Chapter 5.0 — Full-Scale Operation and Implementation of Optimal Corrosion Control Treatment

The purpose of this chapter is to provide guidance on several aspects of full-scale implementation of corrosion control treatment, including the following steps which PWSs and States may encounter:

- Developing the operating ranges for optimal treatment after follow-up monitoring has been completed.
- Diagnosing problems associated with the startup of full-scale treatment.
- Identifying the need to modify the installed treatment to improve corrosion control protection.
- Implementing changes in treatment which may improve the overall performance of corrosion control treatment.

5.1 Overview of Requirements

5.1.1 Installing Optimal Treatment.

The Rule requires that once treatment is installed, follow-up monitoring must be performed by PWSs. At the conclusion of this monitoring effort, States will review the results and establish operational conditions which must be met during all routine monitoring events for all large PWSs and those small and medium-size PWSs that exceed an AL in the follow-up monitoring. The operating conditions will consist of minimum, maximum, or ranges of water quality parameter values which must be achieved in the potable water entering and residing in the distribution system at all times. Additionally, PWSs will be required to at least report the chemical dosages applied during the reporting period.

States will be facing the challenges of: (1) determining whether the recommended treatments provided by PWSs are acceptable, or whether additional action on their part is required; (2) establishing operating conditions which adequately define optimal treatment for each PWS; and (3) determining compliance for each PWS on the basis of continual achievement of the site-specific operating conditions.

PWSs, on the other hand, will be facing challenges regarding the identification and execution of optimizing corrosion control treatment. Many factors act on distribution and home plumbing systems beyond treated water quality to cause corrosion activity increases and decreases. It will be difficult for many PWSs to properly assess the ability of treatment changes to optimize or improve the corrosion control protection afforded due to the complex nature of corrosion activity and the variety of materials targeted for protection.

A two-year installation and startup period follows State designation of optimal corrosion control treatment. Systems

should conduct additional sampling and monitoring during this period in order to optimize their operations prior to conducting the required follow-up monitoring. Information needs to be gathered regarding changes in the active chemical forms used for corrosion control regardless of whether precipitation or passivation techniques are employed. For example, if a polyphosphate inhibitor is added to the treated water, it is important to know the concentrations of both orthophosphate and polyphosphate within the distribution system. Important water quality parameters should be measured at the entry points to the distribution system and at various locations within the system including the extremities. Some of the locations monitored during the initial monitoring period should be included.

The primary goal of corrosion control optimization is to achieve and maintain compliance with the lead and copper ALs. However, optimized treatment may exist even though the ALs are exceeded. Further, corrosion control treatment programs must be coordinated with the requirement that all other drinking water standards be met. As noted previously, variations in pH, calcium, and alkalinity that may have positive impacts on compliance with the lead and copper ALs may be detrimental to meeting other criteria. These interrelationships are site-specific and must be defined in each corrosion study. Additionally, optimization may include economic factors so that the most cost-effective means of implementing optimal corrosion control treatment may be achieved.

After corrosion control facilities are operational, optimization should be viewed as a dynamic, rather than static process, where ongoing efforts are made to minimize lead and copper concentrations over time. In addition, future follow-up monitoring, even at reduced frequencies, will require PWSs to formally review the effectiveness of their programs on a periodic basis. As such, corrosion control is an essential and permanent component of an overall water treatment program and PWSs should audit their programs on a routine basis.

5.1.2 Schedule.

Optimal corrosion control treatment, if required, must be installed and operational by the dates presented in Table 5-1. Large systems will have 30 months from the time the corrosion control study is complete until the optimal facilities are on line. This includes a six-month period for the State to review the study and approve the optimal corrosion control approach. Small and medium systems will be required to submit recommendations for optimal corrosion control treatment to the State within six months of exceeding an AL. The State may then take one of the following actions:

- Approve the recommended treatment approach.
- Disapprove or modify the recommended treatment approach.
- Require the installation of an alternate treatment approach.
- Require the purveyor to prepare a study that identifies the optimal corrosion control approach for that system.

Should a small or medium PWS be required to conduct a corrosion control

Table 5-1. Key Compliance Dates for Large, Medium, and Small Systems

System Designation	System Population	Initiate Tap Sampling Program	Complete Tap Sampling Program	Complete Corrosion Control Study	Complete Installation of Optimal Facilities
Large	>50,000	01/92	01/93	07/94	01/97
Medium	> 3,300 & ≤ 50,000	07/92	01/93*	07/95	01/98
Medium (State Designates Treatment)	> 3,300 & ≤ 50,000	07/92	01/93*	N/A	07/96
Small	≤ 3,300	07/93	01/94*	07/96	01/99
Small (State Designates Treatment)	≤ 3,300	07/93	01/94*	N/A	01/98

* The deadlines for those small and medium-size PWSs that meet the ALs in the first six-month round of initial monitoring and fail in the second six-month monitoring period would be delayed by six months.

study by the State, then 18 months are provided for performing the study and an additional 30 months until treatment must be installed and on line.

5.2 Full-Scale Operation of Treatment Alternatives

The development of reasonable operating criteria by which optimal treatment may be described is a compliance step which PWSs and States will be required to implement. At the completion of follow-up monitoring, States are expected to establish the operating ranges or conditions by which PWSs will be judged to be operating optimal corrosion control treatment. These conditions establish the compliance requirements for large PWSs and those small and medium-size PWSs that exceed an AL in the follow-up monitoring. Therefore, it is extremely important that a balance be achieved between: (1) accurately defining optimal treatment goals, and, (2) realistically setting conditions which are feasible to be met by full-scale treatment facilities *AT ALL TIMES*.

5.2.1 Startup Operations.

The transition between bench scale or pipe loop studies and full scale operation is a major one and some difficulties are to be anticipated. The purchase, installation, and trouble-shooting of new equipment are considered to be a normal part of operating a treatment facility and are not discussed here. These functions are extremely necessary, however, and should be performed accordingly.

Startup procedures will vary from facility to facility depending upon the chemicals fed, whether chemicals are dry or liquid, and the type of metering equipment used. In general, more attention needs to be given the entire system during the startup period to ascertain that the proper results are being achieved. Cumulative feed rates for chemicals should initially be recorded at least once per hour and never should be recorded less than once each shift. Metering equipment should be checked for initial accuracy and occasionally thereafter. Some new equipment has a tendency to "drift" at first and it may take a few weeks of operation before the feed rate is consistent. Routine process control and monitoring the product in the treated water are essential elements of any startup program.

Unfortunately many chemicals can be expressed in different units and this can lead to confusion for the unsuspecting operator. The operator needs to determine the amount of active ingredient that is to be fed for corrosion control and then monitor for that ingredient. For instance, the results of a corrosion control study may have determined that a certain inhibitor should be fed at a dose rate of approximately 0.2 mg/L as phosphorus, P, while the supplier identifies his product in terms of phosphate, PO_4. Calcium is sometimes expressed as calcium (Ca), or as lime (CaO), or as hydrated lime [$Ca(OH)_2$], or as calcium carbonate [$CaCO_3$]. The following information may help to avoid confusion.

- 1 mg/L Ca = 1.40 mg/L Ca as CaO
  = 1.85 mg/L Ca as $Ca(OH)_2$
  = 2.50 mg/L Ca as $CaCO_3$
- 1 mg/L P = 3.1 mg/L P as PO_4

Although the startup of chemical feed systems for pH, alkalinity, and calcium

adjustment may require more in-plant attention to regulate dose rates and final adjusted water quality; the addition of an inhibitor is likely to cause more customer concerns. It is not unusual for inhibitors to loosen existing corrosion byproducts when introduced into a distribution system for the first time. These corrosion materials can then be transported to the user's tap and water quality complaints regarding red water, dirty water, sediment, color, or taste and odor may result. Initial doses may be substantially higher than the recommended maintenance dose (three to ten times) in order to acclimate the distribution system to the inhibitor. Alternatively, some systems may need to gradually increase the initial dosages to the maintenance level to minimize the adverse effects that may result from loosening existing corrosion scale or byproducts in the distribution system. These doses may be necessary from a few days to several months in order to accomplish the objectives of the corrosion control program. Additionally, a flushing program during this time can assist in removing corrosion byproducts from dead end locations within the distribution system and also in ensuring that the inhibitor moves throughout the entire system. Because most inhibitors are proprietary products with unknown formulations, it can be difficult to chemically monitor the residual of the inhibitor in the system. Therefore, physical inspections along with maintaining customer comment logs are recommended. It is important to work closely with a reputable supplier to minimize customer complaints while installing full-scale corrosion control treatment.

5.2.2 *Operating Ranges.*

This section will discuss some of the factors that impact an operator's ability to control chemical feed rates and the concentration of calcium, carbonate, and corrosion inhibitors within the distribution system.

5.2.2.1 Historic operating ranges. Technically, pH is an exponential function of the hydrogen ion concentration and calculating the mean hydrogen ion concentration is the appropriate procedure for determining average pH levels. Practically, however, the finished water pH is normally stable enough to allow the arithmetic mean to be used without introducing significant error into operating guidelines. Table 5-2 presents a statistical summary of pH and alkalinity data taken from a variety of water treatment plants across the country. This table shows the annual average (mean) values and the operating range in which 90 percent of the daily values fell. The table also indicates how far the 90 percent range varied from the mean.

A key finding of this work is that site-specific water quality considerations influence the operating ranges that can be achieved. For example, the 90 percent operating range for pH varied from the mean by ±0.2 units at several sites to ±1.0 units at another. For alkalinity, the variance from the mean was about ±10 mg/L $CaCO_3$ for alkalinities below 50 mg/L $CaCO_3$; ±20 mg/L $CaCO_3$ for alkalinities between 50 to 100 mg/L $CaCO_3$; and ±30 mg/L $CaCO_3$ for alkalinities over 100 mg/L $CaCO_3$.

The type of chemical used to adjust pH may also influence daily variations from the mean. Figure 5-1A shows the pH

Table 5-2. Operating Ranges for pH and Alkalinity for 10 Water Treatment Plants

Facility	pH (units)			Alkalinity (mg/l as CaCO3)		
	Annual Average	90% Range	Variance	Annual Average	90% Range	Variance
Plant A (Texas)	8.6	8.2-9.0	±0.4	36	26-46	±10
Plant B (Texas)	8.4	8.0-8.8	±0.4	29	19-39	±10
Plant C (Illinois)	9.0	8.6-9.4	±0.4	58	30-86	±28
Plant D (North Carolina)	8.0	7.4-8.6	±0.6	29	23-35	±6
Plant E (North Carolina)	7.2	6.8-7.6	±0.4	25	19-31	±6
Plant F (Minnesota)	7.1	6.9-7.3	±0.2	74	56-92	±18
Plant G (Georgia)	7.1	6.1-8.1	±1.0	N/A	N/A	N/A
Plant H (North Carolina)	7.6	7.4-7.8	±0.2	31	23-39	±8
Plant I (Missouri)	7.8	7.6-8.0	±0.2	132	102-162	±30
Plant J (Colorado)	7.5	6.9-8.1	±0.6	37	29-45	±8

frequency distribution for Plant D, where moderate amounts of hydrated lime, 10 to 40 mg/L as $Ca(OH)_2$, are added to neutralize the acidity of the raw water. As shown, the finished pH can vary substantially. In this example, 90 percent of the average daily pH values were within 0.6 units of the mean. In contrast, Figure 5-1B shows the pH frequency distribution for Plant H treating the same type of water using sodium hydroxide. At this location, 90 percent of the values were within 0.2 units of the mean, a tighter range.

In this comparison, sodium hydroxide seemed to provide for tighter pH control. This is not always the case, however. For instance, if the raw water did not have sufficient alkalinity and buffering capacity, the use of sodium hydroxide can result in the same or wider pH variations than for lime. It is also of interest that for both plants noted in this example, a phosphate corrosion inhibitor is used and the pH variations are not a major concern with respect to corrosion control. For those systems, one of the parameters that must be monitored is the active chemical agent within the inhibitor, i.e., orthophosphate or silica. It is not appropriate, for example, to monitor zinc levels when using a zinc orthophosphate inhibitor and presume the orthophosphate concentrations correspond directly.

Figures 5-2A and 5-2B show the finished phosphate content of the water prior to entry into the distribution system. These data indicate that the daily residual may vary from 0.2 to 0.5 mg-P/L from the long-term average. The distribution system residual will, of course, experience even greater variations. Because some of the active chemical ingredient in an inhibitor will be consumed or deposited within the system, the inhibitor dose will need to be larger than the minimum level which should be maintained throughout the distribution system.

States should consider the average, minimum and maximum values for such water quality parameters based on several years of operating data, if possible, in determining the minimum or range to be established for the water quality parameters. Variations in water quality conditions entering the distribution system will affect the effectiveness of corrosion control treatment. Calcium carbonate can be somewhat resistant to interruptions in effective treatment once the deposits have hardened. However, the protection provided by carbonate passivation and inhibitor systems is more vulnerable to disruptions in treatment or water quality variability (Elmund, 1992; Lechner, 1991). In these cases, minimum values rather than average distribution system conditions are preferable for pH, alkalinity, orthophosphate or silica (whichever parameters apply).

5.2.2.2 Recommended operating ranges. Based on the above discussion, site-specific conditions contribute to the achievable operating ranges for finished water quality parameters at each facility. States are required by the Rule to set operating conditions which best describe the "optimal" corrosion control treatment installed at each facility. Additionally, the Rule requires that the results from water quality parameter monitoring at distribution system points of entry—minimally required to be performed every two weeks—and at representative locations

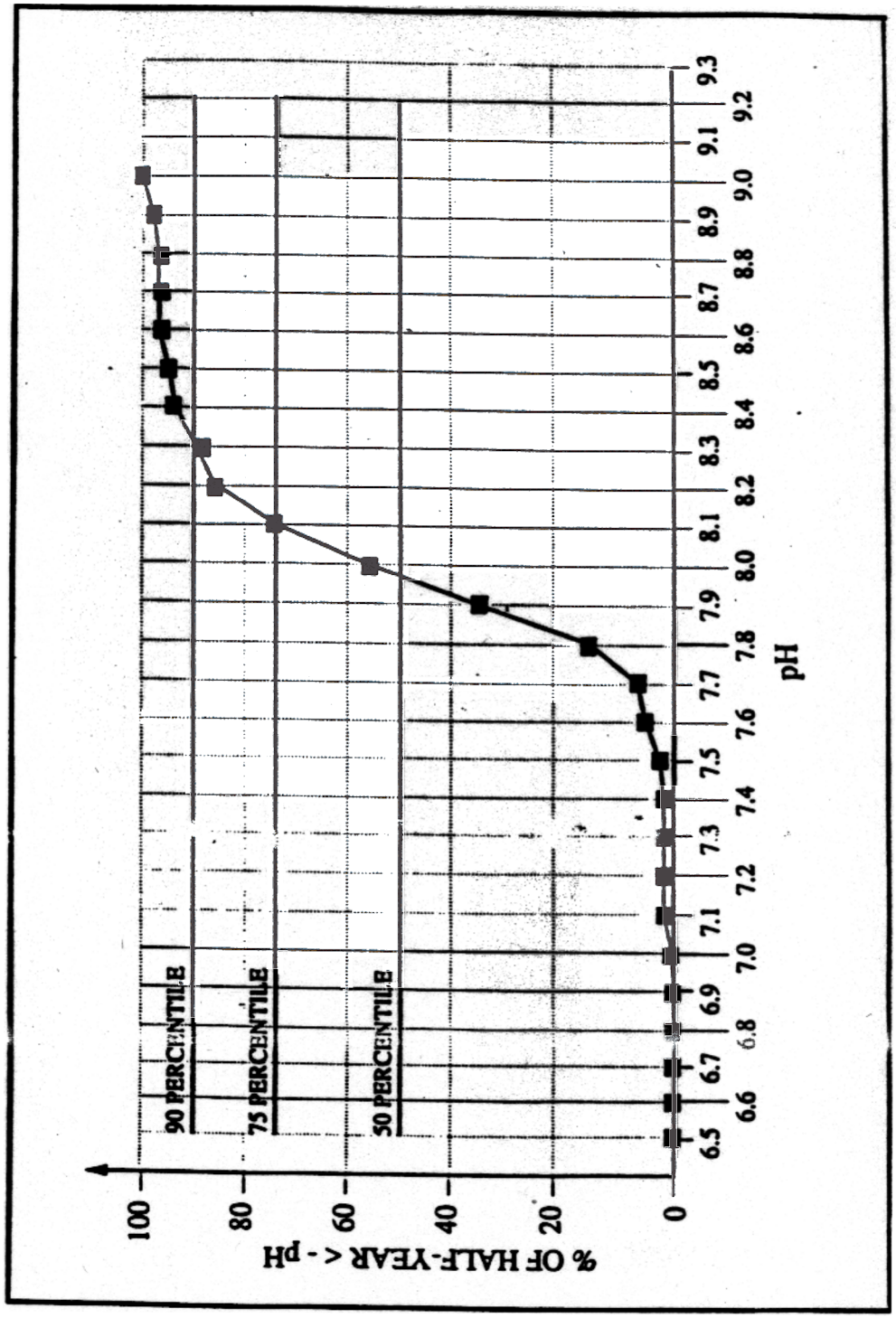

Figure 5-1A. pH Cumulative Frequency Distribution, January to June Plant D

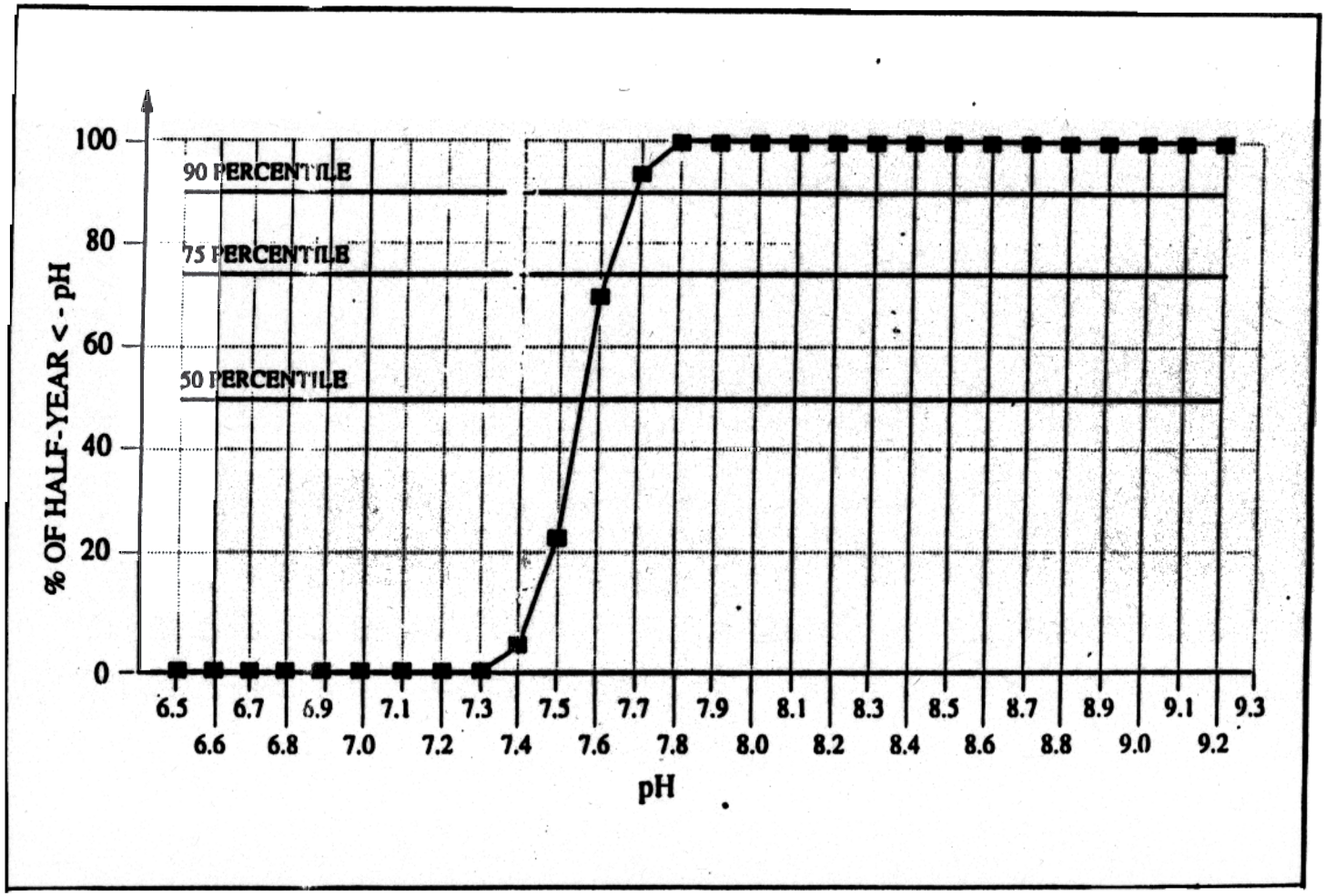

Figure 5-1B. pH Cumulative Frequency Distribution, January to June Plant H

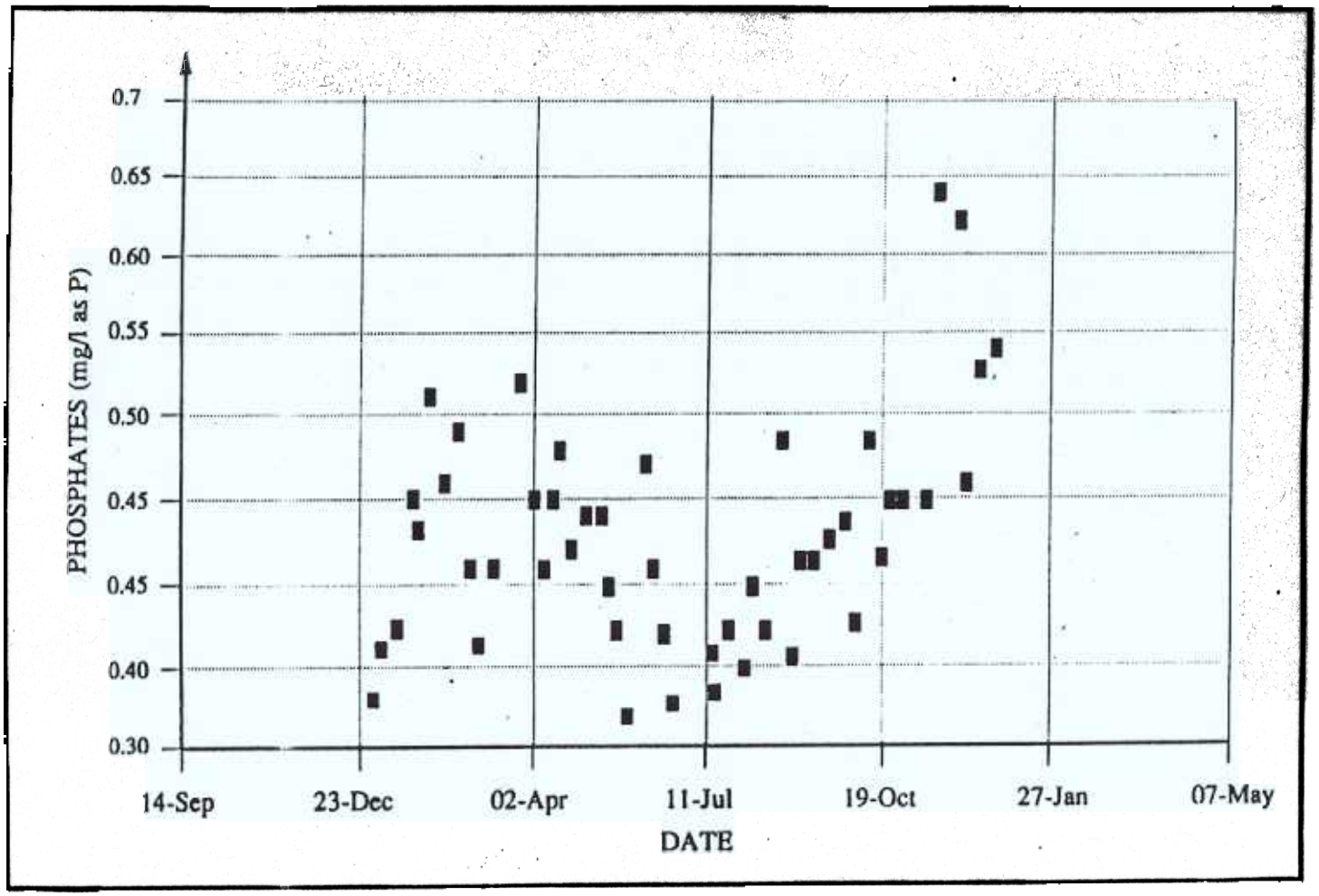

Figure 5-2A. Finished Phosphates vs. Time
Plant D

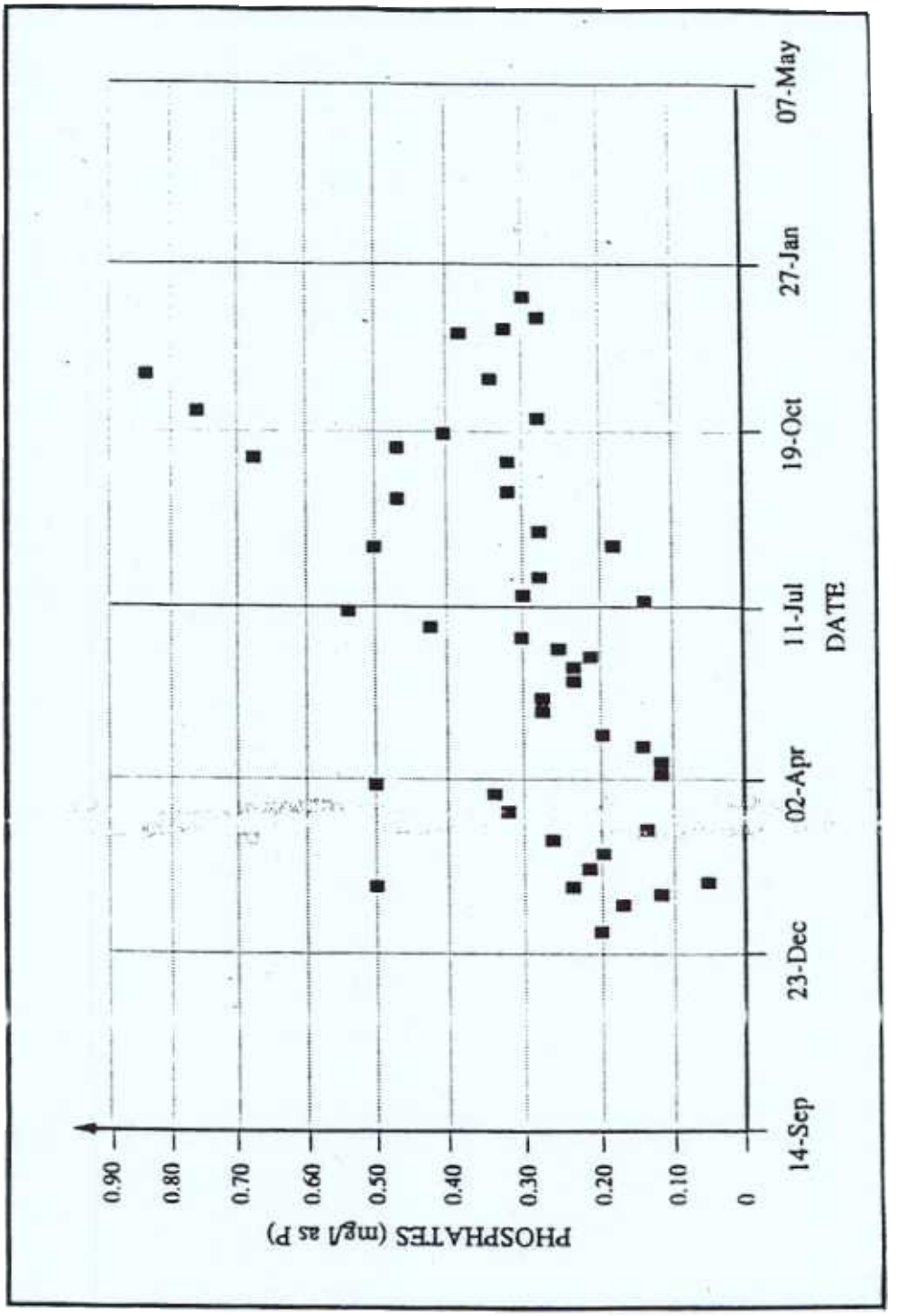

Figure 5-2B. Finished Phosphates vs. Time
Plant H

throughout the distribution system—twice every six months—be reported to the States to demonstrate compliance with the established operating conditions. Real-world variability likely to be encountered at water treatment plants should be considered by States in setting these parameters. To accommodate this feature of the Rule and still provide reasonable operating criteria, States may want to consider establishing one-sided conditions such as minimum values, for the water quality parameters used to describe the optimal treatment process.

For example, assume that a PWS using carbonate passivation as optimal corro-sion control treatment initially set water quality goals for its finished water as follows:

pH	= 7.8 - 8.0
Alkalinity	= 40 - 50 mg/L $CaCO_3$
Total Hardness	= ≥ 30 mg/L $CaCO_3$

During the year of follow-up monitoring, the PWS monitored the finished water for each of these parameters four times a day. The results of this monitoring resulted in the following range of values for each water quality parameter:

pH	= 7.65 - 8.21
Alkalinity	= 37 - 46 mg/L $CaCO_3$
Total Hardness	= 32 - 56 mg/L $CaCO_3$

In this case, the State set as operating criteria for the PWS a minimum pH value of 7.6; minimum alkalinity of 35 mg/L $CaCO_3$; and a minimum hardness of 30 mg/L $CaCO_3$.

For a PWS which practices softening and tries to establish a calcium carbonate precipitation, setting water quality criteria by the pH, alkalinity, and calcium levels independently may be irrelevant to the successful formation of calcium carbonate deposits. States should set minimum water quality parameters such that the PWS can achieve finished water pH, alkalinity, and calcium levels which produce a targeted range in calcium carbonate precipitation potential (CCPP) values. Those systems should include in their reporting data the calculated CCPP value for each monitoring event during the reporting period.

For example, a lime softening system experiences large variability in raw water calcium hardness and alkalinity at different times of the year. The softened water quality also reflects this variability. However, the system can control the finished water pH leaving the plant through its recarbonation process. After reviewing the historical treated water quality, the PWS found that the range for final calcium hardness and alkalinity each was 80 - 160 mg $CaCO_3$/L. The PWS determined that the CCPP target value was 12 mg $CaCO_3$/L for optimal corrosion control treatment. Based on these observations, the PWS calculated the final pH needed to reach the targeted CCPP level based on variable calcium and alkalinity contents as shown below.

The State set the operating guidelines the system based on the above information as follows:

Minimum Alkalinity and Calcium Hardness	= 80 mg $CaCO_3$/L
Minimum pH	= 7.8 units
Average CCPP Value	= 12 mg $CaCO_3$/L

When inhibitors are applied as the method of corrosion control treatment, minimum finished water inhibitor levels should be included in the operating criteria set by the State. In addition, the finished

Table 5-3. Operating Guidelines for Final pH to Meet a CCPP Level of 12 mg/L

Treated Water Alkalinity mg $CaCO_3$/L	Treated Water Calcium Hardness, mg $CaCO_3$/L		
	80	120	160
80	9.2	9.1	9.0
100	9.0	8.9	8.7
120	8.9	8.6	8.3
140	8.7	8.3	8.0
160	8.5	8.0	7.8

water pH is often important to the performance of the specific corrosion inhibitor, and thus an operating criteria for pH is also required. The results of the follow-up monitoring should be evaluated to determine the minimum inhibitor dosage needed to provide an effective residual inhibitor level throughout the distribution system. States should recognize that the introduction of inhibitors into distribution systems can cause initial disturbances in the existing corrosion byproducts and thereby reduce the aesthetic quality of the delivered water to the consumer. Therefore, many PWSs may begin inhibitor treatment with elevated or reduced inhibitor dosages (as compared to that recommended for optimal treatment) in order to cause the least distribution system upset during this initial conditioning period.

In reviewing the follow-up data for inhibitor applications, States should evaluate the inhibitor-demand exerted throughout the distribution system. The inhibitor-demand is the depletion of inhibitor concentration from the points of entry to the distribution system to the locations where water quality parameters monitoring occurs (or the dose minus the residual concentration). Since water systems may either over-dose or under-dose initially, the minimum dosage required by the State should be equivalent to the average inhibitor demand found during follow-up monitoring plus the concentration of an effective inhibitor residual. For example, if a PWS found that the average orthophosphate demand within its distribution system during follow-up sampling was 0.5 mg PO_4/L, the State may require a minimum dosage of 0.8 mg PO_4/L to produce an residual orthophosphate residual of 0.3 mg PO_4/L throughout the distribution system.

5.2.3 Diagnostic Sampling.

The LCR has specific monitoring requirements for initial monitoring, follow-up monitoring, and reduced monitoring. Specified periods in which to monitor as well as certain sampling and testing procedures all must be followed for tap

samples and water quality parameters at points of entry and within the distribution system. Additional sampling, however, should be considered by the PWSs. Termed diagnostic sampling, the purpose of additional sampling and monitoring would be to assist in defining problems so that proper corrective action could be taken. Gathering additional information early in the process can be the key to successfully meeting the lead and copper ALs during the follow-up monitoring period. These additional data do not need to be reported as part of the compliance monitoring.

Sampling procedures do not need to follow the protocol outlined in the LCR, but instead can be designed to evaluate a specific situation. For example, perhaps a certain sampling location gives abnormally high lead values during the initial monitoring period. The initial first-draw tap sample was a one-liter sample as required by the Rule and was collected at the kitchen sink. Additional sequential 100 mL samples collected at the same tap might show an extremely high lead concentration in the first 100 mL while subsequent samples had low lead levels. Data such as these would tend to indicate a problem with the immediate water fixture which the homeowner could be encouraged to replace.

Additional sampling within the distribution system will almost surely be necessary if the water chemistry is changed or an inhibitor is added. In this case, diagnostic monitoring will help stabilize treated water quality by indicating if chemical feed systems are properly adjusted or if inhibitor concentrations are penetrating throughout the distribution system, for example. Using diagnostic monitoring to assist in optimizing corrosion control treatment to meet the ALs can aid a PWS by reducing future monitoring, eliminating the need to replace lead service lines, and allowing the public education program to be discontinued.

5.2.4 Operational Notes on Various Treatments.

Achievement of operating goals is dependent on the raw water quality variability, process control capabilities, chemical feed systems employed, and the equipment used at each PWS. This section discusses aspects of operating a corrosion control treatment program successfully and the various problems which may be encountered based on the chemical feed system used for each treatment approach.

5.2.4.1 Calcium carbonate precipitation. With this technique, the concentration of calcium and carbonate ions is such that their solubility is exceeded and calcium carbonate solids precipitate to form a protective coating on the interior pipe walls. In essence, the use of cement-lined metal pipes is an effort to provide a protective lining even if the water quality conditions do not favor calcium carbonate precipitation.

Depending upon water chemistry, it may be necessary to adjust the calcium, carbonate, or hydrogen ion content of the water to form a calcium carbonate film. Calcium supplementation is usually achieved by adding hydrated or quick lime; and carbonate adjustment can be accomplished by adding soda ash, sodium bicarbonate, or carbon dioxide. Hydrogen ion, or pH, adjustment may be accom-

plished by adding any of these chemicals in addition to other bases or acids such as caustic soda, hydrochloric acid, or sulfuric acid. It is difficult to establish a uniform thickness of calcium carbonate on interior pipe walls throughout the distribution system. If excessive precipitation occurs in some portions of the system, a significant reduction in hydraulic capacity may be experienced.

For large systems, storage silos are provided for solid chemicals, such as lime (CaO), and the bins are equipped with vibrators and compressed air agitators to reduce clumping and promote the flow of chemical into gravimetric or volumetric feeders. The feeders discharge the dry chemical into solution tanks where it is dissolved into water. Lime can have a significant amount of impurities and solution tanks have provisions for collecting and purging inert particles. In some situations, it is more economical to use quicklime, and slake it onsite, rather than purchase hydrated lime directly from the supplier. To use quicklime requires additional equipment to slake the calcium oxide and remove impurities that are contained within the material. As a result, slaking operations are generally used in larger facilities or lime softening plants which use more lime where the investment and operation of such equipment can be justified.

For smaller plants or those requiring low to moderate dosages, hydrated lime is normally used and continuous or semi-continuous solution tanks are more appropriate and economical for large operations. Removal of impurities is still important with hydrated lime, particularly when it is fed downstream of filters or in situations where no filters are used. Depending upon site-specific design factors, the solutions can be fed to the water by gravity, using weirs or rotodip feeders, or chemical feed pumps.

Lime and soda ash systems require a high degree of operator attention due to calcium carbonate plugging of bins, tanks, pumps, and piping. To reduce the amount of downtime due to such plugging problems, bins must be kept dry and provisions should be made for acid cleaning of the feed systems. Because of this concern, the reliability of dry chemical feed equipment is less than that for liquid systems. Redundancy of solution tanks and chemical feed pumps can reduce the likelihood of extensive treatment interruptions, providing further assurances of continuous corrosion control operations.

Where the natural concentrations of calcium and inorganic carbonate contents are sufficient but the pH is too low for a precipitate to form, sodium hydroxide can be used to increase the pH to the point that calcium carbonate precipitation will occur. Sodium hydroxide is normally delivered as a 50 percent solution and diluted at the time of delivery to 20 to 30 percent. Dilution is helpful in reducing crystallization that can occur at temperatures below 50°F. Indoor storage facilities are normally used even for the diluted sodium hydroxide solution. If dilution is practiced, consideration should be given to ion exchange softening of the dilution water to prevent calcium carbonate plugging of the sodium hydroxide feed system. Employee safety and spill containment are important design concerns with sodium hydroxide systems.

For lime and lime/soda softening systems, lime and soda ash are added at various points throughout the treatment train to remove carbonate and non-carbonate hardness. The final pH is adjusted through carbon dioxide or acid addition to prevent excessive encrustation of filters and still provide the long-term accumulation of a calcium carbonate film within the distribution system pipes. For turbidity removal plants using aluminum or iron salts, the location of lime, soda ash, or bicarbonate feed points should be carefully considered, balancing the water quality requirements for coagulation, filtration, and disinfection performance with that of corrosion control.

In summary, the choice regarding which chemical(s) to use and where to apply them must integrate water chemistry, customer acceptance, cost, reliability, safety, and operator preference issues. Therefore, there is no chemical that is right for all locations and representatives of management, operations, and engineering should be included in the decision-making process.

5.2.4.2 Carbonate passivation. Carbonate passivation is a corrosion control technique where the pipe materials are incorporated into a metal/hydroxide/carbonate film that protects the pipe. This technique is most suitable for low hardness and alkalinity waters where the PWS does not want to drastically alter the water chemistry, and historic customer acceptance of the water, to the point that calcium carbonate precipitation will occur.

Passivation may be achieved by alkalinity and pH modification using such chemicals as lime, soda ash, sodium bicarbonate, sodium hydroxide, potassium hydroxide, and/or carbon dioxide. Consequently, the same chemicals and feed systems are used for carbonate passivation as for the calcium carbonate film technique noted above.

5.2.4.3 Inhibitors. A wide variety of specialty chemicals, most of them phosphate or silicate based, can be added to the finished water to reduce corrosion within the distribution system. One phosphate-based inhibitor is zinc orthophosphate. With this chemical, it is suspected that the zinc and phosphate components are involved in forming a protective film and providing corrosion protection. With polyphosphate chemicals, direct corrosion protection appears to be minimal except that which may be afforded by the formation of orthophosphate constituents within the distribution system as the polyphosphate reverts to orthophosphate. Sodium silicate is another corrosion inhibitor for which limited performance data is available regarding the reduction of lead and copper corrosion activity.

A potential problem with orthophosphates is that when they are first added to a distribution system, previously corroded material may be released and cause aesthetic problems with the water. This is especially true if the treated water pH is lowered concurrently with the addition of the inhibitor. Additionally, polyphosphates generally will exhibit more of a tendency to remove corrosion byproducts than orthophosphate formulations. Polyphosphates are sometimes used to chemically remove tuberculation and scale. To minimize the potentially negative customer reaction to such a situation, low dosages may be used initially and then

slowly increased to the desired full strength dose. Alternatively, systems may initially feed inhibitor doses much higher than the maintenance level to acclimate the distribution system when concerns about releasing excess corrosion products in the delivered water are not significant. Properly timed public education and flushing programs can also be used to minimize the temporary aesthetic problems that may occur with orthophosphate addition.

No direct evidence is available indicating that the introduction of phosphate-based corrosion inhibitors would foster or encourage the growth of bacteria in the distribution system. Instead, the findings of a number of studies indicate the positive response of distribution system water quality to the implementation of effective corrosion control programs (LeChevalier et al., 1987, 1988a, 1988b, 1990). Microbiological growth within piping systems appears to be more strongly linked to their tendency to grow in conjunction with corrosion byproducts, such as tubercles, than the supplementation of nutrients in the form of phosphates or inorganic carbonate species (AWWARF, 1990). Corrosion control programs which reduce corrosion scale buildup has appeared to reduce the occurrence of bacteria in distribution system water samples.

However, the potential impact of any treatment method on the microbiological behavior of the distribution system is an important consideration. Some testing methods are available for evaluating this impact.

Although not to be interpreted as corrosion control, a primary use of polyphosphates is to sequester dissolved metal or cationic constituent—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. New orthopolyphosphate blends are being produced which can 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 for other treatment objectives.

With respect to chemical feed systems, silicate and phosphate compounds are not inherently dangerous or corrosive, have a long shelf life, and are highly soluble in water. These features allow the use of relatively small batch tanks and feed pumps. If sodium silicates are being used after dilution, the day tanks should be

sized to fully utilize the solubilized silicate within 24 hours to ensure effective application. Since aging times are not needed and short disruptions of service can be tolerated, single tank systems are feasible. For more reliable service, multiple batch tanks with automatic switch-over can be used. Multiple tanks also facilitate cleaning and maintenance of the system.

Depending upon which chemical is selected, the batch tanks may contain a phosphate-rich solution. Since biological growths can occur in the tanks, provisions should be made to routinely clean them. It may also be desirable to provide for supplemental chlorination of the water in the batch tanks to reduce biological growths. Chlorine addition to polyphosphate or ortho-polyphosphate solution water may not be advisable for those situations where sequestering of iron and manganese is important. The chlorine will tend to oxidize these metals, causing some of them to precipitate before they can be sequestered by the polyphosphates. Silicates are not a nutrient and feed system design and maintenance requirements are less than for phosphate-based inhibitors. In fact, some plants have been known to mix silicates and fluoride in the same tank and feed them concurrently using the same pumps. The sodium concentration is also a consideration when sodium silicate is used.

If the PWS desires the inhibitor to also act as a sequestering agent for iron and manganese, chemical addition should occur upstream of the first point where chlorine is added. If iron and manganese are not a problem, the inhibitor can be added to the finished water downstream of chlorination.

5.2.5 Reliability.

The reliability of the various treatment approaches to continuously provide corrosion control protection is not clearly understood with regard to the home plumbing environment. Some limited evidence has indicated that copper corrosion can recur when carbonate passivation treatment is interrupted for very brief periods of time (on the order of a couple of days) (Elmund, 1992). It has also been reported that phosphate-based inhibitors can support longer interruptions prior to reversion of corrosion activity (30 or more days) (Lechner, 1991). However, the Lead and Copper Rule requires that corrosion control treatment be operated at all times. The water quality monitoring is required every two weeks to demonstrate that treatment is continuously provided. Therefore, treatment interruptions due to maintenance, chemical inventory problems, and/or equipment and instrumentation failures must be minimized regardless of the treatment approach selected.

While the goal for system reliability is operational functioning 100 percent of the time, realistic performance may be less than this goal. The design of the full-scale system, however, can incorporate redundancy and/or alarm features which can assist PWSs in maintaining continuous operations.

5.2.6 Instrumentation and Control.

For calcium carbonate precipitation and carbonate passivation, pH is typically used as a real-time instrumentation and control parameter. While pH is an indirect

measurement of calcium carbonate precipitation or carbonate passivation, it is a proven, direct loop control parameter and with experience, the operators can reliably produce finished water with the pH within the range that works best for a particular system. Although specific ion probes are available for calcium, carbonate is most commonly measured by a titration process. While calcium content or pH can be used for on-line monitoring and chemical feed control, they may be correlated to such corrosion monitors as lead and copper levels in tap sampling programs, or test results from coupons or pipe inserts from the distribution system.

For inhibitors, the treatment goals typically concern only the applied dosage. Therefore, pacing chemical feed according to flow and routinely checking for system residuals of the inhibitor may be sufficient operational control. Through the corrosion control study, PWSs may determine the residual concentration that minimizes corrosion, cost, and undesirable side effects. If a higher level of operational control is desired, it may be possible to tie the inhibitor feed pump to a corrosion activity monitor utilizing electronic measurement techniques with settings predetermined for optimal corrosion control conditions.

5.2.7 Troubleshooting.

The purity of the chemicals used for corrosion control treatment can vary, especially for hydrated lime and quicklime. These chemicals will contain inert material which must be removed through a de-gritting process, and an allowance for inert material must be made when establishing chemical feed rates. For example, the amount of impurities in quicklime can vary from 4 to 30 percent, with a typical value of 10 percent for municipal grade lime. If a PWS determines that the quicklime they are using contains 90 percent calcium oxide (i.e. 10 percent impurities), an additional 11 percent of the bulk chemical must be added to achieve the desired lime dose (100/90 = 1.11, i.e., 11 percent additional). The purity factors are better for hydrated lime which may only contain 1 to 5 percent impurities, and better still for soda ash which may only contain 1 to 2 percent impurities.

Purity factors are less of a concern with sodium hydroxide and corrosion inhibitors. There are many proprietary corrosion inhibitors, particularly for the phosphate group of chemicals. While these chemicals may be effective, PWSs may not always know the exact amount and type of compounds contained in the product. Suppliers should submit documentation that their products are safe to use in a potable water application. In some situations, Food and Drug Administration approvals are appropriate. In other cases, the general type of chemical will be listed by the Code of Federal Regulations as a "...substance generally recognized as safe."

Each State has a drinking water direct additives program which follows either the National Sanitation Foundation Health Effects Standard 60 or its own standards for judging the suitability of direct additives for potable use. Any corrosion control chemical used at a PWS must comply with the State's direct additives program requirements.

Staffing requirements may increase with the implementation of corrosion control treatment and additional testing

required by the Lead and Copper Rule. Due to the factors noted above, labor and maintenance requirements may be higher for calcium carbonate precipitation and carbonate passivation than for the addition of a corrosion inhibitor. Regardless, PWSs that are required to provide optimal corrosion control treatment need to schedule and budget for the additional staff that may be needed. The schedule presented in Table 5-1 can be used to coordinate hiring and training requirements in advance of the dates when corrosion control treatment is required to be on line.

Recognizing that problems may occur with the startup of any new treatment component, PWSs should collect appropriate data and analyze the trends that occur. One of the unique issues about corrosion control is that a substantial amount of time may elapse between the time treatment changes are made and their effects are detected through the analysis of tap samples or corrosion monitors. For this reason, detailed recordkeeping procedures should be developed and followed to correlate proper control of the treatment processes with the desired effects in the distribution system.

Important records will include customer complaints such as colored water, stained fixtures or laundry, taste and odor problems, and the lack of water pressure. These records should also include data regarding the age of the house, type of interior and exterior plumbing, and the utilization of onsite point of use (POU) equipment such as softeners or carbon filtration systems. The PWS's follow-up action to the customer complaint should also be noted in the records.

5.3 Optimization Techniques

Optimization of corrosion control treatment encumbers two overall phases: (1) diagnosis of the need for optimization; and (2) methods for implementing optimization techniques and addressing the possible outcomes from such actions.

5.3.1 Diagnosing the Need for Optimization.

Many PWSs may install optimal corrosion control treatment and still experience excessive lead, copper, or other corrosion byproducts in the delivered water. Determining when treatment has been optimized—i.e., providing the maximum corrosion protection possible through water treatment—is the first step. Additional sampling and monitoring (see Diagnostic Monitoring, Section 5.2.3) should be used to assist in optimizing corrosion control treatment. Monitoring during the two-year installation period can be an important key in meeting ALs during subsequent compliance monitoring periods, and data collected during this two-year period do not have to be reported to the State. PWSs should consider monitoring for the appropriate water quality parameters at the entry point(s) to the distribution system as well as within the distribution system. Collecting tap samples for lead and copper determinations will assist in maintaining contact with homeowners who assisted during the initial monitoring phase as well as providing important information regarding improvements to water quality resulting from the corrosion control treatment.

Since corrosion control practices to minimize lead and copper levels in first-draw tap samples has not been generally practiced by the drinking water community, little information is available demonstrating the performance of treatment optimization techniques. Therefore, PWSs must approach optimization with caution, allowing sufficient time for treatment to become effective and stabilize before implementing any changes in an attempt to improve system performance.

Data collection efforts regarding the corrosion behavior of the distribution system and home plumbing environments should be used to develop long-term trends in system behavior. Given the variability in corrosion activity, observations of improvements in corrosion protection should be confirmed by at least one year of monitoring data before any changes are considered. However, distribution system upsets by the installation of corrosion control treatment—such as the release of existing corrosion byproducts when inhibitors are first applied—may be realized very quickly after startup of treatment. When degradation of water quality in the distribution system and at consumers' taps occurs, a timely response should be made by PWSs to address these problems.

The following steps should be addressed in the priority shown to logically progress through optimization of the installed treatment process:

- Step 1 - Select treatment chemicals which enable the WTP to meet its optimal corrosion control treatment objectives;
- Step 2 - Select chemical application points within the WTP to provide optimal utilization of each chemical additive;
- Step 3 - Reduce water quality parameter variability at the points of entry to the distribution system;
- Step 4 - Reduce water quality parameter variability within the distribution system;
- Step 5 - Modify the water quality parameter goals that define optimal corrosion control treatment and thereby the chemical feed requirements.

Steps 1 and 2 should be addressed initially during the corrosion control study; however, changes in other water treatment processes or the need to improve corrosion control performance may cause their reevaluation. Steps 3 and 4 focus on the ability of the WTP and distribution system to be operated in accordance with the corrosion control treatment goals. In many cases, optimization for PWSs will consist of addressing these conditions. Maintaining consistent water quality leaving plants and within distribution systems can be difficult, and optimizing treatment without such control may not be possible. Step 5 relies on changing the actual goals defining that treatment for optimization, and should only be pursued as the last option by PWSs and must be approved by the State.

Any change in treatment or plant operations can impart adverse effects on other water treatment or water quality goals. General relationships may be described to illustrate the effect of water quality changes on treatment and finished water quality objectives. Table 5-4 identifies the major water quality characteristics of concern and provides a general indication of their influence and effects. Decisions related to corrosion control

Table 5-4. Relational Behavior of Changing Water Quality Conditions for Corrosion Control Treatment and Other Water Quality/Treatment Objectives

Water Quality Change	Impact
Non-Softening WTPs: **pH Increase - After Filtration**	• Increase in TTHM formation. • Decrease in haloacetic acid formation. • Increase in final turbidity when lime is used. • Reduced disinfection efficacy. • Post-filtration precipitation of manganese.
Softening and Non-Softening WTPs: **pH Increase - Before Filtration**	• Reduced disinfection by-product precursor removal when alum coagulation is practiced. • Increase in TTHM formation. • Decrease in haloacetic acid formation. • Reduced disinfection efficacy unless at pH levels above 9.0. • Increased soluble aluminum levels when alum coagulation is practiced. • Increased removal of manganese. • Increased encrustation of filter media when excess calcium carbonate available. • Excess precipitation of calcium carbonate when available in pipe network near WTP.
Softening WTPs: **pH Decrease - Before Filtration**	• Decrease in TTHM formation. • Increase in haloacetic acid formation. • Reduced encrustation of filter media. • Reduced soluble aluminum levels when alum is added during softening.
Alkalinity Increase	• Increase ozone demand for disinfection.
Alkalinity Decrease	At very low levels, reduced coagulation performance when using alum.
Calcium Increase	Increased encrustation of filter media when excess calcium carbonate available. Excess precipitation of calcium carbonate when available in pipe network near WTP. Increase scavenging of phosphate inhibitors used for either corrosion control or chelation. If after filtration, finished water turbidity increases.
Calcium Decrease (Softening WTPs)	• Prevent excess precipitation of calcium carbonate in pipe network near WTP.
Phosphate Increase	• Stripping of existing corrosion by-products in the distribution system causing aesthetic quality degradation and increasing HPC levels initially due to biofilm disturbances.
Silicate Increase	• May reduce useful life of domestic hot water heaters due to "glassification"; silicates precipitate rapidly at higher temperatures.

optimization should not be based solely on the limited information presented in Table 5-4. This table is more appropriately used as a screening tool and a vehicle for focusing current and future investigative efforts in developing optimization approaches.

5.3.2 Methods for Evaluating Treatment.

Identifying the corrosion behavior of the distribution system and home plumbing environments after the implementation of optimal corrosion control treatment is necessary to determine whether potential improvements may be made by optimizing corrosion control treatment. The methods discussed in this section may assist PWSs in developing long-term trends in corrosion control performance. Not all data collection efforts are necessary, but PWSs should consider more than one method for evaluating the actual performance of treatment since no single technique can completely describe the variety of corrosion activity and its possible causes.

5.3.2.1 Water quality parameters. After implementing an optimal corrosion control program, follow-up monitoring is required for pH, alkalinity, and calcium for all large PWSs and those small and medium-size PWSs that exceed an AL. In addition, orthophosphate or silica monitoring is also mandatory if one of these corrosion inhibitors is used. To assist in the optimization process, PWSs are encouraged to measure these water quality parameters in the tap samples collected from consumers' homes. This would be useful in tracking both the success of the corrosion control program and the alteration of water quality within consumers' plumbing systems.

Increases in THM formation are observed with increasing pH and this may be a concern for those systems where the pH is increased as part of the corrosion control program. Therefore, additional THM testing within the distribution system may give insight about whether further adjustments can or should be made in the finished water pH.

Microbiological activity within the distribution system should be closely monitored after installing corrosion control treatment. Several studies investigating the impact of corrosion control on the behavior of biofilms have generally concluded that reductions in corrosion activity significantly reduces: (1) the likelihood of biofilm growth; and (2) the resistance of microorganisms to disinfectants. The additional nutrients which may be added as a result of corrosion control treatment has not been shown to increase the biological activity of the distribution system. Total coliform monitoring as required by the Total Coliform Rule and regular testing for heterotrophic plate count bacteria would assist PWSs in understanding the response of the distribution system to corrosion control treatment.

5.3.2.2 Lead and copper data. All PWSs required to install corrosion control treatment must perform routine monitoring of first-draw tap samples for lead and copper. These data may be used to determine the long-term effectiveness of corrosion control treatment and the ongoing actions required by the Rule, such as public education or lead service line replacement programs.

As a check on the consistency of the treatment process and the impact of varying hydraulic conditions and water blends within the distribution system, the PWS may find it useful to collect first-draw samples for five or more consecutive days at a representative number of sites prior to the start of the follow-up monitoring period. The additional tests should be considered diagnostic monitoring (Section 5.2.3) rather than compliance sampling. If the lead and copper results from a particular tap vary significantly from day-to-day, it indicates that the corrosion control program is not achieving consistent results in that location. Depending upon how widespread the inconsistencies are, the PWS should investigate whether chemical feed problems, variations in raw water source, hydraulic changes in the distribution system, or site-specific conditions are contributing to the daily variation in lead and copper values. The goal of such additional testing is to ensure that corrosion control objectives are consistently met at all times.

5.3.2.3 Coupons and pipe inserts. Coupons are available in a variety of metals, such as lead, copper, cast iron, bronze, and mild steel. Mild steel and copper coupons are most frequently used. Typically, coupons are placed in 8-inch or larger pipes and in locations that have moderate flow velocities (2-6 fps). Coupon locations should avoid both stagnant and high velocity flow conditions that are not representative of the system as a whole.

When properly placed within the distribution system, coupons provide a direct indication of corrosion rates within the pipe network. Some of their limitations, however, include the fact that it takes a long time to obtain accurate values and coupons cannot be used to indicate short-term changes in water quality characteristics. For example, multiple coupons should be used at each site so that corrosion rates over varying lengths of exposure time may be measured. This also provides information regarding the impact of seasonal variations on corrosion activity. In addition, while the coupon insertion and removal equipment is moderately priced, additional costs may be incurred to construct access vaults at the locations where coupons should be placed. Finally, coupons are typically located within the main pipe network and this is not necessarily representative of the home plumbing environment which lead and copper monitoring reflects.

In summary, coupons can provide meaningful information regarding the rate at which exposed metal will corrode or become encrusted with scale-forming deposits within distribution system piping networks. As such, PWSs should consider their use as part of a comprehensive corrosion monitoring program but should not rely solely on these measures to assess corrosion control performance.

Pipe inserts are small segments of uncoated metal pipe that are part of the distribution system. Inserts can be placed in a vault that includes a bypass line so the insert can be removed from service and inspected for corrosion or deposition. Inserts provide the opportunity to see what is happening to the pipe wall itself, rather than pieces of metal inserted into the pipe. By coring or cutting sections from the pipe, the thickness of the remaining metal or deposit can be directly measured. Ultra-

sonic instruments are also available to indirectly measure the thickness of the metal and/or deposit.

Pipe inserts suffer many of the same limitations as coupons since they must remain in place for long periods of time, may be expensive to install and remove, and are not be representative of home plumbing conditions. As with coupons, however, pipe inserts can provide relative information on the effectiveness of a corrosion control program.

5.3.2.4 Corrosion indices. Corrosion indices have been used within the drinking water community to assess the likelihood of forming calcium carbonate scales on pipes, and are derived from calcium carbonate equilibrium relationships. Limitations of the usefulness of these indices needs to be recognized. When optimal treatment consists of calcium carbonate precipitation, indices may properly describe the mechanisms of corrosion control desired. However, the equilibrium relationships upon which most indices are based do not hold true when any inhibitor is present, including polyphosphates which are typically used to prevent metals and/or calcium from precipitating (in the case of many softening plants, polyphosphates are applied before filtration to keep the filters from becoming encrusted by calcium carbonate). Corrosion indices have little merit for those PWSs applying carbonate or inhibitor passivation as corrosion control treatment, and should not be used to describe treatment goals. For calcium carbonate precipitation treatment, the CCPP index is recommended and Appendix A provides a detailed description of its calculation methods.

5.3.2.5 Corrosion monitors. There are several means for making discrete observation or measurement of corrosion. These include X-ray, ultrasonic, visual, and destructive testing. While each of these measurement techniques may be useful in a particular situation, this section will focus on electronic monitoring systems which can be used while the distribution system is in operation. Some of the electronic monitoring devices measure the byproducts of galvanic corrosion and others will detect the loss of metal whether it is due to galvanic action, leaching, or some other corrosion mechanism.

5.3.2.5.1 Hydrogen probes. As part of the oxidation/reduction reaction in acidic solutions, hydrogen atoms will migrate to cathode sites on the inside surface of metal pipes. One type of probe allows these hydrogen atoms to penetrate, combine, and form hydrogen gas. The gas will exert pressure which is proportional to the amount of galvanic corrosion that is occurring within pipeline. Another type of probe uses palladium foil to create an electrical output which is directly proportional to the hydrogen evolution rate. By recording pressure reading or electrical output trends, changes in the corrosion rate can be detected.

5.3.2.5.2 Electrical resistance. This type of instrument measures the electrical resistance of a thin metal probe inserted into the pipeline. Compared to conventional coupons, electrical resistance probes provide results with a minimal amount of effort. Continuous readings can be made and the data analyzed to identify corrosion trends. For example, an increase

in electrical resistance would likely indicate an increase in corrosion rates.

5.3.2.5.3 Linear polarization resistance. In a galvanic corrosion cell, the pipe metal is oxidized, or corroded, at the anode and cations in the solution are reduced at the cathode. In this process, electrons are transferred between anodic and cathodic areas on the corroding metal. When a small voltage potential is applied across the electrolyte fluid, the electrical resistance is linear and the corrosion current flow (corrosion rate) is directly proportional to the measured current flow. In dilute solutions such as drinking water, the resistance of the electrolyte can be significant compared to the polarization resistance of the anode and cathode sites. In these situations, the probe must be of the type that will measure and compensate for the resistance of the solution.

Compared to metal coupon and electrical resistance monitoring, linear polarization probes provide a direct reading of the corrosion current and rate. This allows for instantaneous measurement of the changes that occur with the type and amount of corrosion control chemicals that are added to the water. Linear polarization measurements, however, cannot be made in nonconductive fluids or those which coat the electrodes. Therefore, they may not be appropriate in those situations where a calcium carbonate film is used to coat the distribution system.

5.3.2.5.4 Electrochemical noise. This a monitoring technique which measures the electrochemical disturbances created by corrosion activity. Potential limitations include the fact that other sources of electrical disturbance, such as those from an impressed current system, can result in overestimates of the corrosion rate. This technique, however, is used by some equipment manufacturers to indicate the "pitting index" for a particular pipeline/electrolyte combination.

5.3.2.5.5 Application suggestions. Electronic corrosion monitoring equipment can provide a rapid evaluation of corrosion control treatment alternatives and chemical feed rates. These probes are not infallible, however, and the electronic measurements need to be correlated with the results from other indicators such as lead and copper data, conventional coupons, pipe inserts, and water quality indices. Once the relationship between electronic measurements and actual field corrosion conditions is established, corrosion monitors can be a useful tool for monitoring plant performance and maintaining the finished water within the operating parameters discussed in Section 5.2.2.

5.4 Optimizing Corrosion Control Treatment—Examples

Each PWS will experience unique circumstances surrounding the optimization of corrosion control treatment based on site-specific conditions, treatment objectives, and other considerations affecting the performance and operation of the distribution system. The following examples illustrate the types of problems which PWSs may encounter and approaches to solve treatment and operational concerns.

5.4.1 Optimal Corrosion Control in a Consecutive System.

East Bumford County runs a surface water filtration plant that delivers water to a number of small and medium-size towns. To more efficiently implement the rule, the towns petitioned and received approval to have the county water treatment plant and the entire distribution system be considered as a consolidated large water system.

As part of the consolidation, East Bumford County agreed to be responsible for implementing the provisions of the Lead and Copper Rule. All water treatment, sampling, and monitoring costs were to be paid for by the County with reimbursement by the towns on a population-weighted basis. Additionally, any lead service line replacements were to be paid for by the town in which they were being replaced.

Addition of a phosphate inhibitor to the water treatment plant effluent was approved by the state as optimal corrosion control. While conducting follow-up monitoring to determine their optimal corrosion control parameters, the consolidated system was found to have met both the lead and copper action levels. However, East Bumford County found that the water in a remote section of Wakuska Township was not maintaining a phosphate residual. Apparently, the long residence time between the treatment plant and the remote section of Wakuska caused its depletion.

At a subsequent meeting of East Bumford County's member communities, an agreement was reached whereby Wakuska Township would pay for a chemical feed station to supplement the phosphate inhibitor in their distribution system. It was located downstream of Wakuska's storage reservoir after the Town's master flowmeter. Wakuska Township agreed to pay all costs associated with the chemical feed station and East Bumford County agreed to provide operational and maintenance support.

During the subsequent round of routine monitoring, effective residual phosphate concentrations were achieved throughout the entire consolidated distribution system. This permitted East Bumford County and its member communities to comply with the State-specified operating ranges under the Lead and Copper Rule.

5.4.2 Use of Corrosion Monitors in a Large System.

As a large system with historical corrosion problems, Plimpton City had been experimenting with control strategies for a number of years. The City found that it could reduce the number of red water complaints if the lime-softening plant was operated to achieve a CCPP index of 6 mg/L $CaCO_3$ in the plant effluent. Even with this operation, though, the distribution system still experienced some red water, and early initial monitoring results showed that the system would not meet the lead action levels.

Realizing that their attempts at corrosion control to date would not satisfy the provisions of the LCR, the City supplemented their existing program by installing linear polarization resistance corrosion control monitors in different areas of the distribution system before the beginning of the second round of initial

monitoring for lead and copper. Figure 5-3 shows where the monitors were located. The control monitors used iron electrodes to simulate the material in the actual system piping.

Results from the corrosion monitors indicated that the highest corrosion rates were found in the southeast section of the City. However, those rates were not consistently higher, but often fell to the levels found in other areas of the city. The city realized that the southeast corner contained a large industrial sector, causing the distribution system to experience wide fluctuations in localized demand. This resulted in significantly higher velocities passing through the pipes in that area of the city. Since water quality characteristics remained fairly consistent throughout the entire distribution system, the elevated corrosion rates in the southeast zone was attributed to the intermittently high velocities experienced in that area. This effect appeared to be causing disturbances to the coating on the pipes by either physically stripping the precipitated layer, or preventing the water in the pipe from attaining an equilibrium condition under which a calcium carbonate film could be maintained.

To address this concern, the City installed a 5 million gallon storage tank to service the southeast portion of the distribution system. The storage tank allowed the industries to satisfy their peak demands without causing wide velocity fluctuations in adjoining areas. After the tank's installation, corrosion rates in the southeast section corresponded more closely with rates in the other areas of the City.

While the storage tank was being installed, the City began their required corrosion control study. Pipe-loop systems were set up in the treatment plant's existing filter gallery. The same type of linear polarization resistance monitors used in the distribution system were also used in the study. Corrosion rates were monitored not only in iron electrodes, but lead electrodes as well. The series of runs which were conducted allowed for the comparison of corrosion rates of waters with different CCPP indices. As the treatment plant had discovered years earlier, iron corrosion was not much further reduced as the CCPP index rose above 6.0 mg/L CaCO3. However, lead corrosion reached a minimum at 9.5 mg/L CaCO3.

Before the City began full-scale treatment changes to reflect the new CCPP index, they replaced selected iron electrodes in the distribution system with lead electrodes. When they then changed the main plant treatment, they were able to verify that lead corrosion was reduced when the distribution system was receiving water with a higher CCPP index, and that iron corrosion remained at the same levels as when the system received water with the lower CCPP index. Although the lead corrosion rates were lower than they had been previously, they were not quite as low as the pipe-loop study indicated they could be. The pipe-loop system is still being used to determine whether another parameter might more clearly define optimal treatment, and periodic modifications are being made to the pipe-loop in a continuing attempt to model actual distribution system conditions.

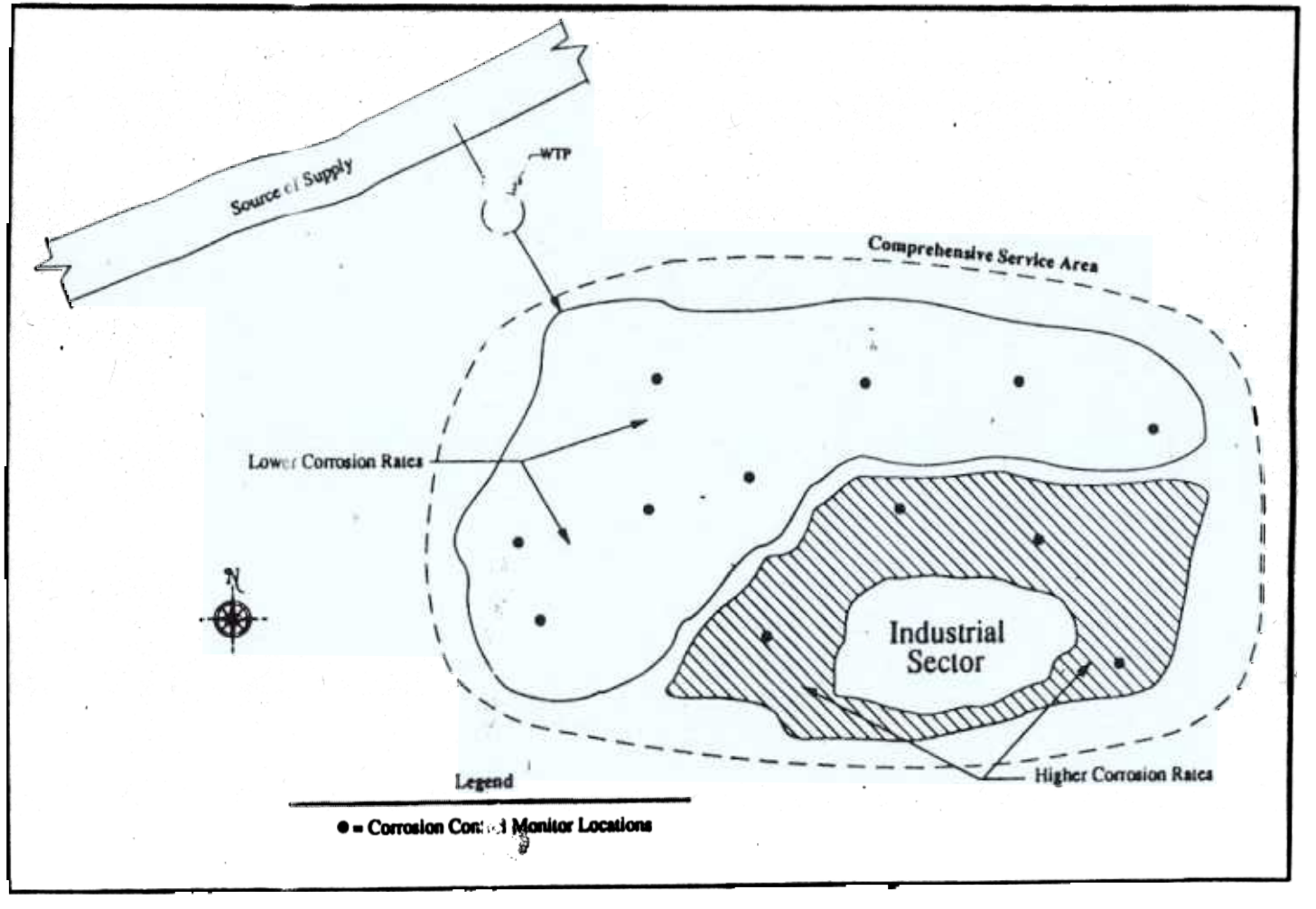

Figure 5-3. Example 5.4.2. — Use of Corrosion Monitors in the Plimpton City Distribution System

5.4.3 *Use of Extra Monitoring.*

Corrosion studies in the small town of Gechlik Mills showed that raising the pH of their direct groundwater supply from 7.2 to 7.8 caused a dramatic decrease in distribution system lead and copper levels. Direct in-line injection of caustic soda at their two wellheads to achieve a pH of 7.8 was designated as the town's optimal corrosion control. Since facilities to house chemical feeds already existed for sodium hypochlorite, installing the caustic soda system was able to be completed quickly. The Town made arrangements for a chemical company to fill the chemical feed tanks biweekly with a 50 percent caustic soda solution that was directly injected at the wellheads. The Town began using the new system six months ahead of the mandated schedule for treatment installation by the LCR.

The early installation allowed Gechlik Mills six months before they had to collect any lead and copper tap samples. However, the Town began monitoring not only the lead and copper levels, but also water quality parameters at selective distribution system sites to verify that the treatment was working correctly. Many sites were found to experience wide fluctuations in pH over time. Lead and copper levels also fluctuated, and a large number of samples continued to exceed the action levels.

By running a series of bench-scale tests, the caustic soda was found to be working as desired. However, very precise amounts had to be used in order to achieve the 7.8 pH. Although the amounts of the 50 percent caustic soda which had to be added were not very large, substantial pH fluctuations often resulted due to slight variations in feeding. By using larger amounts of a more dilute caustic solution, similar misfeedings were not found to have as pronounced an effect on pH.

Before the follow-up monitoring period was to begin, Gechlik Mills had already installed larger caustic holding tanks, and had begun injecting a 25 percent caustic soda solution. In the subsequent monitoring round, pH monitoring was conducted along with the lead and copper monitoring. The pH monitoring was found to be unnecessary for Lead and Copper Rule compliance, since the lead and copper monitoring showed that both action levels had been met. Although Gechlik Mills is not always required to, they routinely monitor their distribution system pH in order to troubleshoot any potential increases in corrosion activity.

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