- TEMP Centigrade 10.0
- TEMP Kelvin 283.15
- TDS mg/L 200.0
- CONDUCT 312.0
- ION STRENGTH 0.0050
- "A" Davies Slagle Ion Activity Constant 0.4976
- Activity Correct Factors log f0-undissoc./no charge 0.0005
- log fm monovalent -0.0392
- log fd-divalent -0.1522
- Equilibrium Constants log Kw (Temp. Corrected) -14.5332
- log K'n (Ion Strength Corrected) -14.4548
- log K1 (temp. Corrected) -6.4633
- log K'1 (Ion Strength Corrected) -6.3845
- log K2 (Temp. Corrected) -10.4879
- log K'2 (Ion Strength Corrected) -10.3357

DIC (mg/L as C =

$$\left[\frac{\text{ALK (mg/L CaCO}_3\text{)} / 50044 \text{ (mg CaCO}_3\text{/equiv.)}}{-K'w / \{H\} + \{H\}} \right] \times \left(\frac{1}{\alpha \text{ HCO}_3 + 2(\alpha \text{ CO}_3)} \right) \times 12011 \text{ (mg C/mode)}$$

SELECTION OF LEAD AND COPPER CORROSION CONTROL STRATEGIES

