

Chapter 3.0 — Screening of Corrosion Control Alternatives

Many small and medium-size PWSs will be required to evaluate, select and implement optimal corrosion control treatment to meet lead and copper action levels (ALs). Additionally, most large PWSs will be required to perform corrosion control studies which includes desk-top evaluations of alternative treatment approaches. States will likewise be required to review the findings and recommendations of corrosion control investigations, and, in some cases, designate treatment for LCR compliance. To assist each in these endeavors, this Chapter provides:

- a discussion of the basic principles of corrosion and the available corrosion control treatment approaches;
- the steps necessary to develop treatment recommendations for small and medium systems exceeding an AL or large systems required to perform desk-top evaluations;
- a checklist for small and medium-size PWSs and States to use in evaluating the selected treatment; and
- several case studies illustrating the procedure and rationale used to perform desk-top evaluations.

References are also provided for those seeking more detailed and rigorous presentations on this subject.

3.1 Principles of Corrosion and Corrosion Control

Corrosion causes the deterioration of crystalline structures that form the pipe materials, and can occur by one of three principle mechanisms: abrasion, metabolic activity, and dissolution. Abrasion is the physical removal of pipe material due to irregularities in the pipe surface which may dislodge under high fluid velocities. Metabolic activity refers to the utilization of pipe materials as a nutrient supply by microorganisms. The dissolution of pipe materials occurs when favorable water chemistry and physical conditions combine, generating the following possible corrosion scenarios:

- *Uniform Corrosion* - when the water freely dissolves metals from the pipe surface;
- *Concentration Cell Corrosion* - when anodic and cathodic points are established along the pipe surface, causing the sacrifice of metals at the anode (dissolved metal species) and the re-precipitation of less soluble metal compounds at the cathode.
- *Galvanic Corrosion* - when two dissimilar metals are in contact with each other, accelerating the dissolution of the material with the greater tendency to corrode.

Corrosion of drinking water distribution systems can result from any of the above mechanisms or combinations of the various types of corrosion activity as illustrated in Figure 3-1. Alteration of water quality characteristics via treatment can extensively reduce some forms of corrosion activity, but may have a less significant affect on others (AWWARF/DVGH, 1985).

Corrosion control treatment is principally intended to inhibit dissolution. The objective is to alter the water quality such that the chemical reactions between the water supply and the pipe materials favor the formation of a protective layer on the interior of the pipe walls. Corrosion control treatment attempts to reduce the contact between the pipe and the water by creating a film that is: (1) present throughout the distribution and home plumbing systems; (2) relatively impermeable; (3) resistant to abrupt changes in velocity and/or flow direction; and (4) less soluble than the pipe material (Neff, 1991).

Coincidental reductions of other corrosion activity may be accomplished when dissolution of lead and copper are minimized. Abrasion of piping materials is typically accelerated when corrosion byproducts, such as tubercles, are present in the distribution system. Abrasion activity normally diminishes when tubercles are reduced or if the tubercles can be coated with a less permeable substance. This effect has been noted by several full-scale systems which have reported fewer customer complaints about red or black water events after corrosion control treatment was implemented.

Most researchers agree that implementing corrosion control will alter the finished water chemistry which subsequently may

influence microbial growths within the distribution system. Recent studies have shown that biofilms are strongly associated with corrosion byproducts within distribution systems (Allen, et al., 1980; Herson, et al., 1991; AWWARF, 1990a). This association makes the biofilms more resistant to disinfection, and therefore, more persistent when active corrosion takes place in distribution system piping. While biofilm formation may be promoted by corrosion, it remains difficult to accurately quantify the effects of microbial activity on corrosion rates in distribution systems and the effect of treatment on such activity.

Some PWSs have also experienced increases in distribution system microbial growth when corrosion control treatment was implemented due to the addition of nutrients (phosphorus, inorganic carbon, silica) to the finished water. In particular, this may become a problem within distribution systems where chloramines are used for final disinfection and a phosphorus-based inhibitor is applied for corrosion control. As chloramines are reduced during oxidation, ammonia (a potential nitrogen source) is released into the water. Thus the presence of two major nutrients, nitrogen and phosphorus, could increase microbial growth. This is especially likely in the extremes of the distribution system where localized areas with inadequate disinfectant may occur (Hoehn, 1991).

Algal growth may also occur in uncovered distribution system reservoirs. The primary nutrients necessary for algae to proliferate are nitrogen and phosphorus. Phosphorus tends to be the controlling nutrient as some algal species are able to obtain nitrogen from the atmosphere for

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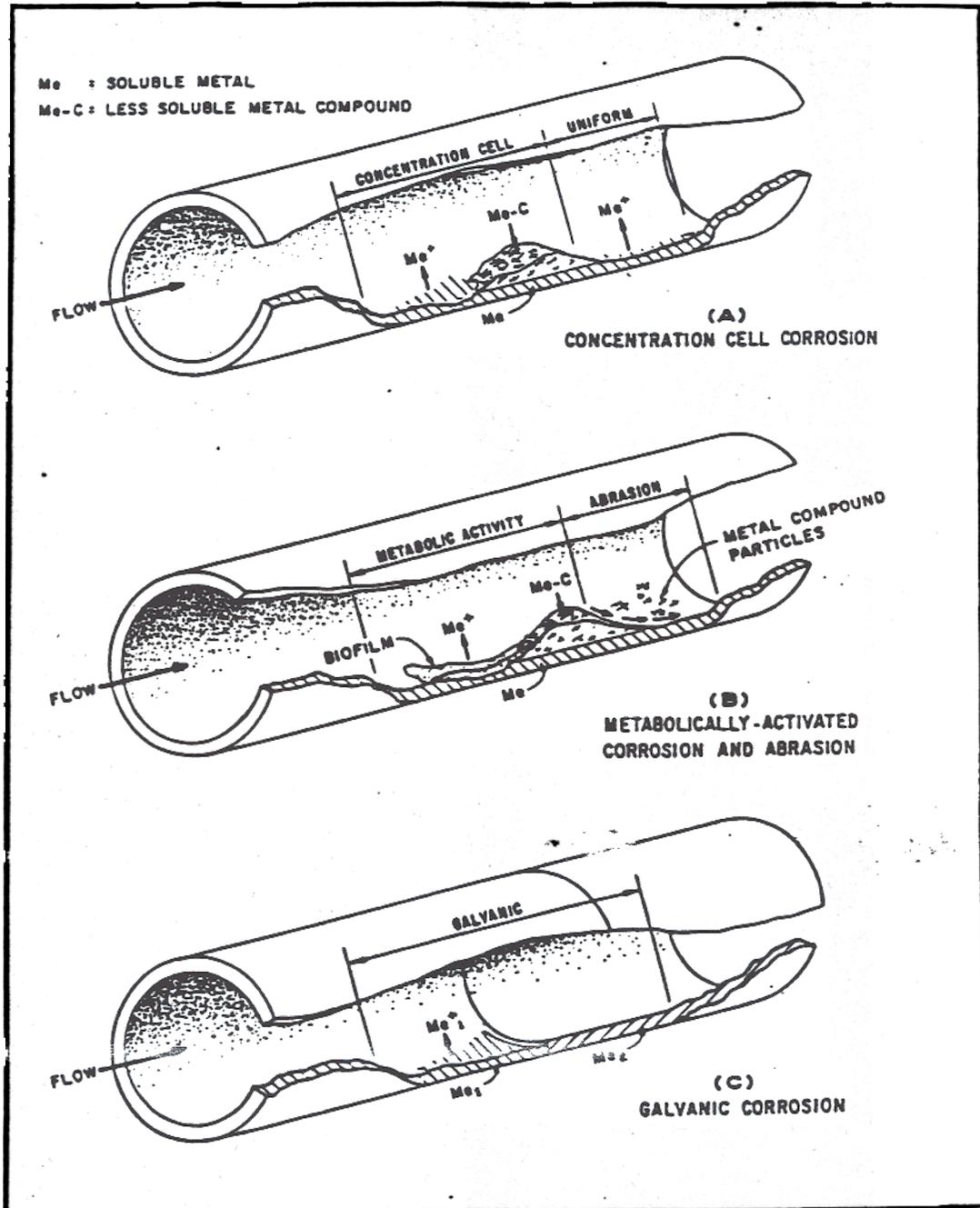


Figure 3-1. Forms of Corrosion Activity Encountered in Potable Water Distribution Systems

their metabolic processes. Thus, the use of a phosphate-based inhibitor may promote unwanted algal growth in some systems. In the early 1980s a state agency, the Metropolitan District Commission (MDC), was responsible for supplying water to the Boston metropolitan area. One reason that MDC chose to discontinue feeding a zinc orthophosphate inhibitor for corrosion control was the possibility that the phosphate was responsible for increased algal growth in the distribution system reservoirs (Karalekas, et al., 1983).

3.2 Corrosion Control Treatment Alternatives

As illustrated in Table 3-1, available corrosion control technologies can be characterized by two general approaches to inhibiting lead and copper dissolution: (1) forming a precipitate in the potable supply which deposits onto the pipe wall to create a protective coating; or (2) causing the pipe material and the potable supply to interact in such a way that metal compounds are formed on the pipe surface, creating a film of less soluble material. The difference in these two approaches is the mechanism by which the protective film is formed. In the former method, insoluble compounds are formed by adjusting the water chemistry to cause the *precipitation* of the compound onto the pipe wall. The success of this method is dependent on: (a) the ability to form precipitates in the water column, and (b) the characteristics of the deposit on pipe walls, including its permeability, adherence strength, and uniformity. In the latter approach, the mechanism is the *passivation* of the pipe material itself through the formation of less soluble metal com-

pounds (carbonates or phosphates) which adhere to the pipe wall. In the case of non-metallic pipe materials, such as asbestos-cement (AC) pipe, passivation and precipitation mechanisms are also operative. The calcium present in the AC pipe acts as the metallic component, being available to react with the carbonate or phosphate species under passivating conditions. Various chemical treatment practices are available to promote precipitation and/or passivation in PWSs. The most effective corrosion control treatment may actually rely on some combination of these two mechanisms (AWWARF/DVGM, 1985; AWWARF, 1991; Kirmeyer and Logsdon, 1983; AWWARF, 1990b).

In general, the available corrosion control treatment technologies are:

- **Alkalinity and pH Adjustment**, which refers to the modification of pH and/or alkalinity (as a surrogate for dissolved inorganic carbonate) to induce the formation of less soluble compounds with the targeted pipe materials. This method utilizes *passivation* as the mechanism for corrosion control.
- **Calcium Hardness Adjustment**, which refers to the adjustment of the calcium-carbonate system equilibrium such that a tendency for calcium carbonate precipitation results. This method of corrosion control depends upon *precipitation* as the means of protecting piping systems. The term "calcium hardness adjustment", in many cases, may be a misnomer since calcium addition or reduction may not be required. Instead, modifying the pH and/or alkalinity through treatment may be the mechanism for achieving a tendency for calcium carbonate precipitation.

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Table 3-1. Conceptual Framework for Corrosion Control Approaches

Control mechanism	→	Passivation		Precipitation
Treatment Approach	→	pH/Alkalinity Adjustment	Corrosion Inhibitor	Calcium Adjustment
Key Water Quality Parameters	→	pH, Alkalinity, TDS, Temperature	pH, Alkalinity, Metals, Hardness, Temperature	Calcium, pH, Alkalinity, TDS, Temperature
Appropriate Chemical Feed Systems	→	Lime Soda Ash Sodium Bicarbonate Caustic Soda Carbon Dioxide	Orthophosphate Silicates Polyphosphate Ortho-Polyphosphate	Lime Soda Ash Sodium Bicarbonate Caustic Soda Carbon Dioxide

- **Corrosion Inhibitors**, which refers to the application of specially formulated chemicals characterized by their ability to form metal complexes and thereby reduce corrosion. This method employs *passivation* of the metal surface as the means of corrosion control. The common corrosion inhibitors generally available include orthophosphate, polyphosphates, poly-orthophosphate blends, and silicates.

Each of these treatment techniques is discussed more extensively in the following sections.

3.2.1 Alkalinity and pH Adjustment.

The solubility of metals is dependent on the specie in which that metal is found. Elemental lead and copper will form complexes with such chemical groups as the hydroxyl (OH), carbonate (CO₃), bicarbonate (HCO₃), orthophosphate (PO₄), and silicate (SiO₂). The pH/alkalinity adjustment method relies upon the formation of less soluble metal species consisting of hydroxyl-carbonate compounds.

Figures 3-2 and 3-3 present an example of the family of solubility contour diagrams for lead and copper, respectively, which are derived for various temperature and ionic strength conditions. These particular contour diagrams are based on the theoretical solubility of various metal hydroxy-carbonate species for a water with moderately low total dissolved solids (200 mg/L TDS = 0.005 Ionic strength) and temperature of 25 °C. To read the chart, the x-axis is the dissolved inorganic carbonate (DIC) content, and the y-axis is the pH of the

treated water. A chart to convert total alkalinity to DIC is provided in Table A-2 of Appendix A. For a particular pH and DIC, the theoretical lead solubility, for example at point A in Figure 3-2, would be $10^{-0.7} = 0.20$ mg/L lead. By increasing the pH alone to pH = 9 (point B) the lead solubility would decrease to $10^{-0.60} = 0.16$ mg/L. If the DIC content were reduced as well (moving from point B to point C on Figure 3-2), the theoretical lead solubility is further reduced to $10^{-0.90} = 0.13$ mg/L.

As Figure 3-2 illustrates, the minimum lead solubility occurs at relatively high pH conditions (pH 9.8) and low alkalinity (30-50 mg/L as CaCO₃ for DIC). Similar pH and alkalinity conditions provide minimum solubility for copper as shown in Figure 3-3. However, copper solubility appears to be more strongly related to pH than alkalinity.

These types of figures may be used to assess the potential value of applying a pH/alkalinity adjustment treatment technique for particular supplies. Alternative water quality goals - consisting of modified pH and alkalinity conditions - may be evaluated by determining the estimated reduction in theoretical lead and copper solubility. The approach which should be considered a candidate is able to: (1) maximize the relative reduction in lead and copper solubility with respect to the existing treatment, and (2) meet all other treatment objectives at the least cost.

The chemical feed systems which may be installed to modify pH and alkalinity conditions in the finished water are summarized in Table 3-2. Many of the chemicals shown in Table 3-2 will both increase the pH and the alkalinity of the finished water. In some cases,

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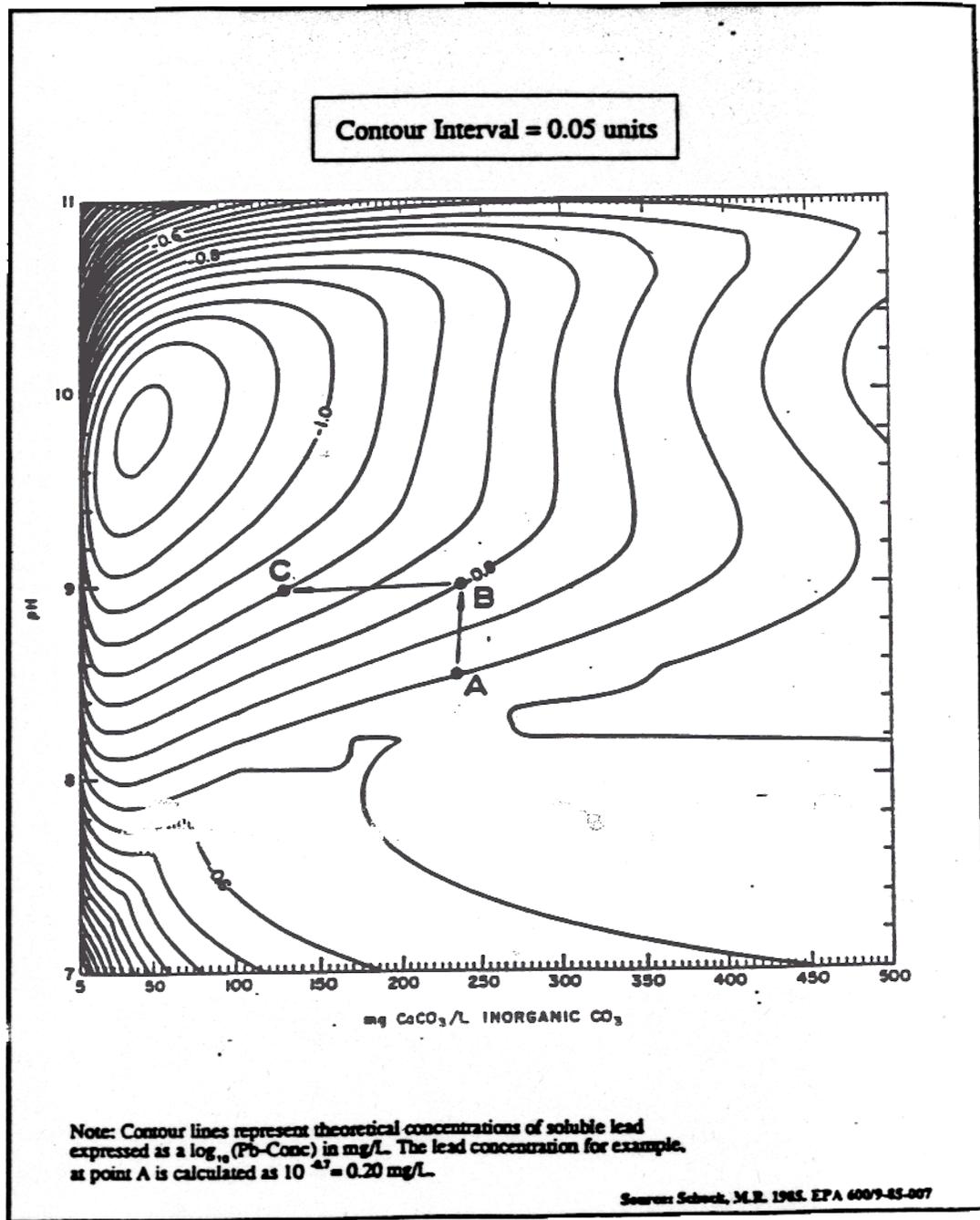


Figure 3-2. Contour Diagram of Lead (II) Solubility in the System Lead (II)-Water-Carbonate at 25°C and an Ionic Strength of 0.005 mol/L

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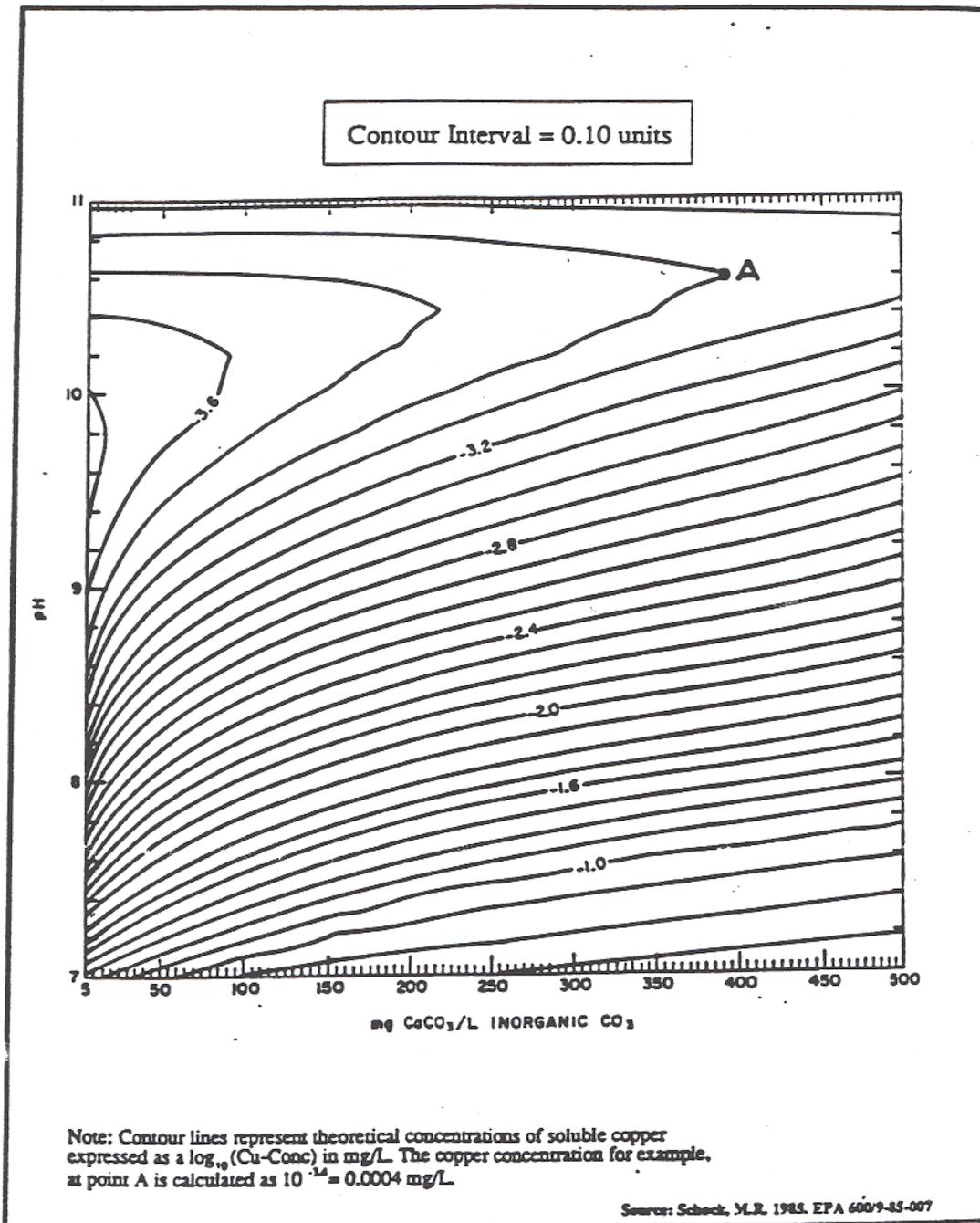


Figure 3-3. Contour Diagram of Copper (II) Solubility in the System Copper (II)-Water-Carbonate at 25°C and an Ionic Strength of 0.005 mol/L

Table 3-2. Summary of Chemicals Typically Used in pH/Alkalinity and Calcium Adjustment Corrosion Control Treatment

Chemical	Use	Composition	Alkalinity Change	Notes
Caustic Soda, NaOH	Raise pH. Convert excess CO ₂ to alkalinity species	93% purity liquid bulk. Colder climates, bulk storage at <50% purity to prevent freezing	1.55 mg/L CaCO ₃ alkalinity per mg/L as NaOH	pH control is difficult when applied to poorly buffered water
Lime, Ca(OH) ₂	Raise pH. Increases alkalinity and calcium content	95-98% purity as Ca(OH) ₂ . 74% Active ingredient as CaO. Dry storage with slurry feed	1.21 mg/L CaCO ₃ alkalinity per mg/L as Ca(OH) ₂	pH control is difficult when applied to poorly buffered water. Slurry feed can cause excess turbidity. O&M intensive
Sodium Bicarbonate, NaHCO ₃	Increases alkalinity with little increase in pH	98% purity. Dry storage with solution feed	0.60 mg/L CaCO ₃ alkalinity per mg/L as NaHCO ₃	Good alkalinity adjustment choice, but very expensive
Soda Ash, Na ₂ CO ₃	Increases alkalinity with moderate increase in pH	95% purity. Dry storage with solution feed	0.90 mg/L CaCO ₃ alkalinity per mg/L as Na ₂ HCO ₃	More pH increase caused as compared to NaHCO ₃ , but less costly
Carbon Dioxide, CO ₂	Lowers pH. Converts excess hydroxyls to bicarbonate and carbonate species	Pressurized gas storage. Fed either through eduction or directly	None	Can be used to enhance NaOH or lime feed systems

combinations of the available chemical feed systems are more appropriate to ensure that pH and alkalinity goals may be met simultaneously. This is especially important in poorly buffered systems where pH adjustment alone through the use of either caustic soda or lime, for example, could cause unacceptably elevated pH levels or erratic pH levels in the treated water and within the distribution system. In these cases, the use of sodium bicarbonate or carbon dioxide may be used in conjunction with the lime or caustic soda system to provide additional buffering capacity.

Apart from those chemical applications shown in Table 3-2, other treatment processes may affect the pH/alkalinity of the finished water; namely, aeration, alum coagulation, chlorination and fluoridation. These additional sources of pH and alkalinity impacts must be incorporated into the comprehensive treatment design in order to successfully achieve the recommended finished water quality goals for pH and alkalinity.

The operation of a full-scale facility using the pH/alkalinity modification approach should consider several factors in the design of the corrosion control program:

- the location of each chemical feed for optimal utilization, including coagulants, oxidants (such as chlorine), fluoride, and pH/alkalinity modification chemicals.
- monitoring locations for process control, whether manual or automatic;
- sequencing the control of chemical feed rates in order to reach all of the water quality goals while minimizing chemical usage; and,

- the available contact time and mixing conditions necessary to achieve a stable finished water prior to entry to the distribution system.

When determining the location of chemical feed points, the pH adjustment resulting from chemical additions must be considered. This is especially relevant for waters that are weakly buffered. Chlorine addition in the gaseous form, for example, will tend to lower the pH while adding chlorine in the hypochlorite form will tend to raise the pH. Likewise, both sodium silicofluoride and hydrofluosilicic acid which are commonly used in fluoridation are acidic and will tend to lower the pH. Adjustment of the finished water pH for corrosion control cannot be permitted to interfere with the objectives of other water treatment operations. Disinfection with free chlorine, for example, is more effective at lower pH values because the hypochlorous acid formed by the addition of chlorine converts rapidly to the hypochlorite ion above pH 7. Hypochlorite ion has long been known to be less effective as a biocide than hypochlorous acid. For instance, under the SWTR, higher CT values are required at higher pH levels to accomplish equivalent microbial inactivation.

3.2.2 Calcium Adjustment.

The formation of a calcium carbonate precipitate may be used to coat the interior walls of pipes and thereby reduce the corrosion of the pipe surface. The success of this treatment depends on delivering a finished water slightly supersaturated with calcium and carbonate (at a specified pH condition) such that calcium carbonate precipitation occurs. The availability of

the supersaturated conditions throughout the distribution system and the reliability of existing techniques to predict the potential formation of calcium carbonate precipitates are key factors to providing corrosion control protection. Success also depends on the ability to control the formation of scale buildup to insure that hydraulic capacity is not unduly sacrificed in the course of providing corrosion protection.

The calcium-carbonate equilibrium is a dynamic system which will change continuously from the point of entry to the final service connection throughout the distribution system. Achieving a continuous coating of calcium carbonate precipitate is difficult without causing excessive precipitation in some portions of the system. This can result in significant reductions to the supply capacity of the distribution system, especially in the vicinity of the treatment plant, and require those lines to be cleaned in order to reestablish the necessary hydraulic conditions.

The complications associated with calcium adjustment are increased by the difficulties in precisely determining the degree of calcium carbonate precipitation in the treated water. Several indices have been proposed to describe the calcium-carbonate equilibrium, and the tendency of water to form precipitates. PWSs should exercise caution, however, when using traditional indices to predict performance for lead and copper control. Such indices may not be adequate to predict the performance of the calcium adjustment approach, although they may be useful to *initially* estimate the water quality conditions necessary to precipitate calcium

carbonate. The Calcium Carbonate Precipitation Potential (CCPP) index may be the most useful for this purpose. A more detailed description of the CCPP and its method of calculation is provided in Appendix A.

To understand and effectively utilize any of the indices discussed in Appendix A, or to derive calcium carbonate saturation conditions without the use of indices, it is necessary to review the calcium-carbonate equilibrium system. Figure 3-4 presents the solubility diagram for calcium carbonate as a function of pH under "closed system" conditions, i.e., no exchange of carbonate species (CO_3) is permitted between the water and air systems. Open systems could involve the dissolving and de-gassing of carbon dioxide, which would affect calcium carbonate solubility. As the pH increases, the solubility of calcium carbonate decreases such that more calcium carbonate will precipitate rather than stay in solution. However, these reactions are not instantaneous, and therefore, sufficient time must be provided within the targeted pH range for precipitation to occur. For example, lime softening plants which have excess calcium carbonate present after softening often re-carbonate the clarified water (reduce the pH) prior to filtration. This increases the solubility of calcium and prevents the filter media from becoming coated with calcium carbonate precipitates which otherwise would continue to form under the elevated pH conditions.

The water treatment goals for this approach should include the pH, carbonate content (alkalinity) and calcium concentrations necessary to achieve calcium carbonate precipitation. The chemical feed

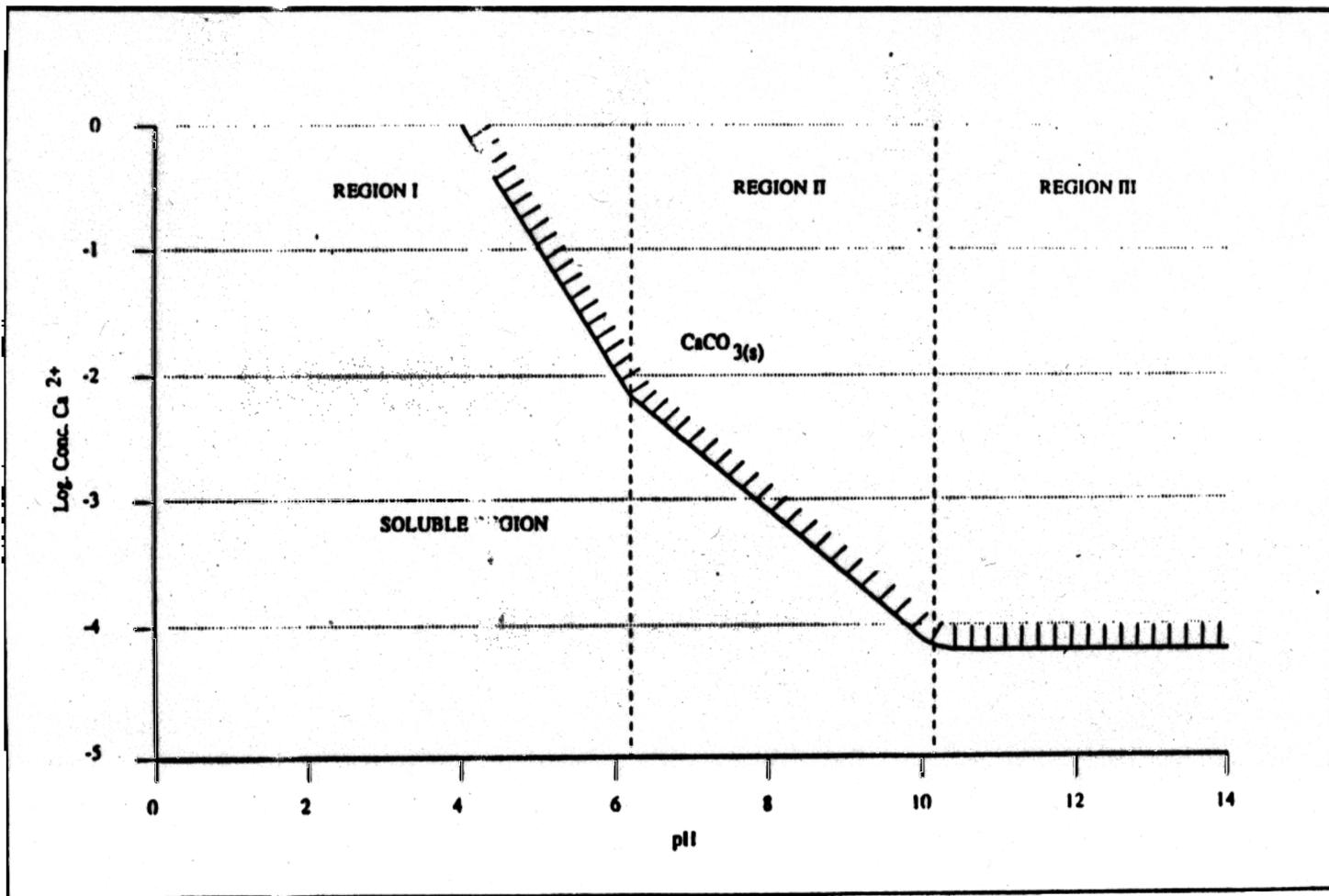


Figure 3-4. Solubility Diagram for Calcium Carbonate in a Closed System at 25°C

systems which may be used to implement calcium adjustment treatment are summarized in Table 3-2. Many of these chemicals are applicable in the pH/alkalinity adjustment approach, but the finished water quality goals would differ.

3.2.3 Corrosion Inhibitors.

Two predominant forms of corrosion inhibitors are available for potable water treatment: phosphate and silicate-based compounds. Somewhat different chemical mechanisms of corrosion control and water quality criteria are associated with the effective use of phosphate and silicate-based inhibitors. However, both utilize passivation as the method of providing corrosion protection.

A plethora of corrosion inhibitor formulations are commercially available to PWSs, and caution must be used in the review and consideration of the alternative products. As a direct additive to drinking water supplies, corrosion inhibitors are subject in most states to the American National Standards Institute (ANSI)/National Sanitation Foundation (NSF) Health Effects Standard 60 for direct additives. Products must be certified or approved by the primacy agent prior to being used in treating potable supplies. PWSs should contact their State agency to determine: (1) whether the State has adopted the ANSI/NSF Standard 60 for direct additives, and (2) a list of the certifying agencies or certified products for corrosion control treatment.

3.2.3.1 Phosphate inhibitors. Lead forms at least one orthophosphate solid of low solubility under typical drinking water conditions, which can serve as the

basis for corrosion control. Solubility contour diagrams like those presented for pH/alkalinity adjustment have been developed for lead when 0.5 mg/L PO_4 is added to the finished water, as shown in Figure 3-5. The minimum theoretical lead solubility is reduced by approximately 0.5-logs with the addition of the orthophosphate, and the corresponding pH is much lower than that associated with the carbonate system alone.

Copper solubility does not appear to be markedly reduced by the inclusion of orthophosphate in solution until extremely high dosages are applied. The results of several corrosion studies using orthophosphate have found conflicting results with respect to their contribution to copper control (AWWARF, 1990b; Moser et al., 1992). Until additional insight can be garnered through additional research, testing should be performed to evaluate copper control by orthophosphate.

The pH range across which orthophosphate appears to be most effective for lead is 7.1 to 7.8 (AWWARF, 1990b; Lee et al., 1989; Lechner, 1991). At pH values much above 7.8, metal phosphate precipitates can form, causing scale buildup and hydraulic capacity losses. Waters with low hardness (calcium < 16 mg/L and a calcium to magnesium ratio of 0.7) are well-suited to the use of orthophosphate inhibitors.

The critical parameters to operating an orthophosphate corrosion control treatment program are: (1) maintaining a stable pH in the inhibitor's effective range throughout the distribution system; (2) determining the inhibitor composition best-suited for the specific water quality objectives and conditions; and (3) applying

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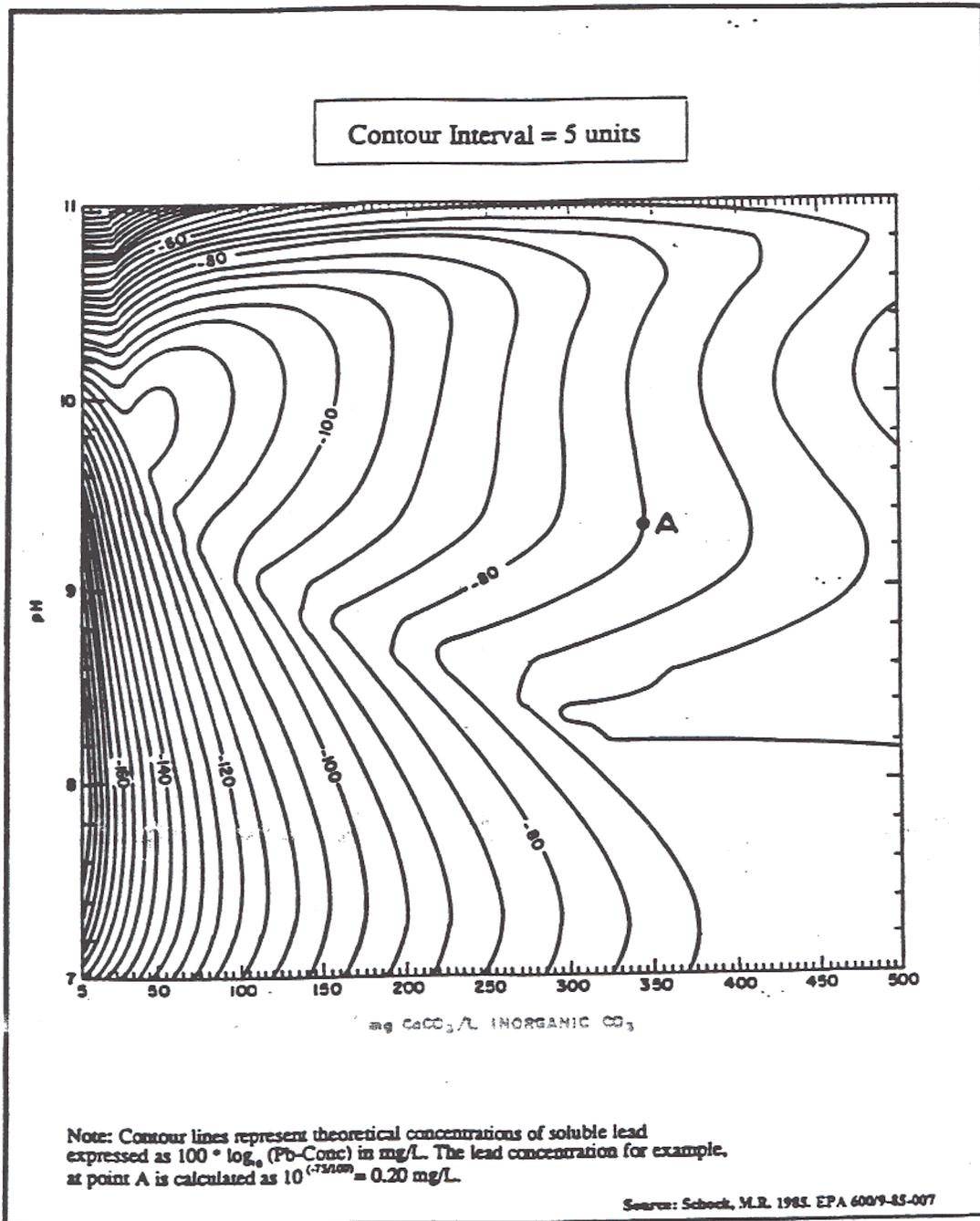


Figure 3-5. Contour Diagram of Lead (II) Solubility in the Presence of 0.5 mg/L PO₄ at 25°C and an Ionic Strength of 0.005 mol/L

the appropriate dosage to accommodate background orthophosphate demand as well as the corrosion control protection sought. Phosphate-based inhibitors are acidic solutions, and the pH effect of their addition to the finished water must be considered in determining the suitability of their application.

Since phosphates are effective over a constrained pH range, maintaining that range throughout the distribution system is an important component of implementing a successful corrosion control program. For systems which are well buffered, and whose pH is within the targeted range, this may not be a critical issue. However, for those PWSs with poorly buffered supplies (low alkalinity levels), pH fluctuations within the distribution system can be significant. For example, with a finished water alkalinity of less than 20 mg/L as CaCO₃ and pH of 7.5, a PWS found distribution system pH values ranging from 6.5 to 9.0, depending on whether the water had passed through unlined ductile iron pipe, lined cast iron pipe, or asbestos-cement pipe. Such fluctuations in distribution system pH would adversely impact the performance of the corrosion inhibitor. Systems with poorly buffered water may have to install treatment to stabilize pH in addition to installing corrosion inhibitor systems for reducing lead and copper levels.

Thus, the use of inhibitors for corrosion control within the distribution system is analogous to maintaining a chlorine residual within the system as a safeguard against secondary contamination. Similar to the chlorine residual, the orthophosphate concentration must be sustained to be effective as a corrosion inhibitor

throughout the distribution system. However, unlike the chlorine residual which will inhibit biological functions at trace concentrations, the inhibitor must be carried above some minimum concentration to be useful. Because the composition of inhibitors vary and in some cases it is proprietary information, this minimum concentration should be determined in conjunction with the supplier.

Phosphate inhibitors are manufactured in a variety of compositions, including sodium orthophosphate, zinc orthophosphate, polyphosphates, and poly-orthophosphate blends. Each of these groups of compounds may have differing formulations as to the percentage of effective PO₄ present. The selection of a specific inhibitor may require a preliminary evaluation of the following: (a) effectiveness in controlling lead and/or copper, (b) effects of depressing the final pH of the treated water, and (c) impacts on wastewater treatment facilities required to meet effluent standards for phosphorus.

Polyphosphates revert (hydrolyze) with time resulting in an increase in the orthophosphate ion. This reversion is affected by, among other parameters, pH, and available metal ions such as calcium and zinc. Because chemical suppliers provide proprietary inhibitors with formulations largely unknown to the user, it becomes essential that polyphosphate additives be tested under actual distribution system conditions. Testing for both orthophosphate and polyphosphate (see the hydrolyzable plus orthophosphate pathway in Figure 4-2, Lead and Copper Rule Guidance Manual, Volume I) should be monitored at the point of entry and throughout the distribution system. These

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data will assist in determining the correct inhibitor dose and in identifying and understanding the predominant mechanism of inhibition.

As Holm and Schock point out (Holm and Schock, 1991a; and Holm and Schock, 1991b), water treatment measures can sometimes unintentionally increase lead solubility. Products that contain polyphosphates can fall into this category. Holm and Schock refer to other research to support their conclusions regarding polyphosphates (Bailey, 1982; Sheiham and Jackson, 1981; Neff, et al., 1987; and Maas, et al., 1991). It is noteworthy that some researchers disagree with Holm and Schock, because some of this supporting research has restrictions which narrow their application. Nevertheless, EPA believes that polyphosphates should be used with caution because: "Applying chemicals whose effects are not well understood may be viewed in the extreme sense as an uncontrolled toxicological experiment on the general population. We feel this is the true disservice to the water utility industry" (Holm and Schock, 1991b).

Polyphosphates are not recommended for corrosion control purposes in general, although their application may be beneficial, if not required, for other water quality, operational, or treatment concerns. The principle use of such chemicals is to sequester dissolved metal or cationic constituents - such as calcium, iron, or manganese - and reduce their ability to precipitate either in the distribution system or within the water treatment plant. In the case of calcium, polyphosphates are used in many softening plants to minimize the encrustation of filter media by post-precipitation of calcium

carbonate. For iron and manganese control, polyphosphates can effectively reduce the aesthetic discoloration caused by these compounds. This is often a useful and necessary benefit of their application, particularly for groundwater systems which are heavily mineralized and devoid of oxygen, ideal conditions for iron and manganese to solubilize. Seasonally high levels of iron and manganese can also occur with surface water supplies when low dissolved oxygen and reducing conditions in upstream reservoirs increase the concentration of these minerals.

While polyphosphates have demonstrated limited direct success toward lead and copper corrosion control, their use at water treatment facilities will be necessary in many instances. Ortho-polyphosphate blends are being produced which may be able to offer some of the benefits of both uses to PWSs. These should be considered when orthophosphate inhibitors are a viable corrosion control approach, but a polyphosphate is also required to meet other treatment objectives.

Additionally, the proper application rate for a specific inhibitor should be determined through testing. As a preliminary assessment, the necessary dosage should include the phosphate-demand exerted by the water quality constituents present in the finished water. Beyond the dosage required for effective lead and/or copper control, metals present in the supply will combine with phosphates to differing degrees, imposing an effective "phosphate-demand" in the following order of preferential sequence (shown as maximum $\text{---} >$ minimum; or equivalent $< \text{---} >$ equivalent) (Lechner, 1991).

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- I. Highest Demand
Manganese ——— >Iron ——— >Copper ——— >Aluminum ——— >Zinc/Lead
- II. Moderate Demand
Calcium< ——— >Magnesium< ——— >Barium< ——— >Radium
- III. Lowest Demand
Sodium< ——— >Potassium

The final dosage required should be sufficient to accommodate the phosphate-demand and provide the effective inhibitor residual necessary to achieve lead and/or copper corrosion control.

3.2.3.2 Silicate inhibitors. The mechanism involved in controlling corrosion is unclear for silicate applications. Silicates are manufactured by the fusion of high-quality silica sands to sodium or potassium salts. Sodium silicates are generally most common with sodium carbonate being used as the bonding salt. Conventional sodium silicates use silica to Na_2CO_3 molar ratios between 1.5 and 4 to 1.

The most common form of silicate in water treatment is the 3.22 weight ratio sodium silicates at 41 °Baume' solution with 37-38 percent solids. This has been used successfully for corrosion control treatment when targeting reductions in iron corrosion. For lower pH waters, a more alkaline silicate product may be appropriate, such as the weight ratio 2.00 $\text{Si}_2\text{O}:\text{Na}_2\text{O}$ with 50.5 °Baume' solution to reduce acidity and increase the overall buffering capacity of the water.

The method of controlling corrosion attributed to silicates appears to be a combination of adsorption and formation of less soluble metal-silicate compounds.

Silicates are considered anodic inhibitors, combining with the free metal released at the anode site of corrosion activity and forming an insoluble metal-silicate compound. These corrosion products crystallize to form a protective barrier on the face of pipe walls. However, microscopic and X-ray examinations have shown two layers of film on iron pipes conveying water treated with silicates. The majority of the silicate appears in the uppermost layer adjacent to the water. This film is an amorphous silicate film adhered to the underlying silicate-metal surface. A slightly corroded surface may be necessary to form the protective silicate film. Simultaneously, the application of silicates in a distribution system with extensive corrosion byproduct buildup may result in their release, causing red and turbid water problems.

Like the use of phosphate inhibitors, silicates can combine with other constituents in the delivered water besides the materials targeted for protection. Therefore, sufficient dosages must be applied to compensate for the consumption of silicate by other metals or cations. Specifically, calcium and magnesium will readily react with silica over a large pH range. Also, silicates are frequently used by small water systems supplied by groundwater for iron control. Silicates can sequester

soluble iron and manganese present in the source water to reduce red and black water events. Attention to the water quality conditions prior to their application is necessary depending on the intended use and performance of the silicate. The additional sodium contributed by sodium silicate formulations should also be considered by PWSs.

3.3 Evaluating Alternative Corrosion Control Approaches

The label "corrosion control" has historically been applied to a variety of water treatment techniques which are frequently used to meet differing water quality objectives. Until quite recently, corrosion control practices by PWSs were typically designed to improve aesthetics, protect marginal hydraulic capacity, and/or reduce long-term pipeline maintenance. Although these objectives remain worthwhile, they have little to do with LCR compliance, which essentially has *redefined* corrosion control primarily on the basis of public health impacts. The principal objective of the LCR is to minimize the concentration of lead and copper in drinking water without compromising other health-related water quality goals. This has created some confusion within certain water supply utilities where long-standing corrosion control procedures are now being found "ineffective" with respect to the new objectives.

A wide variety of proprietary chemicals have evolved to control pipeline and valve deterioration, eliminate "dirty water" complaints, reduce laundry staining, etc. Some of these "corrosion inhibitor" chemi-

cals can also help reduce lead and copper levels in drinking water, although many will not and some could even increase lead concentrations. Comparisons of corrosion inhibitors is often controversial because of the proprietary nature of the specific chemical formulations and varying water chemistries. This issue is further complicated by a lack of understanding by many users about the differences between chemical products (e.g., ortho and polyphosphates) and their relationship to the formation of metallic precipitates and protective films in potable water systems.

Beyond compliance with the LCR and other drinking water standards, additional benefits and detractions from the installation of corrosion control treatment may also be considered when alternative treatment approaches are reviewed and assessed. Some examples of the secondary issues which may be important to PWSs include:

- Improve the aesthetic quality of the potable supply (reducing customer complaints).
- Provide cost savings on the operation and maintenance of the distribution system.
- Extend the sludge disposal options available to wastewater treatment plants (POTWs) by reducing the overall metal content of the domestic wastewater.
- Extend the usable life of customer water systems, especially hot water heaters or industrial applications.
- Minimize any unnecessary public exposure to corrosion byproducts, such as heavy metals or asbestos fibers.
- Reduce or, at least, not foster microbial growth in the distribution system.

- Disturb existing coatings in distribution system piping.
- Develop compatible treatment approaches for multiple sources of supply to a distribution system.
- Improve or maintain the hydraulic capacity of a distribution system.

PWSs must exercise caution in selecting technology which is consistent with conflicting water quality objectives. While it is not possible to devise a universal approach for selecting the best corrosion control scheme, the information provided below is designed to identify interactions between LCR treatment goals and those associated with other SDWA regulations. The use of chemical treatment to reduce lead and copper in drinking water will be dependent upon many site-specific chemical and physical interrelationships and may require side-by-side demonstration testing to assess performance.

Those small and medium-size PWSs exceeding an AL during initial monitoring must submit recommendations for optimal treatment to the State. Large PWSs required to perform corrosion control studies will also have to submit either recommendations for optimal treatment or the alternative treatment approaches to be evaluated further as a result of the desk-top evaluation. To assist in the development of these recommendations, the following sections provide a step-by-step procedure to be used to evaluate alternative treatment approaches and a basis for the selection of optimal treatment.

3.3.1 Steps to Corrosion Control Assessments.

In order to provide a treatment recommendation to the State, those small and medium-size PWSs required to install optimal corrosion control treatment should assess the three general approaches discussed above by a *desk-top evaluation*. The logic diagram shown in Figure 3-6 presents the process involved in performing desk-top evaluations for selecting optimal treatment. This procedure allows systems to eliminate initially any treatment approaches which are infeasible and to then determine the water quality conditions defining optimal corrosion control treatment for the feasible alternatives. Among the resultant alternatives, optimal treatment is to be selected on the basis of the following criteria:

- the results of lead and copper tap sampling;
- corrosion control **performance** based on either the reductions in metal solubility or the likelihood of forming a protective scale;
- the **feasibility** of implementing the treatment alternative on the basis of the constraints identified;
- the **reliability** of the alternative in terms of operational consistency and continuous corrosion control protection; and,
- the estimated **costs** associated with implementing the alternative treatments.

The first step is to describe the existing conditions of the PWS in terms of its water quality parameters. As part of this first

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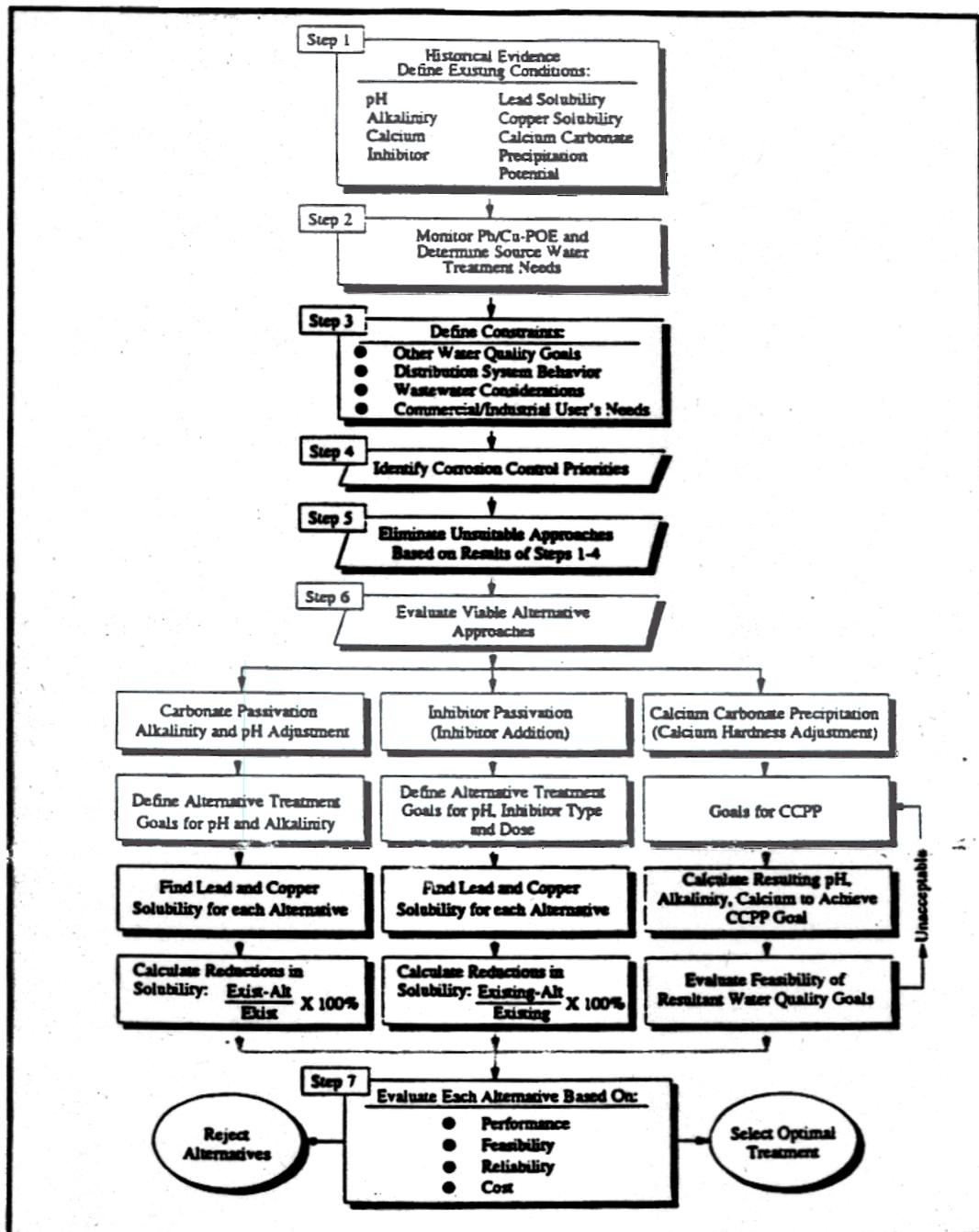


Figure 3-6. Logic Diagram for Evaluating Alternative Corrosion Control Approaches

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step, PWSs can estimate the theoretical lead and copper solubility as well as the potential for calcium carbonate precipitation based on the existing water quality conditions. Changes in water quality conditions for alternative treatments can be compared to the existing conditions to determine their relative performance and potential to reduce corrosion.

Each PWS operates under certain constraints, such as specific water quality goals, existing coatings in distribution system piping, multiple sources of supply of varying water quality, and wastewater permit limits on metals or nutrient levels which may be improved or compromised by corrosion control treatment. Any constraint which could impact the feasibility of implementing an alternative treatment should be identified and documented. This information will be important to the selection of those treatment options which are viable alternatives for the PWS to consider further.

Based on the water chemistry of the supply and site-specific constraints, the PWS may eliminate corrosion control treatment approaches which would be infeasible to implement successfully. The remaining options, deemed to be feasible, should be evaluated on the basis of each PWS's corrosion control treatment priorities to properly judge the performance of the alternative approaches. For example, a system which experiences lead levels in first-draw tap samples greater than the AL for lead should set lead control as its primary goal. A second system which finds low lead levels, but has elevated copper levels in first-draw tap samples should set copper as the primary objective of

corrosion control treatment. However, in the latter case, optimal treatment should not worsen lead corrosion behavior and therefore, the control of lead may be considered as a constraint acting on the decision-making process for selection of optimal treatment.

Each of the three corrosion control treatment approaches that are viable options should be evaluated to determine the water quality characteristics which describes optimal treatment within each option. For the passivation methods, alternative treatments are evaluated by comparing their relative reduction in the solubility of each targeted metal (lead and/or copper). The calcium carbonate precipitation method is evaluated by the ability of alternative treatments to produce sufficient potential for scale-forming conditions to exist in the distribution system. The "rule of thumb" guidelines presented in Appendix A may be used to rank the alternatives evaluated within this treatment approach.

The final selection of optimal treatment will rest on the four factors discussed above: performance, feasibility, reliability, and costs. Direct comparison of corrosion control performance for alternative treatment approaches may be not possible. Professional judgement and related experiences will be necessary to provide a basis for ranking alternatives on the basis of performance.

The following sections provide more detailed descriptions of the various steps involved in performing a desk-top evaluation of alternative treatments and the development of final recommendations for optimal treatment.

3.3.2 Documenting Historical Evidence.

The first step of the desk-top evaluation is to identify and document any existing information pertinent to the evaluation of corrosion control for the system. Four categories of data should be compiled: (a) water quality data; (b) evidence of corrosion activity; (c) available results of corrosion studies performed by other PWSs as reported in the literature that meet LCR conditions, i.e. similar water chemistry, distribution system, etc.; and (d) results from prior corrosion studies or testing performed by the PWS. The most pertinent information is the results of any prior corrosion control testing performed by the system. Beyond the direct testing results, a comprehensive review of the other sources of information should be conducted by the PWS.

3.3.2.1 Water quality data. Current and historical water quality data should be compiled and analyzed. The key parameters of interest include pH, alkalinity, hardness, total dissolved solids or conductivity, temperature, dissolved oxygen, and metals (eg., aluminum, manganese, iron, lead, and copper). These basic water quality parameters only represent those most commonly required. Site-specific requirements should be considered in the selection of water quality parameters for review. The data collected should pertain to raw and finished water conditions, as well as the water quality within the distribution system, if available. Additionally, the results of the initial monitoring program should be considered when available.

Understanding the treatment processes at a PWS facility and their respective impacts on water chemistry is an important aspect of interpreting the water quality data and evaluating the appropriateness of alternative corrosion control treatment techniques. Figure 3-7 illustrates the relationship between water quality and alternative corrosion control treatment approaches. Three major regions are shown on the basis of pH (low, moderate, and high) with alternative treatment approaches which may be viable on the basis of water quality shown for each block by its respective alkalinity and calcium levels (low, moderate, or high). To demonstrate the use of Figure 3-7, consider a PWS with a pH 7.8, alkalinity of 40 mg CaCO_3/L , and calcium content of 60 mg CaCO_3/L . The moderate pH (7.5-9.0) chart is used with treatment alternatives corresponding to the block for low alkalinity (<50 mg CaCO_3/L), and moderate calcium (50-100 mg CaCO_3/L). On the basis of water quality alone, this PWS should consider all four treatment alternatives as viable.

In many cases, site-specific water quality conditions will reduce the feasibility of an alternative treatment approach. For example, it would be reasonable to eliminate the calcium carbonate precipitation option as a viable treatment approach for those PWSs exhibiting low pH, alkalinity, and hardness in the treated water due to the excessive chemical modifications which would be required to achieve sufficient calcium carbonate precipitation in the distribution system.

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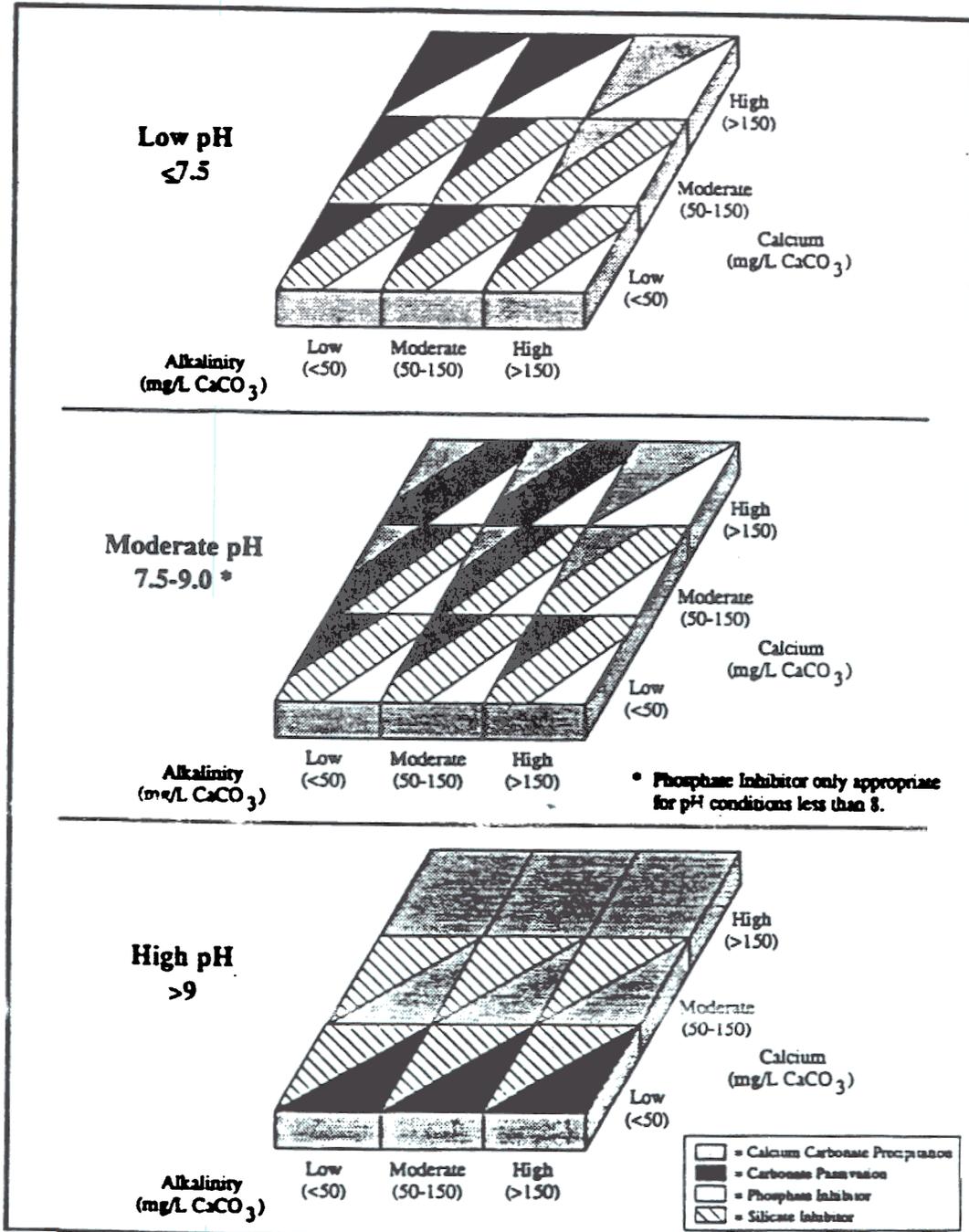


Figure 3-7. Suggested Corrosion Control Approaches Based on Water Quality Characteristics

Conversely, a PWS exhibiting high pH conditions with moderate to high alkalinity and calcium contents might concentrate their efforts on calcium carbonate precipitation for the following reasons:

- While high pH conditions may be optimal for lead control, these water quality conditions are very aggressive towards iron corrosion and would most likely cause severe degradation in distribution system water quality should calcium carbonate precipitation not be pursued; and
- High dosages of corrosion inhibitors may be necessary to maintain an effective residual throughout the distribution system due to the presence of calcium. Also, some inhibitors can cause existing corrosion byproducts to be released in the distribution system causing water quality degradation.

Figure 3-7 is intended to provide general guidelines on water quality conditions versus alternative treatment approaches; it is not intended to serve as the sole basis for selection or elimination of the available alternatives. Further, caution must be raised any time a corrosion control approach requires a severe modification in the existing water quality entering the distribution system. Disruptions and upset of existing corrosion byproducts will impact the overall effectiveness of any corrosion control treatment approach.

3.3.2.2 Corrosion activity. Existing records indicative of corrosion activity within the distribution and home plumbing systems should be identified and analyzed to inform the PWS of the nature and extent of corrosion activity anticipated

within the service area. Evidence of corrosion activity may be obtained by: (1) reviewing customer complaint records for dirty water or metallic taste and odor events, (2) performing an informal survey of area plumbers regarding the frequency and nature of plumbing repairs (especially, for example, hot water heater replacements), (3) reviewing records citing the inspection of distribution system mains and service line when being replaced or repaired, (4) installing and evaluating corrosion coupons placed within the distribution system, and (5) water quality monitoring for metals or other corrosion byproducts within the distribution system or home plumbing environments.

While the information listed above may, in some instances, be incidental in nature - i.e., causative relationships may not be easily developed between the observed effects of corrosion activity and the water quality within the distribution system, PWSs may gain a more complete sense of the corrosion concerns facing their system.

Example: After reviewing several years of data, a PWS observed that complaints from customers about red water was the predominant source of dissatisfaction with the water supply and that the number of complaints was increasing in recent years. The utility manager interviewed City plumbing inspectors, local plumbers, and the PWS's maintenance department about corrosion activity to learn more about the potential problems. As a result of these inquiries, it was discovered that (a) the average life of household water heaters in the PWS's service area is one half of that expected normally; (b) copper plumbing in

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residences often experienced pitting corrosion resulting in pin-hole failures of piping; and (c) the highest repair and replacement rate for distribution system mains and service lines was in the older parts of the service area where unlined cast iron mains and galvanized service lines were still in-place. Based on these findings, the utility manager initiated a monitoring program to determine the presence of corrosion byproducts and water quality conditions in the distribution system and at employees homes. The incidental information indicated that copper and iron corrosion were concerns for the PWS, both in terms of material failure and water quality. The monitoring program confirmed these concerns, finding pH and alkalinity shifts within the cast iron distribution system and elevated copper levels in home tap samples. While the information gathered by the utility manager did not determine the specific cause of the distribution and home plumbing system corrosion, it did further the PWS's understanding of the potential corrosion problems in its service area. It also served as a basis for designing a water quality monitoring program to the corrosion activity experienced in the distribution and home plumbing systems after installation of treatment.

Several factors should be considered in evaluating the usefulness of this information; namely: (1) the frequency of data collection; (2) the number of coupons, if used, and their locations within the distribution system; (3) the analytical methods and their respective detection limits; (4) the consistency of the data temporally and spatially; and (5) the reliability of the incidence reports.

Included in this pool of information should be the results of the initial monitoring program required by the Lead and Copper Rule, if available.

This information may be used to prioritize the corrosion control program elements for the PWS in terms of the key materials for protection and assess the general effectiveness of the existing treatment approach.

3.3.2.3 Review of the literature.

A search and review of the available literature should be performed to ascertain: (1) the findings of similar systems when performing corrosion control testing; and (2) the theoretical basis for alternative corrosion control approaches to be considered by the PWS - thereby, eliminating those approaches which appear to be infeasible.

Several corrosion control studies have been performed and the results published by several water suppliers in the United States. Each study has site-specific goals and objectives relevant to the testing protocols as well as water treatment and quality conditions. However, the experiences of these systems provide a useful resource to other PWSs investigating corrosion control in terms of: (1) study design and execution; (2) data handling and interpretation; and (3) recommended treatment given the goals and constraints acting on the system. A summary of the available literature on corrosion control studies is provided in Appendix B. Note that great care must be taken in evaluating studies reported in the literature so that test protocol, water chemistry, treatment processes, and so forth are matched as closely as possible.

3.3.2.4 Prior experience and studies. Corrosion control treatment is not a new concern for water suppliers, and many have performed studies in the past to assist in the design and implementation of corrosion control treatment. These past experiences and studies should be revisited by PWSs to incorporate their findings and results in the present evaluation of corrosion control for lead and copper. Small systems could use the optimum corrosion control treatment processes which were recommended to the State by the larger PWSs. In some cases, the prior testing targeted lead and copper control, and these findings would be directly applicable to the corrosion control study objectives for the Lead and Copper Rule. Additional testing may not be necessary, therefore, to formulate recommendations for optimal corrosion control treatment (if not already considered to be in place).

Example: The Town of Redfield, a small PWS operating a groundwater well, found lead levels above the action level during initial monitoring. In order to prepare recommendations for optimal treatment, the PWS operator began collecting information regarding the condition of distribution system materials and the experiences of nearby towns and communities. From previous pipe replacement activities, the PWS operator had noticed a thin, buff-colored deposit on the walls of distribution system piping. The groundwater source is well buffered with an average pH 7.4, alkalinity of 160 mg CaCO₃/L, and calcium hardness of 110 mg CaCO₃/L. The CCPP calculated for the system is -2.4 mg CaCO₃/L.

Redfield needed to determine whether they were successfully coating the pipes

of the distribution and home plumbing systems with calcium carbonate deposits. Plumbing materials from service lines, distribution mains, and three homes in the service area were extracting during repair in order to chemically analyze the constituents present in the scale. This analysis confirms that the scale was predominantly calcium carbonate. However, observation of the same showed that it was not uniformly coating the pipe materials, especially the home plumbing piping.

The PWS considered the alternative treatment approaches for corrosion control and eliminated pH/alkalinity adjustment (*carbonate passivation*) due to the excessive alkalinity and calcium levels per Figure 3-7 presented in the *LCR Guidance Manual*. The remaining alternatives were calcium hardness adjustment and corrosion inhibitors.

A nearby township having wells located in the same aquifer as Redfield had previously installed orthophosphate inhibitor feed facilities for corrosion control. After orthophosphate addition, the treated water had a final pH of 7.35 and PO₄ concentration of 5 mg PO₄/L to account for the phosphate demand exerted by the calcium present in the well water and to produce an effective residual throughout the distribution system. Their experience was not altogether positive, having a significant number of turbid and dirty water complaints occurring after the addition of the orthophosphate. Additionally, within three months of beginning the phosphate treatment, it appeared that the hydraulic capacity of the distribution mains in the vicinity of the well heads was being significantly reduced. They gave up

the use of the corrosion inhibitor in order to restore the aesthetic quality of the delivered water supply.

After learning of these experiences, the Town of Redfield decided to eliminate the use of orthophosphate from their alternative corrosion control treatment approaches. Redfield focused their evaluation on the calcium carbonate precipitation technique for the following reasons:

- The CCPP condition for the finished water supply could be readily improved to produce a more reliable calcium carbonate deposit on the pipe walls. This deposit can further be controlled once treatment is in-place by dissolution and precipitation conditions in the treated water to ensure that the hydraulic capacity of the system is not compromised.
- Little documentation exists to confirm the corrosion control performance of silicate inhibitors with respect to lead and copper corrosion control for supplies with high calcium contents.
- Difficulties may arise in controlling silicate-based deposits to maintain the hydraulic capacity of the distribution system since they are not able to be redissolved.

Based on a CCPP goal of 8.5 mg CaCO₃/L, Redfield determined that a pH of 7.9 was needed for its finished well water supply.

3.3.3 Identifying Constraints.

The Rule provides two conditions by which constraints may be considered in limiting the availability of alternative

corrosion control treatments. Namely, options which have been shown either: (1) to adversely impact other water treatment processes and cause a violation of a National Primary Drinking Water Regulation; or (2) to otherwise be ineffective for the PWS.

EPA recommends that all constraints acting on PWSs be identified and considered in the selection of treatment approaches either for additional testing or as the recommended treatment process. Worksheets are provided in Table 3-3 for each of the three treatment alternatives (pH/alkalinity adjustment, calcium adjustment, and corrosion inhibitors) to assist PWSs in evaluating the constraints acting on their systems. Constraints have been extracted from an overview of corrosion control literature (Swayze, 1983; AWWARF, 1990c; Benjamin, 1990; AWWARF/DVGW, 1985; AWWA, 1986; AWWA, 1989).

PWSs should evaluate the impact of alternative corrosion control treatment options on regulatory compliance with existing federal and state drinking water standards in addition to those regulations anticipated to be finalized within the time frame for corrosion control installation by small and medium PWSs. Table 3-4 presents the schedule for regulatory actions during the next decade in conjunction with the compliance timeline for medium-size and small system implementation steps for the Lead and Copper Rule. The key regulatory actions which should be fully evaluated by small and medium PWSs for selecting optimal corrosion control treatment are discussed at more length below.

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Table 3-3a. Constraints Worksheet for pH/Alkalinity or Calcium Adjustment Treatment Alternatives

<p><i>Adjusting pH/Alkalinity and/or calcium for corrosion control typically consists of increasing their levels to generate favorable conditions for lead and copper passivation or calcium carbonate precipitation.</i></p>	
<p>A. National Primary Drinking Water Regulations Constraints</p>	
Rule	Constraint
Surface Water Treatment Rule	<p>Reduces inactivation effectiveness of free chlorine if pH adjusted before disinfection.*</p> <p>Potential for interference with dissolved ozone measurements.</p> <p>May increase turbidity from post-filtration precipitation of lime, aluminum, iron, or manganese.</p>
Groundwater Disinfection	<p>Reduces inactivation effectiveness of free chlorine if pH adjusted before disinfection.*</p> <p>Potential for interference with dissolved ozone measurements.</p>
Disinfection Byproducts	<p>Higher THM concentrations from chlorination if pH adjusted before disinfection.*</p> <p>Reduced effectiveness of some coagulants for precursor removal if pH adjusted before coagulation.*</p>
Coliform Rule	<p>Potential for higher total plate counts, confluent growth, or presence of total coliforms when chlorination is practiced.</p>
Radionuclides	<p>In-plant adjustments may affect removal of radioactive particles if precipitation techniques are used for coagulation or softening.</p> <p>Removal of radionuclides during softening may be linked to the degree of softening. Modifying softening practices to achieve corrosion control could interfere with removals.</p>

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Table 3-3a. Constraints Worksheet for pH/Alkalinity or Calcium Adjustment Treatment Alternatives (continued)

B. Functional Constraints

Increased potential for post-filter precipitation may give undesirable levels of aluminum, iron, or manganese.

Process optimization is essential. Additional controls, chemical feed equipment, and operator attention may be required.

Multiple entry points will require pH/Alkalinity adjustment at each entry location. Differing water qualities from multiple sources will require adjusting chemical doses to match the source.

The use of sodium-based chemicals for alkalinity or pH adjustments should be evaluated with regard to the total sodium levels acceptable in the finished water.

Users with specific water quality needs, such as health care facilities, should be advised of any changes in treatment.

Excessive calcium carbonate precipitation may produce "white water" problems in portions of the distribution system.

It may be difficult to produce an acceptable coating of calcium carbonate on interior piping for large distribution systems. High CCPP levels may eventually lead to reduced hydraulic capacities in transmission lines near the treatment facility while low CCPP values may not provide adequate corrosion protection in the extremities of the distribution system.

- * Unless operating restraints dictate otherwise, the optimum location for pH adjustment is after disinfection and near the entrance to the distribution system. If quicklime is used to adjust pH, for example, it needs to be added prior to filtration so inert material does not accumulate in the clearwell or enter the distribution system.

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Table 3-3b. Constraints Worksheet for Inhibitor Treatment Alternatives

<i>Corrosion inhibitors can cause passivation of lead and copper by the interaction of the inhibitor and metal components of the piping system.</i>	
A. National Primary Drinking Water Regulations Constraints	
<u>Rule</u>	<u>Constraint</u>
Surface Water Treatment Rule	The application of phosphate-based inhibitors to systems with existing corrosion byproducts can result in the depletion of disinfectant residuals within the distribution system. Additionally, under certain conditions phosphate-based inhibitors may stimulate biofilms in the distribution system.
Groundwater Disinfection	Same as above.
Disinfection Byproducts	No apparent effects.
Coliform Rule	If corrosion byproducts are released after the application of inhibitors, coliforms may be detected more frequently and confluent growth is more likely.
Radionuclides	No apparent effects.
B. Functional Constraints	
<p>Potential post-filtration precipitation of aluminum.</p> <p>Consumer complaints regarding red water, dirty water, color, and sediment may result from the action of the inhibitor on existing corrosion byproducts within the distribution system.</p> <p>Multiple entry points will require multiple chemical feed systems.</p> <p>The use of sodium-based inhibitors should be evaluated with regard to the total sodium levels acceptable in the finished water.</p> <p>The use of zinc orthophosphate may present problems for wastewater facilities with zinc or phosphorus limits in their NPDES permits.</p> <p>Users with specific water quality needs, such as health care facilities, should be advised of any treatment changes.</p>	

NOTE: If pH adjustment is necessary to produce an effective pH range for the inhibitor, then the constraints in Table 3-3a would also need to be evaluated.

Table 3-4. Schedule of Drinking Water Regulatory Activity: 1990-2000

Regulatory Action	Proposal Date	Final Date	Effective Date
Phase I VOCs	11/85	07/87	01/89
Phase II SOCs & IOCs	05/89	01/91 & 07/91	07/92 & 01/93
Phase V SOCs & IOCs	07/90	07/92	01/94
Arsenic	11/92	01/95	07/96
Surface Water Treatment Rule	11/87	06/89	01/91
Total Coliform Rule	11/87	06/89	01/91
Radionuclides Rule	07/91	04/93	10/94
Groundwater Disinfection Rule	06/93	06/95	01/97
Disinfectants/Disinfection By-Products	06/93	06/95	01/97
Lead and Copper Rule	08/88	06/91	07/91 & 12/92

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Surface and Groundwater Treatment Rules (SWTR/GWTR) where PWSs will be required to meet disinfection performance criteria. Disinfection efficiency is pH dependent for free chlorine where less effective disinfection results under higher pH conditions.

Total Coliform Rule (TCR) which requires all PWSs to meet minimum occurrence standards for the presence of total and fecal coliforms in distribution system samples. Some PWSs have noted increases in microbiological growth within the distribution system with the installation of corrosion control treatment. However, in most cases, no adverse impact or reductions in heterotrophic plate count bacteria have been found after implementing corrosion control treatment.

Disinfectants/Disinfection Byproducts Rule (D/DBPR), currently under development, will be finalized within the same time frame as PWSs are installing corrosion control treatment as a result of the Lead and Copper Rule. Adjusting pH conditions can affect the level of certain DBPs, most notably, total trihalomethanes (TTHMs) and total haloacetic acids (THAAs). These two contaminant groups are likely to be included in the future DBPR, and they exhibit opposite relationships to pH adjustment; TTHM formation increases with increasing pH, while THAA formation increases with decreasing pH. An additional consideration is the point of pH adjustment within treatment plants since lower pH conditions favor increased removal of DBP precursors during coagulation by alum. Compliance with the DBPR could be compromised by increasing the pH of coagulation as part of the corrosion control treatment approach as it may

reduce the efficiency of conventional treatment in removing precursor material.

Additional constraints should be considered by PWSs beyond those required by the Rule. As presented in Table 3-3b, a selected number of such limiting conditions for alternative corrosion control approaches include:

- Compatibility of a treatment approach with multiple sources of supply.
- Compatibility of a treatment approach for consecutive systems.
- Reliability features for the particular treatment approach, including: (1) process control; (2) operational redundancy requirements; and (3) chemical supply integrity and availability.
- Adverse impacts on the service community, including: (1) commercial users' water quality criteria; (2) health-care facility water quality criteria; and (3) wastewater operations - permit requirements for discharges and solids handling programs.

The particular conditions which define the constraints for each system will be site-specific, and should be thoroughly investigated as part of the desk-top evaluation aspect of the corrosion study. Small and medium systems exceeding the ALs but not required to perform testing should consider each of these items when selecting the optimal treatment for recommendation to the State. For those large PWSs required to perform only a desk-top evaluation, rigorous documentation of any constraints must be presented to support the recommended treatment approach for the system. For any PWS performing corrosion testing, the availability of information regarding system constraints will assist in limiting the optional treatment approaches which must be evaluated through the testing program.

Example: After exceeding the lead AL during initial monitoring, the City of Dannyport

began investigating alternative corrosion control treatment measures to provide the State with recommendations for optimal treatment. The City determined through its desk-top evaluation that raising the pH of the treated water was a viable treatment approach. Two alternative pH levels were identified for further consideration. As a medium-size surface water facility, concerns were raised regarding compliance with the SWTR and the ultimate feasibility of implementing pH adjustment.

The existing treatment provided by Dannyport is conventional coagulation/ flocculation with rapid sand filtration. Under the SWTR, at least 0.5-logs of inactivation of *Giardia* and 2.0-logs of virus inactivation were required.

The SWTR applied CT values - the product of the disinfectant *concentration* at the end of a disinfection segment and the effective contact *time* available within the disinfection segment, to determine the inactivation achieved during treatment. The *SWTR Guidance Manual* (USEPA, 1989) defined the CT_{req} as the CT value required to achieve the desired level of inactivation. The CT_{act} was defined as the CT value actually achieved through treatment for each disinfection segment within a water treatment facility. Compliance with the disinfection requirements is achieved when the sum of the $CT_{act}:CT_{req}$ ratios for all disinfection segments in a facility is greater than or equal to 1.0.

For the *Giardia* requirements, the existing plant's performance was determined to be adequate to meet the CT required with the sum of the $CT_{act}:CT_{req}$ ratios equal to 1.2. Virus inactivation performance was satisfactory and would not be affected by pH changes. However, *Giardia* inactivation performance is a function of pH. At the higher pH levels under consideration for corrosion control, the sum of the $CT_{act}:CT_{req}$ ratios would be 0.90 and 0.83,

respectively. Neither case would provide adequate disinfection performance.

An additional concern is continued compliance with the Total Trihalomethane (TTHM) standard. Currently, an average of 60 $\mu\text{g/L}$ TTHM is found in the distribution system with seasonal peaks of nearly 100 $\mu\text{g/L}$ TTHM. As such, increasing the pH of the finished water supply could only increase the probability of Dannyport exceeding the future TTHM standard, expected to be finalized concurrently with the City's initiation of corrosion control treatment.

Given the above regulatory concerns, the City of Dannyport determined that pH adjustment would not be a feasible option.

3.3.4 Evaluating Source Water Contributions.

When a small or medium PWS exceeds an AL during initial monitoring, lead and copper samples must be collected and analyzed at each point of entry (POE) to the distribution system within six months of exceeding the AL. It is recommended that this monitoring be completed as soon as possible after the AL is exceeded in order to provide information regarding source water lead and copper contributions to the desk-top evaluation effort. The recommendations for treatment which must be supplied to the States within six months of exceeding the ALs must contain source water treatment recommendations in addition to corrosion control treatment recommendations. Therefore, performing lead and copper POE monitoring (Pb/Cu-POE) is critical to the completion of desk-top evaluations.

Table 3-5 presents EPA's guidelines for source water treatment requirements on the basis of lead and copper POE monitoring results. If the source water is contributing more than the AL for either lead or copper, then source water

Table 3-5. Source Water Treatment Guidelines for Systems Exceeding an AL

Note: States have the discretion to set their own guidelines for Source Water Treatment.

Source Water Treatment Guidelines	Point of Entry Monitoring Results	
	Lead, mg/L	Copper, mg/L
Not Necessary	≤ 0.005	≤ 0.2
Optional	0.005 — 0.010*	0.2 — 0.8
Recommended	0.010 — 0.015	0.8 — 1.3**
Required	> 0.015	>1.3

* Source water treatment is recommended if the corrosion treatment is at or near optimal and the lead AL is still exceeded.

** If the copper AL is exceeded, source water treatment may be required when corrosion control treatment is unlikely to reduce copper levels below the AL.

treatment is required. In those cases where a significant amount of lead or copper is present, then treatment is recommended in order to reduce the overall lead or copper exposure and to assist PWSs in meeting the ALs. Table 3-5 also shows that the inclusion of source water treatment is optional when moderate levels of metals are found, and unnecessary when very low levels of either lead or copper are present.

In those cases where systems find elevated levels of lead or copper, the sources of supply should be monitored in the raw water and at various stages within the existing treatment facilities (if providing treatment currently) to determine the source of the metals. This monitoring will also assist in determining whether the existing treatment is already generating any removal of lead and copper.

Several types of treatment may be appropriate for removal of source water lead and copper. EPA specified ion exchange, reverse osmosis, lime softening, and coagulation/filtration as Best Available Treatment (BAT) for removal of lead and copper from source water (USEPA, 1991).

If a PWS is currently providing conventional coagulation/filtration treatment (whether alum or ferric coagulation, iron/manganese removal, or lime softening), then modifying these existing processes may produce the desired removals for lead and/or copper. If treatment is not available, then package treatment units for any of the above technologies may be installed at individual wellheads (especially when the elevated metals are contributed by a small number individual wells) or at a centralized treatment location. In the case of elevated copper, elimination of copper sulfate treatment for those surface water systems employing it as an herbicide or algicide may reduce the background levels of copper without imposing treatment modifications.

States must respond to the recommendations for source water treatment within six months of receiving the submittals from PWSs. If required, PWSs have 24 months to install source water treatment once approved by the State. Source water treatment would be installed, then, six months in advance of corrosion control treatment for medium PWSs and 12 months in advance of corrosion control treatment for small PWSs. Follow-up monitoring would not be required until after all treatment is in place, i.e., after corrosion control treatment has been installed.

3.3.5 Preparing Recommendations for Optimal Treatment.

Small and medium-size PWSs must submit treatment recommendations to the State within six months of exceeding an AL during initial monitoring. To assist in preparing the recommendations, a checklist (Table 3-6) has been developed summarizing the steps of a desk-top evaluation and key findings. More detailed data and discussion regarding the findings of a desk-top evaluation can be provided in the short form, denoted as Form 141-C, at the end of this chapter. Thus, the checklist (Table 3-6) provides the State with a "map" of the evaluation process and considerations involved in the desk-top procedures employed by a PWS, while Form 141-C presents the State with the findings from the desk-top evaluation. Small and medium PWSs may choose to submit the completed checklist and Form 141-C to the State for purposes of recommending optimal treatment, provided that sufficient documentation is available should the State require additional information during the recommendation review period.

3.4 Case Studies

The following case studies illustrate the assessment of source water and corrosion control treatment for PWSs through a desk-top evaluation. Special conditions and considerations have also been shown to assist PWSs and States in addressing the site-specific nature of corrosion control treatment decisions.

3.4.1 Softening Groundwater Supply (Single Source).

The Kashton County Water District (KCWD), a medium-size system, found excessive lead levels (90%Pb-TAP = 22 $\mu\text{g/L}$) but low copper levels ((90% Cu-TAP = 0.6 mg/L) during the initial monitoring period for the LCR. Using the checklist presented in Table 3-6, KCWD initiated a desk-top evaluation to determine optimal treatment per the LCR requirements. The first step taken was to monitor each of the five wells servicing the lime softening plant operated by KCWD. No lead or copper was detected in the source water samples, ruling out the need for source water treatment. The recommended treatment must therefore focus on corrosion control alternatives.

Existing water quality data was reviewed, generating average water quality parameter values, estimates of lead and copper solubility, and calculated values for CCPP. Figure 3-8 presents the treatment scheme and resultant water quality data gathered by KCWD. The water quality parameter monitoring conducted within the distribution system showed no major changes in water quality characteristics once the finished water entered the distribution system. Based on Figure 3-7, all corrosion control treatment alternatives are possible for KCWD except the use of orthophosphate since the finished water pH is above 8.

KCWD has never investigated corrosion control treatment in the past, but has noted occasional red water complaints and some tuberculation of unlined cast iron pipes when replaced. The supervisor of the lime softening plant had spoken with another PWS operator also performing lime softening about their experiences with polyphosphate inhibitors. The other community successfully eliminated red water complaints with the use of polyphosphates, but also experienced elevated lead levels during their initial monitoring period.

An evaluation of the constraints acting on KCWD revealed only one known adverse impact: disinfection byproducts. The current TTHM levels are 75 $\mu\text{g/L}$ on average, and increasing the final pH to 9.0 or above would cause this level to increase even further.

Since phosphate inhibitors were eliminated from further consideration, three treatment alternatives remained: pH/alkalinity adjustment; calcium adjustment; and silicate inhibitor addition. Due to the solubility relationships, little benefit or theoretical reductions in lead or copper could be achieved by altering the pH and/or alkalinity of the existing supply. It would require either a pH greater than 9.0, which is not feasible due to TTHM concerns, or increased alkalinity removal during softening which would be difficult to achieve. Therefore, pH/alkalinity adjustment was eliminated as a feasible option.

To evaluate calcium adjustment, a CCPP of 8.0 mg/L CaCO_3 was selected as an initial target value since it is higher than the existing condition, but will most likely not plug the pipes nearest the plant. To achieve the CCPP goal, either the pH needs to be increased to 8.8 (keeping the alkalinity and calcium the same) or the alkalinity must be increased to 102 mg/L as CaCO_3 (keeping the pH and calcium content the same). Either method of achieving the CCPP goal is feasible, and this option remains viable.

SCREENING OF ALTERNATIVES

Table 3-6. Checklist for PWS Desk-Top Evaluations

i. Historical Evidence Review:

Did your utility:

YES NO

a. Determine Initial Water Quality WQP-POE and WQP-DIS Pb/Cu-POE Lead Solubility Copper Solubility CCPP Index Value		

b. Conduct Prior Corrosion Control Investigations		
---	--	--

c. Assess Corrosion Activity in the Distribution System for: Lead and Copper Iron A/C Pipe Other Materials, please specify		

d. Review the Literature		
--------------------------	--	--

e. Identify Comparable PWS Experience with Corrosion Control Treatment		
--	--	--

(If YES, what was the overall performance of the alternative treatment approaches)

	Very Good	Good	Poor	Adverse
pH/Alkalinity Adjustment				
Calcium Adjustment				
Corrosion Inhibitors				
Phosphates				
Silicates				

f. Source Water Treatment Status

Required	
Recommended	
Optional	
Not Necessary	

SCREENING OF ALTERNATIVES

Table 3-6. Checklist for PWS Desk-Top Evaluations (continued)

g. Based on your water quality characteristics, check the suggested treatment approach(es) per Figure 3-7 in Volume II of the Guidance Manual.

pH/Alkalinity Adjustment	<input type="checkbox"/>
Calcium Adjustment	<input type="checkbox"/>
Corrosion Inhibitors	<input type="checkbox"/>
Phosphates	<input type="checkbox"/>
Silicates	<input type="checkbox"/>

II. Constraint Definitions

Is the constraint identified applicable to your system?
(Based on Rankings of 3 or 4 on Form 141-C)

Regulatory Constraints:

- SOCs/IOCs
- SWTR: Turbidity
- Total Coliforms
- SWTR/GWTR: Disinfection
- D/DBPs
- LCR
- Radionuclides

YES NO

YES	NO
<input type="checkbox"/>	<input type="checkbox"/>

Functional Constraints:

- Taste and Odor
- Wastewater Permit
- Aesthetics
- Operation
- Other

<input type="checkbox"/>	<input type="checkbox"/>

III. Were any treatment approaches eliminated from further consideration in the desk-top evaluation?

- pH/Alkalinity Adjustment
- Calcium Adjustment
- Corrosion Inhibitors:
- Phosphates
 - Zinc Orthophosphate
 - Sodium Orthophosphate
 - _____ Orthophosphate
 - Poly-ortho-phosphates
 - Polyphosphates
- Silicates

YES NO

YES	NO
<input type="checkbox"/>	<input type="checkbox"/>

SCREENING OF ALTERNATIVES

Table 3-6. Checklist for PWS Desk-Top Evaluations (continued)

IV. For each of the feasible treatment alternatives, did your system evaluate the following in the desk-top evaluation?

- Performance
- Feasibility
- Reliability
- Costs

YES	NO

V. What is the recommended treatment approach?

Source Water Treatment:
Method, specify:

YES	NO

Corrosion Control Treatment:

--	--

pH/Alkalinity Adjustment
Calcium Adjustment

Corrosion Inhibitors:
Phosphates
Specify type:

Silicates
Specify type:

--	--

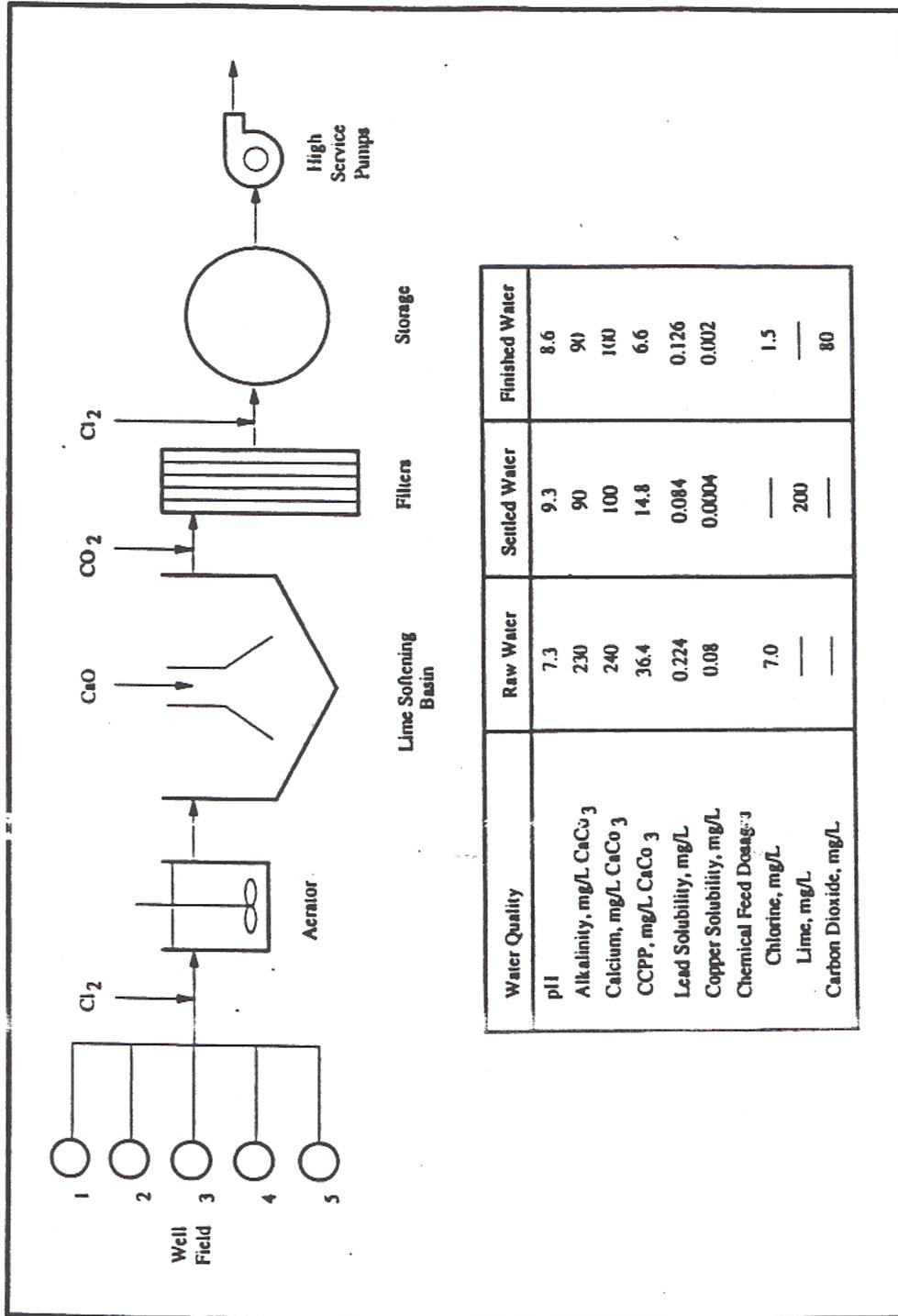


Figure 3-8. Lime Softening PWS: Treatment Schematic and Relevant Data

The use of silicates for corrosion control presented some problems for KCWD in terms of evaluating their usefulness. No other lime softening plant that they knew had any experience with silicates, and yet some promising results had appeared in the literature for different types of supplies. Although they were not required by the Lead and Copper Rule to conduct a treatment study, KCWD decided to do some experimental testing of silicates. Both flow-through and static testing procedures were considered; and after evaluation of the advantages and disadvantages of these methods (see Chapter 4), KCWD decided that the static testing approach was more suitable for their personnel to manage.

The maintenance dosage recommended (10 mg/L SiO_2) was bench-tested with the existing supply and found that it increased the finished water pH to 8.9. However, particles were observed in the containers at the end of the static testing indicating that calcium was probably with the silicate and precipitating. Due to concerns with turbidity problems in the distribution system, the use of silicates were not considered reliable.

Based on the above findings, the recommended treatment was calcium adjustment achieved by increasing either the pH or the alkalinity to meet the CCPP goal of 8.0 mg/L as CaCO_3 . The KCWD checklist for the desk-top evaluation as presented in Table 3-7 was submitted to the State for approval of the recommended treatment in conjunction with a completed short-form 141-C.

3.4.2 Low Alkalinity, pH, and Hardness Surface Water System.

The Town of Mulberry provides potable water to its 1,200 residents and operates a small package water treatment plant (WTP) receiving water from the Lolla River - a low alkalinity, pH, and hardness surface water supply. The existing treatment consists of in-line filtration using polymer coagulation and final disinfection with liquid chlorine. Figure 3-9 illustrates the treatment schematic of the WTP and the relevant water quality information for the system.

During the initial monitoring period for lead and copper, excessive lead and copper levels were found at the targeted sites. Source water monitoring revealed high copper concentrations in river samples, such that source water treatment was needed. Lead levels in the Lolla River, however, were below detection and did not require additional source water removal. Corrosion control treatment, however, was still required for Mulberry since the lead levels exceeded the lead AL.

Reviewing the records of the Town, the PWS operator discovered that the water intake at the Lolla River was within a reach of the river where the County applied copper sulfate for algae control. Since the source water monitoring coincided with the period of copper sulfate applications, Mulberry requested that the County use a substitute algicide to reduce the copper levels. Meanwhile, additional source water monitoring was performed by the Town to determine the extent of copper contamination with the river. After three months of no copper sulfate

SCREENING OF ALTERNATIVES

Table 3-7. Checklist for the Kashton County Water District (KCWD) Desk-Top Evaluations

I. Historical Evidence Review:

Did your utility:

- a. Determine Initial Water Quality
 - WQP-POE and WQP-DIS
 - Pb/Cu-POE
 - Lead Solubility
 - Copper Solubility
 - CCPP Index Value

YES	NO
✓	
✓	
✓	
✓	
✓	
✓	

- b. Conduct Prior Corrosion Control Investigations

	✓
--	---

- c. Assess Corrosion Activity in the Distribution System for:
 - Lead and Copper
 - Iron
 - A/C Pipe
 - Other Materials, please specify

✓	
✓	
	✓
	✓

- d. Review the Literature

✓	
---	--

- e. Identify Comparable PWS Experience with Corrosion Control Treatments

✓ YES	
-------	--

(If YES, what was the overall performance of the alternative treatment approaches)

	Very Good	Good	Poor	Adverse
pH/Alkalinity Adjustment				
Calcium Adjustment				
Corrosion Inhibitors				
Phosphates				✓
Silicates				

- f. Source Water Treatment Status

- Required
- Recommended
- Optional
- Not Necessary

✓

SCREENING OF ALTERNATIVES

Table 3-7. Checklist for the Kashton County Water District (KCWD) Desk-Top Evaluations (continued)

g. Based on your water quality characteristics, check the suggested treatment approach(es) per Figure 3-7 in Volume II of the Guidance Manual.

pH/Alkalinity Adjustment	✓
Calcium Adjustment	✓
Corrosion Inhibitors	
Phosphates	
Silicates	✓

II. Constraint Definitions

Is the constraint identified applicable to your system?
(Based on Rankings of 3 or 4 on Form 141-C)

Regulatory Constraints:

- SOCs/OCs
- SWTR: Turbidity
- Total Coliforms
- SWTR/GWTR: Disinfection
- D/DBPs
- LCR
- Radionuclides

	YES	NO
		✓
		✓
		✓
		✓
	✓	
		✓
		✓

Functional Constraints:

- Taste and Odor
- Wastewater Permit
- Aesthetics
- Operational
- Other

		✓
		✓
		✓
		✓
		✓

III. Were any treatment approaches eliminated from further consideration in the desk-top evaluation?

- pH/Alkalinity Adjustment
- Calcium Adjustment
- Corrosion Inhibitors:
- Phosphates
- Zinc Orthophosphate
- Sodium Orthophosphate
- _____ Orthophosphate
- Poly-ortho-phosphates
- Polyphosphates
- Silicates

	YES	NO
		✓
		✓
	✓	
	✓	
	✓	
	✓	
	✓	
		✓

SCREENING OF ALTERNATIVES

Table 3-7. Checklist for the Kashton County Water District (KCWD) Desk-Top Evaluations (continued)

IV. For each of the feasible treatment alternatives, did your system evaluate the following in the desk-top evaluation?

- Performance
- Feasibility
- Reliability
- Costs

YES	NO
✓	
✓	
✓	
✓	

V. What is the recommended treatment approach?

Source Water Treatment:
Method, specify:

YES	NO
	✓

Corrosion Control Treatment:

✓	
---	--

pH/Alkalinity Adjustment

Calcium Adjustment

Corrosion Inhibitors:

Phosphates

Specify type:

Silicates

Specify type:

✓	

--	--

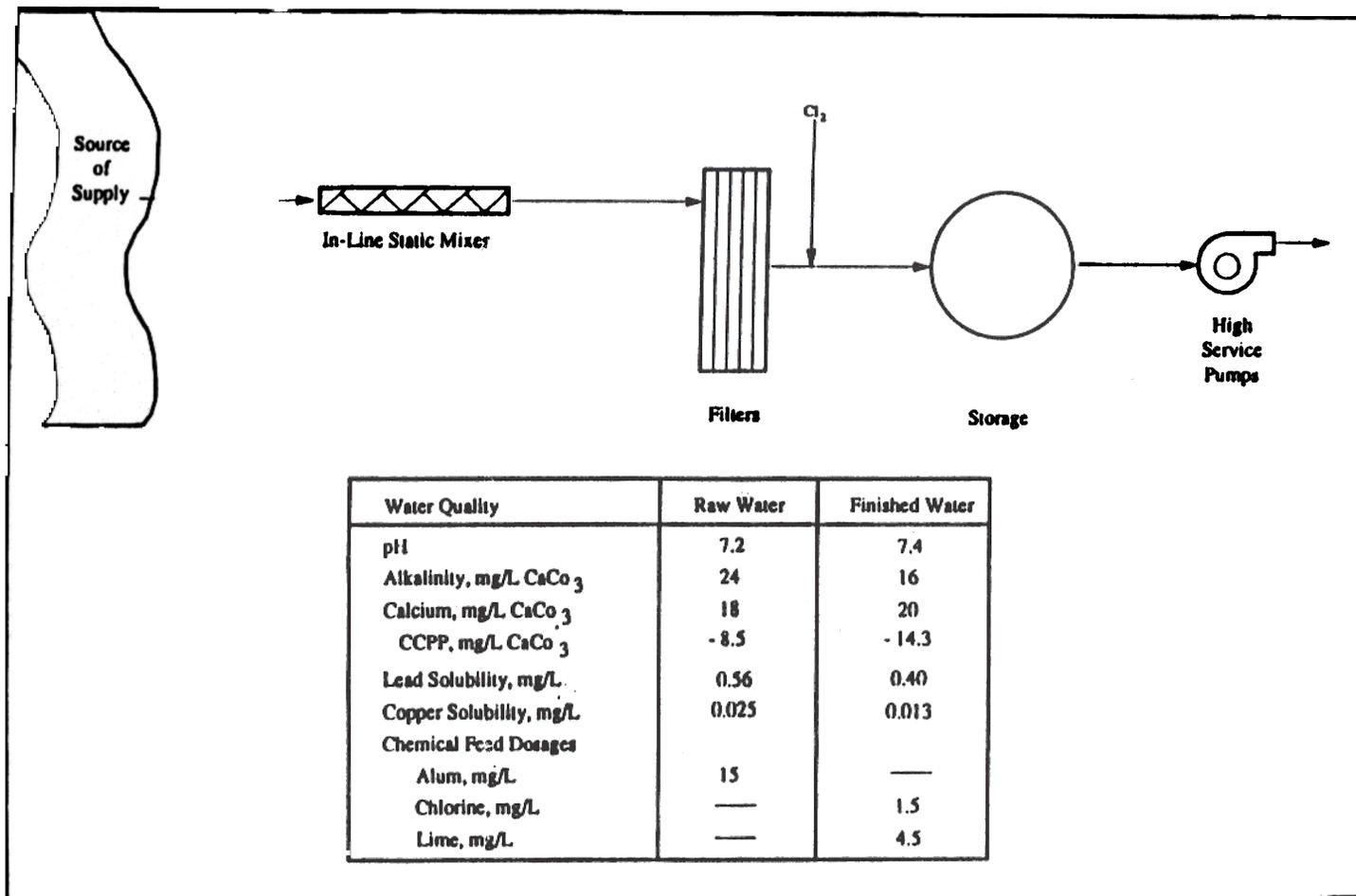


Figure 3-9. Surface Water PWS with Low Alkalinity, pH, and Hardness: Treatment Schematic and Relevant Data

SCREENING OF ALTERNATIVES

applications, the source water copper levels were less than 0.02 mg/L copper. The PWS and the State agreed that additional source water treatment would not be necessary as long as the County did not apply copper sulfate in the reaches of the river directly above Mulberry's intake.

Meanwhile, corrosion control treatment investigations resulted in eliminating pH/alkalinity adjustment and calcium adjustment as viable treatment alternatives. Limited storage is available at the Mulberry package plant, and raising the pH even slightly would jeopardize the disinfection performance capability of the plant. Additionally, the low alkalinity, pH, and calcium content of the water indicated that formation of calcium carbonate deposits would require excessive chemical treatment. The use of inhibitors was selected as the approach of choice for the Town.

Phosphate inhibitors were considered preferable to the silicates given their proven performance in the available literature. Since the control of lead was the targeted objective of corrosion control treatment, zinc orthophosphate was recommended as the optimal treatment approach for Mulberry. Aware of the possibility for initial disturbances within the distribution system, Mulberry instituted a flushing program simultaneously with the startup of the phosphate feed. Higher dosages were selected to initiate the system (3.0 mg/L as PO_4) with a maintenance dose of 0.6 mg/L as PO_4 based on the experiences of two other communities that had worked with Mulberry's chemical supplier.

3.4.3 Multiple Sources of Supply.

Chinnee County, a medium-size system, is in the process of building a new water

treatment plant which will receive surface water from the Monohaggen Water Project. Currently, the County operates several groundwater wells (See Figure 3-10) which have been experiencing increasing iron and manganese levels over the last several years. The objective of the County is to provide the base-load of the distribution system's water demand through the new WTP and continue to use the well supply during periods of high demand.

During the initial monitoring program, the lead and copper ALs were met by the County. The 90th percentile lead level was 0.012 mg/L and 0.010 mg/L for the first and second monitoring periods, respectively. The County applied to the State for reduced monitoring.

While corrosion control treatment is not required at present, concerns have been raised about the corrosion control performance of the distribution system when the new WTP is brought on line as the main supply source for the County. The groundwater supply is well-buffered and contains a moderate amount of calcium hardness. The CCPP for the wells averages 3.2 mg/L as CaCO_3 . However, the surface water source is poorly buffered, contains little hardness, and would have a moderate to low pH after treatment. The existing calcium carbonate films may not be maintained within the distribution system once supplied by the surface water.

Many residences in the county were constructed in the early 1900s and still have lead service lines in place. The County is concerned that future exceedances of the lead AL could invoke LSL replacement requirements, an expense that the County does not want to undertake. Additionally, the design of the surface water plant included provisions for additional chemical feed systems if needed

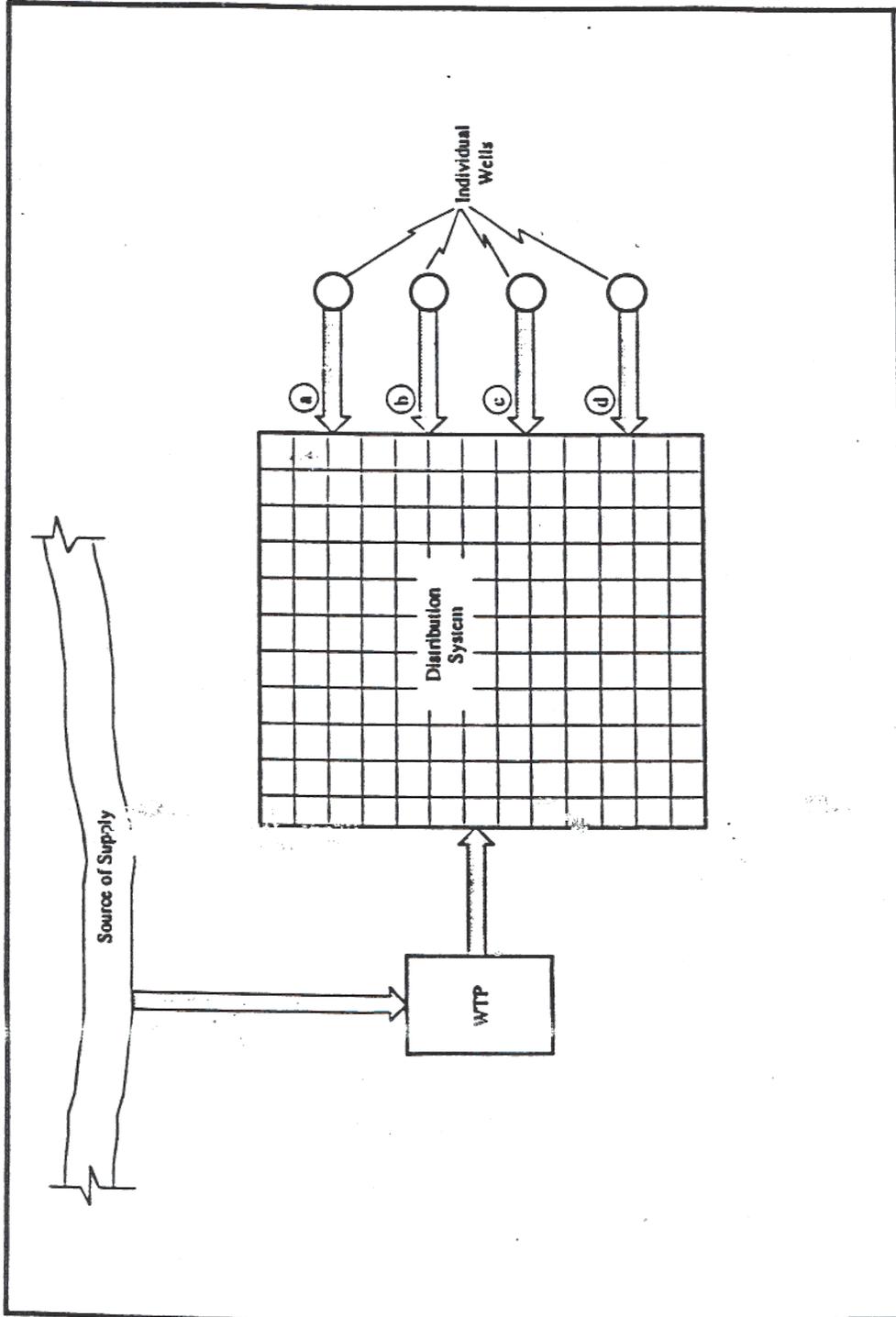


Figure 3-10. PWS with Multiple Sources of Supply

in the future. Since calcium carbonate films currently exist in the distribution system, the corrosion control treatment program for the surface water plant was oriented toward maintaining the existing film and providing lead corrosion control protection in areas where no protective film existed (such as some home plumbing environments). The selected treatment was pH/alkalinity adjustment for lead control with supplemental calcium added to the finished water to prevent dissolution of the calcium carbonate film.

3.4.4 Consecutive Systems.

Fedarry Water Project 4 (the Project) consists of four communities to which the Project supplies potable water as shown in Figure 3-11. Each member community owns and operates their distribution system. The Project initiated and had approved a consolidation agreement whereby the four communities and the Project would be considered a single PWS for purposes of compliance with the LCR. In the consolidation agreement, corrosion control treatment would be required if the monitoring results for the comprehensive service area exceeded an AL. During initial monitoring, the lead AL was met but the copper AL was exceeded with consistently high copper levels found in Community B. The corrosion problem appeared to be limited to this community, since the copper levels in A, C, and D were below the AL in all cases.

The source of supply for the Project is a low alkalinity, pH, and hardness surface water with similar water quality conditions to that presented in Section 3.4.2. However, the Project had implemented pH and alkalinity treatment five years prior

to the promulgation of the LCR to minimize red water complaints occurring within the comprehensive service area. Since that time, the member communities had experienced fewer problems with corrosion-related complaints. Modification of the existing corrosion control program was determined to be needed since the source water lead and copper levels were below detection. The Project considered two approaches to meet the LCR requirements: modify the existing pH/alkalinity adjustment treatment at the water treatment plant (WTP) or implement modified treatment at the master meter location for Community B.

Based on a review of the water quality conditions (using Figure 3-7), the most promising alternative treatments were pH/alkalinity adjustment or corrosion inhibitors, either phosphates or silicates. Since the literature contained mixed results with the use of phosphates for the control of copper corrosion, phosphate inhibitors were eliminated from further consideration. Based on Figure 3-3, further pH/alkalinity adjustment does not appear to present any additional benefit in copper solubility reduction. For these reasons, the use of silicates was determined to provide optimal treatment for controlling copper in Community B. Since silicate feed systems can be easily installed and operated at the storage reservoir located at the master meter for Community B, the Project decided to recommend to the State that silicate inhibitor treatment be installed at this remote location initially. If copper corrosion control was improved and lead levels did not respond adversely, the Project would consider installing the silicate treatment system-wide.

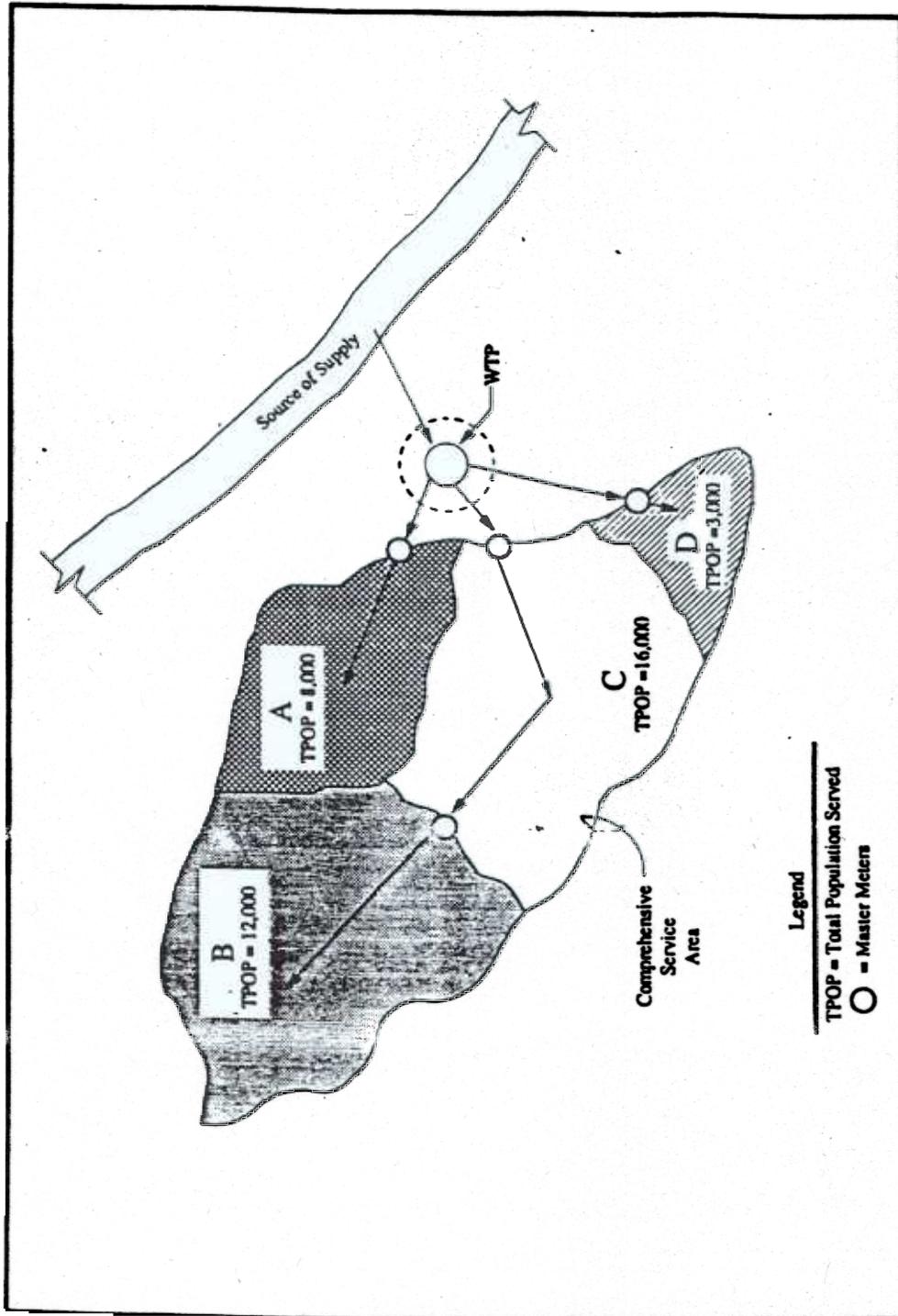


Figure 3-11. Configuration of Consecutive Systems

3.5 References

- Allen, M.J., et al. 1980. The Occurrence of Microorganisms in Water Main Encrustations. *Journal AWWA*. 72(11):614-625.
- AWWA. 1986. *Corrosion Control for Operators*. AWWA (Denver, CO).
- AWWARF. 1990a. *Assessing and Controlling Bacterial Regrowth in Distribution Systems*. AWWA (Denver, CO).
- AWWARF. 1990b. *Chemistry of Corrosion Inhibitors in Potable Water*. AWWA (Denver, CO).
- AWWARF. 1990c. *Lead Control Strategies*. AWWA (Denver, CO).
- AWWARF/DVGW-Forschungsstelle Cooperative. 1985. *Internal Corrosion of Water Distribution Systems*. AWWARF (Denver, CO).
- Bailey, T.L. Corrosion Control Experiences at Durham, NC. *Proc. 1982 WQTC*. (Nashville, TN).
- Benjamin, M.M., et al. 1990. *Chemistry of Corrosion Inhibitors in Potable Water*. AWWA and AWWARF (Denver, CO).
- Corrosion Control for Operators*. 1986. AWWA, Manual No. 20232 (Denver, CO).
- Donlan, R.M. and Pipes, W.O. 1988. Selected Drinking Water Characteristics and Attached Microbial Population Density. *Journal AWWA*. 80(11):70-76.
- Faust, S.D. and Aly, O.M. 1983. *Chemistry of Water Treatment*. Ann Arbor Science Publishers (Stoneham, MA):397-452.
- Faust, S.D. and Aly, O.M. 1981. *Chemistry of Natural Waters*. Ann Arbor Science Publishers (Stoneham, MA).
- Hanson, H.F., et al. 1987. *Deterioration of Water Quality in Distribution System*. AWWARF and AWWA (Denver, CO).
- Herson, D.S., et al. 1991. Association of Microorganisms with Surfaces in Distribution Systems. *Journal AWWA*. 83(7):103-106.
- Hoehn, R.C. 1991. Personal Communication. Virginia Polytechnic Institute & State University (Blacksburg, VA).
- Holm, T.R. and Schock, M.R. 1991a. Potential Effects of Polyphosphate Products on Lead Solubility in Plumbing Systems. *Journal AWWA*. 83(7):76-82.
- Holm, T.R. and Schock, M.R. 1991b. Polyphosphate Debate, in *Letters*. *Journal AWWA*. 83(12):10-12.
- Huck, P.M. 1990. Measurement of Biodegradable Organic Matter and Bacterial Growth Potential in the Distribution System. *Journal AWWA*. 82(7):78-86.
- Karalekas, P.C., et al. 1983. Control of Lead, Copper, and Iron Pipe Corrosion in Boston. *Journal AWWA*. 75(2):92-95.
- Katsanis, E.P., et al. 1986. Soluble Silicate Corrosion Inhibitors in Water Systems. *Materials Performance*. 25(5):19-25.
- Kirk-Othmer: Encyclopedia of Chemical Technology - 3rd Ed.* 1982. Silicon Compounds. Vol 20:855-880.
- Kirmeyer, G.J. and G.S. Logsdon. 1983. Principles of Internal Corrosion and Corrosion Monitoring. *Journal AWWA*. 75(2):78-83.
- LeChevallier, M.W., et al. 1990. Disinfecting Biofilms in a Model Distribution System. *Journal AWWA*. 82(7):87-99.

SCREENING OF ALTERNATIVES

- LeChevallier, M.W., et al. 1988. Inactivation of Biofilms Bacteria. *Applied and Environmental Microbiology*. 54(10):2492-2499.
- LeChevallier, M.W., et al. 1988. Factors Promoting Survival of Bacteria in Chlorinated Water Supplies. *Applied and Environmental Microbiology*. 54(3):649-654.
- LeChevallier, M.W., et al. 1987. Examination and Characterization of Distribution System Biofilms. *Applied and Environmental Microbiology*. 53(12):2714-2724.
- Lechner, J.B. 1991. Personal Communication. Stiles-Kem Div., Met-Pro Corporation, (Zion, IL).
- Lee, R.G. and R.H. Moser. 1988. *Lead at the Tap - Sources and Control: A Survey of the American Water System*. AWW Service Company, Inc. Internal Report.
- Maas, R.P., et al. 1991. A Multi-State Study of the Effectiveness of Various Corrosion Inhibitors in Reducing Residential Lead Levels. *Proc. 1991 AWWA Annual Conf.*, (Philadelphia, PA).
- Moser, R. H. 1992.
- Neff, C.H. 1990. Corrosion and Metal Leaching. *Proc. 1991 AWWA Annual Conf.*, (Philadelphia, PA).
- Neff, C.H., et al. 1987. *Relationship Between Water Quality and Corrosion of Plumbing Materials in Buildings*. EPA Rept. No. EPA/600/S2-87/036. (Cincinnati, OH).
- Robinson, R. B., et al. 1992. Iron and Manganese Sequestration Facilities Using Sodium Silicate. *Journal AWWA*. 84(2):77-82.
- Schock, M. R. 1985. Treatment or Water Quality Adjustment to Attain MCLs in Metallic Potable Water Plumbing Systems. Plumbing Materials and Drinking Water Quality: Proceedings of a Seminar. (Cincinnati, OH). EPA 600/9-85-007.
- Schock, M.R. 1980. Response of Lead Solubility to Dissolved Carbonate in Drinking Water. *Journal AWWA*. 72(12):695-704.
- Sheiham, I. and Jackson, P.J. 1981. The Scientific Basis for Control of Lead in Drinking Water by Water Treatment. *Journal Inst. Water Engrs. & Scientists*. 35(6):491.
- Stumm, W. and Morgan, J.J. 1981. *Aquatic Chemistry*. John Wiley & Sons (New York, NY).
- Swayze, J. 1983. Corrosion Study at Carbondale, Illinois. *Journal AWWA*. 75(2):101-102.
- USEPA. 1991. *Technologies and Costs for the Removal of Lead and Copper from Potable Water Sources*. Office of Ground Water and Drinking Water.
- USEPA. 1989. *SWTR Guidance Manual*. Office of Ground Water and Drinking Water.
- Wagner, I. Effect of Inhibitors on Corrosion Rate and Metal Uptake in Drinking Water Systems. *Proc AWWA Seminar on Internal Corrosion Control Developments and Research Needs*. Los Angeles. AWWA (Denver, CO).

Desktop Evaluation Short Form for Small and Medium PWS Treatment Recommendations

A. PWS General Information:

1. PWS Identification No.	_____		
2. Contact person:	_____		
Name	_____		
Mailing Address	_____		

Telephone	_____	Fax	_____
3. Population served	_____		
4. Person responsible for preparing this form:	_____		
Name	_____		
Signature	_____		
Telephone	_____		

B. PWS Technical Information:

1. Monitoring Results:						
Sampling dates: From _____ To _____						
First-Flush Tap Monitoring Results:						
Lead:						
Minimum concentration	=	_____	mg/L			
Maximum concentration	=	_____	mg/L			
90th percentile	=	_____	mg/L			
Copper:						
Minimum concentration	=	_____	mg/L			
Maximum concentration	=	_____	mg/L			
90th percentile	=	_____	mg/L			
Point-of-Entry Tap Monitoring Results:						
		Points of Entry				
		1	2	3	4	5
Lead Concentration in mg/L:	_____	_____	_____	_____	_____	_____
Copper Concentration in mg/L:	_____	_____	_____	_____	_____	_____
pH:	_____	_____	_____	_____	_____	_____
Temperature, °C:	_____	_____	_____	_____	_____	_____
Alkalinity, mg/L as CaCO ₃ :	_____	_____	_____	_____	_____	_____
Calcium, mg/L as Ca:	_____	_____	_____	_____	_____	_____
Conductivity, µmho/cm @ 25°C:	_____	_____	_____	_____	_____	_____
Phosphate, mg/L as P:	_____	_____	_____	_____	_____	_____
Silicate, mg/L as SiO ₂ :	_____	_____	_____	_____	_____	_____

1. Monitoring Results (continued):

Water Quality Parameter Distribution System Monitoring Results:

Indicate whether field or laboratory measurement.

	Field	Lab
pH: minimum = _____ maximum = _____	_____	_____
alkalinity:	_____	_____
minimum = _____ mg/L as CaCO ₃		
maximum = _____ mg/L as CaCO ₃		
temperature:	_____	_____
minimum = _____ °C		
maximum = _____ °C		
calcium:	_____	_____
minimum = _____ mg/L as Ca		
maximum = _____ mg/L as Ca		
conductivity:	_____	_____
minimum = _____ µmho/cm @ 25°C		
maximum = _____ µmho/cm @ 25°C		
orthophosphate:	_____	_____
(if phosphate-based inhibitor is used)		
minimum = _____ mg/L as P		
maximum = _____ mg/L as P		
silica:	_____	_____
(if silica-based inhibitor is used)		
minimum = _____ mg/L as SiO ₂		
maximum = _____ mg/L as SiO ₂		

2. Existing Conditions:

Is treatment used? yes _____ no _____

Identify water source(s):

Source No. 1 _____
 Source No. 2 _____
 Source No. 3 _____

If treatment is used, is more than one source used at a time?

yes _____ no _____

Identify treatment processes used for each source:

Process	No. 1	No. 2	No. 3
Presedimentation	_____	_____	_____
Aeration	_____	_____	_____
Chemical mixing	_____	_____	_____
Flocculation	_____	_____	_____
Sedimentation	_____	_____	_____
Recarbonation	_____	_____	_____

2. Existing Conditions (continued):

Identify treatment processes used for each source:

Process	No. 1	No. 2	No. 3
2nd Stage mixing	_____	_____	_____
2nd Stage flocculation	_____	_____	_____
2nd Stage sedimentation	_____	_____	_____
Filtration:			
Single medium	_____	_____	_____
Dual media	_____	_____	_____
Multi-media	_____	_____	_____
GAC cap on filters	_____	_____	_____
Disinfection:			
Chlorine	_____	_____	_____
Chlorine dioxide	_____	_____	_____
Chloramines	_____	_____	_____
Ozone	_____	_____	_____
Granular Activated Carbon	_____	_____	_____
List chemicals normally fed:			

List chemicals sometimes fed:

3. Present Corrosion Control Treatment:

None _____

Inhibitor _____

Date initiated _____

Present dose _____

Range in Residual in Distribution System:

Maximum _____ mg/L Minimum _____ mg/L

Brand name _____

Type _____

Has it been effective? Please comment on your experience.

pH/alkalinity adjustment _____

pH Target _____

Alkalinity Target _____ mg/L CaCO₃

Calcium adjustment _____

Calcium Target _____ mg/L CaCO₃

4. Water Quality:

Complete the table below for typical untreated and treated water quality data. Copy this form as necessary for additional sources. Include data for each raw water source, if surface supplies are used, and finished water quality information (point of entry) from each treatment plant. If wells are used, water quality information from each well is acceptable but not necessary if several wells have similar data. For groundwater supplies, include a water quality summary from each wellfield or grouping of wells with similar quality.

Include available data for the following:

Parameter	Untreated Supply	Treated Water (point of entry)
pH, units		
Alkalinity, mg/L as CaCO ₃		
Conductivity, µmho/cm @ 25°C		
Total dissolved solids, mg/L		
Calcium, mg/L Ca		
Hardness, mg/L as CaCO ₃		
Temperature, °C		
Chloride, mg/L		
Sulfate, mg/L		

5. Distribution System:

Does the distribution system contain lead service lines?

yes _____ no _____

If your system has lead service lines, mark below the approximate number of lines which can be located from existing records.

None _____ Some _____ Most _____ All _____

Is the distribution system flushed?

None _____ Some _____ Most _____ All _____

6. Historical Information:

Is there a history of water quality complaints?

yes _____ no _____

If yes, then answer the following:

Are the complaints documented? yes _____ no _____

Mark the general category of complaints below. Use:

- 1 for some complaints in this category
- 2 for several complaints in this category
- 3 for severe complains in this category

Categories of complaints:

- Taste and odor _____
- Color _____
- Sediment _____
- Other (specify) _____

Have there been any corrosion control studies?

yes _____ no _____

If yes, please indicate:

Date(s) of study From _____ To _____

Study conducted by PWS personnel? yes _____ no _____

Brief results of study were:

(optional) _____, recommended? yes _____ no _____

Were treatment changes recommended? yes _____ no _____

If yes:

Were treatment changes implemented? yes _____ no _____

Have corrosion characteristics of the treated water changed? yes _____ no _____

If yes, how has change been measured?

- General ooservation _____
- Coupons _____
- Frequency of complaints _____
- Other _____

Briefly indicate, if other: _____

7. Treatment Constraints:

Optimal corrosion control treatment means the corrosion control treatment that minimizes the lead and copper concentrations at users' taps while insuring that the treatment does not cause the water system to violate any national primary drinking water regulations. Please indicate below which constraints to treatment will apply to your PWS. Use the following code:

- 1 Some constraint = Potential Impact but Extent Is Uncertain
- 2 Significant constraint = Other Treatment Modifications Required to Operate Option
- 3 Severe constraint = Additional Capital Improvements Required to Operate Option
- 4 Very severe constraint = Renders Option Infeasible

Constraint	Treatments			
	pH/Alkalinity Adjustment	Calcium Adjustment	Inhibitor	
			PO ₄	Si
A. Regulatory				
SOCs/IOCs				
SWTR: Turbidity				
Total Coliforms				
SWTR/GWDR: Disinfection				
Disinfection Byproducts				
Lead and Copper Rule				
Radionuclides				
B. Functional				
Taste & Odor				
Wastewater Permit				
Aesthetics				
Operational				
Other				

8. Desktop Evaluation:

Briefly summarize the review of the corrosion control literature that pertains to your PWS. A report or summary can be appended to this form if preferred.

Were other similar facilities located which are experiencing successful corrosion control? yes _____ no _____

If yes, identify their corrosion control treatment method.

- None _____
- pH/Alkalinity adjustment _____
- Calcium adjustment _____
- Inhibitor _____
 - Phosphate based _____
 - Silica based _____

9. Recommendations:

The corrosion control treatment method being proposed is:

- pH/Alkalinity adjustment _____
 - Target pH is _____ units
 - Target alkalinity is _____ mg/L as CaCO₃
- Calcium adjustment _____
 - Target calcium concentration is _____ mg/L Ca
- Inhibitor _____
 - Phosphate based _____
 - Brand name _____
 - Target dose _____ mg/L
 - Target residual _____ mg/L orthophosphate as P
 - Silica based _____
 - Brand name _____
 - Target dose _____ mg/L
 - Target residual _____ mg/L as SiO₂

Rationale for the proposed corrosion control treatment is:

- Discussed in the enclosed report _____
- Briefly explained below _____

List your proposed operating guidelines:

Parameter Operating Range

Briefly explain why these guidelines were selected.

10. **Please provide any additional comments that will assist in determining optimal corrosion control treatment for your PWS.**