FINAL REPORT

CITY OF BELLINGHAM

LEAD AND COPPER RULE CORROSION CONTROL OPTIMIZATION STUDY

June 1994

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File #: 43940.7

June 28, 1994

Bill McCourt
Public Works Department
City of Bellingham
2221 Pacific Street
Bellingham, WA 98226

Re: Final Report—Lead and Copper Rule Corrosion Control Study

Dear Mr. McCourt:

Enclosed please find 6 copies of the final report for the City of Bellingham's Corrosion Control Optimization Study. Also included are 6 copies of the Executive Summary. This report has been developed to meet the requirements for a corrosion control study under the USEPA's Lead and Copper Rule.

It has been a pleasure working you with, Julie Hirsch, Bill Evans, and others at Bellingham on this project. Your efforts in helping to provide necessary data, review products, and generally facilitate this study were greatly appreciated. We look forward to working with you in the future.

For your convenience, a camera-ready copy of the report has been included, should additional copies be required. If you have any questions regarding this project, please do not hesitate to call.

Sincerely,

ECONOMIC AND ENGINEERING SERVICES, INC.

Gregory J Kirmeyer

Gregory J. Kirmeyer, P.E.
Vice President

GJK:smn
Enclosure
cc: S. Gillette, MW

CITY OF BELLINGHAM

LEAD AND COPPER RULE CORROSION CONTROL OPTIMIZATION STUDY

GREGORY J. KIRMEYER
001848
EXPIRES 09/07/95

June 1994

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Executive Summary

Introduction and Background

The purpose of this report is to fulfill state and federal requirements regarding drinking water quality and treatment. As a result of the Safe Drinking Water Act (SDWA) Amendments of 1986, the U.S. Environmental Protection Agency (EPA) published final drinking water regulations for lead and copper in the June 7, 1991, *Federal Register*. Those regulations, known as the Lead and Copper Rule (LCR), include the following:

- ☐ Monitoring requirements for lead and copper at customers' kitchen taps,
- ☐ Optimal corrosion control treatment for lead and copper,
- ☐ Public notification and education regarding lead in drinking water,
- ☐ Compliance schedules based on system size, and
- ☐ Lead service line replacement in certain instances.

Large utilities such as the City of Bellingham (Bellingham), serving populations greater than 50,000, are required to conduct corrosion control studies to demonstrate that they are either already providing optimal corrosion control treatment or to determine optimal treatment for their system. The LCR requires sampling in homes, which is a major departure from historical regulations which have required monitoring at the treatment plant and in the distribution system. Also, the LCR does not use the traditional maximum contaminant level approach. Instead, it uses action levels to trigger studies and treatment implementation. The LCR requirements and compliance schedule that apply to Bellingham are summarized in Table ES-1 on the following page.

In response to the regulations, Bellingham conducted three rounds of monitoring at home water taps for lead and copper, collecting over 60 samples during each round. Because the lead action level was exceeded during Rounds 1 and 2, pH/alkalinity levels were increased after Round 2. A third monitoring round was then conducted in an effort to include consecutive systems that purchase water from Bellingham and to determine the impact of pH/alkalinity adjustment on lead solubility. The results from lead and copper sampling are summarized in Table ES-2. The results indicate that Bellingham's water supply is mildly corrosive toward household plumbing materials; however, increasing pH/alkalinity levels prior to Round 3 appeared to have had a positive impact on corrosion of lead and copper in Bellingham's distribution and plumbing systems. Because the lead action level was exceeded during Rounds 1 and 2, public education was required and conducted. Bellingham's copper levels do not present a problem. Because Bellingham's lead levels exceeded the lead action level (0.015 mg/L at the 90th percentile) and therefore do not meet the EPA's strict definition of "optimized" corrosion control, Bellingham is conducting this optimization study to meet the requirements for large systems under the LCR.

Table ES-1
LCR Compliance Schedule for the City of Bellingham

Date	Action	Comments
January 1, 1992	Begin first round of system monitoring for lead and copper, and water quality parameters.	Complete. Bellingham exceeded the lead action level. Public notification was conducted.
July 1, 1992	Begin second round of monitoring for lead, copper, and water quality parameters	Complete. Bellingham exceeded the lead action level. Public notification was conducted.
January 1, 1993	Submit monitoring results to DOH.	Complete. Initiated corrosion study by April 1993.
July 1, 1994	Submit recommended corrosion control treatment to DOH.	Corrosion study complete. Will meet deadline.
January 1, 1995	DOH designates optimal corrosion control treatment for Bellingham. Bellingham may begin conducting two consecutive rounds of follow-up monitoring.	Awaiting DOH response to report.
January 1, 1997	Corrosion control systems must be complete. Begin two consecutive 6-month monitoring periods for lead, copper, and water quality parameters if not conducted during installation period.	Recommended treatment system already installed. May require additional instrumentation/equipment for redundancy.
January 1, 1998	Complete follow-up monitoring and submit results to DOH.	Determine if lead and copper AL's are met.
July 1, 1998	DOH designates water quality parameter limits for corrosion control. Begin two consecutive 6-month monitoring periods for lead, copper, and water quality parameters.	Based on monitoring results, DOH may modify water quality parameter limits.

Table ES-2
City of Bellingham
Summary of Lead and Copper Monitoring Results
(Standing Tap Water Samples)

	Round 1		Round 2		Round 3		Round 4*	
Parameter	Lead	Copper	Lead	Copper	Lead	Copper	Lead	Copper
EPA Action Level (mg/L) at 90th Percentile	0.015	1.3	0.015	1.3	0.015	1.3	0.015	1.3
90th Percentile from Samples (mg/L)	0.023	0.45	0.019	0.53	0.011	0.1	0.009	0.13
Measured Range (mg/L)	<0.001–0.042	<0.002–0.62	<0.001–0.047	0.024–0.84	<0.001–0.022	<0.002–0.27	<0.001–0.018	<0.002–0.17
Samples Exceeding Action Level	22.7%	0%	15%	0%	4.1%	0%	1.6%	0%
Number of Samples	66	66	60	60	73	73	63	63

* *Round 4 was conducted for demonstration testing (full-scale) purposes.*

Lead and copper enter drinking water primarily through corrosion of materials in home plumbing systems which contain these materials. The amount of lead and copper release due to corrosion depends on a number of factors, including the amount of lead and copper bearing materials in contact with the water, the length of time the water is in contact with the materials, and physical and chemical water quality characteristics.

Lead is a highly toxic metal with no known benefits to human health. EPA has set a non-enforceable health goal of zero mg/L for lead. Lead has been associated with a number of adverse health effects including impaired or delayed neurological, physical, and behavioral development in infants and children, impaired cognitive performance, impaired reproductive function, elevated blood pressure, impaired red blood cell production, kidney damage, and interference with Vitamin D metabolism. In very limited cases, copper can also have adverse health impacts, especially for the small percentage of the population with Wilson's Disease.

Bellingham contracted with Economic and Engineering Services, Inc. and Montgomery Watson to perform a lead and copper corrosion control study. The purpose of the study was to determine the optimal approach for reducing lead and copper concentrations in Bellingham's drinking water without adversely affecting other water quality characteristics. In determining the optimal treatment approach, the LCR mandates that utilities must consider three basic treatment approaches for achieving corrosion control:

- ☐ pH/alkalinity adjustment,
- ☐ Calcium carbonate precipitation, and
- ☐ Inhibitor addition.

The approach taken for Bellingham's corrosion control study included the following steps:

- ☐ **Step 1**—Determine the magnitude and extent of the problem and identify the causative factors of lead and copper corrosion. This included a review of existing water quality data, existing distribution system pipe materials, and results of the lead and copper sampling.
- ☐ **Step 2**—Identify constraints to the mitigation of lead and copper corrosion concerns, and possible secondary impacts from corrosion. These constraints could be both regulatory and functional in nature, and consist of issues which may:
    - ■ Cause a violation of the National Primary Drinking Water Regulations, or
    - ■ Be ineffective or incompatible with the utility's specific treatment, operational, and/or customer concerns.

☐ **Step 3**—Evaluate viable treatment alternatives and determine the need for demonstration testing. Additional full-scale monitoring was conducted and results were evaluated along with results from analogous systems.

☐ **Step 4**—Recommend optimal treatment to the State, including a recommended implementation program.

This report presents the results and recommendations for Bellingham's Lead and Copper Corrosion Control Optimization Study.

Existing Conditions

Bellingham supplies drinking water to approximately 60,000 people within its City limits and to an additional 6,000 people within consecutive systems. Lake Whatcom has served as the primary water source in the Bellingham area since 1960. In 1960, construction of a dam and tunnel allowed diversion of additional water from the middle fork of the Nooksak River into Lake Whatcom.

The Bellingham Water Filtration Plant has been in operation since 1968. Pretreatment at the screenhouse consists of prechlorination with the option of coagulant addition. At the treatment plant, alum may be added at the rapid mix basin. Coagulant aids (cationic polyelectrolytes) are added prior to filtration. Six mixed-media filters can treat up to 24 MGD. Current water demand is approximately 11 MGD. After filtration, the water is chlorinated using gaseous chlorine to produce a residual of 0.6 mg/L in the plant effluent. A 16.5 MG dual-use reservoir is currently under construction and should be on-line in the fall of 1994. The reservoir will provide needed storage to the year 2040 and will also ensure that Bellingham will continue to meet contact time requirements of the Surface Water Treatment Rule. Water quality characteristics of the treated water which can potentially impact corrosion and metals leaching are summarized in Table ES-3.

Table ES-3
City of Bellingham
Treated Water Quality

Parameter	Units	Range of Values	Typical Values	Dates of Collection
Temperature	°C	8.9–20.5	14.9	1992
Conductivity	umhos/cm	53–134	74	1963–1992
pH*	standard units	7.06–7.4	7.3	1992
pH**	standard units	7.7–8.1	7.9	1993
Alkalinity*	mg/L as $CaCO_3$	16.7–23.5	19	1985–1992
Alkalinity**	mg/L as $CaCO_3$	26.0–28.6	27.7	1993
Hardness*	mg/L as $CaCO_3$	17.7–24	22	1985–1992
Dissolved Oxygen	mg/L	8.7–11.8	9.9	1992
Calcium**	mg/L as $CaCO_3$	---	22	1993

* *Pre-pH adjust (Round 1).*

** *Post-adjust in response to LCR (Rounds 2 and 3).*

Source water quality characteristics that are most likely affecting the corrosivity of Bellingham's water include:

- ☐ Low pH
- ☐ Low alkalinity and buffering capacity
- ☐ Influence of the carbonate system
- ☐ Low mineral content
- ☐ High dissolved oxygen content

Based on water quality data and preliminary tests completed by Bellingham, corrosion of a variety of piping and plumbing materials is occurring, but at low rates in the Bellingham service area. Various materials used in transmission, distribution, and premise plumbing are susceptible to corrosion by aggressive water. There is no single corrosion control strategy that can address each material; therefore, the materials which warrant the most concern for health, aesthetic, and economic reasons have been targeted. These materials and their susceptibility to corrosion and/or leaching in Bellingham's service area are summarized in Table ES-4 below.

Table ES-4
City of Bellingham
Materials of Concern in Bellingham's Service Area

Material	Susceptibility	Potential Type of Concern
50:50 Lead:Tin Solder (currently banned)	Leaching	Health - Lead Leaching
Brass	Leaching	Health - Lead Leaching Health and Aesthetic - Potential Copper Leaching
Unlined Cast Iron and Steel	Potential Corrosion	Aesthetic - Rusty/Red Water Economic - Tuberculation
Copper	Leaching and Corrosion	Aesthetic - Blue/Green Staining Economic - Pitting/Failure

Evaluation of Viable Treatment Alternatives

The LCR Guidance Manual Volume II outlines four criteria on which to base the evaluation of the viable corrosion control treatment approaches as follows:

- ☐ Corrosion control **performance** based on either reductions in metal solubility or the likelihood of forming a protective scale. Performance can be based on theoretical calculations, bench-scale, pilot-scale, or full-scale testing, and/or the experience of other systems already practicing optimized corrosion control.

- ☐ The feasibility of implementing the treatment alternative on the basis of the **constraints** identified. These constraints may be regulatory based by impacting the system's ability to comply with existing federal or state drinking water standards in addition to anticipated regulations that may impact the system in the future. Also included in this criterion category are functional constraints such as wastewater impacts, the effects upon industrial, commercial and public customers, and other system impacts.

☐ The **reliability** of the alternative in terms of operational consistency and continuous corrosion control protection. The advantages and disadvantages of the available chemical feed systems should be considered including the ability to minimize interruptions in treatment due to maintenance, chemical inventory problems, or equipment and instrumentation failure. The LCR requires that corrosion control treatment be operated continuously.

☐ The estimated **costs** associated with implementing the alternative treatments. Costs for a corrosion control treatment system should be amortized over the expected life of the feed system and include chemical costs, capital expenditures, and operations and maintenance costs.

Performance

The performance of each approach was determined based on results of lead solubility models, corrosion indices, and analogous system information. Additionally, the results of bench-scale and full-scale testing conducted by analogous systems and full-scale testing conducted by Bellingham, were used to estimate the performance of treatment approaches.

Six sites in the distribution system have been sampled four times to date: a one liter sample was collected during Round 1; a fractionated 1.125 liter sample was collected during Round 2; a fractionated 1.125 liter sample was collected after pH adjustment (Round 3), and a one liter sample was collected during recent full-scale monitoring (Round 4). Results are shown in Exhibit ES-1.

The results in Exhibit ES-1 appear to indicate that pH adjustment from 7.3 to 8.0 at the treatment plant has had a positive effect on reducing lead leaching levels. At all six sites, lead levels after pH adjustment decreased significantly, and all sites except 038 K dropped below the lead action level after pH adjustment prior to Round 3. However, site 038 K was well below the action level during Round 4. pH and/or alkalinity adjustment is being used as a corrosion control measure by several utilities in the Pacific Northwest who have similar waters.

Concerning calcium carbonate precipitation, Bellingham should not pursue this as a viable option. Its effectiveness is not proven, the costs are high, industry would object and it would be a drastic change in water quality.

Bellingham has not used inhibitors in their water treatment process and so this study relied on results from other systems. Full-scale use of orthophosphates indicates that they are most effective over a pH range of 7.4 - 7.8. Metal phosphate precipitates can form at pHs greater than 7.8, causing scale build up and decreasing hydraulic capacity (LCR Guidance Manual Volume II). Results obtained during pilot-scale testing conducted by Portland Water Bureau suggested that orthophosphates were effective at decreasing lead leaching at a pH of 7.5. General experience indicates that a stable pH may be required throughout the distribution system and alkalinity adjustment may be required to attain this.

There is little information available with respect to the performance of silicate inhibitors for control of lead and copper leaching, since silicate addition for larger municipal water systems is not commonly practiced in the U.S. Pilot-scale results obtained from Portland Water Bureau indicated that silicates performed as well as pH adjustment to 9.0 and alkalinity to 20 mg/L. It could not be ascertained whether silicates were effective because of the presence of silicates or whether they were effective because of the pH increase that naturally accompanies their addition. Limited available data indicate that protective films form relatively slowly on lead pipe. High initial doses (3 to 8 weeks at levels as high as 20 mg/L SiO_2 above background silicate levels) may be necessary to establish a film.

Constraints

The constraints identified in Section 5 are summarized below:

- ☐ Constraints associated with pH/alkalinity adjustment are primarily regulatory in nature, with emphasis on DBP formation. However, laboratory testing conducted by Bellingham to evaluate this concern indicated that increased DBP formation may occur due to increased contact time at a higher chlorine residual level (which will likely occur when the new reservoirs in place), rather than from corrosion control treatment. It is likely that Bellingham will be able to decrease DBP formation by optimizing chlorine dosages and application points within the new reservoir. CT compliance will not be a problem due to the increased contact time provided by the new reservoir.
- ☐ Constraints associated with inhibitor addition (phosphate and silicate) were primarily functional in nature. Issues involving public acceptance of phosphate addition, impacts on the service community, impacts on the wastewater treatment plant, and potential unknowns with respect to water quality changes were identified.

Recommended Treatment Approach and Implementation Program

The recommended corrosion control treatment approach for Bellingham at this time is pH/alkalinity adjustment. Bellingham is familiar with pH/alkalinity adjustment and has a history of successful operation of its soda ash feed facility. Furthermore, drastic changes in water quality will not occur if Bellingham maintains the same chemical addition program.

Corrosion control treatment using pH/alkalinity adjustment has been demonstrated to be effective for reducing lead and copper uptake using theoretical calculations for metals solubility; analogous system information including full-scale demonstration testing results from Bellingham, Seattle Water Department, pipeloop pilot plant testing by Portland Water Bureau and other Pacific Northwest utilities. It has been determined that alkalinity adjustment is also beneficial to serve as a buffering agent, thereby maintaining adjusted pH levels, and to aid in the formation of passivating carbonate films.

With pH/alkalinity adjustment, the question becomes what pH and alkalinity levels should be targeted? Determining the recommended pH and resulting alkalinity levels was based on performance issues and constraints summarized in Table ES-5.

Table ES-5
Factors Used to Establish Target pH and Alkalinity Levels

pH	Alkalinity (mg/L $CaCO_3$)	Comments	Conclusions
9.8	28	☐ Theory suggests ideal for minimizing lead solubility ☐ TTHM formation would be dramatically increased ☐ Disinfection efficiency of chlorine would decrease ☐ Extremely high chemical cost ☐ Result in drastic water quality changes ☐ Constraints on service community ☐ Bellingham met ALs for lead and copper at pH = 7.8-8.0, alkalinity 25-27 mg/L $CaCO_3$	High pH levels have too many serious drawbacks.
9.0	20–30	☐ Recommended for Portland based on pilot-scale testing; however, Portland chloraminates ☐ Same comments as above	With use of free chlorine for secondary disinfection, too many drawbacks.
8.5	20–25	☐ Probably would not meet Stage 2 of D/DBP Rule ☐ Increased cost for minimal additional corrosion control. ☐ Bellingham met AL at pH 7.8-8.0, alkalinity 25-27 mg/L $CaCO_3$ ☐ Disinfection efficiency lower at pH 8.5	Same as above.
7.8-8.0	25–35	☐ Recommended for Bellingham ☐ Would potentially meet Stage 2 of D/DBP Rule ☐ Disinfection more effective ☐ Least impact on service community ☐ Less expensive than increasing pH/alkalinity to higher levels ☐ Bellingham met AL at pH 7.8-8.0, alkalinity 25-27 mg/L $CaCO_3$	Most likely solution for achieving optimization and best over all water quality.
7.6	13	☐ May be able to meet AL, however, corrosion control may not be optimized based on desk-top study results ☐ Bellingham would need to conduct at least two consecutive monitoring rounds to confirm effectiveness	Questionable as to meeting requirements for large systems under LCR.
		Recommended Target pH Level: **Resulting Alkalinity:**	**7.8–8.0 ± 0.2 units** **22–32 mg/L $CaCO_3$**

Based on theoretical calculations, analogous system information, and constraints; the recommended pH operating goal at this time is 7.8–8.0 ± 0.2 units. The resulting alkalinity should be maintained in the range of 22–32 mg/L $CaCO_3$. These goals can be achieved using the existing soda ash addition facilities located at the Bellingham Water Treatment Plant. The dose to reach a finished water pH of 7.8–8.0 is estimated to be 12–15 mg/L of soda ash.

Because a consistent pH level is needed for effective lead control, additional instrumentation may be required to enhance chemical feed and control. Redundancy of certain components and minimal upgrading would ensure continuous pH/alkalinity levels during routine maintenance of feed equipment and potential equipment failure. Further, for purposes of treatment control, continued monitoring of pH at the present frequency of determining a daily average from continuous monitoring equipment is recommended for Bellingham. Alkalinity monitoring should be increased to once per day.

To minimize disruptions in the balance that exists between physical conditions, chemical parameters, primary and secondary disinfection including installation of the new 16.5 MG reservoir, microbiological organisms, and residual maintenance in Bellingham's distribution system, a start-up approach was developed as shown in Exhibit ES-2. pH/alkalinity have already increased to approximately 8.0 and evaluations can be made relating to distribution system water quality conditions. If needed, an additional pH adjustment could be made, either to higher or lower levels within the two-year time period allowed for corrosion control treatment installation based on results of system monitoring. Since Bellingham has already installed what is considered optimal corrosion control treatment, the two-year treatment installation and implementation period (1995 and 1996) provided in the LCR would be an opportune time to conduct additional non-regulatory monitoring in the distribution system. The purpose of this recommended approach is to allow time for evaluation of the following areas of potential concern: 1) lead and copper levels at the tap; 2) bacteriological quality and disinfectant levels in the distribution system; 3) disinfection-by-product levels; 4) CT compliance status; 5) water quality effects associated with the new 16.5 MG reservoir; and 6) customer response including consecutive systems and wastewater treatment impacts. The overall implementation strategy is shown in Exhibit ES-2.

Based on the results of the evaluations at pH 8.0/alkalinity 25–27 mg/L $CaCO_3$, further adjustments above or below pH 8.0 may or may not be useful. If 90th percentile lead levels remain less than or equal to 0.015 mg/L and monitoring indicates that all other parameters are in compliance with existing and possible future regulations, Bellingham would be optimized. If 90th percentile lead levels are less than or equal to 0.015 mg/L, but one or more of the other criteria are a major problem, Bellingham should consider reverting to pH 7.6–7.8 and the resulting alkalinity level of 20–25 mg/L $CaCO_3$. If 90th percentile lead levels are greater than 0.015 mg/L and there are no major problems in other areas, Bellingham should consider increasing pH further.

The costs for implementing Bellingham's corrosion control treatment strategy were calculated for capital, chemical, and O&M expenditures. These costs are summarized in Table ES-6.

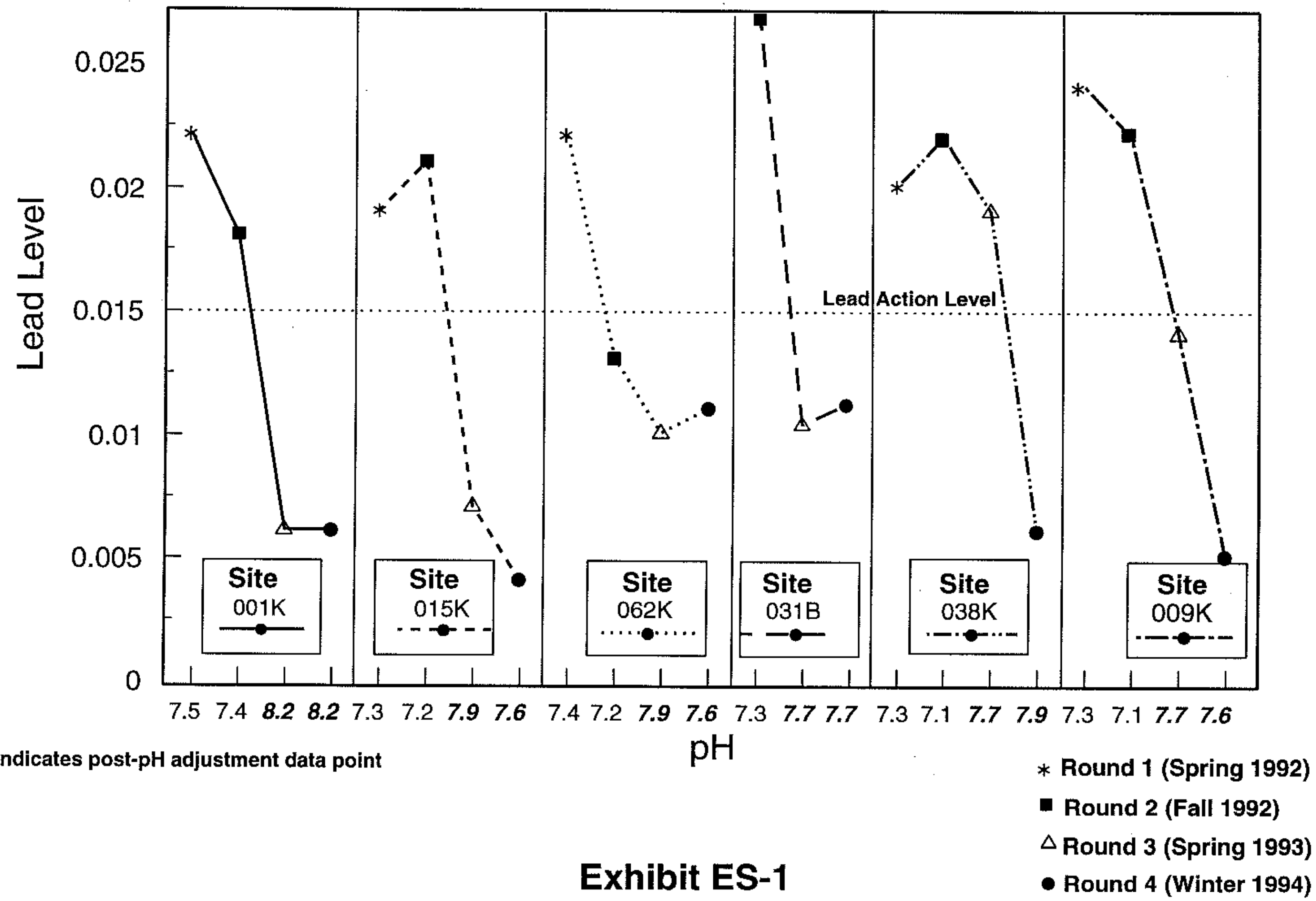
Table ES-6
Estimated Costs for pH Adjustment as Corrosion Control Strategy

	Average Cost*
Chemical Cost	$48,000/year
O&M Cost	$11,000/year
Capital Cost	potentially $15,000**

* *Costs are for planning purposes only; ±30%. Average daily flow assumed to be 11 mgd, dosage assumed to be 12–15 mg/L of soda ash.*

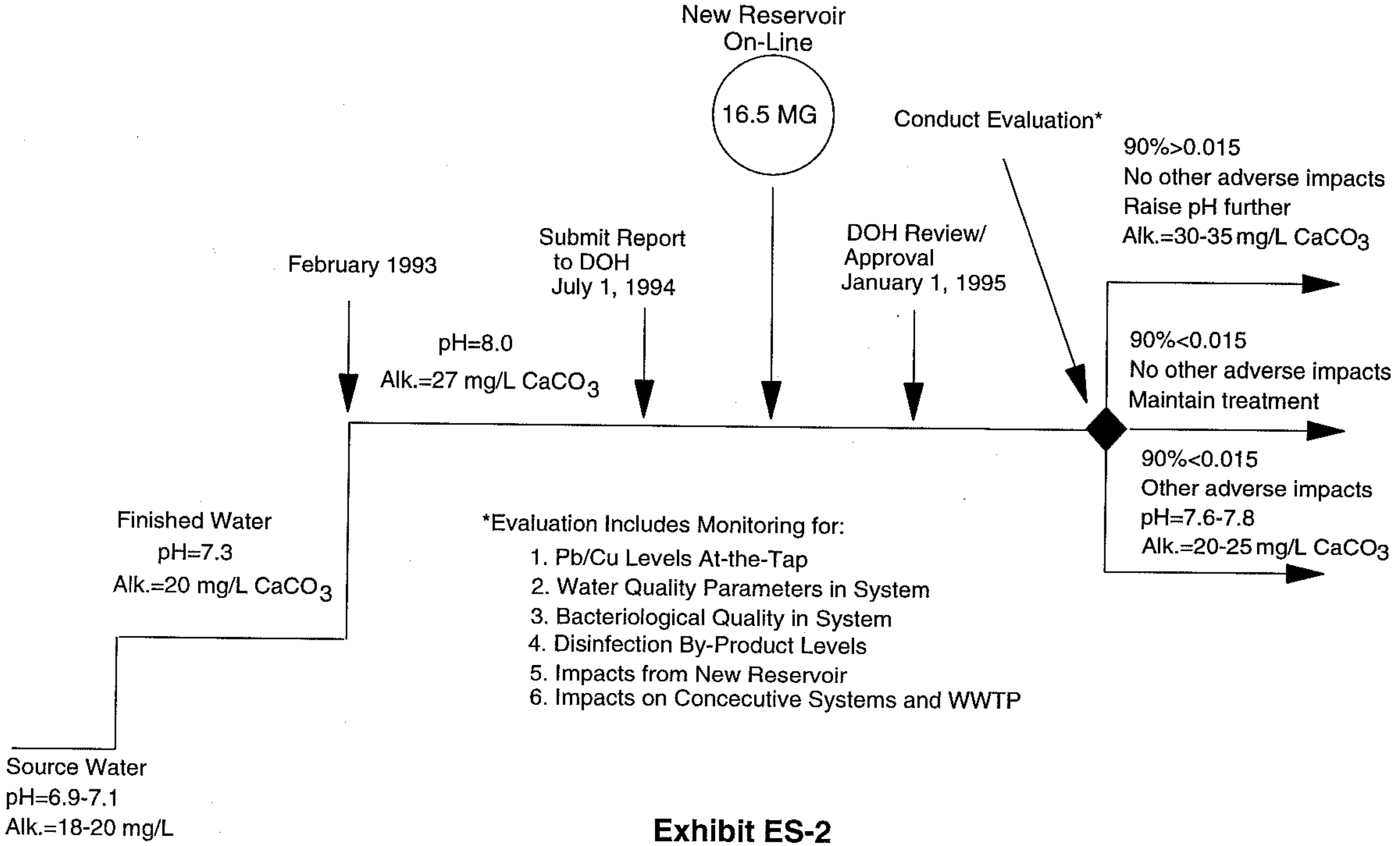
** *Additional capital expenditures may be necessary (such as alarm functions) to supply complete corrosion control treatment redundancy capabilities.*

The next step for Bellingham is to submit this report to the Washington State Department of Health by the required deadline of June 30, 1994. After receiving approval from DOH, Bellingham should begin collecting additional data to determine the impacts of the new reservoir plus corrosion control treatment on the system. In addition, Bellingham should collect point of entry pH/alkalinity data to provide information to the State for determining the water quality parameter ranges. It is Bellingham's objective to design and install any additional equipment which may be required for redundancy considerations by the January 1, 1997 deadline.



Bold indicates post-pH adjustment data point

Exhibit ES-1
City of Bellingham
Soluble Lead Levels at "High-Risk" Sites
During Consecutive Monitoring Rounds



*Evaluation Includes Monitoring for:

1. Pb/Cu Levels At-the-Tap
2. Water Quality Parameters in System
3. Bacteriological Quality in System
4. Disinfection By-Product Levels
5. Impacts from New Reservoir
6. Impacts on Concecutive Systems and WWTP

Exhibit ES-2
City of Bellingham
Suggested Implementation Strategy

Section 1
Introduction and Background

1.1 Purpose of Study

The City of Bellingham (Bellingham) is conducting a corrosion control optimization study as part of the requirements of the recently-enacted federal Lead and Copper Rule (LCR). The LCR was promulgated by the United States Environmental Protection Agency (EPA) in an attempt to reduce lead and copper concentrations in drinking water. Ingestion of lead and/or copper via drinking water has been determined to have certain health risks, especially for young children. The LCR requires that all large water systems complete water quality monitoring programs for lead and copper as well as determine the "optimized" corrosion control treatment for reducing lead and copper levels in their drinking water supply. The critical elements of the LCR include:

☐ At the tap monitoring,
☐ Desk-top evaluation of treatment alternatives,
☐ Recommendations of alternatives,
☐ Bench scale and/or pilot scale testing of alternatives,
☐ Full-scale implementation of treatment, and
☐ Long-term monitoring.

To date, Bellingham has conducted both of the required consecutive six-month monitoring rounds between January of 1992 and January of 1993, plus a third monitoring round which included results from consecutive water wholesaler's systems. The Consecutive System Supply Plan is included in Appendix A. The 90th percentile lead action level of 0.015 mg/L was exceeded during both monitoring rounds (0.023 mg/L and 0.019 mg/L, respectively), and therefore, Bellingham was required to conduct a detailed Corrosion Control Study. However, during the third monitoring round, the 90th percentile lead level was 0.011 mg/L which was below the lead action level. Bellingham retained Economic and Engineering Services, Inc. (EES) in association with Montgomery Watson (MW) to conduct the desk-top evaluation and to help develop recommendations for optimal corrosion control treatment.

1.2 Regulatory Requirements

The USEPA published final national primary drinking water regulations for lead and copper on June 7, 1991 in the Federal Register (56 FR 26460) as part of the mandate of the 1986 Safe Drinking Water Act (SDWA) amendments. The Lead and Copper Rule (LCR) replaced an interim maximum contaminant level (MCL) for lead with requirements for treatment optimization to control lead. The LCR also established maximum contaminant level goals (MCLGs) for lead and copper based on health concerns.

The treatment technique requirements of the LCR for lead control include:

☐ Optimal corrosion control treatment,
☐ Source water treatment,
☐ Public education, and
☐ Lead service line replacement.

Optimal corrosion control treatment for copper is also part of the LCR. In addition to the treatment technique requirements, the LCR also includes:

☐ Monitoring requirements for lead, copper, and water quality parameters,
☐ Analytical methods and laboratory certification requirements,
☐ Public notification requirements,
☐ Recordkeeping and reporting requirements,
☐ Variances and exemptions, and
☐ Compliance schedules based on system size.

1.2.1 Compliance Schedule for the City of Bellingham

The LCR compliance schedule that applies to large water systems is summarized in Table 1-1.

Table 1-1
LCR Compliance Schedule for the City of Bellingham

Date	Action	Comments
January 1, 1992	Begin first round of system monitoring for lead and copper, and water quality parameters.	Complete. Bellingham exceeded the lead action level. Public notification was conducted.
July 1, 1992	Begin second round of monitoring for lead, copper, and water quality parameters	Complete. Bellingham exceeded the lead action level. Public notification was conducted.
January 1, 1993	Submit monitoring results to DOH.	Complete. Initiated corrosion study by April 1993.
July 1, 1994	Submit recommended corrosion control treatment to DOH.	Corrosion study complete. Will meet deadline.
January 1, 1995	DOH designates optimal corrosion control treatment for Bellingham. Bellingham may begin conducting two consecutive rounds of follow-up monitoring.	Awaiting DOH response to report.
January 1, 1997	Corrosion control systems must be complete. Begin two consecutive 6-month monitoring periods for lead, copper, and water quality parameters if not conducted during installation period.	Recommended treatment system already installed. May require additional instrumentation/equipment for redundancy.
January 1, 1998	Complete follow-up monitoring and submit results to DOH.	Determine if lead and copper AL's are met.
July 1, 1998	DOH designates water quality parameter limits for corrosion control. Begin two consecutive 6-month monitoring periods for lead, copper, and water quality parameters.	Based on monitoring results, DOH may modify water quality parameter limits.

1.2.2 Monitoring Requirements

The LCR requires water systems to perform extensive monitoring for lead and copper at interior taps in residences. The monitoring schedule and number of samples is based on the system's population. An initial monitoring round was performed by large water systems (>50,000 people) during 1992 to establish further LCR compliance requirements. Monitoring is also required after the installation of corrosion control treatment (if applicable), and after the State specifies the water quality parameter values for optimal corrosion control. Table 1-2 summarizes the LCR monitoring schedule applicable to Bellingham.

Sites selected for tap sampling are required to be "high-risk" locations—homes that contain lead solder installed since 1982, that have lead plumbing or are served by lead service lines. The samples must be 1 liter, first-draw water drawn from a cold water kitchen or bathroom tap that has stood motionless for at least 6 hours. Since there are no lead service lines nor homes that have lead plumbing in the Bellingham service area, the only pertinent tap sampling sites are homes that contain copper pipe with lead:tin solder built after 1982.

Table 1-2
Lead and Copper Rule Monitoring Schedule

Monitoring Period	Dates	Parameters	Locations
Initial Monitoring	January—June 1992 and July—Dec. 1992	☐ Pb and Cu ☐ Water quality parameters(1)	☐ High-risk interior taps ☐ Taps and entry point to distribution system
After Installation	January—June 1997 and July–Dec. 1997	☐ Pb and Cu ☐ Water quality parameters(2) ☐ Water quality parameters(2)	☐ High-risk interior tap ☐ Taps ☐ Entry points to distribution system (bi-weekly)
After State Specifies Parameter Values for Optimal Corrosion Control	July–December 1998 and Jan.–June 1999	☐ Pb and Cu ☐ Water quality parameters(2) ☐ Water quality parameters(2)	☐ High-risk interior taps ☐ Taps ☐ Entry points to distribution system (bi-weekly)
Reduced Monitoring	Once every year* (Once every 3 years)**	☐ Pb and Cu ☐ Water quality parameters(2) ☐ Water quality parameters(2)	☐ High-risk interior taps ☐ Taps ☐ Entry points to distribution system (bi-weekly)

* *If system meets Pb and Cu ALs or maintains state-specified optimal corrosion control treatment for two consecutive 6-month periods, may reduce tap sampling to once per year and collect reduced number of samples.*

** *If system meets Pb and Cu ALs or maintains state-specified optimal corrosion control treatment for three consecutive years, may reduce tap sampling*

Notes: (1) pH, alkalinity, calcium, conductivity, temperature; (2) pH, alkalinity

The results of LCR tap sample monitoring must be evaluated in terms of action levels (ALs) for both lead and copper to determine the steps needed for compliance. An AL is not an MCL. It represents a level at which the utility must take additional action to reduce lead (or copper) exposure from water. If the concentration at the 90th percentile from either of the first two rounds of monitoring exceeds 0.015 mg/L for lead or 1.3 mg/L for copper, further compliance with the LCR involves optimization of corrosion control treatment techniques. Large-sized utilities were required to also monitor for additional water quality parameters in the system. Bellingham conducts extensive distribution system monitoring at 19 locations for pH, alkalinity, calcium, conductivity, and temperature, plus other compounds on a monthly basis. Samples were also collected from the entry point to the distribution system, fulfilling the monitoring requirements for corrosion related water quality parameters.

1.2.3 Corrosion Control Optimization

All large water systems must conduct corrosion control studies unless they can demonstrate to the State that corrosion control has already been optimized. For large systems, if the difference between the lead concentration in the source water and the 90th percentile level from the tap water monitoring for lead is <0.005 mg/L for two consecutive six-month monitoring periods, then the system is already considered to be optimized under the LCR. This is not the case for Bellingham since their 90th percentile lead concentrations were 0.023 mg/L and 0.019 mg/L for the two sampling rounds, and Lake Whatcom source water has non-detectable lead concentrations.

Corrosion control studies must compare the relative effectiveness of pH and/or alkalinity adjustment, calcium adjustment, and corrosion inhibitors (phosphate or silicate-based). Demonstration of corrosion treatment optimization must be based on pipe rack tests, metal weight-loss coupon tests, full-scale tests, or documentation of the treatment technique in analogous systems. Based on the results of the corrosion study, a plan for corrosion control optimization must be submitted to the State by July 1, 1994 for large systems.

Large water systems have until January 1, 1997 to install the State-approved optimal corrosion control treatment system. Two consecutive rounds of tap monitoring must then be carried out to document treatment performance, after which the State will designate the range of water quality parameters (WQPs) within which the utility must operate to maintain compliance with the LCR. If a system does not meet the WQPs set by the State at the entry point to the system or at any of the required monitoring sites in the distribution system, then it is considered a rule violation. Hence, it is important for the State and the system to negotiate reasonable WQP ranges and that the installed treatment system be capable of providing consistent chemical doses and water quality throughout the service area.

1.2.4 Public Education and Public Notification

Water systems that exceed the lead AL must deliver the USEPA-approved public education program to its customers within 60 days of determination. This program informs the public about the health impacts of lead and how to reduce exposure to lead from water, such as tap flushing and checking for lead solder in new plumbing. Additionally, systems exceeding the lead AL must include mandatory alert language on all water bills within 60 days. Bellingham conducted the required public notification program during the first and second monitoring periods since the lead action level was exceeded.

The general public notification requirements of the SDWA (52 FR 41534, October 28, 1987 and 54 FR 15185, April 17, 1989) also apply to the LCR. Tier 1 notification is required for violations of treatment technique requirements and failure to comply with deadlines. Tier 2 notification is triggered by failure to comply with testing and monitoring requirements. Violations of reporting requirements and exceedances of the copper AL do not require public notification, however, lead AL exceedances do require public education.

1.2.5 Record Keeping and Reporting

Water systems must retain original records of all sampling data and analyses, reports, surveys, evaluations, schedules, state determinations, and other information required by the LCR for at least 12 years. Separate reports are required for each of the following:

- ☐ Tap water monitoring for lead, copper, and water quality parameters,
- ☐ Source water monitoring,
- ☐ Corrosion control treatment,
- ☐ Lead service line replacement, and
- ☐ Public education program.

1.3 Study Approach

The approach taken for the City of Bellingham Corrosion Control Optimization Study conformed with the requirements of the Lead and Copper Rule (LCR) for larger water systems. The approach was designed to meet all regulatory requirements for the evaluation of chemical treatment alternatives for the control of lead and copper uptake by drinking water. The study approach was as follows:

Task 1	Determine the magnitude and extent of the problem and identify the causative factors of lead and copper corrosion.
Task 2	Identify constraints to the mitigation of lead and copper concerns and possible secondary impacts from corrosion.
Task 3	Develop evaluation criteria and evaluate alternatives.
Task 4	Recommend optimal treatment to State.

Section 2
Review of Existing Information

2.1 Water System Facilities

Bellingham supplies drinking water to approximately 60,000 people within the City limits and to an additional 6,000 people within consecutive systems. Lake Whatcom serves as the primary water source in the Bellingham area. In 1960, construction of a dam and tunnel allowed diversion of additional water from the middle fork of the Nooksack River into Lake Whatcom. A water supply system schematic provided in Bellingham's Comprehensive Water Plan (1993) is shown in Exhibit 2-1.

The Bellingham Water Filtration Plant has been in operation since 1968. Water is drawn from a depth of 38 feet from a 72 inch wooden pipe in Lake Whatcom. Pretreatment at the screenhouse consists of prechlorination with the option of coagulant addition. At the treatment plant, alum is added at the rapid mix basin. Coagulant aids (cationic polyelectrolytes) are added prior to filtration. In response to high lead levels at the tap, pH was adjusted from 7.3 to 8.0 with additional soda ash between monitoring Rounds 1 and 2. Six mixed-media filters can treat up to 24 MGD, and current average water demand is approximately 11 MGD. After filtration, the water is chlorinated using gaseous chlorine to produce a residual of 0.6 mg/L in the plant effluent.

2.2 Water Quality

Historical water quality data providing relevant corrosion-related information were reviewed including:

☐ Source Water Quality,
☐ Point of Entry Water Quality,
☐ Distribution System Water Quality, and
☐ At the Tap Water Quality

This section includes a review of changes in water quality within the distribution system and an evaluation of piping conditions and plumbing materials within the distribution system.

Information reviewed for this evaluation included:

☐ Lead and Copper Monitoring Results - 1992 and 1993
☐ Water Quality Parameter Results 1992 and 1993
☐ Coliform Monitoring Plan - 1992
☐ Water Treatment Plant Annual Report - 1992

☐ Yearly Averages of Baseline Distribution System Monitoring - 1991, 1992 and 1993
☐ Monthly Averages of Raw and Treated Water Quality - 1985 - 1990
☐ Regulatory Inorganic Analyses - 1953 - 1992
☐ THM Monitoring Results - 1992
☐ SOC/IOC Scan of Clearwell Water - 1992
☐ Response to AWWA LCR Survey of Large Utilities - 1992
☐ Comprehensive Water Plan - 1993

In addition, a site visit was conducted in April of 1993 to better understand treatment processes and operations at the Bellingham Water Treatment Plant.

2.2.1 Water Quality Data

Source Water Quality Data

Historical data collected by Bellingham show that there has been little significant change in the water quality characteristics of Lake Whatcom water over the past 20 years, either from natural causes or from human activity in the watershed (Comprehensive Plan, 1993). Lake Whatcom and the surrounding watershed are used for recreational development and logging practices, and water quality degradation in the form of elevated metals levels and fecal coliform counts have been observed in streams feeding Lake Whatcom. These streams are primarily located in urban drainages. Concerns for protecting water quality have been increasing and restrictions on activities within the watershed have been developed.

Table 2-1 summarizes Lake Whatcom raw water quality parameters which potentially affect the corrosivity of the water. These water quality parameters include temperature, pH, alkalinity, hardness, dissolved oxygen, and specific conductivity. Dissolved oxygen levels in the source water are measured on a monthly basis and range from 70–100% saturation, resulting in levels of 9–12 mg/L at a temperature range of 6 of 20°C. The data used to generate Table 2-1 were collected at various times from 1963 to 1992.

Table 2-1
City of Bellingham
Summary of Historical Water Quality Data

Parameter	Units	Range of Values	Typical Values	Dates of Collection
Conductivity	umhos/cm	44 - 90	60	1973 - 1992
Temperature	°C	6.6 - 20.0	12 - 13	1985 - 1992
pH	standard units	6.9 - 7.3	7.1	1985 - 1995
Alkalinity	mg/L as $CaCO_3$	18 - 21	19	1985 - 1990
Hardness	mg/L as $CaCO_3$	17 - 23	21	1985 - 1990
Dissolved Oxygen*	mg/L	9 - 12	10.6	1985 - 1992

* *Dissolved oxygen levels calculated from saturation levels over the temperature range indicated.*

These data represent the general conditions of past and present raw water quality. Generally, these parameters indicate a pH neutral water with low alkalinity, low hardness, and saturated levels of dissolved oxygen. The conditions described above are typical of corrosive surface waters. Lead levels have also been measured in the source water since 1979. Historical source water levels are listed in Table 2-2.

Table 2-2
City of Bellingham
Historical Source Water Lead and Copper Levels

Concentration (mg/L)			
Lead	**Copper**	**Data Source**	**Date**
<0.001	0.016	LCR Round 2	1992
<0.001	0.002	LCR Round 1	1992
<0.010*		Regulatory Analyses	1979 - 1987
<0.002**	<0.20	Regulatory Analyses	1989 - 1992

* *A lead level of 0.022 mg/L was measured from the source in 1980.*
** *A lead level of 0.013 mg/L was measured from the source in 1988.*

Historical data indicate that elevated levels of lead measured at the tap during LCR regulatory monitoring were not a result of excessive levels in the source water.

Finished Water Quality

Water quality characteristics of the treated water which can potentially impact corrosion and metals leaching are summarized in Table 2-3.

Table 2-3
City of Bellingham
Treated Water Quality

Parameter	Units	Range of Values	Typical Values	Dates of Collection
Temperature	°C	8.9–20.5	14.9	1992
Conductivity	umhos/cm	53–134	74	1963–1992
pH*	standard units	7.06–7.4	7.3	1992
pH**	standard units	7.7–8.1	7.9	1993
Alkalinity*	mg/L as $CaCO_3$	16.7–23.5	19	1985–1992
Alkalinity**	mg/L as $CaCO_3$	26.0–28.6	27.7	1993
Hardness*	mg/L as $CaCO_3$	17.7–24	22	1985–1992
Dissolved Oxygen	mg/L	8.7–11.8	9.9	1992
Calcium**	mg/L as $CaCO_3$	---	22	1993

* *Pre-pH adjust (Rounds 1 and 2).*
** *Post-adjust in response to LCR (Round 3).*

In response to unacceptable lead levels measured at the tap during Round 1, Bellingham increased pH from 7.3 to 8.0 using soda ash. Prior to pH adjustment for corrosion control purposes (February 4, 1993), treated water quality did not vary significantly from raw water quality with respect to corrosion related parameters. pH and alkalinity were still "low" according to classifications in the LCR Guidance Manual Volume II, and the treated water would be considered corrosive. Table 2-4 lists categories of water types based on water quality characteristics.

Table 2-4
pH, Alkalinity, Calcium Categories

	pH	**Alkalinity ($mg/L\ CaCO_3$)**	**Calcium ($mg/L\ CaCO_3$)**
Low	≤ 7.5	<50	<50
Moderate	>7.5 - 9	50 - 150	50 - 150
High	>9	>150	>150

Source: USEPA LCR Guidance Manual Volume II: Corrosion Control Treatment, 1992

Distribution System Water Quality

Water quality data is regularly collected from each of the reservoirs and from sites in the Bellingham distribution system (Exhibit 2-2). Nineteen sites were also sampled for specific water quality parameters listed in the LCR. An additional 66 homes were targeted and sampled for first flush lead and copper levels. Data collected during 1992 and 1993 from the distribution system reservoirs were reviewed to assess any changes in water quality during storage and distribution.

With respect to most sampling sites in the distribution system, only slight changes in water quality conditions were observed. Alkalinity levels at Foster Reservoir were typically 1–3 mg/L (as $CaCO_3$) greater than alkalinity levels in the clearwell, especially during summer months, and free chlorine residual levels ranged from 0.6 mg/L in the clearwell to trace levels at far points of the distribution system. Based on this review, it appears that slight changes are occurring in the distribution system water quality when compared to water quality conditions in the clearwell. However, there were no apparent trends in corrosion-related water quality parameter concentrations with distance or travel time in the distribution system (with the exception of conditions at Northshore Drive), indicating that the treated water is fairly stable. Distribution system water quality conditions are summarized in Table 2-5.

Table 2-5
City of Bellingham
Distribution System Water Quality Characteristics

Parameter	Units	Range of Values	Typical Values	Date of Collection
Temperature	°C	7.2 - 20.5	14.0	1992
Conductivity	umhos/cm	64.9 - 89.5	73 - 77	1992
pH*	standard units	7.0 - 9.0	7.3	1992
pH**	standard units	7.6 - 9.3	7.8	1993
Alkalinity*	mg/L as $CaCO_3$	17 - 25.5	22 - 23	1992
Alkalinity**	mg/L as $CaCO_3$	24.5 - 29.8	26	1993
Hardness**	mg/L as $CaCO_3$	22.3 - 35.2	26	1992
Dissolved Oxygen	mg/L	7.0 - 11.3	9 - 10	1992
Calcium**	mg/L as $CaCO_3$	17.2 - 25	23	1993

* *Levels measured prior to pH adjustment*

** *Levels measured post-pH adjustment*

The most dramatic changes in water quality conditions consistently occurred at the Northshore Drive sampling point. Consistent increases in pH, alkalinity, conductivity, and iron were observed at this site as shown in Table 2-6 below.

Table 2-6
Changes in Water Quality at Northshore Drive

Parameter	Units	Clearwell	Northshore Drive
pH	Standard Units	7.1 - 7.4	7.4 - 9.3
Alkalinity	mg/L $CaCO_3$	19	23
Conductivity	umhos/cm	74	83
Iron	mg/L	0.05	0.15

Iron levels were occasionally two orders of magnitude greater than the levels measured in the clearwell. On three occasions, iron levels nearly exceeded the 0.3 mg/L secondary MCL at this site.

At the Tap Water Quality

Results of two initial monitoring rounds under the LCR indicate plumbing materials are susceptible to the corrosivity of Bellingham's water supply. Sixty-six Tier 1 sites were sampled during round one, and fifty-nine Tier 1 sites and one Tier 3 site were sampled during round two. A summary of the monitoring results are shown in Table 2-7, and an example of the information gathered for each sampling location is provided for Rounds 1 and 3 in Appendix B. The 90th percentile results were 0.023 mg/L and 0.019 mg/L, for lead during Rounds 1 and 2, respectively, as shown in Exhibit 2-3. Copper concentrations were well below the 1.3 mg/L action level. Round 1 and 2 90th percentile copper levels were 0.45 and 0.53 mg/L, respectively, as shown in Exhibit 2-4. The third monitoring round, which included sites from wholesale water systems (both Tier 1 and Tier 2), resulted in a 90th percentile lead level of 0.011 mg/L, below the USEPA action level of 0.015 mg/L.

Table 2-7
City of Bellingham
Summary of Lead and Copper Monitoring Results
(Standing Tap Water Samples)

	Round 1		Round 2*		Round 3		Round 4**	
Parameter	Lead	Copper	Lead	Copper	Lead	Copper	Lead	Copper
EPA Action Level (mg/L) at 90th Percentile	0.015	1.3	0.015	1.3	0.015	1.3	0.015	1.3
90th Percentile from Samples (mg/L)	0.023	0.45	0.019	0.53	0.011	0.1	0.009	0.13
Measured Range (mg/L)	<0.001–0.042	<0.002–0.62	<0.001–0.047	0.024–0.84	<0.001–0.022	<0.002–0.27	<0.001–0.018	<0.002–0.17
Samples Exceeding Action Level	22.7%	0%	15%	0%	4.1%	0%	1.6%	0%
Number of Samples	66	66	60	60	73	73	63	63

* *Seven Round 2 samples consisted of 1.125 L total volumes.*
** *Round 4 was conducted for demonstration testing (full-scale) purposes.*

According to City personnel, there are no known single family structures that contain lead pipe, nor are there any known lead service lines within the Bellingham service area. Although there are some lead goosenecks, these are not regulated under the LCR. To fulfill the requirements of the materials survey outlined in the LCR Guidance Manual Volume I, Bellingham reviewed plumbing and building codes, water quality data, historical documentation of development within the service area, and also interviewed building inspectors and local contractors and developers for identification of Tier 1 sites.

Nearly all of the sites tested during each monitoring round were equipped with chrome plated brass fixtures and copper piping with lead solder. Homes were inspected and tested for the presence of lead solder, as recommended in the LCR. The 90th percentile lead level obtained during Round 1 (0.023 mg/L) exceeded the action level, and therefore Bellingham decided to determine the contribution of the brass fixtures on the overall lead level. "Fractionated" samples were collected to determine the mass of lead in the first 125 mLs of sample (in contact with the brass fixtures) versus the mass of lead in the subsequent liter. This sampling protocol resulted in a 1.125 L total volume from which the lead level was calculated.

Analyses of the results of the seven sites from which fractionated samples were collected indicates that approximately 34% of mass of lead in the 1.125 L sample was contributed by leaching from brass fixtures and immediate connective piping. The percent mass contribution from the fixtures was calculated by determining the mass of lead in the first 125 mLs, and dividing this mass by the total mass of lead in the 1.125 L sample. For example, at Site 015K during Round 2, the total mass of lead in the 1.125L sample was calculated according to the mass balance equation:

$$C_1V_1 + C_2V_2 = C_3V_3$$

where C_1 = Laboratory measured concentration (0.051 mg/L) for first fraction
V_1 = Actual volume of sample (0.125 L) for first fraction
C_2 = Laboratory measured concentration (0.013 mg/L) for second fraction
V_2 = Actual volume of sample (1 L) for second fraction
C_3 = Concentration of combined sample (0.017 mg/L)
V_3 = Volume of combined sample (1.125 L)

The mass of lead in the first 125 mLs [C_1V_1 = (0.051 mg/L)(0.125 L] equaled 0.006 mg. The mass of lead in the total 1.125 L sample equaled 0.019 mg. Therefore, the percent mass contribution from the brass fixture and immediate connective piping equaled 33.6%. The percent mass contributions for the seven fractionated sites were calculated and averaged together, resulting in 34% contribution from the first 125 mLs of sample in contact with the brass fixtures. The remaining 66% of the lead in the calculated 1.125 L sample was most likely contributed by lead-soldered copper pipe.

2.3 Piping and Plumbing Materials

2.3.1 Pipeline Materials

Bellingham staff provided information about the material make-up and corrosion condition of pipes in their distribution system and the make-up of service lines connecting homes to the distribution mains. Table 2-9 presents a numerical summary of the distribution system information for the City water service area, indicating that cast iron and ductile iron comprise over 95 percent (roughly 286 miles) of the Bellingham's distribution system. Staff estimate that about 25 percent of the cast iron pipe is unlined; all DI is cement lined. Smaller quantities of Transite (asbestos cement), concrete, steel, and plastic account for the remaining 14 miles of piping.

Table 2-8
City of Bellingham
Distribution System Piping Materials
(Estimated 1993)

Pipe Material	Size	Quantity (feet) (1993)	Percentage
Cast Iron	4" to 36"	815,800	51.5
Ductile Iron	4" to 24"	695,800	43.9
Transite	4" to 12"	42,600	2.7
Concrete	24" to 48"	19,500	1.2
Steel	12" to 66"	9,600	0.6
Plastic	2"	650	0
Galvanized	2" to 4"	0	0
TOTAL		1,583,950 (300.0 mi.)	99.9

2.3.2 Pipeline Corrosion Conditions

Conversations with Bellingham staff indicate that the corrosion condition of 90 percent of the existing system is good and the remaining 10 percent is fair. Some tuberculation of the older (unlined) cast iron mains has been observed. The unlined cast iron pipes are gradually being replaced with ductile iron pipe. As part of the maintenance of the distribution system, water mains are flushed annually during April to remove accumulated particulates and stagnant water. Dead end portions of the system are flushed more frequently.

2.3.3 Household Service Line Connections

Household service lines generally consist of two distinct portions. The first portion of the service line consists of pipe connecting the water main to the home's water meter and is almost always installed by the City. The second portion of service line connects the water meter to the home plumbing system and almost always is installed by the contractor who built the home.

The first portion of service line (from the main to the meter) historically has been installed in either copper, galvanized steel, PVC, or brass. According to information provided by City staff, Type K copper pipe with flared end connections make up the majority of all connections (estimated at 90 percent of all service-line connections), while galvanized steel is estimated to account for about 8 percent. PVC and brass connections each account for about 1 percent of the remaining services. The galvanized service-line connections also have lead goosenecks. Copper service connections began to replace the galvanized connections in residential service applications in the late 1940s. Galvanized pipe was still used in the 1960s for larger service connections.

City staff estimated nearly all of the second portion of the service line (from the water meter to the house) installed from about 1980 to the present is plastic (i.e. polyethylene); installations prior to 1980 were estimated to be primarily copper or galvanized. Because the City is not directly involved in the installation of the second portion of the service line (from the water meter to the home), these estimates of the make-up of home plumbing system materials may not be entirely reliable; additional information from plumbing contractors is discussed below.

2.3.4 Survey of Plumbing Contractors and Suppliers

The project team conducted a phone survey of several local plumbing contractors who perform work in the City and its water service area. Questions regarding pipe and solder material types and installation practices were asked of those surveyed. The results of the telephone survey can be summarized as follows:

- ☐ The plumbing contractors stated they prefer to use Type L soft copper for the portion of the service line running from the water meter to the house. Depending upon the customer and the project budget, PVC or polyethylene pipe is also being used. Two companies stated that 75 percent of the new installations they see in the field were polyethylene pipe.

- ☐ Nearly all of the new residential plumbing systems these contractors installed are copper. The use of lead-free solder is required by law. One company did mention that they had started to install polybutylene plumbing systems in new homes within the last several months.

- ☐ When homes are remodeled or the existing plumbing system is updated, galvanized pipes are usually replaced with copper.

- ☐ While the contractors surveyed could remember galvanized pipes which had scale deposits or rust, in general, this was an uncommon occurrence.

- ☐ Several of the contractors observed corrosion between galvanized and copper fittings in the field. Pitting also has been observed, but the contractor stated he felt it was related to poor workmanship and improper procedures during construction.

- ☐ The only corrosion related complaints received or noticed from customers were when water mains were being flushed.

☐ Based on their observations, none of the plumbing contractors surveyed thought the water supplied by the City to be corrosive, especially in contrast to other water supplies in the county.

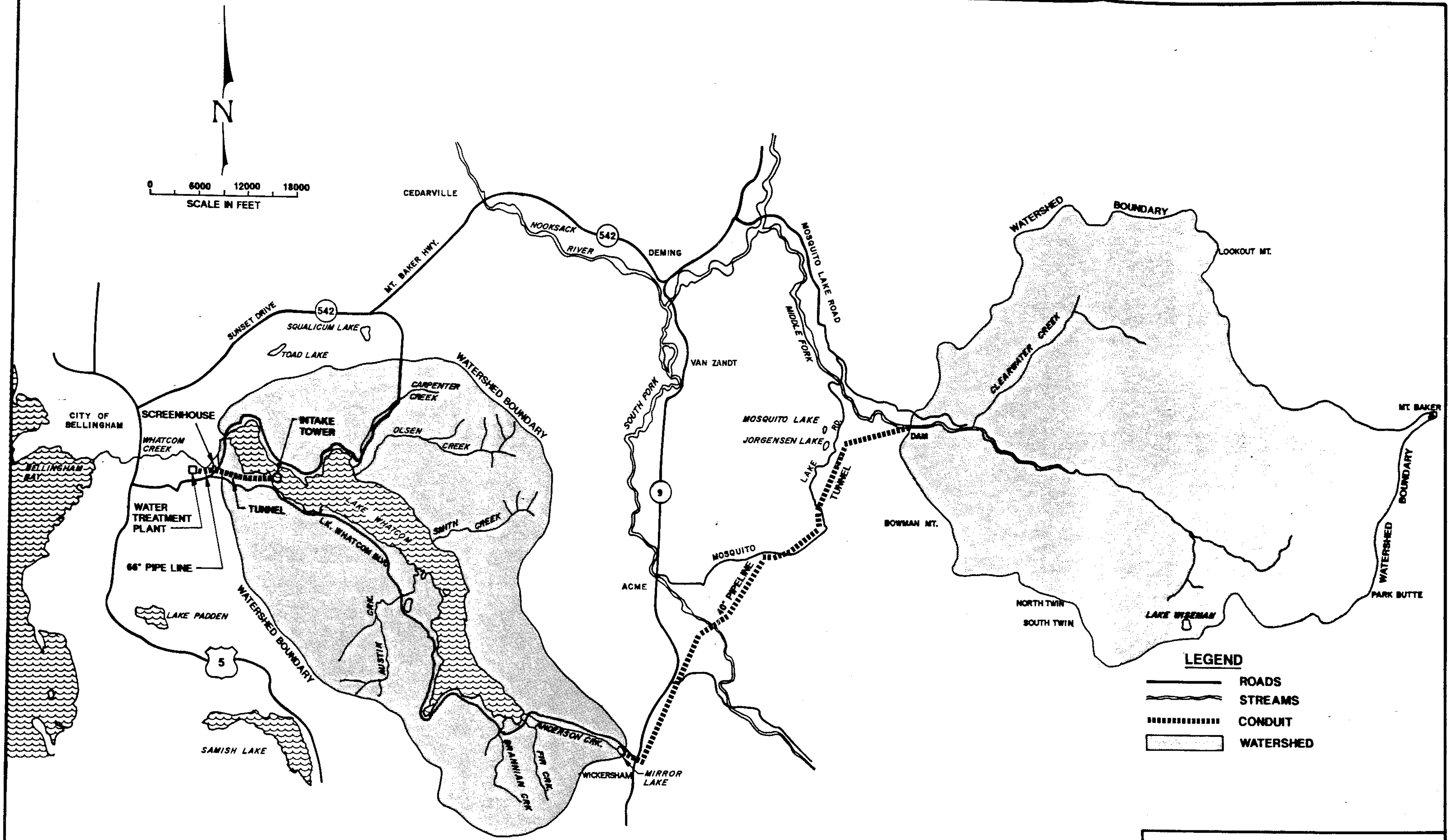
2.4 System Information Summary

Based upon the information presented and discussed above, the following conclusions can be made:

☐ Lead leaching has historically occurred in the Bellingham service area based on lead levels measured in first-draw samples taken from home taps for LCR monitoring. However, pH adjustment to 8.0 using soda ash appeared to passivate lead containing surfaces, resulting in significantly lower solubilized lead levels. Less than 10% of the homes tested had lead levels greater than 0.015 mg/L during both the third and fourth rounds of monitoring, conducted after pH/alkalinity adjustments, and including homes from consecutive systems.

☐ While staff estimate the corrosion condition of 90 percent of the system to be good, the City does have a main flushing program to remove rust and accumulated particles. Some tuberculation has been observed in portions of the unlined cast iron pipes.

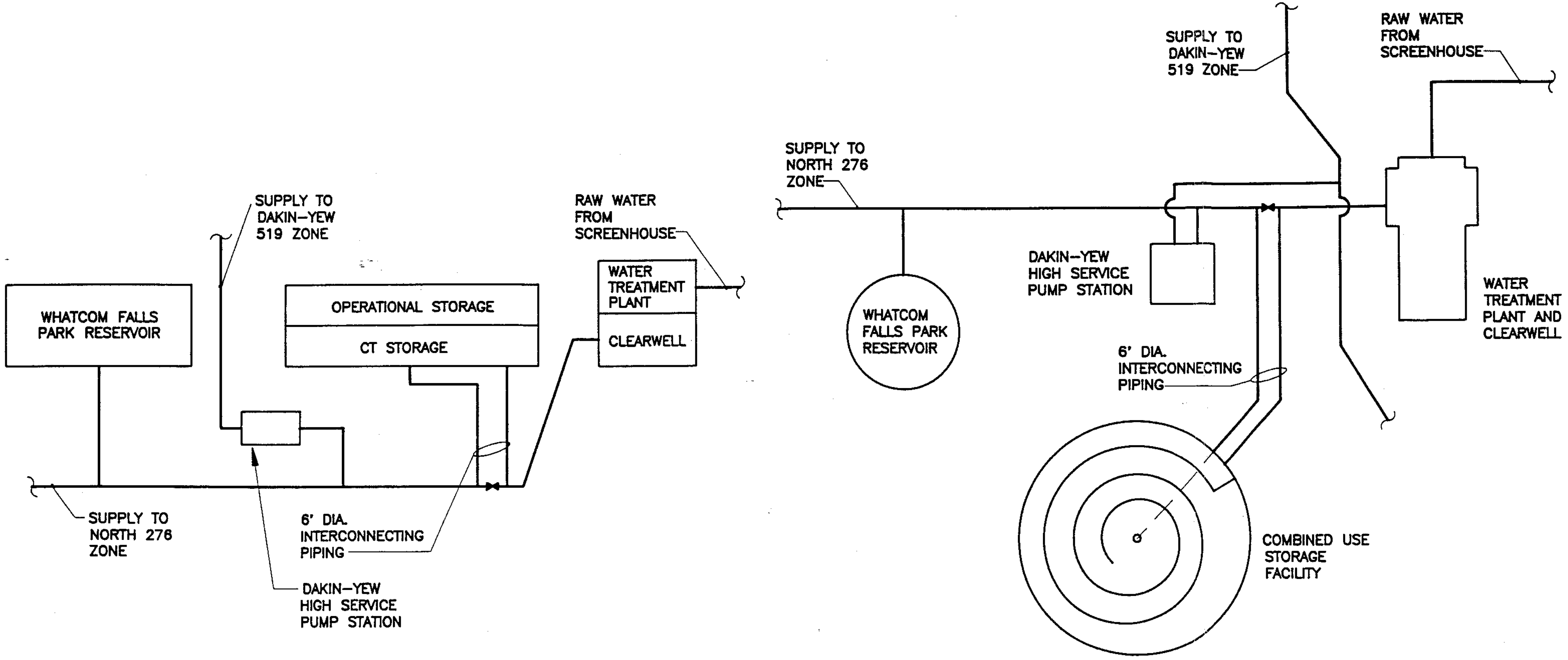
☐ Nearly all of the new residential plumbing systems and repairs to existing residential systems are copper. Corrosion of copper plumbing does not appear to be a problem, based on results of at-the-tap monitoring and no history of blue-water or staining complaints.



Source: Comprehensive Water Plan, Barrett Consulting Group, 1993

Exhibit 2-1

Water Supply Plan



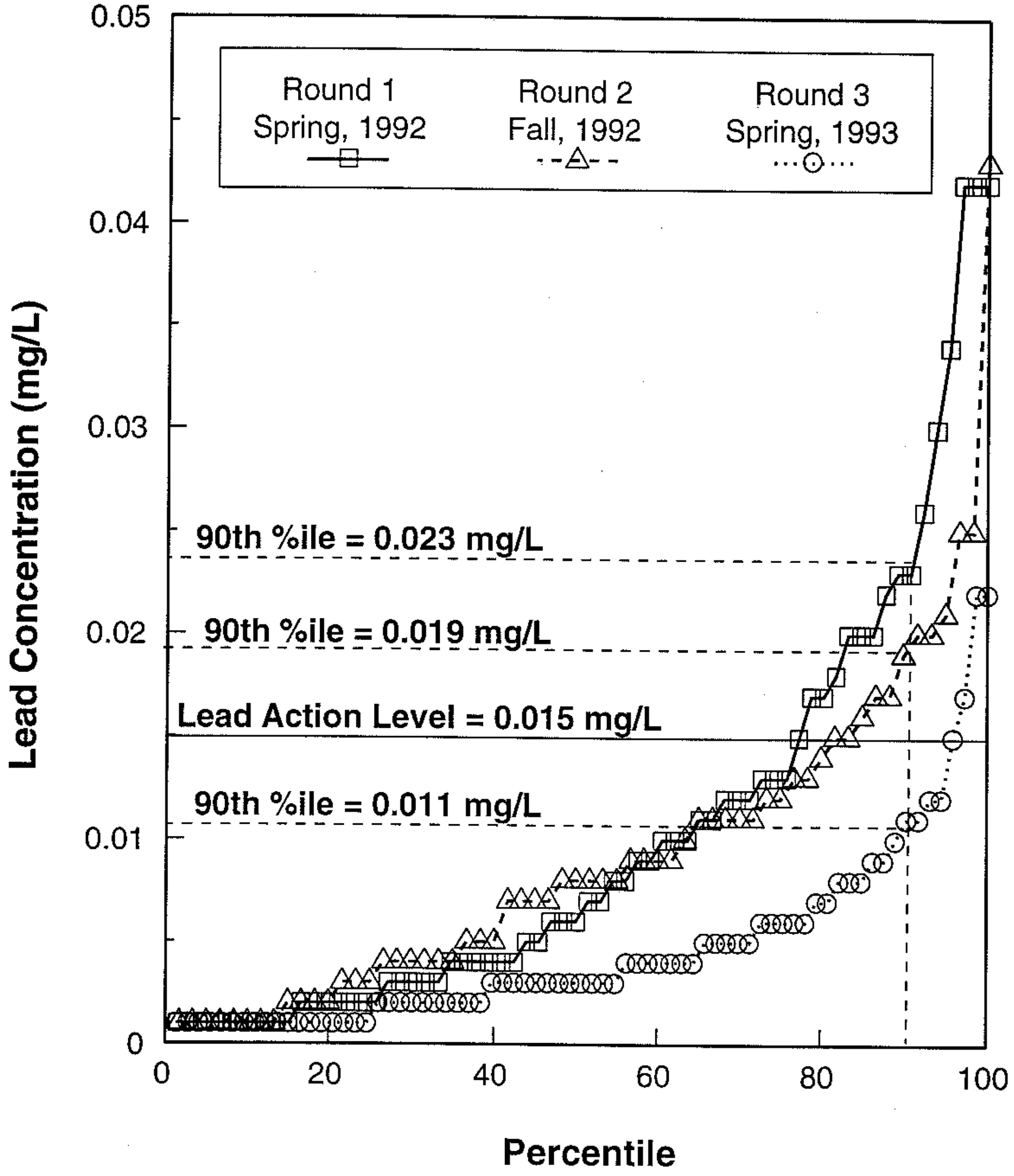
SCHEMATIC PROFILE

SCHEMATIC PLAN

Source: Comprehensive Water Plan, Barrett Consulting Group, 1993

Exhibit 2-2

Facility Schematics
Water Treatment Plan Facility

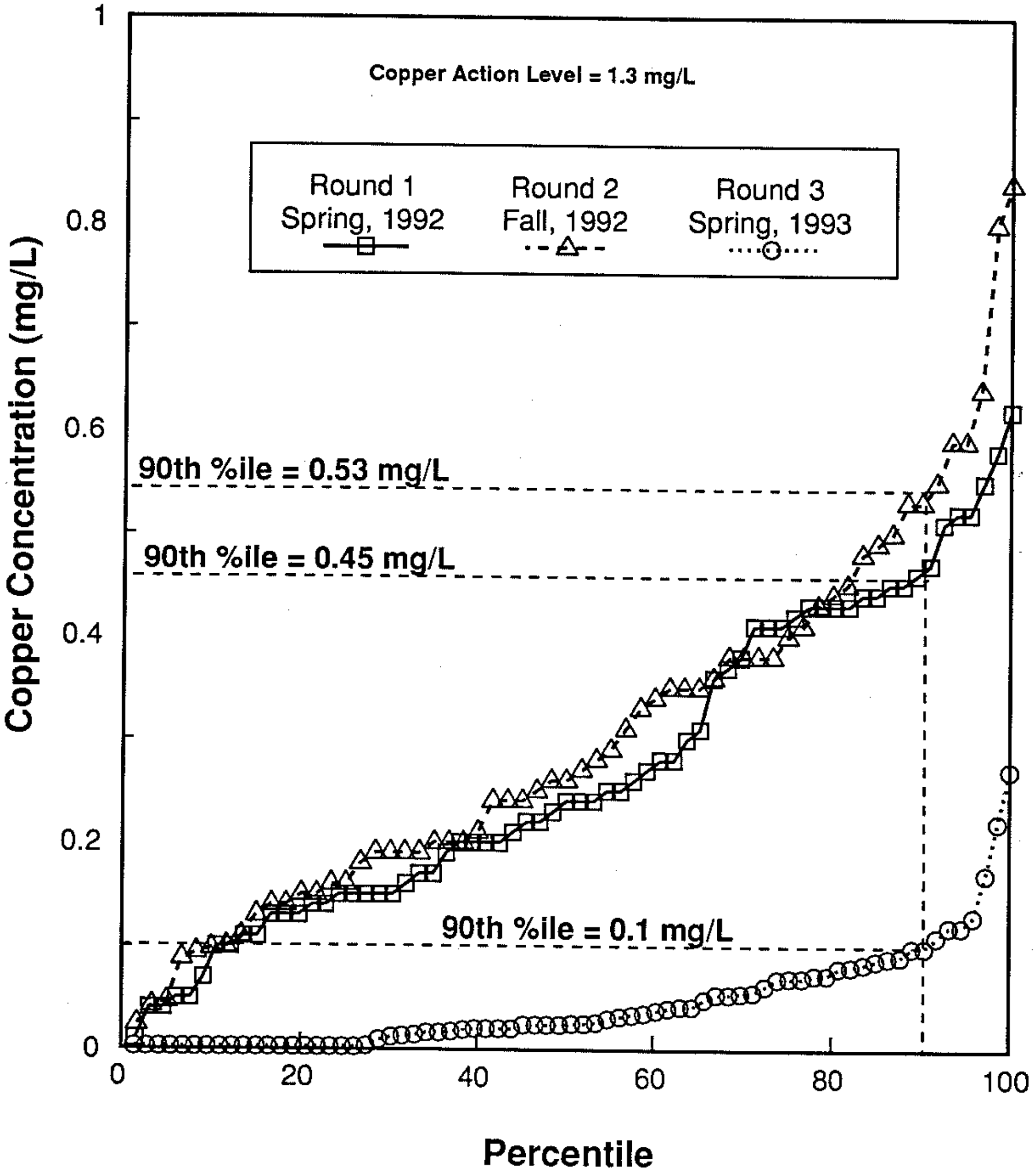


Note: The 90th percentile for Round 4 (full-scale testing) was 0.009 mg/L.

Exhibit 2-3

City of Bellingham

90th Percentile Lead Levels



Note: The 90th Percentile for Round 4 (full-scale testing) was 0.13 mg/L.

Exhibit 2-4
City of Bellingham
90th Percentile Copper Levels

Section 3
Causes and Effects of Corrosion

3.1 Overview

This portion of the report summarizes the possible causes of lead and copper corrosion within Bellingham's service area. Some metals release is noted; however, lead and copper are not leaching at excessive rates in the Bellingham system. The causes of corrosion can be divided into two categories: 1) susceptible materials (especially unlined, metallic piping and home fixtures) and 2) slightly aggressive water conditions. Corrosion and metals leaching can potentially cause undesirable health and aesthetic impacts on water quality, as well as decrease plumbing material life. Leaching increases the metal concentration in the water through the mobilization of metals when contacted with an aggressive water.

3.2 Corrosion of Materials of Concern in Bellingham Service Area

The wide variety of materials present in Bellingham's distribution system, and the variability of corrosion-related properties associated with each material prevents the development of a corrosion control strategy that equally addresses each type of piping material. Therefore, the most critical materials should be targeted in corrosion optimization studies. Based on the review of pipeline and plumbing condition, the materials which warrant the greatest emphasis in Bellingham's service area are:

☐ 50:50 lead - tin solder,
☐ Brass fixtures and fittings,
☐ Copper piping, and
☐ Unlined iron and steel piping.

3.2.1 Lead Solder

Lead solder appears to serve as the most significant source of lead in drinking water in the Bellingham service area. This has been demonstrated by high levels of lead in standing samples despite the absence of lead service lines, and lead plumbing in the Bellingham service area. The galvanic reaction between lead solder and copper pipe can result in significant amounts of lead leaching (AWWARF, 1990). Although lead leaching can also be caused by the use of lead-containing brass fixtures, widespread use of 50-50 lead-tin solder in the Bellingham service area until 1987 appears to be a significant cause of high lead levels at the tap.

Analysis of seven fractionated samples collected from the Bellingham distribution system indicated that an average of 66% of the mass of lead in a 1.125 liter sample was contributed from lead solder. Adjusting water quality so that corrosion of lead solder is minimized will likely result in significant reduction of lead levels at the tap.

In addition to measuring lead levels in fractionated first-flush samples, Bellingham collected a 1 L fully flushed sample at each of the fractionated sampling sites. Lead levels in the flushed samples were consistently lower than in the standing samples and most were at or near the lead detection level (0.002 mg/L) with the highest concentration (0.006 mg/L) measured at site 062 K. It is likely that the lower levels measured in the flushed sample reflect the absence of lead solder in the distribution system or indicate that extended contact time is necessary for significant levels of lead to be leached into the water.

3.2.2 Brass Fixtures and Fittings

Brass is mainly composed of copper and is commonly found in valve parts, faucets, and water meters. Brass can contribute significant amounts of both lead and copper to the first flush samples through metal leaching. The brasses most commonly used as household fixtures contain 1.5 to 7.5 percent lead. Brass can be termed "lead free" yet still contain up to 8 percent lead according to EPA guidelines. A 1988 survey conducted for the American Water Works Service Company estimated that 33 percent of the mass of lead in 1.0-liter first-draw samples was contributed by lead-containing brass faucet fixtures (AWWARF, 1990). Compositions of commonly used brasses are provided in Appendix A.

Comparison of 125 mL and 1000 mL standing samples in Bellingham's service area indicate that a significant portion of the lead in 1.125 liter samples is contributed from the first 125 mL, which is the portion in contact with plumbing fixtures and immediate connective piping. Bellingham's tap sampling program found lead levels in the first 125 mLs of samples as high as 0.27 mg/L. It is estimated that any where from 7 - 70% of the lead measured in the 1.125 L sample was contributed by the first 125 mLs in contact with brass fixtures and fittings. An average of 34% of the mass of lead measured in samples that exceeded the action level was contributed by the first 125 mL portion of the sample. It will be important to verify that the chosen corrosion control strategy will not increase the susceptibility of brass towards leaching of lead or copper.

3.2.3 Unlined Iron and Steel Pipe

Unlined cast iron pipe can be very susceptible to corrosive attack. Internal corrosion of iron distribution pipes is generally in the form of pits and tubercles, with pipe plugging rather than leakage being the major problem. Although this reduces the risk of pipe failure resulting from leakage, leaching of iron into the water can adversely impact water quality (AWWARF, 1985). Cast iron mains comprise the largest portion of Bellingham's distribution system, with the unlined portion estimated at 25%. Corrosion control strategies for lead and copper may potentially increase the water's aggressiveness to ferrous pipe materials because the pH of minimum solubility is lower for iron and steel than for lead. Table 3-1 presents theoretically optimum pH levels to achieve minimal solubility for various distribution system materials.

Table 3-1
Theoretically Optimum pH Levels for Minimum Solubility

Material	Optimum pH
Lead	9–9.5
Copper	8
Steel	7.5
Zinc	7.5
Galvanized Pipe	7.5–8

By increasing pH to levels greater than 8.0, it is possible that lead solubility will decrease, however the solubility of other materials such as steel and zinc could theoretically increase slightly.

3.2.4 Copper Piping

The main source of copper in drinking water is the copper pipe itself. Copper levels in Bellingham's distribution system were consistently below the 1.3 mg/L action level, indicating that the treated water quality does not need alteration in order to meet the copper action level. Corrosion control measures will need to ensure that the condition of the copper pipe in the Bellingham service area is maintained.

3.2.5 Conclusions

Various materials used in transmission, distribution, and premise plumbing are susceptible to corrosion by aggressive water. There is no single corrosion control strategy that can address each material; therefore, the materials which warrant the most concern for health, aesthetic, and economic reasons have been targeted. These materials and their susceptibility to corrosion and/or leaching in Bellingham's service area are summarized in Table 3-2 below.

Table 3-2
Materials of Concern in Bellingham's Service Area

Material	Susceptibility	Potential Type of Concern
50:50 Lead:Tin Solder (currently banned)	Leaching	Health - Lead Leaching
Brass	Leaching	Health - Lead Leaching Health and Aesthetic - Potential Copper Leaching
Unlined Cast Iron and Steels	Potential Corrosion	Aesthetic - Rusty/Red Water Economic - Tuberculation
Copper	Leaching, Corrosion	Aesthetic - Blue/Green Staining Economic - Pitting/Failure

3.3 Potential Causes of Corrosion

Various chemical and physical properties of water can accelerate or inhibit corrosion of piping materials. Source water quality parameters such as pH and alkalinity are most often targeted for corrosion control since these parameters can be changed with chemical addition. Water treatment practices should also be investigated since disinfectants can significantly alter source water quality and act as oxidizing agents. Physical properties of water such as temperature and velocity can also impact the corrosivity of water. These potential causes of corrosion and the effect on materials of concern in Bellingham's distribution system are reviewed in this section.

3.3.1 Source Water Quality Parameters

Source water quality parameters that are most likely affecting the corrosivity of Bellingham's source water include:

☐ Low pH,
☐ Low alkalinity and buffering capacity,
☐ Influence of the carbonate system,
☐ Low mineral content, and
☐ High dissolved oxygen content.

Information available in the literature and past experiences of other utilities have indicated that the occurrence of all the above conditions often results in water that is aggressive to various metals commonly found in distribution and household/building piping systems.

Low pH Levels

A dominant factor in corrosivity of Bellingham's supply is pH. The influence of pH differs for various metals. pH has a controlling effect on solubility, reaction rates, and, to a more limited extent, the surface chemistry of most corroding metals. Low pH in Bellingham's supply potentially increases the solubility of lead from lead-based solder and from brass fixtures. This may be seen in samples with higher lead levels in the initial flush of plumbing systems after any prolonged period of non-use. Theoretically, the solubility of lead decreases with increasing pH up to a pH of approximately 9.5. Although pH increases may be desirable for controlling lead, the effect on other metals present in the distribution system must also be considered.

Studies conducted by the Greater Vancouver Water District and reported elsewhere in the literature, have shown that pH variation over the range of 6 to 9.5 has little direct effect on the corrosion of steel and iron. However, pH has an indirect effect on the corrosion rate of these metals because it can influence the potential for protective scale formation. Decreasing pH appears to increase the corrosion rate of zinc; however, very few studies have investigated the contribution of pH alone on zinc corrosion. Bellingham recently increased pH in the treated water from 7.3 to 8.0, and analyses of fractionated samples indicated that lead leaching may have decreased, as theory would predict. This data was previously shown in Exhibit 2-5. Even though it is likely that pH adjustments will be an important step in minimizing corrosion in Bellingham's distribution system, the resulting increase in alkalinity and interactions between pH and alkalinity must also be considered.

Low Alkalinity Levels

Low alkalinity waters typically lack buffering capability; and can therefore also lack stability with respect to pH. Low alkalinity waters are very limited in their ability to form protective carbonate scales on piping. Providing adequate alkalinity may be a significant factor in limiting lead dissolution into water. Alkalinity levels in Bellingham's source water vary between 14 and 21 mg/l as $CaCO_3$ with average values around 18 mg/l. Increasing alkalinity and pH to certain levels can precipitate lead carbonate, forming a protective scale and reducing the rate of corrosion and dissolution of lead into the water. This is potentially an important aspect in reducing lead concentrations in Bellingham's water.

Influence of the Carbonate System

The carbonate system controls acid-base equilibrium in natural waters. Species that make up the carbonate system include:

☐ Gaseous CO_2 ($CO_{2(g)}$)
☐ Dissolved CO_2 ($CO_{2(aq)}$)

☐ Carbonic Acid (H_2CO_3)
☐ Bicarbonate (HCO^{3-})
☐ Carbonate (CO_3^{-2})
☐ Carbonate Containing Solids

It is through reactions with the carbonate system that alkalinity (HCO_3^- and CO_3^{-2}) is imparted to the water (Stumm and Morgan, 1970). Surface waters have limited contact with the lithosphere, causing the exchange of CO_2 with the atmosphere to control pH and provide buffering capacity to the water. Therefore, the carbonate system controls the interaction of pH and alkalinity for natural water systems (Exhibit 3-1). As pH increases between 7 and 9, the carbonate in solution is converted to bicarbonate ion which is the primary buffer in natural waters. The effects of pH and alkalinity levels on theoretical lead leaching are demonstrated in Exhibit 3-2. As alkalinity increases, its impact on solubility decreases and leaching is primarily controlled by pH. However, field and pilot tests do illustrate that alkalinity levels are an important factor in lead leaching.

Low Mineral Levels

Soft, low-mineralized waters can be corrosive to galvanized steel, iron, copper, asbestos cement, and lead materials. These waters typically lack the ability to precipitate a protective calcium carbonate scale inside piping. Bellingham's water with a calcium level of 22 mg/L as $CaCO_3$ is considered low in mineral content.

High Dissolved Oxygen Levels

Dissolved oxygen (DO) must be present in potable water to cause corrosion of metal piping. It is extremely important in the corrosion rates of iron and steel piping. Generally, the corrosion rate of steel increases linearly with increasing DO concentrations up to 9 mg/l. DO in Bellingham's raw water and in the distribution system is near saturation conditions, indicating there is always sufficient DO to maintain high rates of iron and steel corrosion.

Dissolved oxygen also serves as the most common oxidant for lead in potable waters (AWWARF, 1985). The corrosion of lead is highly dependent on a combination of the free lead species activity, dissolved oxygen concentration, and pH. Bellingham's source water is typically saturated with dissolved oxygen (between 9 - 12 mg/L) at various temperatures.

3.3.2 Water Treatment Practices

The presence of hypochlorous acid and hypochlorite ion can influence water corrosivity even though these species are often present in low concentrations (Internal Corrosion, 1985). Copper and its alloys are typically most susceptible to corrosion from water treatment with chlorine species. Injection of gaseous chlorine lowers the pH through liberation of hydrogen ions and the formation of hypochlorous acid according to the following equation:

$$Cl_2 + H_2O \text{ ---> } HOCl + H + Cl^-$$

Hypochlorous acid (HOCl) further dissociates to the hypochlorite ion (OCl^-). Source water pH determines the degree of dissociation of HOCl. Although lower pH levels are advantageous in terms of disinfection efficiency, they can also serve as a primary contributor to corrosion. The presence of hypochlorous acid can contribute to copper corrosion. Bellingham uses free chlorine in primary and secondary disinfection and this could be a contributing factor in corrosion.

3.3.3 Physical Parameters

Physical factors such as water temperature and velocity can also contribute to or inhibit the aggressiveness of a water.

Temperature

Corrosion theory predicts that corrosion rates will increase with temperature. Typically, rates of chemical reactions tend to double with each 10°C increase in temperature (AWWARF, 1985). The effects of temperature on corrosion are not necessarily material specific; however, temperature effects will vary for different waters.

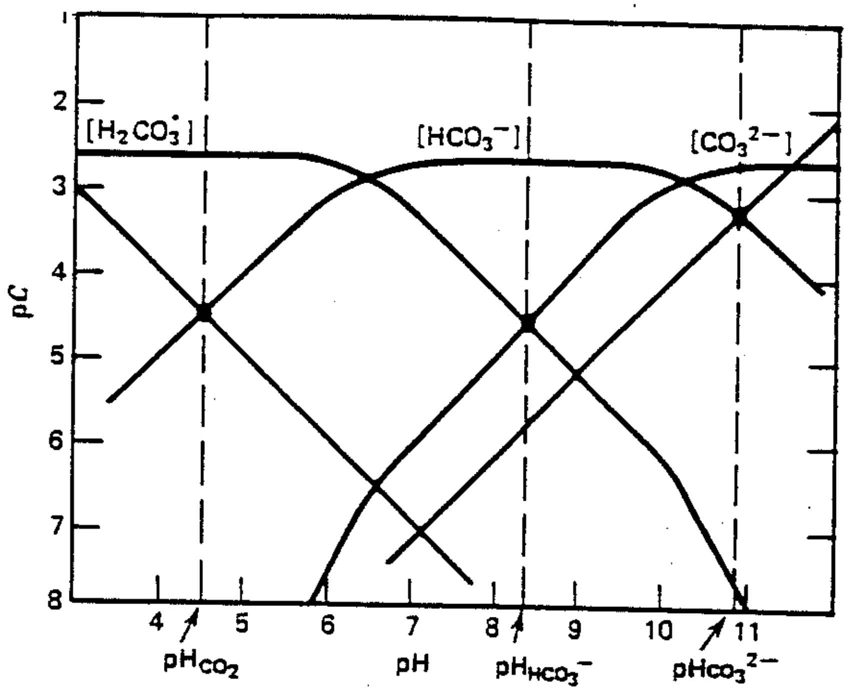
The generally cold temperature of Bellingham's water (with average annual water temperatures ranging from 12° C to 13° C and average winter water temperatures ranging from of 4° to 6° C) would tend to inhibit corrosion electrochemical reactions. Temperature rises increase the reaction rate constants for corrosion, shift chemical equilibrium, and affect the solubility of gases. Hot water (30° C to 45° C) undersaturated with calcium carbonate, is potentially much more corrosive to most premise plumbing than water at cooler temperatures. In Seattle, hot water pipe pitting rates were two to three times greater than for cold water pipe. In contrast, warmer temperatures may induce scale formation, thereby reducing corrosivity. Additionally, increases in temperature can drive off corrosive gases such as dissolved oxygen and carbon dioxide (AWWARF, 1985). Therefore, the impact of temperature on corrosivity is a function of other water quality characteristics such as the potential for scale formation. For Bellingham's water, increasing temperatures would most likely increase the aggressiveness of the water.

Velocity

Water velocity can enhance corrosion by two general processes. Both are a result of higher than desirable velocities. High velocities have the ability to scour protective films and prevent scale formation. Also, higher velocities carry more oxygen to the corrosion cell, increasing the corrosion rate, particularly over neutral pH ranges. Velocities in excess of 1.5 feet per second (fps) in hot water circulating systems and/or 6.0 fps in cold water lines increasingly accelerate pitting and corrosion failures (AWWARF, 1985).

3.3.4 Conclusions

Water quality characteristics such as low pH, low alkalinity, interactions of the carbonate system at low pHs, low mineral levels (soft water), and saturation with respect to dissolved oxygen are the most likely contributors to the aggressiveness of Bellingham's water. Preliminary investigations indicate that pH levels may have a large impact on metals leaching, based on the apparent decrease in soluble lead levels at the tap after pH adjustment. The presence of adequate alkalinity levels may be crucial to maintaining adjusted pH levels in the far ends of the distribution system. Although physical characteristics may effect corrosion, it is probable that these characteristics are not primary causes of metals leaching in Bellingham's service area.



Source: Snoeyink and Jenkins (1980)

Exhibit 3-1

Distribution of Carbonate Species with pH

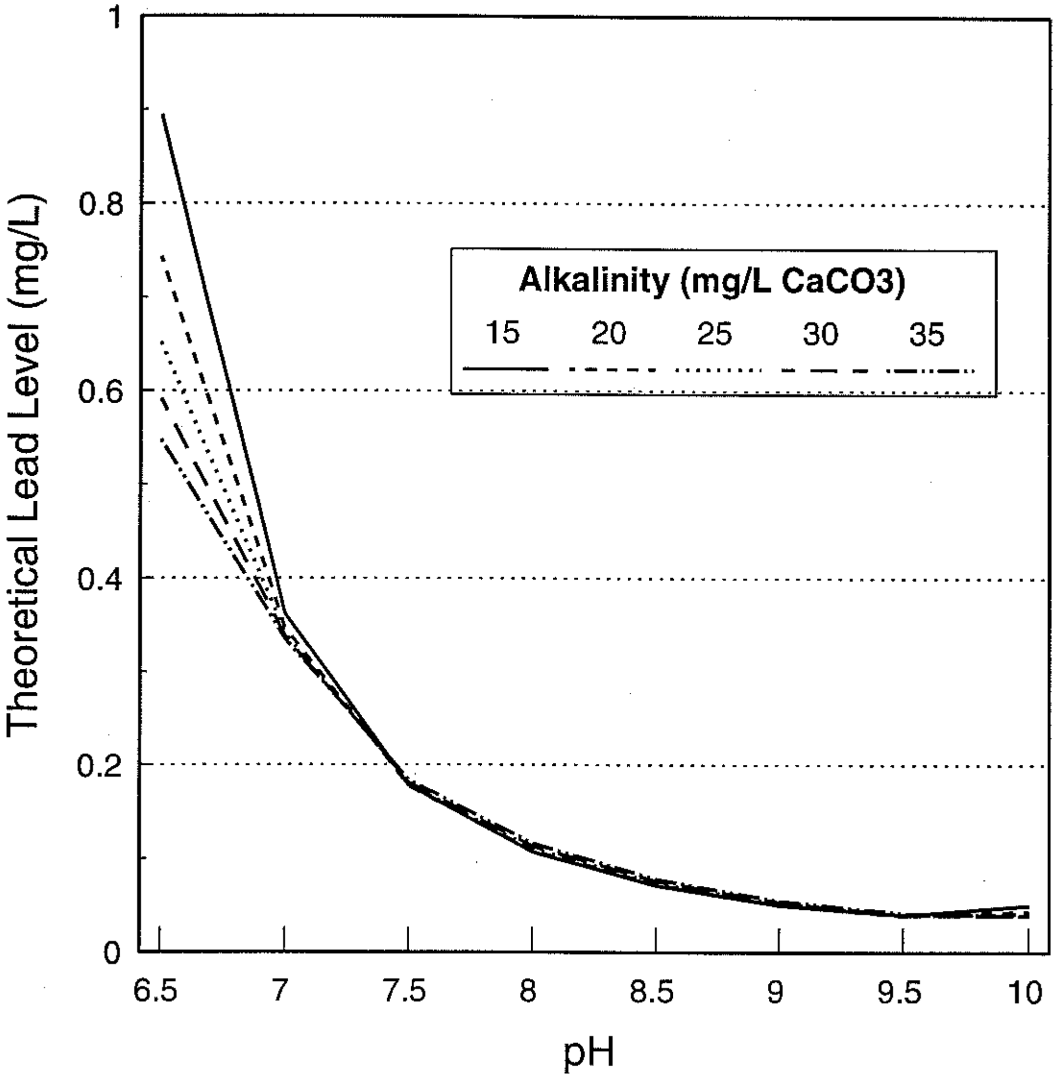


Exhibit 3-2

City of Bellingham

Effect of Alkalinity on Lead Solubility

Section 4
Corrosion Control Treatment Technologies

4.1 Overview

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 water systems were typically designed to improve aesthetics, protect hydraulic capacity, and/or reduce long-term pipeline maintenance. Although these objectives remain worthwhile, they may not directly address Lead and Copper Rule (LCR) compliance, which essentially has redefined corrosion control solely on the basis of public health impacts. The 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 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, and reduce laundry staining, etc. Some of these "corrosion inhibitor" chemicals can also help reduce lead and copper levels in drinking water, although many will not, and some could even increase lead concentrations. Comparison of corrosion inhibitors is often controversial because of the proprietary nature of the specific chemical formulations. This issue is further complicated by a lack of understanding by many users about the differences between chemical products (e.g., ortho- and poly-phosphates) and their relationship to the formation of metallic precipitates and protective films in potable water systems. The use of chemical treatment to reduce lead and copper in drinking water will be dependent upon many chemical and physical interrelationships and usually requires side-by-side testing to assess performance.

At a minimum, the Lead and Copper Rule mandates that utilities must consider three basic approaches for achieving corrosion control:

- ☐ pH/alkalinity adjustment
- ☐ Calcium adjustment ($CaCO_3$ deposition)
- ☐ Inhibitor addition

Characterizing corrosion control in this fashion tends to oversimplify the range of options available to a utility when tailoring a program to its specific needs. A more accurate approach is to recognize that corrosion control technologies can be characterized by two very general mechanisms, each of which has a multitude of variations that carry specific advantages and disadvantages:

☐ Barrier Protection—the deposition of a precipitate film on the plumbing surfaces to prevent oxidizing agents in the water from reaching the pipe wall and/or oxidized metals from the pipe wall from leaching into the water.

☐ Passivation—The manipulation of water quality so as to cause plumbing materials and a number of water constituents to form metal complexes and/or insoluble oxide layers that change the electrochemical nature of the metal surface and limit the underlying rate of the corrosion process.

As summarized in Table 4-1, various chemical treatment systems are available to promote barrier protection and/or passivation. Each of these systems must be evaluated relative to dosage range and specific water quality concerns. Moreover, it should be realized that a particular treatment system will not be universally effective on all metal types, and that corrosion control must be tailored to the plumbing material of interest. In the evaluation of materials susceptible to corrosion in Bellingham's system (Section 3), lead and lead containing materials such as brass and lead:tin solder were rated as the highest priority for corrosion control treatment. However, a corrosion control treatment approach for lead must not increase corrosion rates on other metal surfaces in the distribution system such as iron, steel, and copper.

Table 4-1
Conceptual Framework for Corrosion Control Approaches

Control Mechanism	**Passivation**		**Barrier**
Treatment Approach	pH/alkalinity adjustment	corrosion inhibitor	calcium adjustment
Key Water Quality Parameters	pH/alkalinity TDS temperature	pH/alkalinity hardness temperature metals	calcium pH/alkalinity TDS temperature
Appropriate Chemical Feed Systems	lime soda ash sodium bicarbonate caustic soda carbon dioxide	orthophosphate polyphosphate phosphate blends silicates silicate/phosphate blends	lime soda ash sodium bicarbonate caustic soda carbon dioxide

Source: Lead and Copper Rule Guidance Manual, Volume II.

The secondary corrosion control impacts associated with each potential strategy must also be evaluated, including compatibility with future and planned disinfection practices, inhibitor impacts on microbial regrowth within the distribution system, commercial and industrial water users, and potential impacts to wastewater treatment plant operations and wastewater NPDES discharge permit status. Secondary impacts have been evaluated as part of Section 5.

4.2 Barrier Protection

The primary technique for barrier protection is calcium and/or carbonate addition coupled with pH control. $CaCO_3$ deposition 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 forming a protective barrier on the piping systems. The term "calcium adjustment" is frequently used to describe the process, but in many cases this 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 precipitation.

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 adequate corrosion control. Success also depends on the ability to control the formation of scale build-up to ensure that hydraulic capacity is not significantly reduced in the course of providing corrosion protection.

Calcium-carbonate equilibrium is a dynamic system which will change continuously from the point of entry throughout the distribution system to the final service connection. 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 facilities, and require those lines to be cleaned periodically in order to restore adequate hydraulic conditions.

Because Bellingham's Lake Whatcom water supply has a neutral pH, low mineral and alkalinity levels, and a relatively large distribution area (including consecutive systems), calcium carbonate precipitation is not being considered as a viable approach for lead and copper leaching control. Exhibit 4-1 shows EPA's suggested corrosion control approaches based on water quality characteristics. The exhibit is divided into several zones based on three key water quality parameters; pH, alkalinity, and calcium. Using the chart for Bellingham's water, the zones for 1) low pH, low alkalinity, and low calcium; and 2) moderate pH, low alkalinity, and low calcium would be considered. By examining these areas and referring to the key in the lower right-hand corner of the exhibit, the suggested corrosion control approaches for Bellingham are carbonate passivation (pH/alkalinity adjustment), phosphate inhibitors, and silicate inhibitors.

4.3 Passivation

Passivation alternatives include pH/alkalinity adjustment and phosphate and silicate-based inhibitors.

4.3.1 pH/Alkalinity Adjustment

pH/alkalinity adjustment refers to the modification of pH and/or alkalinity (as a surrogate for dissolved inorganic carbonate) to induce the formation of less soluble compounds on the targeted pipe materials. While seemingly simple in practice, the nature of passivation is complex and not well understood. It involves solubility considerations for the oxidized species of the targeted pipe material, but the presence of an insoluble scale alone does not determine the degree of passivation. Passivation is ultimately a change in the electrochemical process of corrosion. The presence of a passivating film changes the nature and rate of the underlying electron exchange reactions. Manipulating water chemistry to promote the formation of an insoluble metal oxide film may achieve passivation in some circumstances, but solubility considerations alone cannot guarantee successful passivation.

The solubility of metals is dependent on the species in which that metal is found. Elemental lead and copper will form complexes with hydroxyl (OH^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), orthophosphate (PO_4^-), and silicate (SiO_2). The pH/alkalinity adjustment method relies upon the formation of less soluble metal species consisting of hydroxyl-carbonate complexes. A summary of chemicals used to adjust pH and alkalinity is provided in Table 4-2.

4.3.2 Corrosion Inhibitors

Corrosion inhibitors are specially-formulated chemicals characterized by their ability to form insoluble metal complexes and thereby enhance passivation. The corrosion inhibitors generally available include orthophosphates, polyphosphates, poly-orthophosphate blends, and silicates.

Orthophosphates

Lead forms at least one orthophosphate solid of low solubility under typical drinking water conditions, which can serve as the basis for corrosion control. A significant amount of theoretical, laboratory, and field evidence indicates that orthophosphates reduce lead corrosion (AWWA 1990). In addition, the results of several corrosion studies using orthophosphate have found positive results with respect to their contribution to copper control.

The pH range across which orthophosphates are most effective for lead and copper is between 7.0 and 7.8. At pH values much above 8.0, metal phosphate precipitates can form, causing turbid water, scale build-up, and hydraulic capacity losses. Waters with low hardness (calcium < 20 mg/L and a calcium to magnesium ratio of 0.7) are well-suited to the use of orthophosphate inhibitors, regardless of the alkalinity of the supply.

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 the appropriate dosage to accommodate background orthophosphate demand as well as the degree of corrosion control protection sought.

Table 4-2
Summary of Chemicals Typically Used in pH/Alkalinity and Calcium Adjustment Corrosion Control Treatment

Chemical	Use	Composition	Theoretical 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.	1.25 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.	1.35 mg/L* $CaCO_3$ alkalinity per mg/L as $Ca(OH)_2$.	pH control is difficult when applied to poorly buffered waters. Slurry feed can cause excessive turbidity. O&M intensive.
Soda Ash, Na_2CO_3**	Increases alkalinity with moderate increase in pH.	95% purity. Dry storage with solution feed.	0.94 mg/L* $CaCO_3$ alkalinity per mg/L as Na_2CO_3.	More pH increase caused as compared to $NaHCO_3$, and 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.
Sodium Bicarbonate $NaHCO_3$	Increase alkalinity with little increase in pH.	98% purity. Dry storage with solution feed.	0.56 mg/L* $CaCO_3$ alkalinity per mg/L as $NaHCO_3$.	Good alkalinity adjustment choice, but very expensive.

Source: LCR Guidance Manual Volume II.

* *From an EPA report* Corrosion Manual for Internal Corrosion of Water Distribution Systems, *1984.*

** *Currently used in Bellingham's water treatment strategy.*

Since the use of inhibitors is most effective over a narrow pH range, maintaining that range throughout the distribution system is an important component of implementing a corrosion control program with inhibitors. For poorly to moderately buffered systems, such as Bellingham's, pH fluctuations within the distribution system can occur and should be tracked during the implementation program.

Phosphate-based 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 phosphate present. The selection of a specific inhibitor may require some preliminary testing. Extraordinary product claims have been made by the various vendors of inhibitor products, and oftentimes the formulation of a specific trade name product will remain proprietary. It is important to realize that there is little evidence to suggest that the proprietary formulations are in any way more effective than the generic blends for which the formulations are known.

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." 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.

Polyphosphates

Polyphosphates are controversial corrosion inhibitors because they are typically proprietary chemicals. There is evidence that polyphosphates revert back to orthophosphates with time and water quality. Certain studies have also indicated that use of polyphosphates can increase lead solubility by dissolving existing protective films on pipelines. Sodium and zinc hexametaphosphates are examples of polyphosphates, with zinc formulation typically out-performing the sodium. Because polyphosphates can revert back to orthophosphates, glassy polyphosphates are sometimes recommended. Polyphosphates can sequester soluble iron and manganese in the water and have proven useful in reducing complaints of red and black water. The most common application form for polyphosphates is in a blend with orthophosphate.

Silicates

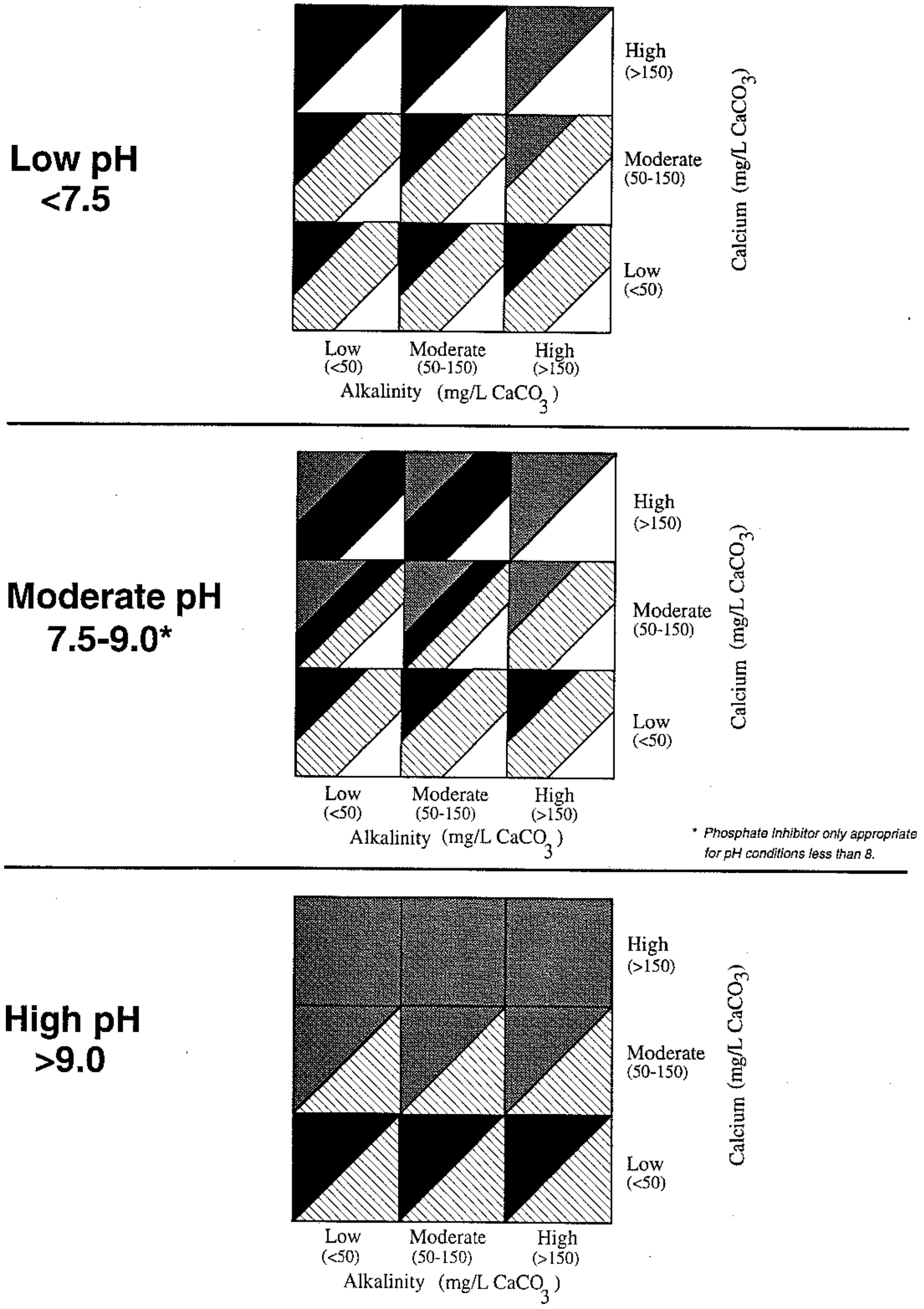
The use of silicates in water treatment has had a long history and yet the mechanism involved in controlling corrosion is unclear for silicate applications. Silicate-based inhibitors are produced as various silicate (SiO_2) to alkali (Na_2O or K_2O) ratios ranging from 0.5 to 3.8. The most common form of silicate in water treatment is the 3.22 weight ratio of SiO_2:Na_2O containing approximately 30% SiO_2. 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 SiO_2:Na_2O.

The method of controlling corrosion attributed to silicates appears to be a combination of absorption 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 pipes conveying water treated with silicates. The majority of the silicate appears in the uppermost layer adjacent to the water. This layer is comprised of an amorphous silicate film adhered to the underlying silicate-metal surface. A slightly corroded surface may be necessary to form the protective silicate film. However, the application of silicates in a distribution system with extensive corrosion by-product build-up 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 and silica can sequester soluble iron and manganese present in the source water to reduce red (iron) and black (manganese) water events. Attention to the water quality conditions prior to their application is necessary depending on the intended use and performance of the silicate. For poorly to moderately buffered waters the relatively caustic silicate solutions offer the added advantage of limited pH control. Therefore it is difficult to separate the corrosion control effectiveness associated with silicate addition from that associated with resultant increases in pH.

4.4 Conclusions

Because Bellingham's Lake Whatcom source water supply has a neutral pH, very low mineral and alkalinity levels, and a relatively large distribution area, calcium carbonate precipitation is not being considered as a viable approach for lead and copper leaching control. Exhibit 4-1 shows EPA's suggested corrosion control approaches based on water quality characteristics. Using the chart for Bellingham's water, the suggested corrosion control approaches are carbonate passivation (pH/alkalinity adjustment), phosphate inhibitors, and silicate inhibitors.



** Phosphate Inhibitor only appropriate for pH conditions less than 8.*

Exhibit 4-1. Suggested Corrosion Control Approaches Based on Water Quality Characteristics

▒ = **Calcium Carbonate Precipitation**	□ = **Phosphate Inhibitor**
■ = **Carbonate Passivation**	▨ = **Silicate Inhibitor**

Source: LCR Guidance Manual, Volume II

Section 5
Constraints

5.1 Overview

The Environmental Protection Agency (EPA) Guidance Manual for the Lead and Copper Rule (LCR) recommends that all constraints which may limit corrosion control treatment alternatives be identified. These constraints are both regulatory and functional, and consist of issues which may:

- ☐ Cause a violation of the National Primary Drinking Water Regulations, or
- ☐ Be ineffective or incompatible with the utility's specific treatment, operational, and/or customer concerns.

This section identifies both regulatory and functional constraints which may limit the type and effectiveness of corrosion control treatment alternatives for this project. These constraints will be used during the preparation of Section 7, which evaluates and recommends corrosion control alternatives.

5.2 Regulatory Constraints

Regulatory constraints consist of federal and state water quality and treatment requirements which may limit the range of available corrosion control options. Of major concern are the potential impacts of the existing Surface Water Treatment Rule (SWTR), the existing Total Coliform Rule (TCR), the anticipated Disinfectant/Disinfection By-Products (D/DBP) Rule, and the future Enhanced SWTR. Each rule is analyzed with respect to this particular project to determine the possible constraints placed on corrosion control treatment options. All of these constraints would be applied to the City of Bellingham (Bellingham), as well as Bellingham's wholesale customers.

Compliance with specific drinking water regulations may limit the changes to water quality characteristics resulting from corrosion control treatment. The purpose of this assessment was to review all existing and proposed drinking water quality regulations that pose potential constraints to chemical corrosion control treatment strategies.

The approach taken for the regulatory constraints assessment was to:

- ☐ Identify those water quality characteristics that may change as a result of corrosion treatment processes;

☐ Identify federal and state water quality regulations that are applicable to the corrosion treatment alternatives under consideration for the Bellingham system; and

☐ Identify and summarize the potential constraints that these regulations may have on the corrosion treatment alternatives.

5.2.1 Water Quality Parameters that May Change as a Result of Corrosion Treatment

Several water quality parameters that may change as a result of passivation corrosion control approaches were identified and are outlined below.

General Physical / Chemical:

pH
Alkalinity
Hardness
Turbidity
Calcium
Phosphorous
Silica
Ammonia

Microbiological:

Coliforms
Heterotrophic Plate Count
Chlorine Residuals

Metals:

Lead
Copper
Zinc
Iron
Cadmium
Antimony

Disinfectants and Disinfection By-Products:

Trihalomethanes
Haloacetic Acids
Total Organic Halides (TOX)
Chlorine Residuals
Chloral Hydrate
Cyanogen Chloride

5.2.2 Potential Constraints of Specific Drinking Water Regulations

Based on the water quality parameters that may change as a result of corrosion control treatments, the Safe Drinking Water Act (SDWA) regulations that may potentially constrain treatment strategies are as follows:

SDWA Regulations in Effect:

☐ Lead and Copper Rule (LCR)
☐ Surface Water Treatment Rule (SWTR)
☐ Total Coliform Rule (TCR)
☐ Phases II and V Inorganic Chemical/Synthetic Organic Chemical (IOC/SOC) Rules
☐ Trihalomethane (THM) Regulation

SDWA Regulations Under Development:

- ☐ Disinfectant/Disinfection By-Products (D/DBP) Rule
- ☐ Enhanced Surface Water Treatment Rule

The relationship and possible constraints of each of these regulations to corrosion control treatment strategies are summarized in the following sections.

5.2.3 SDWA Regulations in Effect

Lead and Copper Rule (LCR)

Background. With regard to optimizing corrosion control treatment, the intent of the LCR is that corrosion treatment should not adversely affect the overall water quality of the water system. EPA defines "optimal corrosion control" as "the corrosion control treatment that minimizes lead and copper levels at users' taps, while ensuring that the treatment does not cause the water system to violate any national primary drinking water regulation". Therefore, for the State to approve a corrosion control strategy, it must be demonstrated that this strategy will not cause the water system to be out of compliance with other water quality regulations. Under the LCR, the State will specify ranges of values for the water quality parameters to control corrosion under which a system must operate. Once the State specifies the range of values, parameter values become enforceable requirements of the National Primary Drinking Water Regulations (NPDWR).

Potential Constraints. After a system installs the state-approved, optimal corrosion control treatment and subsequent lead and copper monitoring data are collected and evaluated, the State will designate the target values for several key water quality control parameters that must be met for compliance. The control parameters that will be regulated are:

- ☐ An optimum range of pH values measured at each entry point to the distribution system;

- ☐ If a corrosion inhibitor is used, a minimum or a range of inhibitor concentrations as measured at each entry point to the distribution system and in tap samples; and

- ☐ If alkalinity adjustment is part of optimal corrosion treatment, a minimum or a range of alkalinity concentrations as measured at each entry point to the distribution system and in tap samples.

Surface Water Treatment Rule (SWTR) and Future Enhanced SWTR

Background. The SWTR specifies filtration and disinfection requirements for surface water sources to protect against acute health risks from waterborne microbiological contaminants. The SWTR sets requirements for regulating *Giardia* and turbidity, as well as viruses, *Legionella*, and heterotrophic plate counts (HPC). The requirements are 99.9 percent (3-log) reduction (removal and/or inactivation) of *Giardia lamblia* cysts and 99.99 percent (4-log) reduction (removal and/or inactivation) of enteric viruses. Direct filtration systems, such as the Bellingham Water Treatment Plant, are given credit for 2.0 log removal from filtration and must disinfect to maintain at least an additional 1.0 log inactivation of *Giardia*, through CT requirements.

The inactivation credit associated with disinfection is a function of calculated CT values. CT is defined as the residual disinfectant concentration (C, in mg/L) multiplied by the disinfectant contact time (T, in minutes) prior to reaching the first customer. For chlorine, the inactivation credit associated with CT is dependent on disinfectant type, pH, and temperature. When free chlorine is the primary disinfectant, as is the case in Bellingham's system, the required CT value at any given temperature becomes larger as pH is increased. To achieve the same level of inactivation with free chlorine at a higher pH, more chlorine would need to be added and/or the contact time would need to be increased.

Potential Constraints. Bellingham is in the process of constructing a new 16.5 MG finished water reservoir. The reservoir has been designed as a dual use facility, combining disinfection contact time and operational storage. Early in the useful life of the reservoir, and at lower flow rates, contact time in the reservoir will be longer, providing excess disinfection contact time. Although this is of benefit for disinfection CT purposes, extended contact time at higher chlorine residual levels could result in increased DBP formation. Therefore, the dual use facility was designed with nine possible chlorine injection ports so that the CT requirements can be maintained while balancing DBP formation prior to distribution.

It may be necessary for Bellingham to conduct CT/DBP formation evaluations using various chlorine feed locations under changing flow conditions once the reservoir is operating. Feed locations can be selected on a yearly, seasonal, or more frequent basis, as required, to optimize CT and DBP formation (Comprehensive Plan, 1993). pH adjustment will occur after CT requirements have been met, thus, longer CT's will not be required as a result of corrosion control treatment. Bellingham recently completed laboratory-scale tests to determine DBP formation potential resulting from corrosion control treatment. Results are discussed in Section 5.2.4.

Possible requirements for the Enhanced SWTR include greater log removal for systems with poorer source water quality. Thus a system with poor source water

Giardia or *Cryptosporidium* concentrations may be required to provide up to 6-log reductions, while a system with less than one cyst per 100 L would still be required to provide 3-log inactivation. Data collected for the future Information Collection Rule (ICR) will likely be used to determine Bellingham's source water quality and disinfection requirements.

Total Coliform Rule (TCR)

Background. This rule, which became effective on January 1, 1991, set standards for the microbiological quality of water in the distribution system. It sets MCLs for total coliforms using the presence/absence of coliforms approach in specified numbers of routine monthly samples from the distribution system and source waters based on system population. Best Available Technologies (BATs) to meet the Rule include filtration/disinfection of surface water sources and maintenance of a detectable disinfectant residual (chlorine or chloramine) throughout the distribution system. Disinfection and residual maintenance are currently successfully practiced by Bellingham. Since Bellingham has been monitoring under the TCR, the City has never had a routine violation.

Potential Constraints. There are two concerns associated with corrosion treatment and the maintenance of an adequate disinfectant residual in the distribution system to meet TCR requirements. The first concern is that elevation of pH may detrimentally affect the speciation and stability of Bellingham's chlorine residual. At pH 7, approximately 80% of the chlorine is in the HOCl species. At pH 7.5, the percent of HOCl drops to around 50%, and at a pH of 8, the percent of HOCl is only about 25% with 75% of the residual as OCl^-, as shown in Exhibit 5-1. The OCl^- species is a less effective form of chlorine than HOCl. A change in species may allow more bacterial growth to occur in the system. However, routine TCR monitoring conducted by Bellingham since pH was adjusted in February of 1993 do not show any increase in positive coliform results versus results prior to pH adjustment.

Phases II and V - IOC/SOC Rules

Background. National Primary Drinking Water Regulations (NPDWR) for the control of 38 selected inorganic and synthetic organic contaminants were finalized January 30, 1991 as Phase II of the Safe Drinking Water Act. MCLs for these contaminants took effect on July 30, 1992. Of these 38 Phase II contaminants, only cadmium may be considered a potential regulatory concern related to corrosion control. Cadmium is a trace metal often found as an impurity in zinc-galvanized coatings of pipes and in brass faucet fixtures. It is classified as a chronic toxicant by the EPA. The new MCL and maximum contaminant level goal (MCLG) for cadmium is 5 µg/L. The cadmium MCL is to be met in samples taken at distribution system point of entries (POE's), not from monitoring at residential taps as is done for lead and copper. Sampling for cadmium at taps in Greater Vancouver Water District was done in 1988. In 24 overnight, first-draw 125 mL samples, only 7 had cadmium above the detection limit of 0.5 µg/L. Cadmium was not detected in any consecutive samples, indicating that faucet fixtures are the source of detectable levels of cadmium. Cadmium level information is present in Bellingham's raw water quality data base, and recent data indicated levels are undetectable at 1 µg/L.

On July 17, 1992 the EPA published final NPDWR regulations (Phase V Rule) for 18 additional synthetic organic chemicals (SOC) and five additional inorganic chemicals (IOC). Of these contaminants, only antimony may be considered a potential concern for corrosion control issues. Antimony levels in drinking water systems have been found to be very low by the National Inorganics and Radionuclides Survey; however antimony is being used increasingly in lead-free (tin/antimony) plumbing solders. The new MCL for antimony is 6 µg/L and the maximum contaminant level goal (MCLG) is 3 µg/L. The MCL is to be met in samples taken at entry points to the distribution system, not from monitoring at residential taps as is done for lead and copper.

Very little information from the literature is available concerning antimony dissolution in plumbing systems. The single best antimony study is cited in EPA's Phase V Rule and was performed by Herrera, et al. This study examined antimony leaching in Seattle's finished water using static immersion tests with tin-antimony soldered coupons and field sampling of copper plumbing with tin-antimony solder. The highest antimony concentration measured during the immersion tests was 3.7 µg/L after 27 hours standing time. In the field sampling, only one overnight standing sample out of a total of eight had a detectable antimony level (2 µg/L total and 1 µg/L dissolved antimony). This study was performed before Seattle began adjusting pH and alkalinity for corrosion control. The EPA also cites an antimony leaching study by Subramanian, et al. Antimony levels from newly-soldered joints were measured in a "high purity" water with pH 6.8; a surface water with pH 7.8 and 30 mg/L as $CaCO_3$ alkalinity; and a groundwater with pH 8.1 and alkalinity of 155 mg/L. The antimony concentrations were at or below the analytical detection limit of 1.2 µg/L for standing times of 7 days, regardless of the water quality. Thus, it appears that this research may be part of the reason that the EPA is not requiring tap sampling/monitoring for antimony. As for Bellingham's system, it is likely that POE antimony levels do not exceed this new MCL of 3 µg/L. Bellingham has been monitoring source and treated water antimony levels since 1993 and all results have been below the detection level of 2 µg/L.

Potential Constraints. Because regulatory compliance for cadmium and antimony is based on samples taken at distribution system entry points rather than customers' taps, it is unlikely that the Phase II and Phase V IOC/SOC Rules will pose any constraints to corrosion control treatment alternatives. Leaching of these metals may occur under conditions that also promote lead and copper leaching, but this would need to be confirmed during testing.

Trihalomethane (THM) Regulation

Background. The existing regulation for THMs was promulgated in 1979 as part of the National Interim Primary Drinking Water Regulations. In the State of Washington, the MCL is 100 µg/L total THMs (TTHM) and is based on the running annual average of four quarterly samples from the entry point to the distribution system. TTHM levels are and have been measured at several different stations within Bellingham's distribution system. TTHM levels measured historically at the maximum detention time within the distribution system have ranged between 25–54 µg/L, well below the current 100 µg/L regulatory level.

Potential Constraints. It is well established that the potential for THM formation increases with elevations in pH. Therefore, raising the pH for corrosion control would likely increase THM concentrations to some extent. Bellingham is in the process of determining potential TTHM changes resulting from corrosion control alternatives such as pH/alkalinity adjustments. Results of laboratory testing for TTHMs are discussed in Section 5.2.4.

5.2.4 SDWA Regulations Under Development

Disinfectant and Disinfection By-Products (D/DBP) Rule

Background. EPA is in the process of developing a D/DBP Rule. A number of health, analytical, and treatment issues associated with DBPs are currently unresolved. EPA has drafted a rule developed through a regulation - negotiation ("reg-neg") process. Under an optimistic scenario, the final rule is expected in 1995.

The most striking feature of the draft D/DBP Rule will likely be the increased number of contaminants to be regulated. The only DBPs currently regulated - trihalomethanes (THMs) - will likely have an MCL less than 100 µg/L, and will probably be reduced to 80 µg/L as a first stage and may be reduced to 40 µg/L as a second stage. An MCL is also proposed for total haloacetic acids (THAAs–60 mg/L for Stage 1 and 30 mg/L for Stage 2). Limited THAA data are currently available from Bellingham's distribution system, however one sample collected from the end of the distribution system had undetectable levels of all the HAAs with the exception of trichloroacetic acid, which was measured at 5.8 µg/L. Additionally, a treatment technique is proposed for systems with high total organic carbon (TOC) concentrations (>2.0 mg/L in the finished water). Exceeding the TOC action level would require enhanced coagulation at the filter plant. However, this requirement applies to conventional plants and Bellingham's plant is a direct filtration facility.

Potential Constraints. Increases in pH generally result in increases in THM levels in chlorinated systems, assuming all other factors are unchanged. Therefore, there may be upper limits to pH adjustments if the THM levels resulting from corrosion control treatment are at or near an anticipated MCL. However, the impact of pH adjustment on THAA formation is not as well documented. Laboratory testing conducted by the City of Everett indicated that THAA levels decreased as pH levels increased to pH 8.5. A similar study was conducted in April 1994 to determine the effect of pH increase on DBP formation in Bellingham's system.

Laboratory-scale testing was conducted to determine the potential impacts of additional contact time provided by the new 16.5 MG reservoir and pH adjustment for corrosion control purposes on DBP formation levels. A control scenario was developed which simulated current treatment practices, i.e., pH/alkalinity adjustment to 8.0 at the clearwell effluent with a residual chlorine level of approximately 0.6 mg/L. Cases 1 A and B were developed to simulate contact time in the new storage reservoir. Case 1A represented contact time in the new reservoir at an initial chlorine residual of 1.0 mg/L and pH of 7.0. Case 1B represented rechlorination to 0.6 mg/L after 52 hours of contact time in the reservoir, and then pH adjustment to 8.0 prior to entry to the distribution system. Both the Control and Case 1B were held at pH 8.0 for 168 hours to simulate conditions in the distribution system. Overall results are provided in Table 5-1. TTHM and THAA formation levels over time are shown in Exhibits 5-2 and 5-3.

Table 5-1
Results of DBP Formation Testing

		Case 1			
Case	**Time**	**THAA**	**TTHM**	**pH**	**Chlorine**
1A	0	8	11.4	7.0	1.05
1A	2	11	14.5	7.0	0.8
1A	6	13	13.4	7.0	0.71
1A	24	19	23.6	6.9	0.55
1A	48	25	26.6	6.9	0.43
1B	52	28	16.2	8.0	0.56
1B	54	26	20.7	7.7	0.48
1B	76	32	27.2	7.8	0.28
1B	172	36	38.5	7.9	0.07
1B	220	36	42.3	7.8	0.05

	Control			
Time	**THAA**	**TTHM**	**pH**	**Chlorine**
0	8	14.4	7.7	0.72
2	12	16.3	7.7	0.66
6	12	19.6	7.7	0.54
24	18	26.4	7.7	0.39
48	23	31	7.5	0.29
120	24	44.9	7.7	0.11
168	26	40.7	7.7	0.05

Review of Exhibit 5-2 suggests that TTHM levels did not change dramatically between the two treatment scenarios. Ultimately, after 168 hours at pH 8.0, approximately 40 ug/L of TTHMs were formed regardless of initial pH or contact time at the initial pH level of 7.0. These results indicate that Bellingham should easily meet Stage 1 of the D/DBP Rule for TTHMs, however, compliance with Stage 2 may be more difficult.

Review of Exhibit 5-3 shows that THAA formation levels were nearly identical for the first 52 hours, even though the pH of the Control was 8.0 and the pH of Case 1A was 7.0. After the simulated 52 hours of contact time for Case 1A, the pH was increased to 8.0 and the chlorine residual was brought up to 0.6 mg/L (Case 1B). THAA formation continued for Case 1 where as formation appeared to level off for the Control. If the THAA levels formed in the Case 1 scenario represent system conditions after the new reservoir is on-line, it seems likely that compliance with the Stage 1 MCL for THAAs of 60 ug/l will be easily met but the Stage 2 MCL of 30 ug/L may present more of a problem for Bellingham. Theory suggests that pH may have limited impact on the formation of HAAs, and laboratory results obtained from Everett showed decreasing HAA formation as pH increased. Therefore, it seems more likely that the continued increase in HAA formation after pH increase for Case 1 may have been due to rechlorination, rather than corrosion control practices.

It is possible that Bellingham will be able to optimize CT compliance and DBP formation with continued laboratory and field testing once the new reservoir is in operation. Additional testing should be conducted on a seasonal basis to incorporate the effects of changing TOC levels in the raw water, and potential temperature effects for CT compliance.

Zinc

Washington has established a secondary MCL for zinc in drinking water at 5 mg/L. Secondary MCLs are non-enforceable standards that are set based upon aesthetic water qualities (such as color, and taste and odor), whereas primary MCLs are usually health-based standards. It is unlikely that zinc concentrations resulting from corrosive leaching of galvanized steel pipe or the use of zinc-phosphate inhibitors would result in zinc levels that approach or exceed this MCL.

However, the EPA recently finalized its Reference Dose (RFD) for zinc to 0.3 mg/kg. Based on this RFD, the National Sanitation Foundation (NSF) has lowered the allowable level at which zinc may be added to drinking water from NSF certified chemical products. For a 70 kg person, 0.3 mg/kg equates to 21 mg zinc/day. Assuming that the Recommended Daily Allowance for zinc consumed in food is 15 mg/day, and that person drinks an average of 2 liters of water/day, the Maximum Drinking Water Level (MDWL) for zinc would be 6 mg/kg or 3 mg/L. Consistent with NSF product certification policy, which takes into consideration multiple sources of a contaminant, the Maximum Allowable Level (MAL) for addition of zinc from a single product was set at two-thirds of the zinc MDWL or 2.0 mg/L. NSF finalized this MAL on November 1, 1992. Therefore, the use of zinc orthophosphate products for corrosion will be limited to 2.0 mg/L of zinc to conform to NSF standards.

5.2.5 Summary of Potential Regulatory Constraints

Table 5-2 presents a summary of potential regulatory constraints to corrosion control treatment. The two chemical treatment options being considered for Bellingham's system are:

☐ pH and/or alkalinity adjustment; and
☐ Corrosion inhibitors (phosphate or silicate-based)

Table 5-2
Summary of Potential Regulatory Constraints to Corrosion Control Treatment

		Potential SDWA Regulatory Constraints				
Corrosion Control Treatment Approach	**Regulated Water Quality Parameters That May Change**	**Lead and Copper Rule**	**SWTR and Enhanced SWTR**	**Total Coliform Rule**	**NPDWR Phase II and V Rules for IOCs/ SOCs**	**Existing THM Regulation and Future D/DBP Rule**
pH/Alkalinity	pH Metals Chlorine Coliform THMs Turbidity	pH range optimized to meet NPDWR compliance	* pH elevation would require higher CTs for chlorine for equivalent level of disinfection.	* Shift in form of chlorine from HOCl to OCl-, lowering disinfection efficiency. May require higher chlorine residual to control coliforms and HPCs	pH shift may impact solubility of iron, zinc, antimony, and cadmium.	* pH increase generally results in THM level increases. Possible elevation of chlorine residuals may result in changes in chlorinated by-product concentrations.
Phosphate Inhibitor Addition	Phosphorus Metals Coliform Turbidity	* Phosphate level optimization. Polyphosphates may increase solubility of lead and copper.		Possible nutrient source for microbiological growth in distribution system.	Addition of zinc orthophosphates may be limited by EPA's Reference Dose for zinc and NSF product policy for chemicals.	
Silicate** Inhibitor Addition	Same as for pH Adjustment	Silicate level optimization, plus same as for pH adjustment	Higher silicate levels can form precipitates, resulting in turbidity increases., plus same as for pH adjustment.	Same as for pH adjustment.	Same as for pH adjustment.	Same as for pH adjustment.

Note: * *Indicates a constraint of greater concern.*
** *Constraints associated with silicates are similar to pH adjustment since silicate addition can increase pH levels by 2 units.*

Because Bellingham's Lake Whatcom supply source has a neutral pH with very low mineral and low alkalinity levels, calcium carbonate precipitation is not being considered as a viable approach for lead and copper corrosion control.

Some of the regulatory constraints listed in Table 5-2 are potentially more restrictive or have greater implications upon the current system facilities and operations than do others. The constraints of greatest concern (indicated with an asterisk in Table 5-2) are briefly described below:

- ☐ An increase in pH at the treatment plant would require larger CT's to meet SWTR requirements, thereby constraining pH adjustment to a point after CT requirements have been met. Design of the new 16.5 MG storage reservoir has provided more than adequate contact time to accommodate CT's requirements at the year 2040 flow rates. pH adjustment will occur at the effluent end of the storage reservoir.
- ☐ Compliance with future THM and other chlorinated by-product MCLs may limit the upper range of pH increases, as well as possibly limit chlorine dosages. Bellingham should have no problem meeting Stage 1 of D/DBP Rule, regardless of pH (over the range of 7.0–8.0) or contact time in the new reservoir. It is possible that Bellingham may also meet the Stage 2 requirements of 40/30 µg/L for TTHM/THAA, once operation of the new reservoir is optimized for CT, DBPs, and operational storage. Although DBP formation may be a concern with respect to proposed Stage 2 MCLs, the configuration of the new reservoir should provide the operational flexibility to address these regulatory requirements.

5.3 Functional Constraints

There are three categories of functional constraints which need to be evaluated including water quality impacts, operational impacts, and impacts on the service community. Each of these categories is discussed below in terms of preliminary efforts and research which has been performed to determine the impacts of these constraints upon the project.

5.3.1 Water Quality Impacts from Corrosion Control Options

Sodium

pH/alkalinity adjustment as well as the use of sodium silicate and sodium phosphate compounds can also have impacts on water quality. Sodium could be added from pH adjustment with sodium hydroxide or pH/alkalinity adjustments with sodium carbonate or sodium bicarbonate. Presently, the EPA has no MCL goal or other specific regulation on sodium levels. In the November 1985 Federal Register, the EPA discusses its position on sodium as the following:

> "EPA is not proposing a recommended maximum contaminant level goal (RMCL) for sodium due to insufficient data showing an association between sodium in drinking water and hypertension in the general population and because of the normally minor guidance level for sodium of 20 mg/L in drinking water for the high risk population as recommended by the American Heart Association, since drinking water meeting this goal would not present a sodium-related hazard to those segments of the population thought to be at high risk (e.g. individuals with genetic predisposition to hypertension, pregnant women, hypertensive patients). EPA will reconsider the development of an RMCL for sodium if additional data become available. A secondary standard based upon aesthetic effects will be prepared for sodium."

To date, EPA has not developed a secondary MCL for sodium, nor is there any known present activity in developing such a standard.

Increasing pH from 7.3 to 8.0 using soda ash resulted in the addition of approximately 9 mg/L of sodium to the finished water. Considering the low background levels of sodium naturally present in the Lake Whatcom supply (less than 5 mg/L), there should not be any serious health concerns about sodium additions to the drinking water. Therefore, it is unlikely that concern over sodium additions to the water supply will constrain the selection of corrosion control treatment for Bellingham.

Silica

One concern with sodium silicate use as a corrosion inhibitor comes from industries who use boilers or who demand ultra pure water. Use of sodium silicate as an inhibitor could double or triple silica levels over the existing background levels of 4 mg/L SiO_2, resulting in higher boiler treatment costs for industry and decreased membrane run life for reverse osmosis systems.

Possible Secondary Effects of Corrosion Control Treatments

Several possible secondary effects of corrosion control treatment include iron and manganese precipitation, calcium carbonate precipitation, and the disruption of existing corrosion by-products within the distribution system.

Calcium levels are fairly low in Lake Whatcom water (approximately 9 mg/L). Because natural Lake Whatcom alkalinity levels are also low and the addition of both calcium and carbonate to the water for calcium carbonate precipitation is not considered a practical alternative, it is very unlikely that calcium carbonate precipitation will occur as a result of corrosion control treatment and become problematic.

The use of corrosion inhibitors often requires the application of a higher than normal dose, over an initial several weeks or months, which aids in the formation of an initial protective film within the distribution system. These high initial dosages can disrupt existing corrosion by-product films or scales within the distribution system and cause such particles or scales to release into solution. The resulting increased turbidity levels and presence of higher than normal corrosion by-product concentrations could potentially require Bellingham to undertake a water main flushing program during start-up of any new chemical addition period. Also, a consumer education campaign may have to be undertaken to inform customers of the situation and provide suggestions for flushing turbid water from home plumbing systems. Problems associated with the disruption of existing corrosion by-products should diminish significantly after a few months of operation of the new corrosion control treatment program. Although it is possible that the use of pH/alkalinity adjustment chemicals could have similar results over an initial start-up period, full scale testing at pH of 8.0 and alkalinity of 25–27 mg/L $CaCO_3$ did not create any significant problems.

5.3.2 Operational Impacts

Operational impacts from corrosion control treatment include, but are not limited to, the following:

☐ Large distribution system size and possible variations in water quality throughout the system,
☐ Future changes in treatment, and
☐ Locations for corrosion control treatment facilities with respect to other possible future treatment facilities.

These possible operational impacts are discussed in more detail below.

Distribution System Size

Considering the relatively large size of Bellingham's distribution system consisting of 30 square miles with 9 pressure zones, 13 reservoirs, and 11 pump stations, and the relatively low buffering intensity of the finished water, it is possible that significant variations in corrosion control effectiveness could exist from one end of the system to the other. Such variations in corrosion related water quality parameters, especially with regard to pH and alkalinity, have been observed in the Northshore Drive area. However, referring to Tables 2-3 and 2-5 of Section 2, water quality sampling by Bellingham throughout the distribution system found that corrosion related water quality parameters changed very little. If this data is representative of typical conditions in Bellingham's distribution system as well as the systems of its wholesale customers, then it may be possible that a pH/alkalinity adjustment treatment at just one application point could be effective from a corrosion control perspective. Preliminary testing conducted after pH was adjusted from 7.3 to 8.0 indicated that soluble lead levels have decreased at many of the homes resampled.

With respect to corrosion inhibitors, the use of one central inhibitor application point may require a longer, high dosage startup period in order to begin forming the protective films at the distribution system extremities. Whether or not one central application point would be sufficient for achieving corrosion control goals over the entire system is an issue which would require further data and investigation.

Future Changes in Water Treatment

There are hypothetical scenarios where the Enhanced Surface Water Treatment Rule (ESWTR) or the Disinfectant/Disinfection By-Product Rule (D/DBP) could cause Bellingham to alter its present treatment practices. Scenarios where the Lake Whatcom supply and treatment could be affected include:

- ☐ EPA sets higher removal requirements for *Cryptosporidium* or changes CT requirements on surface water supplies.
- ☐ The new D/DBP Rule could necessitate modifications to Bellingham's treatment process as a result of TTHM/THAA formation.

These scenarios were considered in developing possible locations for corrosion control facilities.

Location of Corrosion Control Facilities

Currently, Bellingham adds approximately 10–15 mg/L of soda ash at the treatment plant clearwell, resulting in a finished water pH of 8.0. Soda ash is added at the same point that chlorine is added.

Once the 16.5 MG reservoir is incorporated into the treatment and supply system, Bellingham will have more than adequate contact time to meet CT requirements over a wide range of potential pH levels. However, in the interest of minimizing DBP formation, the water will be returned from the reservoir effluent to the treatment plant for pH adjustment. Under this treatment scenario, it is anticipated that chlorine dosages can be lowered back to 0.6 mg/L. Seasonal DBP formation testing, in the laboratory and in the distribution system, will help to determine the impact of contact time, chlorine residual, and pH on TTHM and THAA levels for Bellingham's water supply.

5.3.3 Impacts on the Service Community

Four classes of water consumption have been identified in Bellingham's service area. These include: water districts, non-metered residential, medium commercial and industrial and large commercial and industrial. Corrosion control treatment alternatives can potentially impact commercial and industrial users, health care facilities and other water users who may have special water quality requirements for their operations. Also, wholesale customers such as Water Districts #2 and #10 may be impacted by Bellingham's decision regarding which corrosion control treatments to pursue in that an optimal treatment for Bellingham may not necessarily be the optimal treatment for all water users.

Ten water users in Bellingham's service area were contacted and surveyed regarding their water quality and operational requirements. Although the needs of every customer cannot feasibly be met simultaneously, a summary of the requirements for the larger water users has been compiled to aid in the selection of a corrosion control strategy which would have the least impact on current water quality needs. The facilities which were contacted included the wastewater treatment plant (WWTP), hospitals and kidney dialysis centers, food processors, and various businesses. A list of the customers which responded is provided in Table 5-3.

Table 5-3
Top Ten Water Users

Water Customer	Average Use (gpd)
Bellingham Frozen Foods	286,000
Western Washington University	225,000
Water District #10	187,000
Bellingham Cold Storage	162,000
Water District #2	161,000
Georgia Pacific	151,000
St. Joseph's Hospital	115,000
City Parks	84,000
Port of Bellingham	73,000
Mount Baker Kidney Center	

Each facility was asked to describe the potential impact if:

☐ Bellingham changed pH from 7.5 to 8.0 or 8.5,
☐ There were an additional 0.5 to 2.0 mg/L orthophosphate (PO_4) present in the water,
☐ There were an additional 5-10 mg/L of silica present in the water, and
☐ There was 0.5 mg/L of zinc present in the water.

Facilities were also asked to provide a description of the processes that require water and to outline any treatment currently practiced on site.

Industrial/Commercial Users

Many of the facilities contacted required the use of boilers and expressed concern over increased silicate levels. St. Joseph's Hospital and Western Washington University currently provide minimal treatment for boiler water, however Bellingham Frozen Foods does not provide any pre-treatment. Western Washington University expressed concern over increased sludge production if silicates were added to the water. Georgia Pacific uses its own water supply for its industrial water needs and therefore was not concerned with changes in water quality that Bellingham might initiate for their domestic water use. Bellingham Frozen Foods and Bellingham Cold Storage do provide additional chlorination and mentioned that larger chlorine doses may be necessary if pH were increased to 8.5.

The Mount Baker Kidney Center uses extensive on-site treatment to produce ultra-pure water. Treatment consists of multi-media filters, water softeners, carbon contactors, post-filtration, and reverse osmosis. It is the Center's belief that any chemical addition for corrosion control purposes would most likely be removed during the on-site treatment process.

Wholesale Customers

Both Water District's #2 and #10 were contacted regarding potential changes in the water they purchase from Bellingham. Water District #10 receives half of its supply from Bellingham and the other half of the supply is treated using direct filtration and pH adjustment. During regulatory monitoring under the LCR, only 1 of 48 samples exceeded the action level for lead. This sample was collected from the Geneva portion of the service area which is supplied by water purchased from Bellingham. Because there is no commercial or industrial activity in Water District's #10's service area, they were unsure whether phosphate or silicate addition would negatively impact water users.

Water District #2 purchases 100% of its water from Bellingham (161,000 gpd). No additional treatment is provided to the water once it is received. There is only one commercial water user in the service area (a nursery) and it is anticipated that corrosion control treatment of Bellingham's supply will also be beneficial to Water District #2. Bellingham included Water District #2 during Round 3 of its regulatory sampling under the LCR.

Wastewater Treatment Plants

Bellingham Department of Public Works operates the wastewater treatment plant, currently treating approximately 11 MGD. The plant is being updated to provide secondary treatment for an average flow of 18 MGD. Currently, Bellingham is in the information collection phase of their secondary National Pollution Discharge Elimination System (NPDES) permit, therefore, the City of Edmond's wastewater effluent permit limits are provided below in Table 5-4 for reference purposes only.

Table 5-4
Effluent Metal Concentration Limits for the City of Edmonds

Metals	Daily Maximum (μg/L)	Monthly Average (μg/L)	City of Bellingham Typical Range (μg/L)
Copper	52	22	11 - 160
Mercury	4.46	1.09	<0.02
Silver	46	19.0	<0.1 - 3.8
Zinc	1,894	804.0	62 - 180
Lead	995	422	10

Typical metals levels measured in Bellingham's effluent are also listed in Table 5-4 above. If a similar permit is developed for Bellingham, then Bellingham may exceed copper discharge limitations. Although copper corrosion control is not a priority for Bellingham under the LCR, any decrease in copper corrosion due to corrosion control treatment will help decrease metals levels observed in the wastewater effluent. Exhibits 5-4 through 5-6 show that metals levels have decreased dramatically in post point effluent samples since corrosion control treatment has been on line (February, 1993). Average monthly copper levels were reduced by approximately 50% since March of 1993. Similar decreases have been observed for zinc, silver, and lead. Bellingham's sludge is incinerated and then landfilled.

Bellingham does not anticipate limitations on nutrient loading (other than BOD) and according to the Washington Department of Ecology, there is currently no State phosphorous discharge limitation. Theoretically, a 1 mg/L dose of PO_4 as a corrosion inhibitor would impart 92 lb/d of PO_4 (30 lb/d phosphorous) to the water, based on an average flow rate of 11 MGD. The secondary treatment plant currently removes approximately 38% of incoming phosphate, according to conversations with wastewater treatment plant staff. Bellingham Bay is classified as a Class A water under WAC 173-201A-140. Class A waters "shall meet or exceed the requirements for all or substantially all uses."

Summary of Impacts on Service Community

Discussions with wastewater treatment plant operators, industrial/commercial water users, and wholesale customers indicate that any change to present water quality will impact current operating procedures to some degree. It appears that silicate addition would have the largest impact on water users that are not currently treating the water supply on-site. Results of the survey are shown in Table 5-5 below.

Table 5-5
Summary of Corrosion Control Treatment Survey Results

	Number of Respondents			
Corrosion Treatment	**Major Impact**	**Minor Impact**	**Not Sure**	**No Impact**
pH Adjustment				
8.0		1	1	7
8.5		2	1	3
Orthophosphate Addition (0.5-2 mg/L PO_4)		4	2	2
Silicate Addition (5-10 mg/L SiO_2)	3	1	3	1

The addition of calcium or zinc would appear to have a similar impact on industrial/commercial operations as silica addition. It is likely that treatment units would have to be regenerated more frequently and more waste may be generated. A primary concern with phosphorous addition was increased risk of contamination due to the potential for stimulated biological growth. pH adjustment to a level of 8.0 would probably have the lowest impact on the service community since on-site adjustment of pH (where necessary) could be accomplished relatively easily. Furthermore, water users have been receiving water which has been adjusted to a pH of 8.0 since February of 1993 with no known adverse impacts.

5.3.4 Summary of Functional Constraints

Results from the analysis of functional constraints can be summarized as follows:

- ☐ The use of phosphate inhibitors could potentially impact water quality from a biological growth and taste and odor perspective.
- ☐ The use of sodium silicate inhibitor may have a greater impact upon water quality due to scaling in water heaters and boilers, especially for water users who do not currently have on-site treatment. Many industrial/commercial users contacted believe they could remove excess silica using on-site treatment processes, however, many were unsure of the impact on current operating procedures.
- ☐ pH/alkalinity adjustment to 8.0 would probably have the least amount of impact upon water quality, wastewater treatment plants, and industry, since addition of soda ash is currently part of the treatment process. Water users

which were contacted did not report any negative impacts from Bellingham's recent adjustment from pH 7.3 to 8.0. In fact, effluent metals levels have decreased at the WWTP since corrosion control treatment has been on line. Further, pH adjustment alone may receive the least resistance from the general public considering that addition of new chemicals would be kept to a minimum.

☐ pH adjustment alone may not produce a stable enough water to maintain treatment effectiveness throughout the distribution system. Therefore alkalinity addition is also desirable to help produce a more stable water. Minimal alkalinity dosages would be preferred in order to minimize carbonate loading and potential TDS increases.

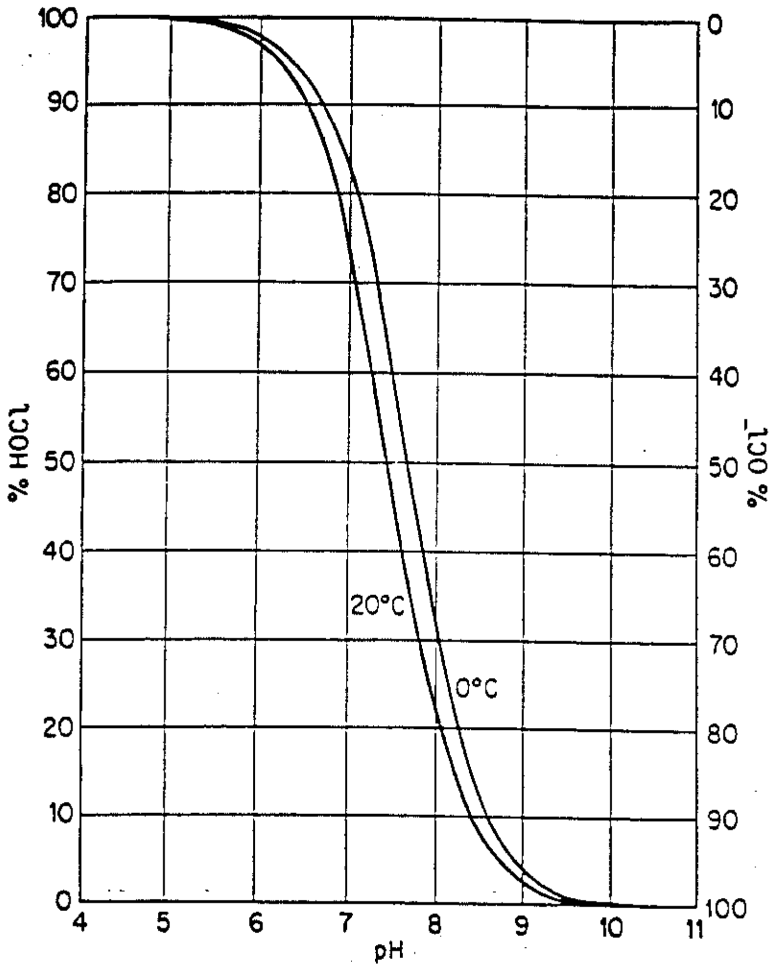
5.4 Conclusions

Careful evaluation of potential regulatory and functional constraints imposed by various corrosion control optimization alternatives will aid in selecting the most effective and compatible treatment technique as recommended under the LCR. A matrix of potential constraints is provided in Table 5-6. Table 5-6 indicates that any alteration of water quality for corrosion control purposes will result in some impact on either water users, water treatment, or regulatory compliance. However, pH adjustment would alter existing water quality to a lesser degree, and changes in operations could be minimal if soda ash is maintained as the treatment chemical.

Table 5-6
Summary of Impacts for Implementing an "Optimal" Corrosion Control Program

Treatment Alternative	Potential Adverse Impact	Level of Concern(1)	Comments
pH Adjustment	Higher CT Required for disinfection regulations	4	Only if pH is raised before CT requirement is met.
	Reduced coagulation efficiency	1	Only if pH is raised before filtration.
	Turbidity increases	1	Only with the use of lime.
	THM and other DBP increases	3	
	Slight increase in sodium levels	1	Could be avoided if lime is used.
	Precipitation of metals post-filtration. Industrial/commercial water treatment adjustments	2	Precipitation of aluminum, iron, or manganese could increase.
	Additional storage/feed requirements	1	Soda ash is currently used in treatment scheme.
Orthophosphate Addition	Potential for increased bacterial concentrations in the distribution system.	2	Greater problem for utilities with open reservoirs.
	Increase bacteriological contamination for industrial/commercial users	2	
	More WWTP chemicals may be needed and more sludge produced	2	
	Long time required to passivate the far ends of the distribution system	2	
	Industrial/commercial water treatment adjustments	2	
	Additional storage/feed requirements	2	
Silicate Addition	Additional storage/feed requirements	2	
	More WWTP chemicals may be needed and more sludge produced	2	
	Long time required to passivate the far ends of the distribution system	2	
	Industrial water treatment adjustments	3	
	May increase turbidity in finished water	1	Especially during start-up.
	Will increase sodium levels	1	
Large Calcium Adjustments	Additional storage/feed requirements	2	Would require multiple chemical additions.
	May increase turbidity levels in finished water	2	
	Require industrial water treatment adjustments	2	
	Requires uniform precipitation throughout distribution system	2	
	More sludge produced at WWTPs	2	

(1) *Range of 1 to 4, 4 is highest concern.*
1 = Minor Level of Concern *2 = Medium Level of Concern*
3 = High Level of Concern *4 = Major Concern - Potentially Eliminate Option if Concern Cannot be Avoided*



Source: Sawyer and McCarty, 1978

Exhibit 5-1

Effect of pH on the Distribution of Hypochlorous Acid and Hypochlorite Ion in Water

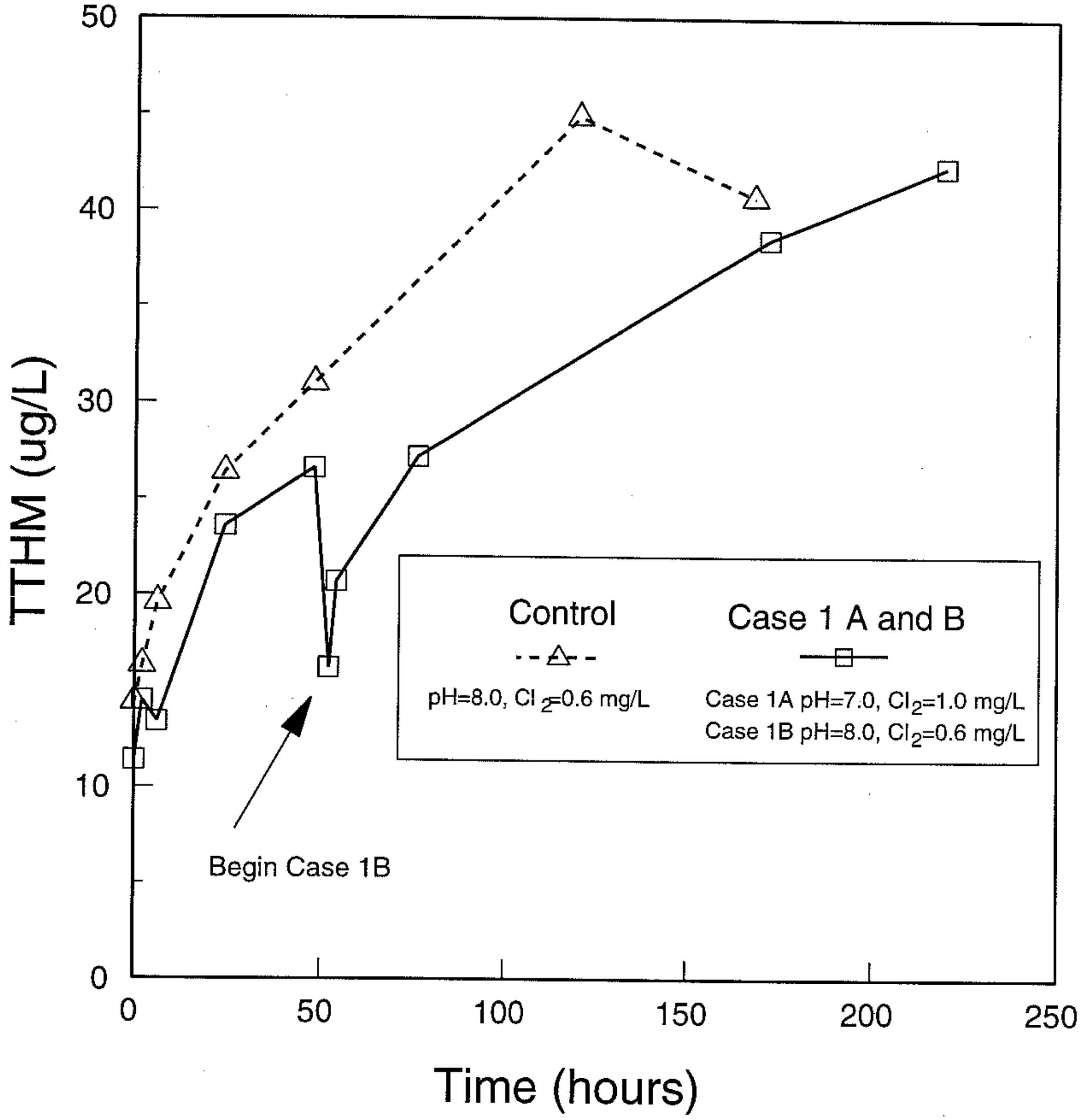


Exhibit 5-2
City of Bellingham
TTHM Formation over Time

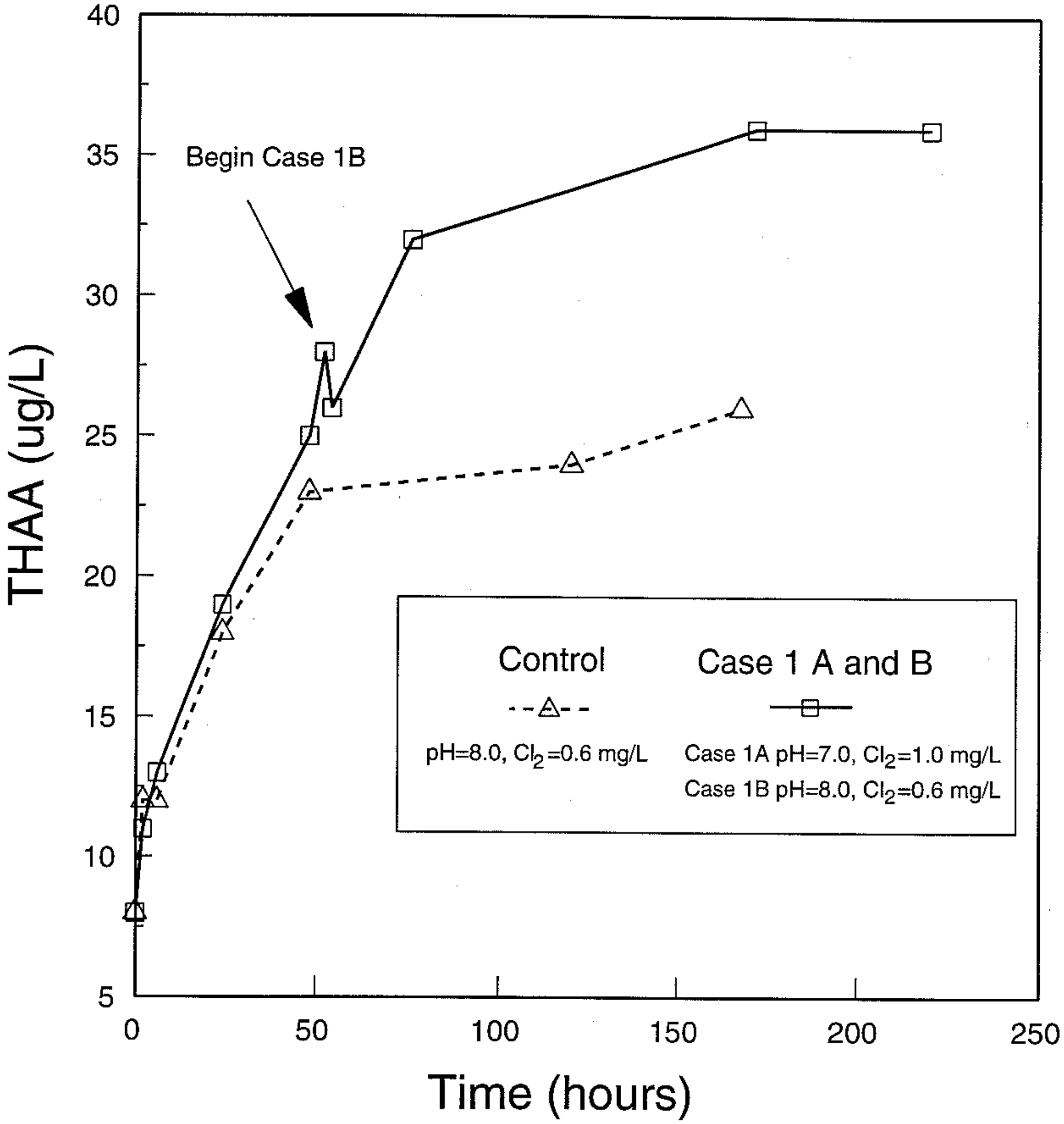


Exhibit 5-3
City of Bellingham
THAA Formation over Time

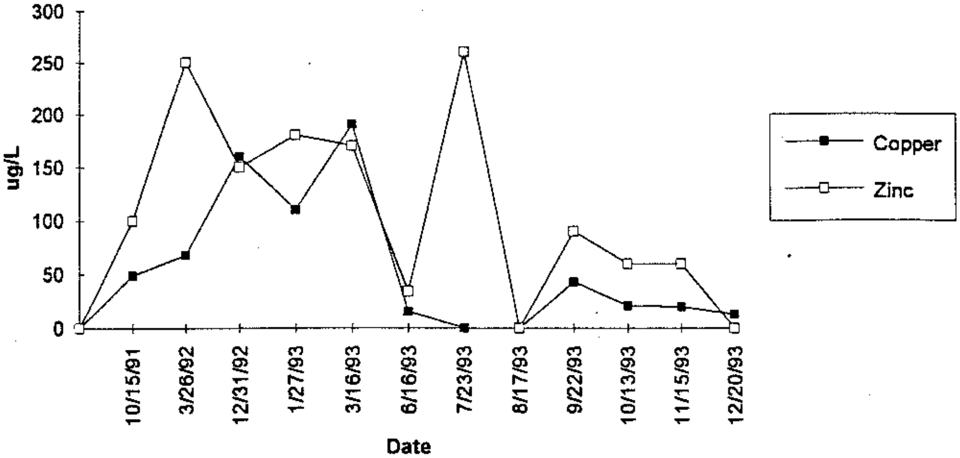


Exhibit 5-4

Post Point Effluent Metals—Copper and Zinc

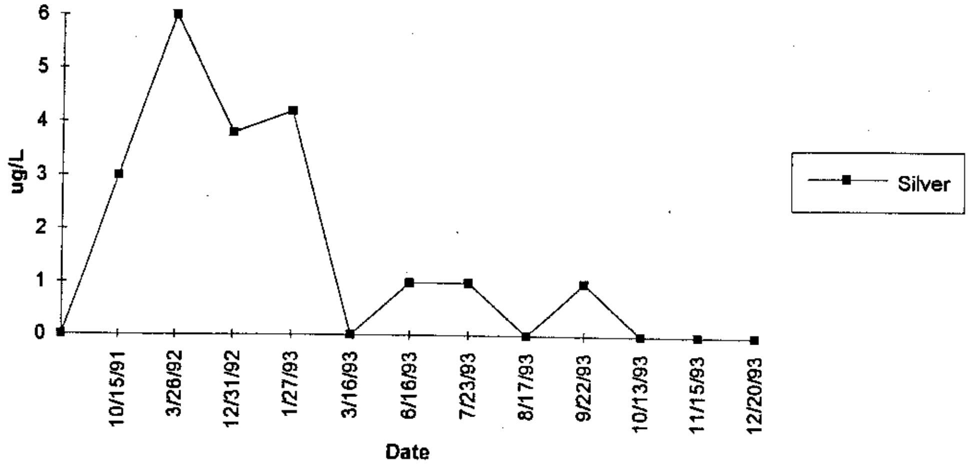


Exhibit 5-5

Post Point Effluent Metals—Silver

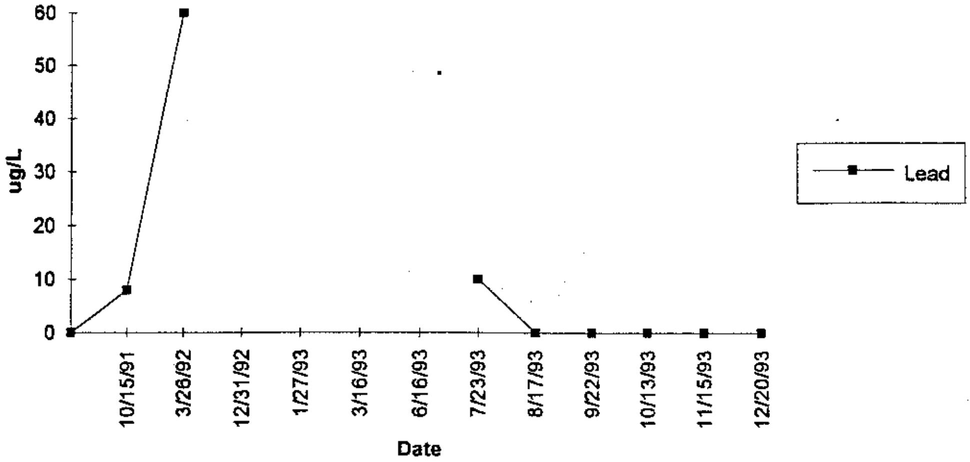


Exhibit 5-6

Post Point Effluent Metals—Lead

Note: pH/alkalinity was increased at the Water Treatment Plant during February 1993.

Section 6
Experience of Analogous Systems

6.1 Overview

Water utilities located in the Pacific Northwest with water quality characteristics similar to Bellingham's have undertaken various approaches for identifying and mitigating corrosion and metals leaching in their systems. Corrosion related water quality parameters for several utilities were reviewed and the following utilities were selected for comparison with Bellingham.

☐ Bureau of Water Works, Portland, Oregon
☐ Skagit PUD #1, Washington
☐ Eugene Water & Electric Board, Eugene, Oregon
☐ City of Everett, Washington
☐ City of Seattle, Washington

Key water quality and treatment parameters are listed in Table 6-1 for comparison with Bellingham.

6.2 Bureau of Water Works, Portland, Oregon

The City of Portland and 18 wholesale customers throughout the Portland region who purchase water from the Bureau of Water Works, have conducted monitoring and are studying corrosion treatments. Portland exceeded the lead action level for both sampling rounds and copper on the first round. The major water source for Portland is runoff from the Bull Run Watershed which originates on the western slopes of the Cascade Mountains. Due to steep topography and nature of the soils, little opportunity exists for the water to naturally increase in mineral content. The source and treated water quality characteristics of Bull Run water which can cause it to be an aggressive water towards metal piping and fixtures include:

☐ Acidic conditions as indicated by the chloraminated water's low pH values (6.5 to 7.2);
☐ Low alkalinity (7 to 13 mg/L as $CaCO_3$) in the treated water;
☐ Low mineral content (hardness of 8 to 12 mg/L as $CaCO_3$) in the treated water;
☐ Low buffering capacity which offers little resistance to pH change with addition of acids or bases and can lead to localized low pH conditions; and
☐ High dissolved oxygen content (9 to 12 mg/L), essentially at saturation.

Table 6-1
Water Quality Characteristics of Analogous Systems

	Everett, WA	**Portland, OR**	**Skagit PUD, WA**	**Bellingham, WA**	**Seattle, WA**	**EWEB, OR**
Source Water	Spada Reservoir	Bull Run Watershed	Judy Reservoir	Lake Whatcom	Cedar River Tolt River	McKenzie River
Population	350,000+	470,000+	45,000	66,000	1,200,000	140,000
Treatment	Direct filt., fluoridation, soda ash addition, disinf.	Disinfection	Direct filt., NaOH addition disinfection	Direct filt., disinf., soda ash addition	Disinf., lime and/or soda ash addition, fluoridation	Direct filt., disinf., lime addition
Source pH	6.5–7.0	6.5–7.2	7.0	7.1	7.0 Cedar 6.0 Tolt	7.0
Finished pH	7.2–7.6	6.5–7.2	7.3	7.9	8.2	7.2–7.6
Source Alk. as $CaCO_3$	9.0	7–13	14	19	15 Cedar 4 Tolt	22
Finished Alk. as $CaCO_3$	16.0	7–13	14–16	27.7	22 Cedar 13 Tolt	17–22
Disin-fectant	Primary and Secondary—free chlorine	Primary - free chlorine Secondary—chloramines	Primary - free chlorine Secondary—chloramines	Primary and Secondary—free chlorine	Primary and Secondary—free chlorine	Primary and Secondary—free chlorine
Corrosion Treatment	pH/alkalinity adjustment using soda ash	None currently	Slight pH adjustment using NaOH.	pH/alkalinity adjustment using soda ash	pH using lime on Cedar, pH and alk. using lime and soda ash on Tolt	pH/alkalinity adjustment using lime (capable of feeding soda ash)
1st Round 90% Lead, mg/L	0.023	0.044	0.049	0.023	Cedar 0.0147 Tolt 0.021	0.0145
90% Cu	0.798	1.8	0.37	0.45	0.34	0.37
2nd Round 90% Lead, mg/L	0.013 (0.010)*	0.053	NA	0.019 (0.011)*	Cedar 0.014 Tolt 0.025	0.009
90% Cu	0.408	1.3		0.53	<1.3	0.27
LCR Sample Sites	Lead Solder	Lead Solder	Lead Solder	Lead Solder	Lead Solder	Lead Solder

* *Third Round*

The Bureau has made considerable efforts over the past 10 years to evaluate the corrosivity of Bull Run water with respect to home plumbing and distribution piping. The Bureau has compiled a large water quality data base from which relevant corrosion-related information can be obtained.

Chloramination has been used to disinfect the Bull Run water supply for over 60 years. In September 1991, the Bureau changed their chlorine/ammonia ratio (Cl_2:NH_3-N) from 7:1 to 5:1. In January 1992, the ammonia addition point was moved downstream from the Headworks to Lusted Hill to allow for more free chlorine contact time. Ammoniation and chlorination rates were adjusted to maintain a permanent ratio of 5:1, resulting in approximately 1 mg/L of combined chlorine residual in the distribution reservoirs located throughout the City.

The Bureau and twelve of its wholesale water customers are participating in a regional study as part of the requirements of the LCR. Because EPA action levels for lead and copper were exceeded in the first monitoring period, the Bureau embarked on a detailed Corrosion Control Study. Recommendations from a desktop analysis which evaluated performance, constraints, and costs for chemical treatments were as follows:

- ☐ Calcium carbonate precipitation is not recommended for further evaluation in Phase II pilot testing because changes in water quality required to form a $CaCO_3$ precipitate would be drastic along with very high capital and operational costs necessary to make such changes.

- ☐ pH adjustment and alkalinity addition should be retained for further investigation during Phase II. Many different types of chemicals are available which could be used for full-scale pH and/or alkalinity adjustment.

- ☐ Phosphate inhibitors, along with pH adjustments, should be evaluated further during Phase II because of documented past success with the use of phosphate inhibitors for reducing lead corrosion and leaching.

- ☐ Silicate inhibitors should also be tested based on preliminary successes during bench-scale testing for reducing copper levels.

In addition to desktop analysis, bench scale testing was conducted by the University of Washington and results are summarized below.

A two-month evaluation of corrosion mitigation treatments using jar tests with water replacement, metals leaching, and electrochemical corrosion rate measurements was conducted. Nearly 25 treatments, modifying the quality of chloraminated Bull Run water, were evaluated. The main parameters influencing the corrosion rate, as well as the release of metals into the solution, were pH, alkalinity, and concentration of phosphate. Sodium silicate and a silicate/phosphate blend were also tested. Unchlorinated and free chlorine treated Bull Run water and distribution system waters were also tested, along with a groundwater source by itself, and blended with Bull Run water. The metal surfaces were exposed to the different water qualities for 40 - 45 days. The results provided useful data for selecting treatment alternatives for further pilot testing.

Conclusions of bench-scale testing included:

☐ pH increase to above 7.5 was beneficial in reducing copper and lead solder corrosion.

☐ Alkalinity increases to 15 mg/L were also highly beneficial; further benefit was realized by increases to 25 mg/L.

☐ There was no indication that differences in corrosion protection were achieved between sodium hydroxide, lime, sodium bicarbonate, and carbon dioxide when used to reach equivalent pH and alkalinity values.

☐ Phosphate and zinc phosphate, when the pH and alkalinity were increased, were effective in reducing corrosion rates, especially lead release.

☐ Silicate and a silicate/phosphate inhibitor were effective in reducing copper corrosion and release, but less so for lead/tin solder.

☐ The groundwater was the least corrosive water tested. Its inhibiting effect was quite apparent when blended 50:50 with the chloraminated Bull Run water.

Portland recently completed evaluation of corrosion treatments through continuously flowing pipe loop test apparatus. The treatments which were evaluated are listed below:

☐ Control - chloraminated Bull Run water
☐ pH adjustment to 8.0 and alkalinity adjustment to 25 mg/L
☐ pH adjustment to 9.0 and alkalinity adjustment to 20 mg/L
☐ pH adjustment to 7.5 and phosphate addition at 0.5 mg/L (as P)
☐ Sodium silicate addition at 10 mg/L (as SiO_2)

All four chemical treatment approaches reduced the release of lead and copper from lead solder, brass, and copper pipe into water compared to the current chloraminated Bull Run water. The pH 9/alkalinity 20, the orthophosphate, and the silicate treatments performed effectively in reducing lead uptake from lead solder and brass and copper uptake from copper pipe. However, the pH 8/alkalinity 25 treatment was consistently less effective than the other three treatments. The silicate treatment appeared to perform better than the other treatment in reducing iron release from used galvanized pipe. Consideration of constraints and changes in water quality lead to the recommendation of pH 9/alkalinity 20 mg/L $CaCO_3$ as the optimal corrosion control treatment technique.

6.3 Skagit County #1, Washington

Skagit County PUD #1 (the District) serves water to over 45,000 people within its service area, and is therefore classified as a medium-sized water system for the purposes of the Lead and Copper Rule. As a medium-sized system, the District was required to conduct initial monitoring for lead and copper and several water quality parameters during an initial six-month monitoring period between July - December of 1992. The pool of targeted sampling sites was comprised of 62 "Tier 1" sites, which consisted of single-family structures containing copper pipes with lead solder installed after 1982. According to District personnel, there are no known single family structures that contain lead pipe, nor are there any known lead service lines within the District's service area. A summary of the monitoring results are presented in Table 6-2 below.

Table 6-2
Skagit County PUD #1
Summary of Lead and Copper Monitoring Results
(Standing Tap Water Samples)

	Round 1	
Parameter	**Lead**	**Copper**
EPA 90% Action Level (mg/L)	0.015	1.3
90th Percentile from Samples (mg/L)	0.049	0.37
Measured Range (mg/L)	<0.005 - 0.159	<0.020 - 0.95
Samples Exceeding Action Level	46.7%	0.0%

The District's Water Treatment Plant has been in operation since 1990. Water flows by gravity from Judy Reservoir to the raw water pump station. Treatment currently consists of chlorine dioxide addition at the raw water pump station. Polymers, alum, and chlorine are added prior to the static mixer. Coagulant aids (cationic polyelectrolytes) are added prior to flocculation and caustic (for pH adjustment) is added to the finished water. Four mixed-media filters can treat up to 15 MGD. Average current water demand is approximately 8 MGD. After filtration, the water is chlorinated using chloramines to produce a residual of 1.0 mg/L or higher in the plant effluent.

In response to unacceptable lead levels measured at the tap during Round 1, the District increased pH from 7.3 to 8.0 using caustic. Prior to pH adjustment for corrosion control purposes, treated water quality did not vary significantly from raw water quality with respect to corrosion related parameters. pH and alkalinity were still "low" according to classifications in the LCR Guidance Manual Volume II, and the treated water would be considered corrosive.

The District also decided to determine the contribution of the brass fixtures on the overall lead level. "Fractionated" samples were collected to determine the mass of lead in the first 250 mLs of sample (in contact with the brass fixtures and connective plumbing) versus the mass of lead in the subsequent 750 mLs. This sampling protocol resulted in a one L total volume from which the lead level was calculated. Analyses of the results from twenty-seven fractionated sampling sites indicated that approximately 48% of mass of lead in the one L sample was contributed by the first 250 mLs of sample, predominantly in contact with brass fixtures. The remaining 52% of the lead in the calculated one L sample was most likely contributed by lead-soldered copper pipe.

Comparison of at-the-tap lead levels measured during the initial regulatory sampling round (at pH of 7.3) versus fractionated samples collected after pH was adjusted to 8.0, indicated that soluble lead levels increased at many of the homes which were resampled. Twelve of the twenty-one homes resampled exceeded the 0.015 mg/L lead action level after pH adjustment. Ten of these same homes exceeded the action level prior to pH adjustment. Lead levels in the calculated one liter samples after pH adjustment were an average of 0.0130 mg/L higher than prior to adjustment, suggesting that pH adjustment from 7.3 to 8.0 using caustic has had a negative effect on lead leaching levels. Theoretically, an increase in pH from 7.3 to 8.0 should have resulted in a decrease in lead solubility over a wide range of alkalinities. However, an increase in soluble lead levels at-the-tap was observed in the District's distribution system after pH was adjusted using caustic. The observed increase may have resulted from any combination of the following factors:

☐ Resampling was conducted before conditions in the system stabilized,

☐ Collection of fractionated sampling resulted in higher lead levels than measured in the one liter sample collected during initial monitoring,

☐ Apparent trends are actually a result of inherent distribution system variability.

☐ A simultaneous increase in alkalinity may be needed to maintain pH levels throughout the distribution system.

Bench-scale testing is underway to compare treatment performance of various alternatives under controlled conditions. The effectiveness of pH adjustment using NaOH, pH/alkalinity adjust using soda ash, and orthophosphates are being evaluated for lead, copper, and lead/tin solder-dipped pipe coupons.

6.4 Eugene Water & Electric Board, Oregon

Eugene Water & Electric Board's (EWEB) system is supplied entirely by water from the McKenzie River. From the intake near the Hayden Bridge, water is pumped to the Hayden Bridge Water Filtration Plant located approximately 7 miles northeast of Eugene. Treatment consists of chemical addition, rapid mixing, hydraulic flocculation, filtration, and disinfection. Current chemical addition includes aluminum sulfate as a coagulant, powdered activated carbon for seasonal taste and odor control, a polymer filter aid, sulfur dioxide for dechlorination, lime for pH adjustment, and disinfection with chlorine. Average daily demand is 26 mgd, while maximum daily demand is 65 mgd. EWEB's distribution system serves approximately 141,000 people, including four purveyors; the Santa Clara Water District, the River Road Water District, the Glenwood Water District, and the Willamette Water Company.

In response to LCR regulations for large public water systems, EWEB conducted two rounds of monitoring at home water taps for lead and copper, collecting over 100 samples each round. Although neither the lead or copper action levels were exceeded, results indicate that EWEB's water supply is mildly corrosive toward household plumbing materials. EWEB's lead levels were close to the lead action level, and do not meet the EPA's strict definition of "optimized" corrosion control, thus EWEB conducted an optimization study to meet the LCR.

Review of corrosion conditions in EWEB's distribution system indicates that the corrosion that is occurring is located in the small diameter, unlined metallic portions of service lines and premise piping systems. Leaching of metal contaminants into the water from these systems is evident at low rates. The larger diameter pipelines located in the distribution system, such as ductile iron, and lined cast iron and steel, are lined with epoxy or cement mortar, and consequently are protected because the aggressive water does not normally gain access to the metal piping. Lined pipe comprises approximately 43 percent of the piping system; however, there is another 35 - 40 percent of the piping system which is unlined and therefore susceptible to corrosion. Limited red or "rusty" water complaints are attributed to corrosion of unlined piping.

As a method of screening corrosion control treatment alternatives, each of the four evaluation criteria outlined in the LCR Guidance Manual Volume II were assigned a maximum point total relative to its overall importance to the selection process. Five feasible corrosion control strategies were evaluated in the four categories and assigned a point value based on how well they fulfilled the criteria. The overall point total from the four categories was used to determine the strategy rank in the completed assessment.

Table 6-3 presents a summary of the evaluation point scores and a ranking of five strategies determined to be feasible for EWEB's system. The evaluation indicated that, largely on the strength of its demonstrated effectiveness and economics, pH adjustment ranked highest, with orthophosphate addition a close second. The remaining strategies scored well below pH adjustment and orthophosphate addition.

The recommended corrosion control method for EWEB at this time is pH adjustment although orthophosphate addition would also likely perform well. EWEB is familiar with pH adjustment and has a long history of successful operation of its lime feed facility. Because of the consistent levels of alkalinity in the range of 17 to 22 mg/L $CaCO_3$, alkalinity adjustment is not needed for EWEB.

Table 6-3
Corrosion Strategy Screening Evaluation and Ranking

Strategy	Corrosion Control Performance (40 possible)	Regulatory and Functional Constraints (35 possible)	Reliability (10 possible)	Economics (15 possible)	Total (100 pts possible)	Rank
1. pH Adjustment	35	25	9	15	84	1
2. Alkalinity Adjustment	20	29	9	12	70	3
3. Orthophosphate Addition	35	28	10	8	81	2
4. Orthopoly-phosphate Blends	10	27	10	5	52	4
5. Silicate Addition	25	27	10	5	67	5

Based on theoretical calculations, analogous system information, and constraints; the recommended pH operating goal at this time is 7.7, with a maximum of 8.0 and a minimum of 7.4. This goal can be achieved using the existing lime addition facilities located at the Hayden Bridge Water Filtration Plant. The dose to reach a finished water pH of 7.7 is higher than present levels and is estimated to be 4 to 6 mg/L of lime.

6.5 City of Everett, Washington

The Everett Water Department provides drinking water to over 60,000 people within the city limits of Everett, and to over 350,000 people in Snohomish County. Using water from Spada Reservoir in the Sultan Basin watershed area as a source, drinking water treatment employs coagulation direct filtration, pH adjustment using soda ash, and disinfection with free chlorine and fluoridation. Finished water pH and alkalinity levels range from 7.2 to 7.6, 10–20 mg/L as $CaCO_3$, respectively. Both primary and secondary disinfection are provided with free chlorine.

In response to LCR regulations, Everett conducted three rounds of monitoring at home water taps for lead and copper, collecting over 60 samples during Round 1 from within Everett's city limits. Samples were then collected from over 200 homes during Rounds 2 and 3, including consecutive systems that purchase water from Everett. The results from lead and copper sampling are summarized in Table 6-4. The results indicate that Everett's water supply is mildly corrosive toward household plumbing materials; however, increasing pH/alkalinity levels prior to Round 3 appeared to have had a positive impact on corrosion of lead and copper in Everett's distribution system. Because the lead action level was exceeded during Round 1, public education was required and conducted. Everett's copper levels do not present a problem.

Table 6-4
City of Everett
Summary of Lead and Copper Monitoring Results
(Standing Tap Water Samples)

	Round 1		**Round 2**		**Round 3***	
Parameter	**Lead**	**Copper**	**Lead**	**Copper**	**Lead**	**Copper**
EPA Action Level (mg/L) at 90th Percentile	0.015	1.3	0.015	1.3	0.015	1.3
90th Percentile from Samples (mg/L)	0.023	0.95	0.013	0.79	0.010	0.41
Measured Range (mg/L)	0.001 - 0.047	0.028 - 1.4	0.001 - 0.068	0.2 - 1.9	0.001 - 1.096	0.009 - 1.7
Percent of Samples Exceeding Action Level	26.5	2.9	7.1	1.3	6.3	1.2
Sample Volume (L)	1.0	1.0	1.125	1.125	1.0	1.0
Number of Samples	68	68	227	227	256	256

As a method of screening alternatives, a rating and ranking system was also developed for Everett to provide a quantitative guideline for selecting the most appropriate corrosion control treatment technique. Three of the four criteria: performance; constraints; and reliability; were assigned a maximum point total relative to their overall importance to the selection process, with the highest point totals representing the most favorable corrosion control treatment approach. The sum of the potential point totals in the three categories was 100. Cost, the fourth treatment selection criteria, was not included in the rating and ranking system since Everett's intention was to select the optimal treatment strategy based primarily on performance, constraints and reliability. The results of the ranking and rating evaluation are provided in Table 6-5.

Table 6-5
City of Everett
Overall Corrosion Strategy Evaluation and Ranking

Strategy	Corrosion Control Performance (45 possible)	Regulatory and Functional Constraints (40 possible)	Reliability (15 possible)	Total (100 pts possible)	Rank
1. pH/Alkalinity Adjustment	40	35	13	88	1
2. pH Adjustment	30	29	12	71	4
3. Orthophosphate Addition	40	32	13	85	2
4. Orthopolyphosphate Blends	15	25	13	53	5
5. Silicate Addition	30	31	13	74	3

Based on theoretical calculations, analogous system information, and constraints; the recommended pH operating goals at this time is 7.8–8.0 ± 0.2 units. The resulting alkalinity should be maintained in the range of 15–25 mg/L $CaCO_3$. These goal can be achieved using the existing soda ash addition facilities located at the Everett Water Treatment Plant. The dose to reach a finished water pH of 7.8–8.0 is higher than present levels and is estimated to be 15–17 mg/L of soda ash. Everett is familiar with pH/alkalinity adjustment and has a history of successful operation of its soda ash feed facility. Furthermore, drastic changes in water quality will not occur if Everett maintains the same chemical addition program.

6.6 Seattle Water Department, Seattle, Washington

Seattle receives its water from the Cedar River and the South Fork Tolt River; both sources originate on the western slope of the Cascade Mountains. These waters are generally of very high quality with low hardness, low to neutral pH, low mineral content, and high dissolved oxygen concentrations. Source water from the Tolt River is considerably more corrosive than water from the Cedar River mainly due to significantly lower pH, alkalinity, and hardness levels. The number of corrosion related complaints increased substantially when the Tolt River supply came on line in 1964. The corrosion rates and corrosion related complaints again increased in 1970 when Seattle switched from chloramination to maintaining a free chlorine residual of at least 0.4 mg/L. Seattle began fluoridating with hydrofluosilicic acid at that time, which also contributed to increased corrosion by lowering pH levels and increasing the halogen:alkalinity ratio.

Prior to 1982 when corrosion treatment measures were implemented, the corrosiveness of Seattle's water was attributed to:

- ☐ Low pH of treated water (6.5 to 7.0 for the Cedar River and 5.5 to 6.0 for the Tolt River),
- ☐ High dissolved oxygen concentrations,

- ☐ Insufficient calcium and alkalinity to form $CaCO_3$ scale on pipe surfaces, and
- ☐ Relatively high halogen (chloride and fluoride) to alkalinity ratios resulting in conditions favorable to the pitting of iron piping.

In the fall of 1970, Seattle began a series of investigations into the corrosion problems caused by the water supply. These studies, which were conducted between 1970 and 1975, included: a literature search, tap sampling surveys, measurements of lead levels in blood, and coupon tests evaluating pipe corrosion rates. The effort focused on defining the nature of the corrosive tendencies and possible treatment alternatives.

Based on two years of study including pilot plant pipe loop investigations, a corrosion control program was proposed. The corrosion control plan included: (1) a corrosion treatment program; and (2) a program relating to the selection of corrosion resistant materials for use in distribution and plumbing systems.

The corrosion treatment program included increasing concentrations of minerals that were already present in the existing water supplies. The program proposed to raise the pH and alkalinity of the water and reduce the (halogen + sulfate)/alkalinity ratio. Silicate addition to the Tolt supply was also considered for further evaluation. The goal of the corrosion treatment program was to modify the characteristics of both water supplies to achieve a water quality that balanced corrosivity considerations with other water quality parameters, such as THM formation.

Corrosion treatment facilities were constructed on both water sources. The pH of the Cedar River supply was raised from 7.0 to 8.2 through the addition of 2 mg/L of lime ($Ca(OH)_2$) at Lake Youngs. The pH and alkalinity for the Tolt River supply were raised to 8.2 and 13.5 mg/L as $CaCO_3$, respectively, by addition of 2 mg/L of $Ca(OH)_2$ and 9 mg/L of sodium carbonate (Na_2CO_3). Water treatment to reduce corrosion in Seattle's system has dramatically decreased metal leaching as shown in Table 6-6.

Table 6-6
Percent Reduction in Standing Metal Concentrations After Corrosion Treatment for the Seattle Water Department

Metal	Percent Reduction
Lead	65
Cadmium	59
Copper	64
Iron	29
Zinc	58

Monitoring of water quality, corrosion rates, and metal leaching before and after corrosion treatment has verified the success of Seattle's corrosion control program. Both metal leaching and corrosion rates have been significantly reduced by treatment. Aesthetic problems related to blue-green stains from copper corrosion have been eliminated and rusty water from iron pipe has been reduced.

Seattle Water Department's 90th percentile lead level from LCR monitoring was 0.019 mg/L which exceeded the action level of 0.015 mg/L. However, closer examination of the results indicated that samples from the Tolt supply exceeded the action level during both rounds (90th percentiles equaled 0.021 and 0.025 mg/L) and samples from the Cedar River supply did not (90th percentile equaled 0.0147 and 0.014). It is believed the 90th percentile levels for both the Tolt and Cedar service areas would have been much higher without the corrosion control measures taken. Seattle Water Department's 90th percentile copper level of 0.34 mg/L was well below the action level of 1.3 mg/L.

To complement the corrosion treatment program, the recommended corrosion control plan included a program relating to selection of distribution and plumbing system materials. This program encouraged the use of corrosion resistant materials including: cement mortar linings, copper, brass, and plastic pipe. It also recommended the use of thicker walled copper piping and against the use of galvanized steel. Use of low lead solders (less than 0.2 percent lead) was required through the Plumbing Code to prevent further use of 50:50 lead/tin solder. Use of asbestos cement piping was also prohibited.

6.7 Results of a WITAF Project

AWWA recently published a report sponsored by WITAF entitled "Initial Monitoring Experiences of Large Water Utilities Under USEPA's Lead and Copper Rule." The project surveyed 660 large drinking water systems to collect information regarding the impact of the Lead and Copper Rule on their supply. Included in the information obtained was first round lead and copper 90th percentile monitoring results, corrosion control effectiveness, and changes in operation due to the Lead and Copper Rule. Surveys were completed and returned for 60% of the utilities, representing 114 million people.

One section of the WITAF report focused on water quality and corrosion factors and their apparent influence on 90th percentile lead levels at the tap as reported by responding utilities. The term "percent action level (AL) exceedance" was used and indicates the percentage of utilities in a certain category that exceeded the 90th percentile action level of 0.015 mg/L for lead. Where possible, the data was divided into two categories before further analysis--water *without* an inhibitor (uninhibited) and waters *with* an inhibitor (inhibited). It should be noted that data in the WITAF report is not based on a rigorously controlled laboratory study, but are the results from the field efforts of hundreds of different utilities collecting samples at thousands of homes across the United States.

Distribution system pH levels showed an influence on the 90th percentile lead levels for utilities with and without corrosion inhibitors. Higher pH levels, i.e. ≥7.5, have lower percent lead AL exceedances when compared with lower pH levels, i.e. ≤7.5. As indicated in Exhibit 6-1, the percent exceedances were 36 percent for uninhibited waters at pH <7.5, and were typically lower in higher pH ranges. Overall, higher pH levels were associated with lower percent AL exceedances for lead.

The 90th percentile lead levels were influenced by distribution system alkalinity levels as depicted in Exhibit 6-2 for all respondents. Waters with alkalinity <50 mg/L had several very high 90th percentile lead levels.

As indicated by Exhibit 6-3, low alkalinity waters (<25 mg/L $CaCO_3$) had a significantly higher percentage of systems exceeding the lead AL than did waters >25 mg/L ($CaCO_3$). This exhibit also indicates that as alkalinity increased, the percent of systems exceeding the AL decreased for both inhibited and uninhibited waters. Waters with alkalinities >150 mg/L as $CaCO_3$, had no AL exceedances. There did not appear to be large or substantial differences in percent exceedances between inhibited and uninhibited waters at each respective alkalinity range.

The combination of pH and alkalinity for inhibited and uninhibited water's influence on lead levels is shown in Exhibits 6-4 and 6-5. Exhibit 6-4 is for those utilities using inhibitors and Exhibit 6-5 is for uninhibited waters. Low pH and low alkalinity are most likely to have lead levels that exceed the AL for both inhibited and uninhibited waters. In general, as the pH and alkalinity levels increase, the chance of exceeding action levels decreases although there are always anomalies evident. For uninhibited waters with pH <7.5 and alkalinity <25 mg/L, major benefits could potentially be derived from increasing pH or alkalinity, individually or in combination, to higher levels. (Utilities are reminded, however, that any change to the treatment process must be evaluated for possible negative consequences as well, e.g., disinfection efficiency is reduced as pH is increased.) Although the data base is not large, the combined low pH and low alkalinity waters appear to have been aided by inhibitors.

Of the 176 respondents without inhibitors and 77 with inhibitors, the median 90th percentile lead levels were 0.007 mgPb/L and 0.008 mgPb/L, respectively, indicating little or no difference. However, the percentage of respondents exceeding action levels was greater for the waters containing inhibitors (20.9 percent) than those without inhibitors (15.9 percent). The reason for this difference is unknown. However, since utilities use inhibitors because of corrosive water, it is possible that many more utilities could have exceeded the action level, had they not been using inhibitors. It is possible that inhibitors are reducing 90th percentile levels, but there is no way of knowing that from the data. It can be concluded that use of inhibitors as they are presently being applied, does not necessarily ensure that lead ALs will be met.

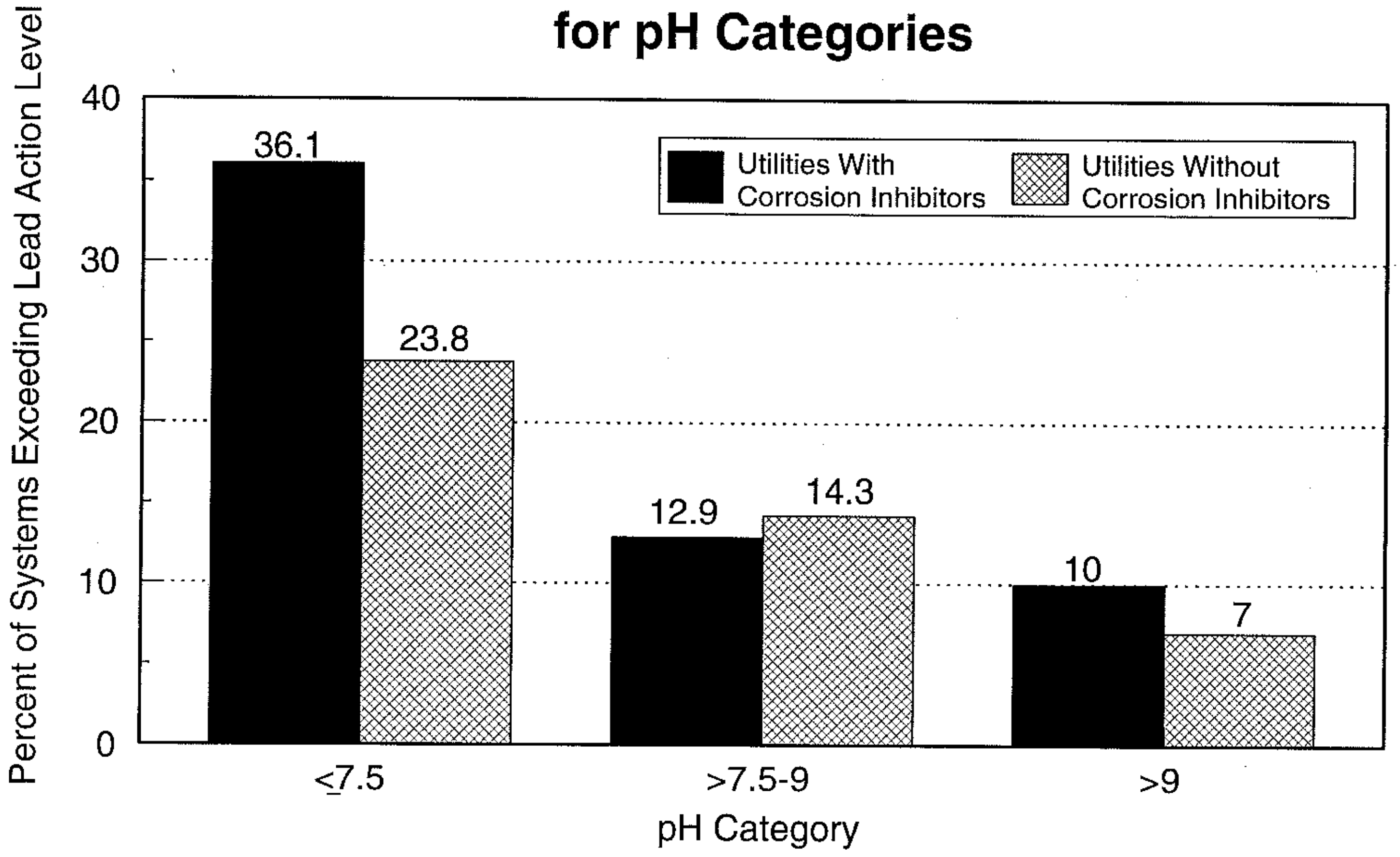
6.8 Analogous System Summary

Large water systems (>50,000 consumers) are the first required to implement optimized corrosion control treatment under the Lead and Copper Rule. Analogous system information must be included when determining corrosion strategies as required by the LCR. The five utilities described in this section were chosen for Bellingham's corrosion study because of similar treatments and water quality characteristics. The corrosion control strategies implemented (or being considered for implementation) include: pH and/or alkalinity adjustment, use of phosphates, and use of silicates for passivation, use of public education, and careful selection of distribution and plumbing system materials. None of the utilities described used calcium hardness precipitation as the focus of their corrosion control studies.

Lead levels at the tap in Everett, Washington; EWEB, Oregon; and Bellingham, Washington appeared to have decreased after pH and/or alkalinity adjustment using soda ash or lime were implemented full scale. In Seattle, 90th percentile lead levels at the tap were below the lead action level at homes receiving water from the Cedar River, a supply which is treated with lime to increase pH levels from 7.0 to 8.2. Bench-scale and pilot-scale results from Portland indicate that pH/alkalinity adjustment to pH 9.0 and alkalinity of 20 mg/L $CaCO_3$ will provide optimal corrosion control treatment. Bench-scale results from Skagit PUD #1 are not yet available for review.

Exhibit 6-1

Lead Action Level Exceedance for pH Categories

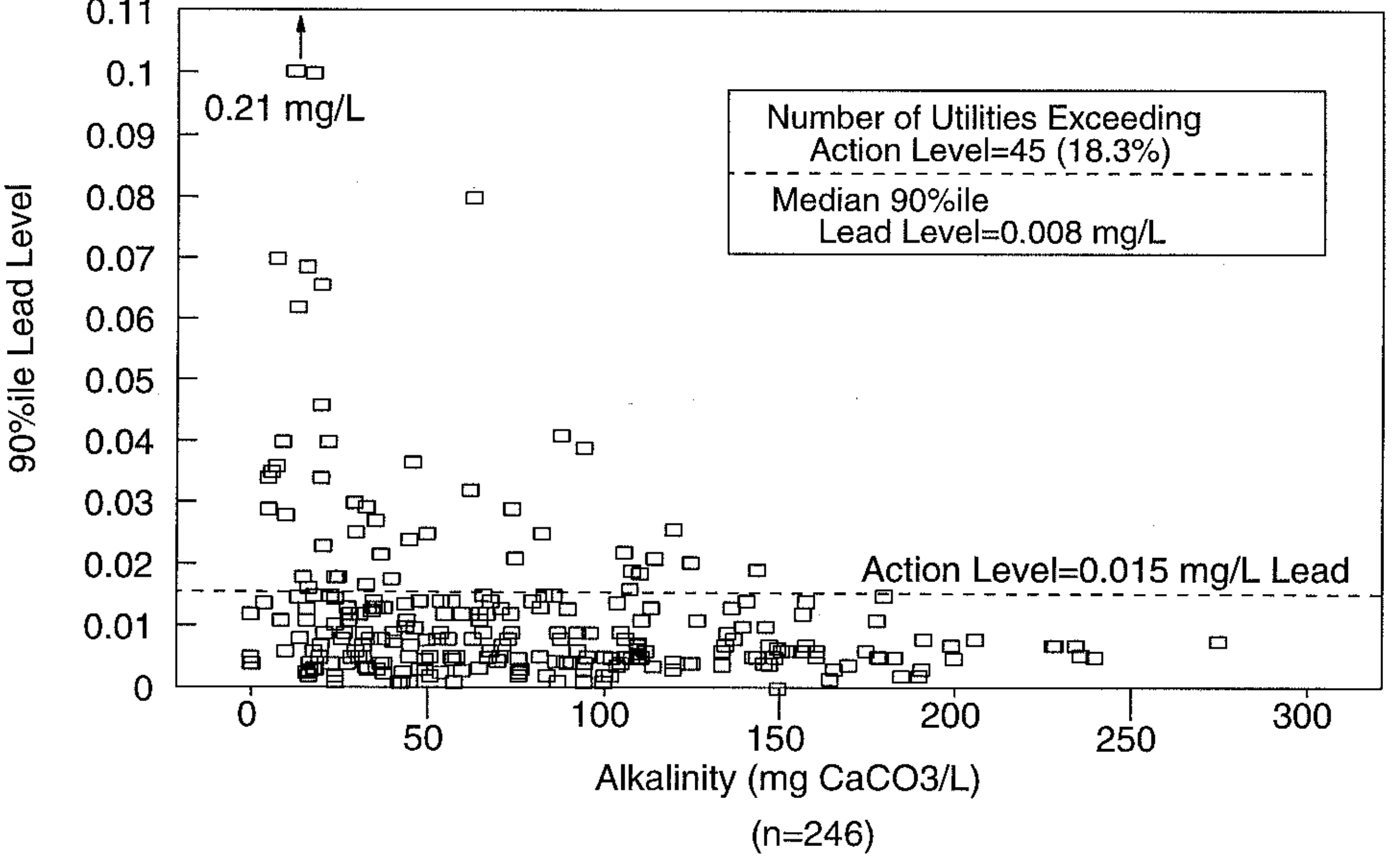


Note: Initial monitoring results of systems > 50,000 customers.
For systems with pH less than 7, 50% exceeded with inhibitors and 50% exceeded without inhibitors.

Exhibit 6-2

Distribution System Alkalinity vs. 90th Percentile Lead Levels

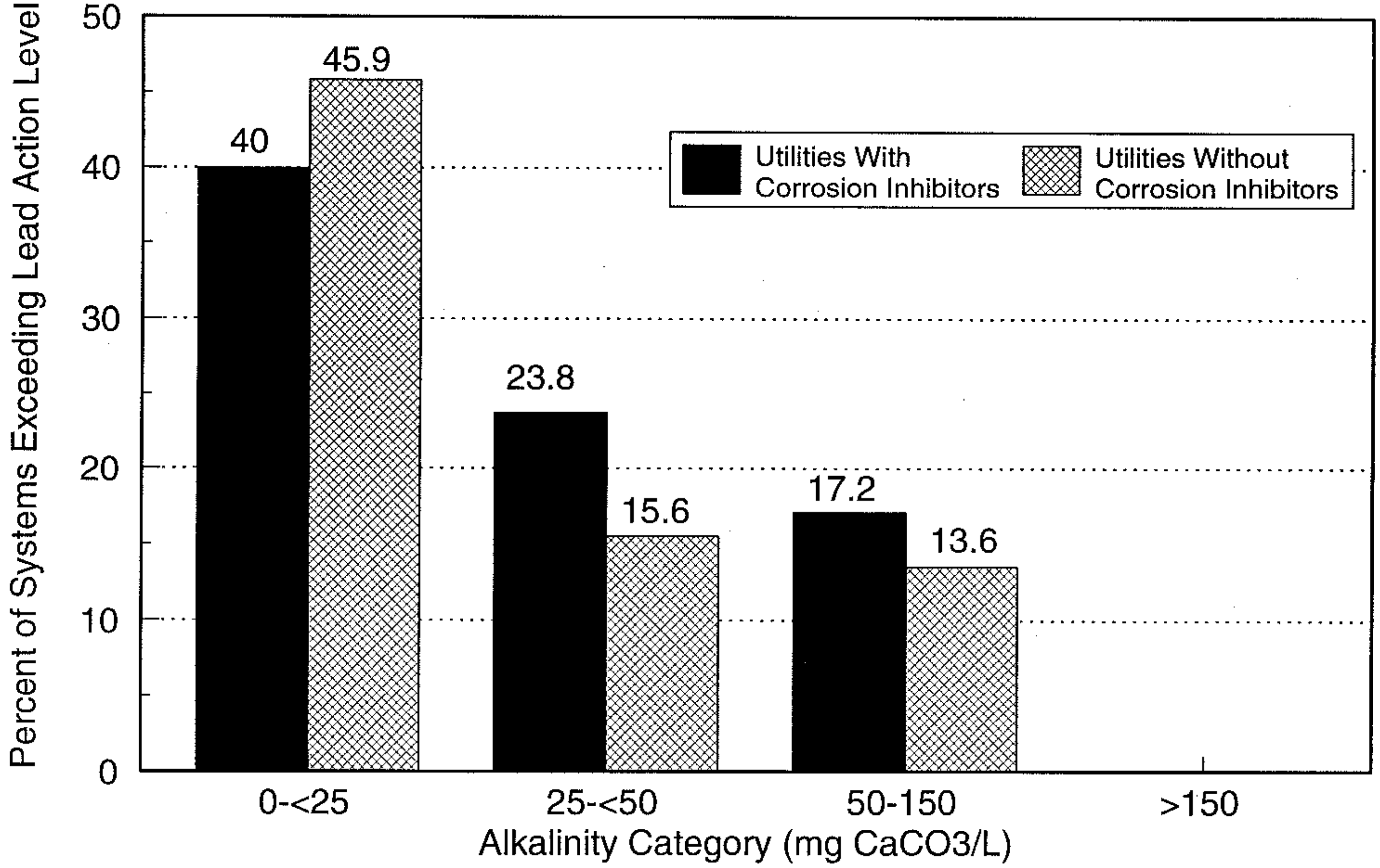
All Respondents



Note: Initial monitoring results of systems > 50,000 customers.

Exhibit 6-3

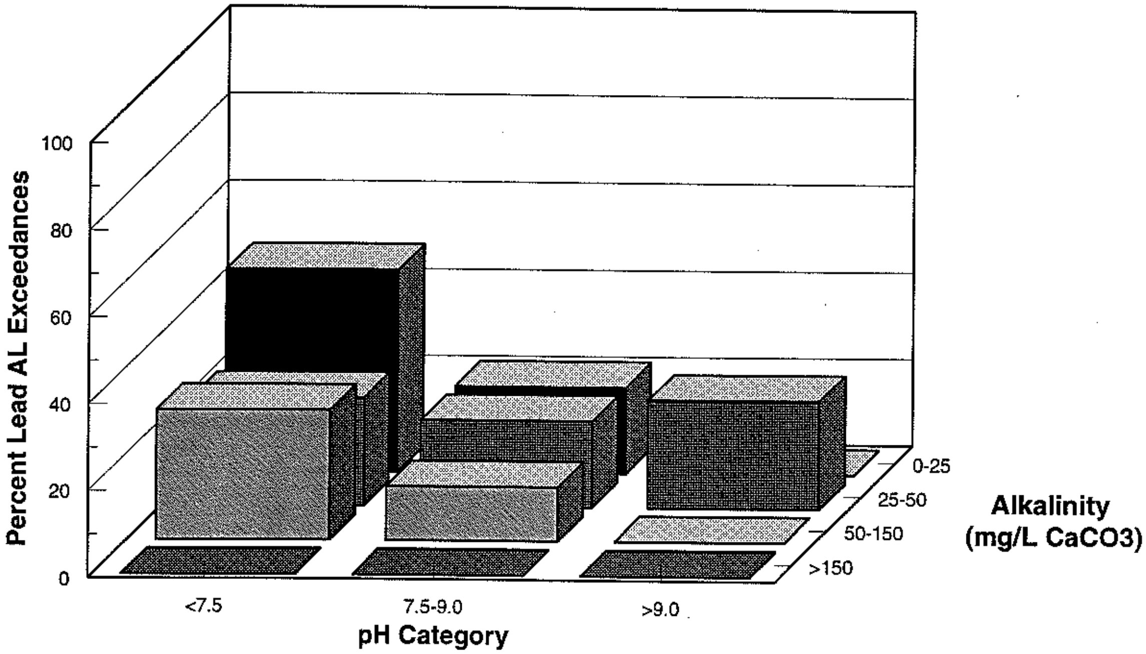
Lead Action Level Exceedances for Alkalinity Categories



Note: Initial monitoring results of systems > 50,000 customers.

Exhibit 6-4

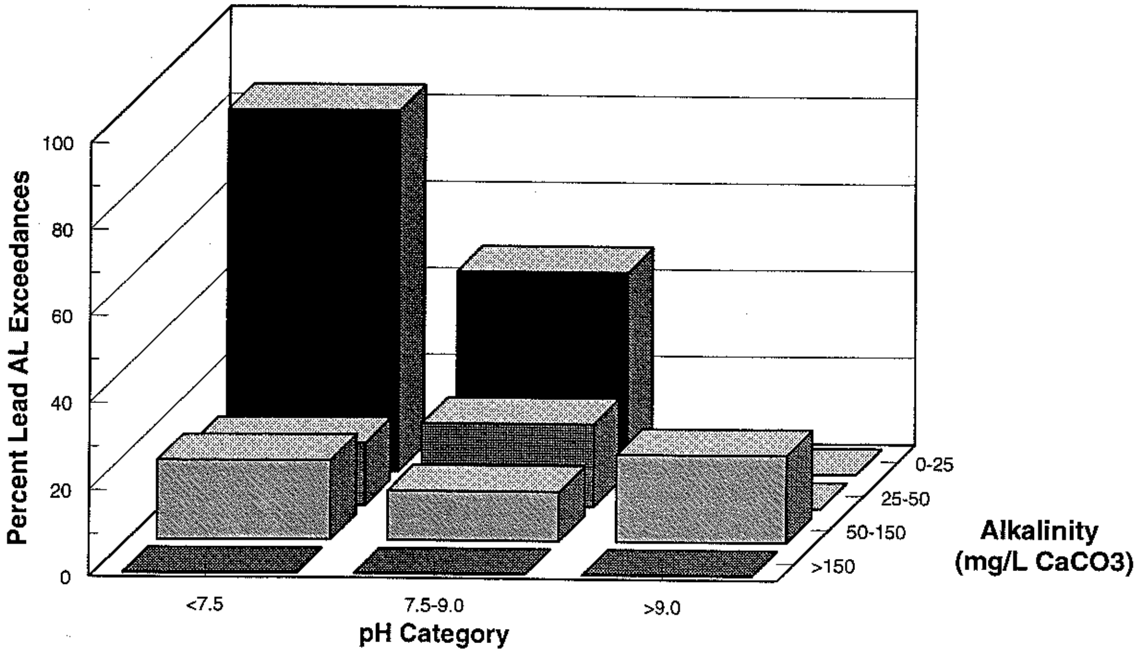
Percent of Lead Action Level Exceedances
As a Function of pH and Alkalinity, Inhibited Waters



Source: WITAF Report Initial Monitoring Experience of Large Utilities Under USEPA's Lead and Copper Rule - Utilities serving > 50,000

Exhibit 6-5

Percent of Lead Action Level Exceedances
As a Function of pH and Alkalinity, Non-Inhibitor Waters



Source: WITAF Report Initial Monitoring Experience of Large Utilities Under USEPA's Lead and Copper Rule - Utilities serving > 50,000

Section 7
Evaluation of Treatments and Recommendation of Preferred Alternative

7.1 Overview

Based on the information reviewed in Sections 1 through 6, it is recommended that only the passivation techniques (pH/alkalinity adjustment and inhibitor addition) be evaluated further. The LCR Guidance Manual Volume II outlines four criteria on which to base the evaluation of the viable corrosion control treatment approaches as follows:

- ☐ Corrosion control **performance** based on either reductions in metal solubility or the likelihood of forming a protective scale. Performance can be based on theoretical calculations, bench scale tests, pilot plant testing, and/or the experience of other analogous systems already practicing optimized corrosion control.

- ☐ The feasibility of implementing the treatment alternative on the basis of the **constraints** identified. These constraints may be regulatory-based by impacting the system's ability to comply with existing federal or state drinking water standards in addition to anticipated regulations that may impact the system in the future. Also included in this criteria category are functional constraints such as wastewater impacts, the effects upon industrial, commercial and public customers, and system impacts.

- ☐ The **reliability** of the alternative in terms of operational consistency and continuous corrosion control protection. The advantages and disadvantages of the available chemical feed systems should be considered including the ability to minimize interruptions in treatment due to maintenance, chemical inventory problems, or equipment and instrumentation failure. The LCR requires that corrosion control treatment be operated at all times.

- ☐ The estimated **costs** associated with implementing the alternative treatments. Costs for a corrosion control treatment system should be amortized over the expected life of the feed system and include chemical costs, capital expenditures, and operations and maintenance costs.

The performance of each approach will be determined based on results of lead solubility models, corrosion indices, and analogous system information.

Additionally, the results of bench-scale and full-scale testing conducted by analogous systems and full-scale testing conducted by Bellingham, will be used to estimate the performance of treatment approaches. The feasibility of each treatment will be determined based on the extent and severity of regulatory and functional constraints identified in Section 5. The cost of each approach will be evaluated based on capital costs and operational and maintenance costs as a function of an average plant flow of 11 MGD. Costs will be generated for various chemicals within each suitable treatment approach for comparison purposes only and are provided at the end of this section. Treatment reliability will be summarized based on operational experiences of other utilities, manufacturers literature, and existing treatment facilities in operation at Bellingham's Water Treatment Plant. As discussed in previous sections, calcium carbonate is not considered a viable treatment option and therefore will not be considered as part of the treatment evaluation. Only these passivation techniques will be considered further:

- ☐ pH/alkalinity adjustment
- ☐ pH adjustment
- ☐ Orthophosphate inhibitor addition
- ☐ Silicate inhibitor addition

7.2 Treatment Evaluation

7.2.1 pH/Alkalinity and pH Adjustment

The chemicals used to modify pH and alkalinity are the same as those used for calcium carbonate precipitation including lime, soda ash, sodium bicarbonate, caustic soda, and carbon dioxide. pH/alkalinity adjustment is a passivation technique, theoretically decreasing both metals leaching and corrosion of piping materials.

Performance

Past studies, theoretical solubility curves (Exhibits 7-1 and 7-2), and full-scale testing conducted by Bellingham indicate that upwards pH adjustment is effective for reducing lead corrosion. Several sites in the distribution system have been sampled four times to date: a one liter sample was collected during Round 1; a fractionated 1.125 liter sample was collected during Round 2; a fractionated 1.125 liter sample was collected after pH adjustment (Round 3), and a one liter sample was collected during recent full-scale monitoring (Round 4). Results are summarized in Table 7-1.

Table 7-1
City of Bellingham
Lead Levels in the Bellingham Distribution System

Sample I.D.	Lead Level (mg/L)	Monitoring Round*	Distribution System pH	Distribution System Alk.	Water Quality Zone
001K	0.020	1	7.5	20.3	South
	0.016	2	7.4	18.5	
	0.004	3	8.2	27.0	
	0.004	4	8.2	28.0	
015K	0.017	1	7.3	24.5	Padden
	0.019	2	7.2	17.5	
	0.005	3	7.9	29.5	
	0.002	4	7.6	26.4	
062K	0.020	1	7.4	19.8	Padden
	0.011	2	7.2	17.5	
	0.008	3	7.9	29.5	
	0.009	4	7.6	26.4	
031B	0.010	1	7.3	19.0	Upper Yew
	0.010	3	7.7	25.0	
	0.011	4	7.7	26.0	
038K	0.018	1	7.3	22.5	North
	0.020	2	7.1	19.0	
	0.017	3	7.7	25.7	
	0.004	4	7.9	27.0	
009K	0.022	1	7.3	22.5	North
	0.020	2	7.1	21.5	
	0.012	3	7.7	27.0	
	0.002	4	7.6	26.0	

* *Monitoring Round 1 = 1 Liter Sample*
Monitoring Round 2 = 1.125 L Fractionated Sample
Monitoring Round 3 = 1.125 L Fractionated Sample Post-pH Adjustment
Monitoring Round 4 = 1 L sample Post-pH Adjustment

The results in Table 7-1 appear to indicate that pH adjustment from 7.3 to 8.0 at the treatment plant has had a positive effect on reducing lead leaching levels. At all sites, lead levels after pH adjustment decreased significantly, as shown in Exhibit 7-3, and all sites except 038K dropped below the lead action level after pH adjustment. However, site 038 K was well below the action level during Round 4.

Results of computer-generated lead solubility calculations (Table 7-2) also indicate that significant reductions in theoretical lead solubility would result by adjusting the pH from 7.3 to the range of 7.5 to 9.0, and by increasing alkalinity from 15 mg/L as $CaCO_3$ (which is similar to Bellingham's initial levels) to 25 mg/L $CaCO_3$.

Table 7-2
Theoretical Lead Solubility at Various pH Values

pH	Initial Alkalinity (mg $CaCO_3$/L)	Initial Lead Solubility	Adjusted Alkalinity (mg $CaCO_3$/L)	Existing Soluble Lead Level (mg/L)
6.5	15	0.796	25	0.592
7.0	15	**0.340**	25	0.326
7.5	15	**0.172**	25	**0.175**
8.0	15	0.105	25	**0.110**
8.5	15	0.070	25	0.073
9.0	15	0.049	25	0.051
9.5	15	0.039	25	0.039
10.0	15	0.048	25	0.039

Prior to pH adjustment, approximately 0.172- 0.34 mg/L of lead could be solubilized. If pH was adjusted to 7.5 - 8.0 and alkalinity increased to 25 mg/L $CaCO_3$, theoretical lead solubility could decrease to approximately 0.11 - 0.17 mg/L, as demonstrated by the bold entries on Table 7-2.

Exhibits 7-1 and 7-2 demonstrate the effects of both pH and dissolved inorganic carbonate (DIC) on theoretical lead solubilities, not just pH and alkalinity. Although alkalinity is a component of DIC, they are not the same water quality parameter. DIC levels can increase without resulting in an increase in alkalinity, where as increases in alkalinity will affect DIC levels. It is more appropriate to determine lead solubility as a function of DIC, since this parameter considers all carbonate species in solution, including ion pairs and complexes. The importance of DIC and alkalinity with regards to lead corrosion control is not entirely understood. For copper, it is clear that elevated pH values will reduce copper leaching and corrosion and that alkalinity may not be as significant as pH. It may be necessary to increase carbonate alkalinity along with pH in order to reduce lead corrosion, but this has not always been demonstrated under real-world conditions. pH adjustment using caustic, soda ash, lime, or sodium bicarbonate will automatically result in some alkalinity increase. The magnitude of the change in alkalinity is a function of which chemical is used to increase pH. Increasing pH from 7 to 8 using soda ash would theoretically increase total alkalinity by approximately 10 mg/L as $CaCO_3$. Such a change was observed after pH adjustment since alkalinity increased from 17 mg/L $CaCO_3$ to 27 mg/L $CaCO_3$. Because of the low alkalinity of Bellingham's raw water, an increase in pH may necessitate an increase in alkalinity to maintain stable, higher pH values within the distribution system, regardless of whether or not alkalinity adjustment helps to reduce lead leaching and corrosion. Results of analogous systems also indicate that upwards adjustment of pH and alkalinity may decrease soluble lead levels.

Constraints

The following constraints and impacts relative to pH and/or alkalinity adjustment were previously identified in Section 5.

Regulatory.

- ☐ An increase in pH prior to chlorination would require higher free chlorine CT values to meet SWTR requirements and would likely cause higher trihalomethane (THM) levels. Thus, the chemical addition point to adjust pH will be located after storage in the 16.5 MG reservoir scheduled for completion in the fall of 1994. The new 16.5 MG reservoir will provide more than adequate contact time so that disinfection CT requirements can be fulfilled.

- ☐ Compliance with future THMs and other chlorinated by-product MCLs may limit the upper range of pH increases, as well as possibly limit chlorine dosages. Laboratory tests which were conducted to assess DBP formation as a result of both increased contact time and pH adjustment to 8.0 indicated that contact time was the predominant factor causing increases in TTHM and THAA formation. Bellingham should not have a problem meeting Stage 1 of the D/DBP Rule, regardless of pH (in the range of 7.0–8.0) or contact time in the new reservoir. It is possible that Bellingham may also meet the Stage 2 requirements of 40/30 µg/L for TTHM/THAA, once operation of the new reservoir is optimized for CT, DBPs, and operational storage. Although DBP formation may be a concern with respect to proposed Stage 2 MCLs, the configuration of the new reservoir should provide the operational flexibility to address these regulatory requirements.

Functional.

- ☐ pH/alkalinity adjustment will most likely have the least impact upon water quality, Wastewater Treatment Plant operations, and industrial/commercial water users. Beneficial results have already been observed in the form of lower effluent metals levels at the wastewater treatment facility.

- ☐ pH/alkalinity adjustment may receive the least resistance from the general public considering that chemical addition would be kept to a minimum and potentially no new chemicals would be added to the water. Furthermore, little or no uncertainties with respect to health risks exist with the use of pH adjustment inorganic chemicals.

Reliability

Chemical addition of lime will require a high degree of operator attention due to potential plugging of bins, tanks, pumps, and piping. Thus, the reliability of dry chemical feed equipment for pH/alkalinity adjustment (especially for lime addition) is less than that for liquid systems. A dry feed soda ash system is currently in operation, and treatment plant staff have not experienced operational difficulties to date. Installation of bulk storage hoppers will greatly reduce chemical feed operational requirements currently in use. Regardless of which chemical is used for pH/alkalinity adjustment, a feed system must be designed and operated such that personnel can safely, reliably, and consistently produce finished water within the pH range that minimizes corrosion in Bellingham's distribution system.

7.2.2 Corrosion Inhibitors

Phosphate- and silicate-based compounds are the two principal forms of corrosion inhibitors, both of which use passivation as the means of corrosion prevention. Passivation inhibits metal corrosion through the formation of less soluble metal compounds (carbonates, phosphates, or silicates) which adhere to interior pipe surfaces, thereby protecting the metal from the corrosive water.

Performance

The past use of phosphate inhibitors in other waters indicated that they have been effective in decreasing lead leaching. Theoretical solubility curves with the addition of 1 mg/L PO_4 (0.3 mg/L as P) shown in Exhibits 7-4 and 7-5 indicate that the maximum lead solubility could be reduced significantly over a wide range of pH and DIC levels. Additionally, Bellingham's treated water would not require further pH adjustment to reach the theoretical solubility minimum for phosphate use. Table 7-3 presents the theoretical reductions in lead solubility associated with the use of a phosphate inhibitor for a water with an alkalinity similar to Bellingham's, versus the use of soda ash for pH/alkalinity adjustment. A minimum in lead solubility can be observed between pH 7.5 - 8.0.

Table 7-3
Theoretical Lead Solubility
(I = 0.0012, T = 25°C)

Phosphate Without pH/Alkalinity Adjustment				pH/Alkalinity Adjustment Only			
pH	**Alkalinity (mg/L $CaCO_3$)**	**Lead Level (mg/L)**	**Phosphate Level (mg/L PO_4)**	**pH**	**Alkalinity (mg/L $CaCO_3$)**	**Lead Level (mg/L)**	**Phosphate Level (mg/L PO_4)**
6.5	15	0.041	1	6.5	25	0.592	0
7.0	15	0.019	1	7.0	25	0.326	0
7.5	15	0.014	1	7.5	25	0.175	0
8.0	15	0.016	1	8.0	25	0.110	0
8.5	15	0.018	1	8.5	25	0.073	0
9.0	15	0.021	1	9.0	25	0.051	0
9.5	15	0.026	1	9.5	25	0.039	0
10.0	15	0.038	1	10.0	25	0.039	0

Although not demonstrated by theoretical calculations, full-scale use of orthophosphates indicates that they are most effective over a pH range of 7.4 - 7.8. Metal phosphate precipitates can form at pHs greater than 7.8, causing scale build up and decreasing hydraulic capacity (LCR Guidance Manual Volume II). Results obtained during pilot-scale testing conducted by Portland Water Bureau suggested that orthophosphates were especially effective at decreasing lead leaching at a pH of 7.5. General experience indicates that a stable pH may be required throughout the distribution system and alkalinity adjustment may be required to attain this.

There is little information available with respect to the performance of silicate inhibitors for control of lead and copper leaching, since silicate addition for larger municipal water systems is not commonly practiced in the U.S. To date, silicates have been mainly used as an inhibitor for copper and galvanized steel, particularly in hot water systems (Larsen, 1993). Limited available data indicate that protective films form relatively slowly on lead pipe. High initial doses (3 to 8 weeks at levels as high as 20 mg/L SiO_2 above background silicate levels) may be necessary to establish a film.

Constraints

Constraints associated with the use of corrosion inhibitors were discussed previously in Section 5 and can be summarized as follows:

Regulatory.

☐ The use of phosphate inhibitors may have negative impacts upon water quality from a biological growth and taste and odor perspective. Pilot testing of phosphate inhibitors would require complementary HPC formation potential testing by Bellingham to attempt to quantify the severity of this issue. Should microbiological degradation of the water quality occur, increased chlorine residuals, contact time, or rechlorination within the distribution system may be necessary to meet the Total Coliform Rule and general disinfection requirements.

Functional.

- ☐ Phosphate inhibitors may have some negative impact upon the wastewater treatment plant in terms of phosphorus loading to receiving waters.
- ☐ Phosphate additions could have some negative impact upon industries (who demand ultra-pure water for their processes) from a biological growth and phosphorous removal perspective.
- ☐ Public reaction to the use of a new chemical in the water treatment process would need to be addressed, both from a health and environmental perspective.

Reliability. Liquid and dry chemical feed systems can be used for inhibitors and both are considered reliable. Although single tank systems are feasible, multiple batch tanks with automatic switch-over can provide a more reliable service since the LCR requires corrosion control treatment be operated at all times.

7.2.3 Costs

Chemical costs for the passivation treatment approaches are presented in Table 7-4, based on an average flow of 11 MGD and a final pH between 7.5 - 8.5. For pH and/or alkalinity adjustment alternatives, the costs will vary considerably depending on whether both pH and alkalinity adjustment are required, the type of chemical selected, and the applied chemical dose. However, chemical costs are not be the only consideration for selecting the preferred alternative; other O&M costs (labor, power, maintenance, etc.) may also be considerable. Capital costs will also influence the decision as well, as shown in Table 7-5.

From Table 7-5 it is clear that corrosion control treatment costs increase dramatically as chemical costs increase. The capital cost associated with retaining soda ash addition as the optimal corrosion control treatment strategy is more than an order of magnitude lower than the capital cost of incorporating a new chemical treatment strategy such as pH adjustment using lime. However, the present worth of the twenty year total cost stream is nearly double for soda ash versus lime. Regardless of cost, it will be beneficial for Bellingham to retain soda ash addition because of other O&M issues and so that buffering capabilities in the distribution system are adequate for maintaining adjusted pH levels.

Table 7-4
Estimated Chemical Costs for Treatment Alternatives

Treatment Alternative	Percent Strength	Unit Chemical Cost* ($/pure lb.)	Estimated Range of Dosages (mg/L)	Estimated Range of Treated Water pH	Estimated Range of Alkalinity Added (mg/L as $CaCO_3$)	Range of Chemical Costs ($/mil. gal. treated)
pH and Alkalinity Adjustment						
1. Hydrated Lime ($Ca(OH)_2$)	90	0.065	1 to 3	7.5 to 8.5	2 to 4	0.54 to 1.63
2. Caustic Soda (NaOH)	50	0.20	1 to 3	7.5 to 8.5	2 to 4	1.67 to 5.00
3. Soda Ash (Na_2CO_3)**	99	0.11	12 to 15	7.5 to 8.5	5 to 15	11 to 13
Inhibitors						
4. Orthophos. (as PO_4)***	35 to 80	0.5	1 to 3	2 to 7.8	Minimal	4.2 to 12.5
5. Sodium Silicate (as SiO_2)	28	0.2	4 to 10	7.5 to 8.5	Minimal	6.7 to 16.7

* *All unit costs are developed costs computed with percent strength incorporated.*

** *Based on actual costs (1992) according to Bellingham WTP staff.*

*** *The unit price given is an average of several different brands of sodium phosphate and orthophosphate compounds.*

Table 7-5
Comparative Cost Evaluation of Corrosion Control Alternatives+

Strategy	Capital Costs*	Average Chemical Costs $/MG	O&M Costs $/MG**	Present Worth*** (20 yr. cost stream)
1. **pH/Alkalinity Adjustment**	$15,000	12	2.7	$700,000
2. **pH Adjustment**	$183,000	1.6	3.6	$420,000
3. **Orthophosphate Addition++**	$150,000	4.2	3.0	$470,000
4. **Silicate Addition**	$155,000	7.2	3.0	$610,000

\+ *Costs are for planning purposes only; ±30%. Costs are based on an average flow of 11 MGD.*

* *Capital costs for Alternatives 2, 3, and 4 include chemical storage, handling, injection and process control instrumentation. Capital costs for Alternative 1 includes additional process control instrumentation and piping for duplicate feed facilities.*

** *O&M excludes chemical costs.*

*** *The 20 year cost stream is not adjusted for growth and assumes an average of 11 MGD treated water over the entire 20 year period. A 6.5% discount rate is assumed.*

++ *Capital costs for orthophosphate addition do not include additional equipment for pH adjustment to 7.5. However, these capital costs have already been incurred by Bellingham.*

7.3 Conclusions

The purpose of this section is to determine which treatment approach would work best for Bellingham and water users, and eliminate the least viable corrosion control treatment options based on evaluation criteria.

The primary tools used to select the preferred treatment alternatives are:

- ☐ Experiences of analogous systems, and
- ☐ Results of the Evaluation Criteria Analysis presented above. Evaluation criteria included:
  - ☐ Performance,
  - ☐ Constraints,
  - ☐ Reliability, and
  - ☐ Cost.

Of the four analogous systems reviewed for the desk-top study including Seattle, Eugene Water & Electric Board, Portland, and Greater Vancouver Water District:

☐ None used or tested calcium carbonate precipitation,

☐ None have used silicate-based inhibitors full-scale, and

☐ All four systems are currently using or proposing to use some form of pH/alkalinity adjustment for treatment.

Results of analysis of the four evaluation criteria in Section 7.2 suggest that:

☐ Either pH/alkalinity adjustment or phosphate addition would theoretically decrease soluble lead levels in Bellingham's distribution system. However, phosphate inhibitors may have some negative impact upon the wastewater treatment plant in terms of phosphorus loading to receiving waters. Furthermore, phosphate additions could have some negative impact upon industries (who demand ultra-pure water for their processes) from a biological growth and phosphorous removal perspective.

☐ Calcium carbonate precipitation is not a suitable treatment option given Bellingham's water quality.

☐ pH/alkalinity using soda ash will result in the lowest cost increase from a capital standpoint since soda ash is currently part of Bellingham's treatment scheme. However, lime addition would actually result in the lowest overall cost over the 20-year cost stream.

☐ The alkalinity added when soda ash is used will help to increase buffering capacity in the distribution system.

☐ Silicates may be effective at reducing lead levels, based on preliminary results obtained from other studies; however industrial water users may object to silicate addition to the water.

☐ Public reaction to the use of a new chemical in the water treatment process would need to be addressed, both from a health and environmental perspective.

7.4 Recommended Optimal Corrosion Control Treatment

7.4.1 Overview

Based on the results of this desk-top evaluation of corrosion control treatment alternatives, and full scale testing of pH and alkalinity adjustment the recommended optimal corrosion control treatment method for the City of

Bellingham is pH/alkalinity adjustment, which utilizes passivation as the mechanism for corrosion control.

pH/alkalinity adjustment was the best overall strategy based primarily on performance and functional constraints including impacts on the water treatment process and impacts on the service community. Corrosion control treatment using pH/alkalinity adjustment has been demonstrated to be effective for reducing lead and copper dissolution using theoretical calculations for metals solubility, analogous system information including demonstration testing results from Seattle Water Department, Portland Water Bureau, and other Pacific Northwest utilities. Monitoring results comparing the pre- and post-pH/alkalinity adjustment of lead and copper levels in Bellingham's system also indicate that this is an effective treatment option.

7.4.2 Target pH and Resulting Alkalinity Levels

pH/alkalinity levels in Bellingham's finished water were increased to reduce lead solubility at-the-tap. A target pH of 8.0 was selected based on regulatory constraints and chemical costs. Theoretically, the optimum pH for lead control is 9.8 with an alkalinity of about 28 mg/L as $CaCO_3$. However, the pH increase implemented for corrosion control treatment must not cause a violation of any other existing drinking water quality regulations. Bellingham would not be able to meet CT requirements at such high pH levels, and TTHM formation would probably have increased dramatically. Bellingham desires to balance overall water quality characteristics by anticipating effects of future regulations as well, such as Stage II of the D/DBP and ESWTR Rules.

For Bellingham, a pH level of approximately 7.8–8.0 ± 0.2 units is recommended based on the constraints identified in Section 5 of this report and performance which was evaluated previously in this section. A summary of the factors used to establish target pH levels is provided in Table 7-6. Since soda ash will be used to increase pH, a resulting increase in alkalinity will also occur. This is beneficial from both a corrosion control and buffering capacity standpoint. It is expected that the resulting (and recommended) finished water alkalinity will fall between 25–35 mg/L $CaCO_3$.

Table 7-6
Factors Used to Establish Target pH and Alkalinity Levels

pH	Alkalinity (mg/L $CaCO_3$)	Comments	Conclusions
9.8	28	☐ Theory suggests ideal for minimizing lead solubility ☐ TTHM formation would be dramatically increased ☐ Disinfection efficiency of chlorine would decrease ☐ Extremely high chemical cost ☐ Result in drastic water quality changes ☐ Constraints on service community ☐ Bellingham met ALs for lead and copper at pH = 7.8-8.0, alkalinity 25-27 mg/L $CaCO_3$	High pH levels have too many serious drawbacks.
9.0	20–30	☐ Recommended for Portland based on pilot-scale testing; however, Portland chloraminates ☐ Same comments as above	With use of free chlorine for secondary disinfection, too many drawbacks.
8.5	20–25	☐ Probably would not meet Stage 2 of D/DBP Rule ☐ Increased cost for minimal additional corrosion control ☐ Bellingham met AL at pH 7.8-8.0, alkalinity 25-27 mg/L $CaCO_3$ ☐ Disinfection efficiency lower at pH 8.5	Same as above.
7.8-8.0	25–35	☐ Recommended for Bellingham ☐ Would potentially meet Stage 2 of D/DBP Rule ☐ Disinfection more effective ☐ Least impact on service community ☐ Less expensive than increasing pH/alkalinity to higher levels ☐ Bellingham met AL at pH 7.8-8.0, alkalinity 25-27 mg/L $CaCO_3$	Most likely solution for achieving optimization and best over all water quality.
7.6	13	☐ May be able to meet AL, however, corrosion control may not be optimized based on desk-top study results ☐ Bellingham would need to conduct at least two consecutive monitoring rounds to confirm effectiveness	Questionable as to meeting requirements for large systems under LCR.
		Recommended Target pH Level: **7.8–8.0 ± 0.2 units** **Resulting Alkalinity:** **22–32 mg/L $CaCO_3$**	

7.4.3 Chemical Selection

There are three primary reasons that Bellingham should retain soda ash for accomplishing pH adjustment. These include:

☐ Added alkalinity associated with soda ash addition will help to maintain adjusted pH levels within the distribution system. Buffering capacity may be a key factor in providing optimal corrosion control treatment.

☐ Bellingham maintains and operates existing facilities for soda ash feed. Operators are familiar with the chemical and operational issues.

☐ Carbonate (primarily contributed by alkalinity in soft water supplies) is an important player in the passivation technique.

Thus, the recommended chemical for increasing pH and alkalinity levels in Bellingham's system is soda ash.

7.4.4 Operating Ranges

As stated earlier, a target pH of 7.8–8.0 is recommended at the treatment plant, plus or minus 0.2 units. It is recognized that the pH will sometimes be outside this target range and it is suggested that Bellingham evaluate its ability to feed and control soda ash dosages in the next 24 months. Resulting alkalinity levels with use of soda ash will most likely fall between 22–32 mg/L $CaCO_3$. The pH range is based on Bellingham's previous monitoring results from analogous systems, and previously discussed constraints. Large pH fluctuations are not conducive to formation of adherent lead scales and can cause release of lead. pH levels in the distribution system must be 7 or greater to remain in compliance.

7.4.5 Dosage Requirements

The estimated dose to reach a finished water pH of 7.8-8.0 ± 0.2 units (and resulting alkalinity of 22–32 mg/L $CaCO_3$)is 12 to 15 mg/L of soda ash. The actual dose will depend on varying water quality characteristics, i.e., mainly the alum and chlorine doses required and seasonal changes in source water pH and alkalinity levels.

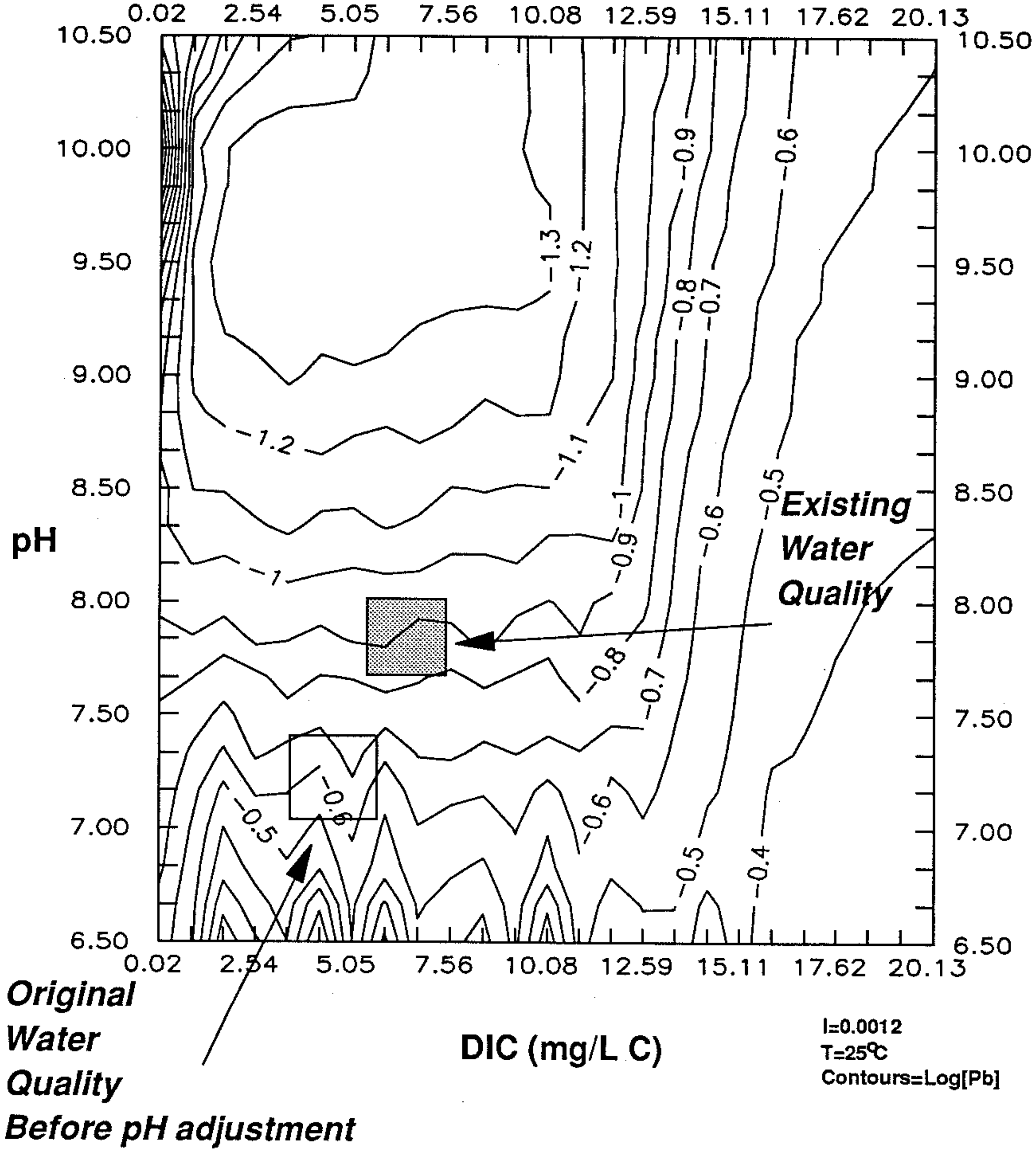


Exhibit 7-1

City of Bellingham

Effect of pH and DIC on Theoretical Lead Solubility

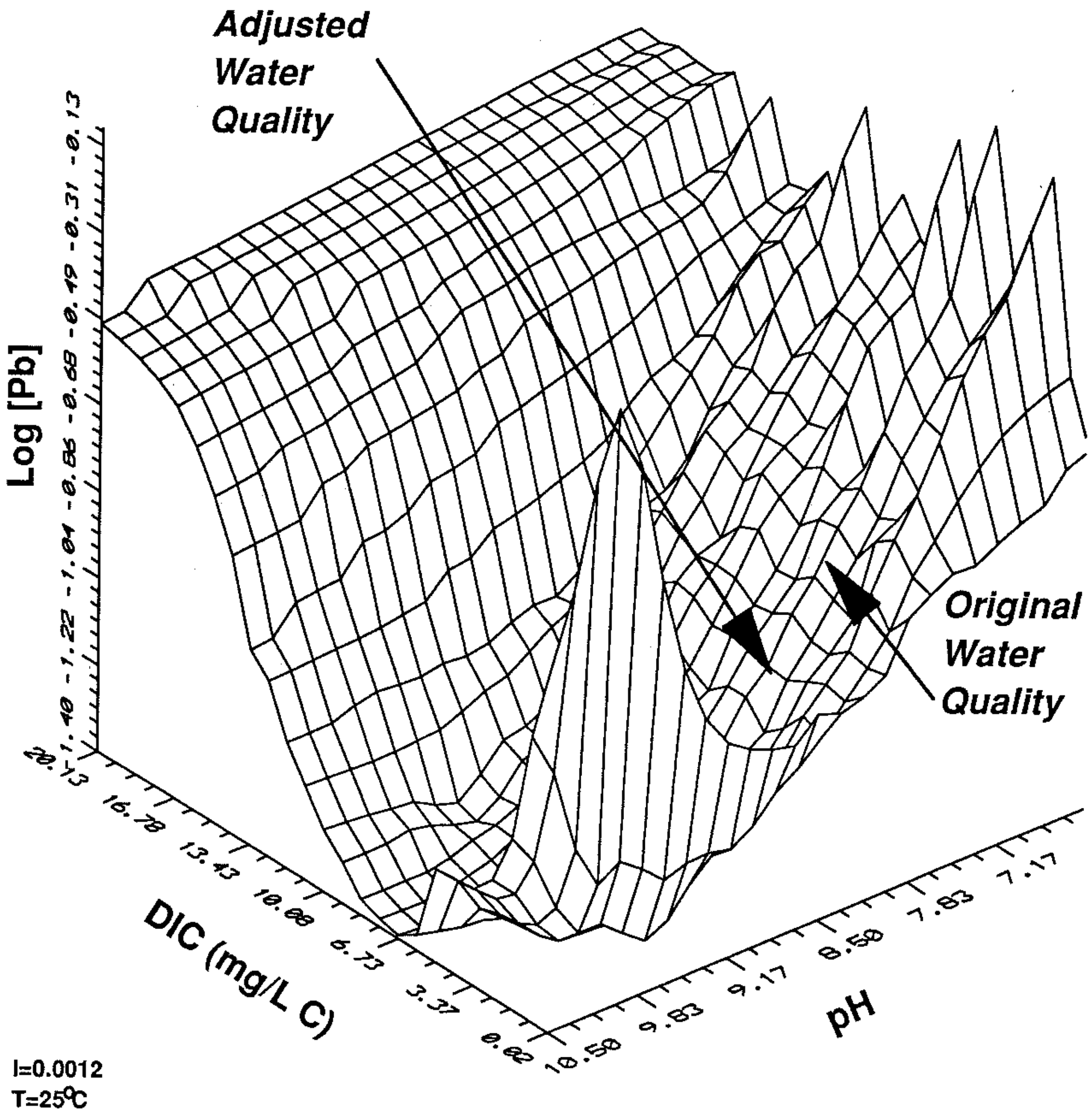
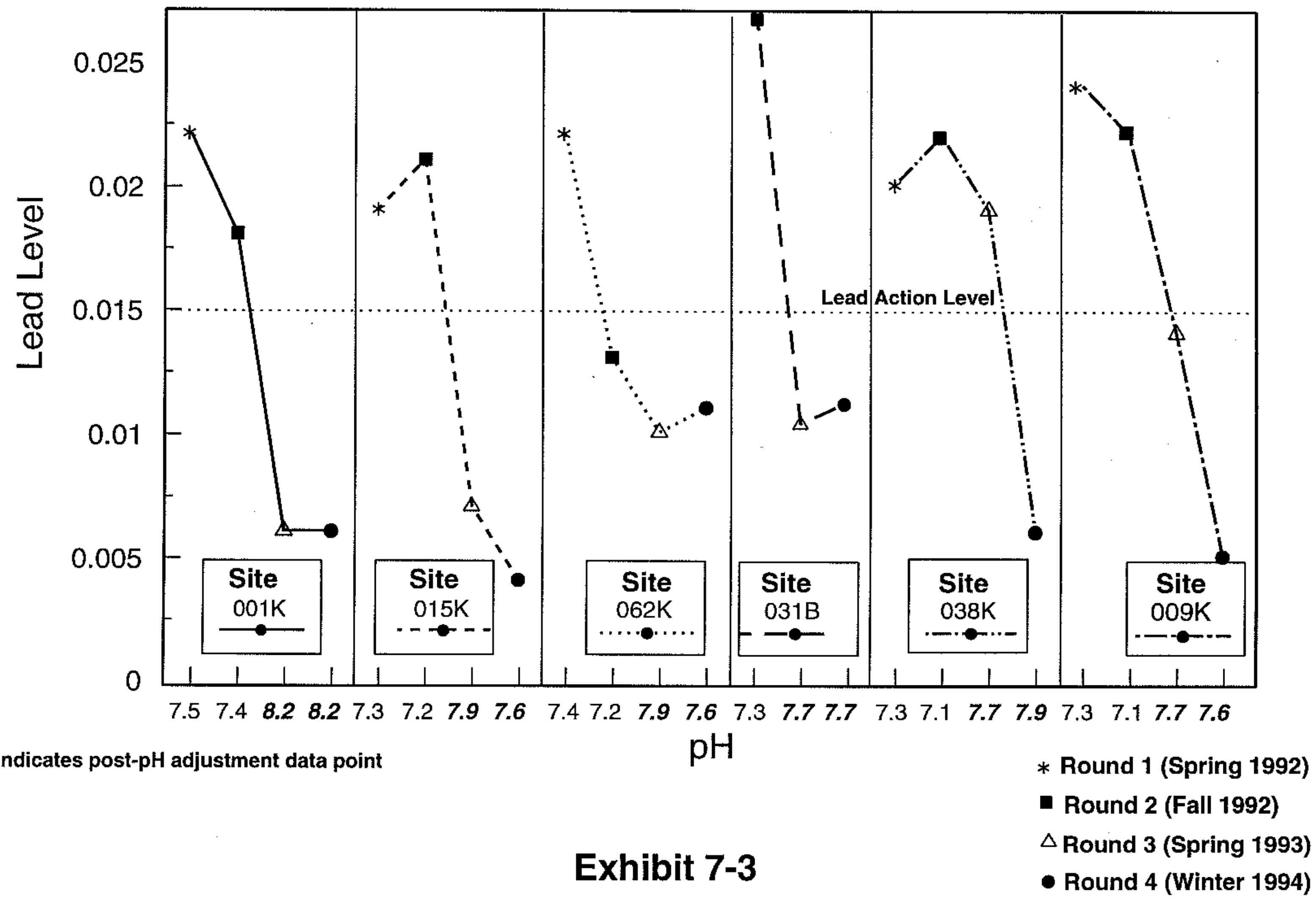


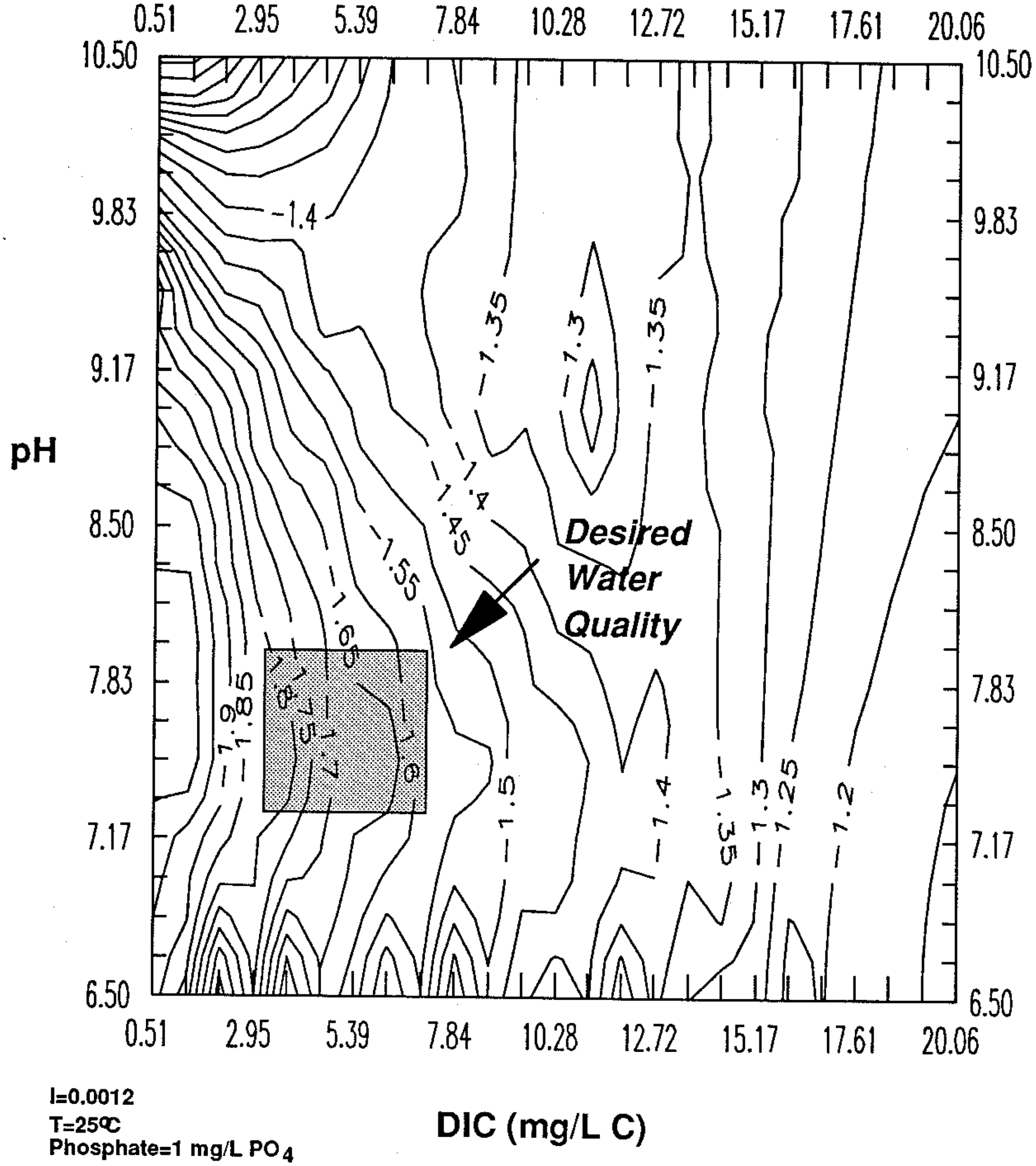
Exhibit 7-2

City of Bellingham Three-Dimensional Lead Solubility Curve



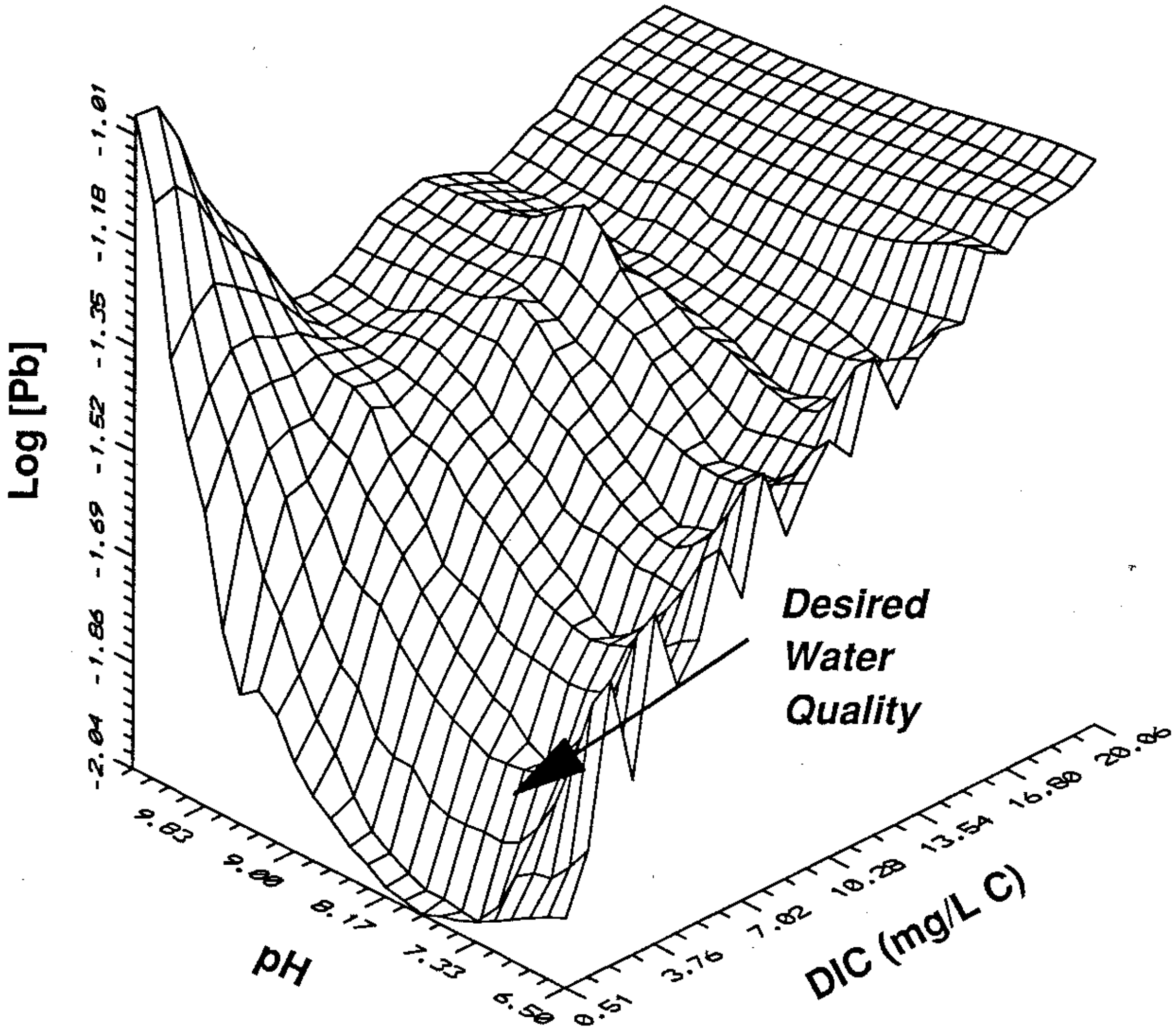
Bold indicates post-pH adjustment data point

Exhibit 7-3
City of Bellingham
Soluble Lead Levels at "High-Risk" Sites
During Consecutive Monitoring Rounds



I=0.0012
T=25°C
Phosphate=1 mg/L PO_4
Contours=Log[Pb]

Exhibit 7-4
City of Bellingham
Effect of Phosphate on Lead Solubility



I=0.0012
T=25°C
Phosphate=1 mg/L PO_4

Exhibit 7-5
City of Bellingham
Effect of Phosphate on
Three-Dimensional Lead Solubility Curve

Section 8
Recommended Implementation Program

8.1 Monitoring

8.1.1 Required Regulatory Monitoring

The Lead and Copper Rule specifies monitoring requirements both after installation of corrosion control facilities and after the State specifies the water quality parameter ranges. When pH/alkalinity adjustment is identified as the optimal corrosion control treatment, both pH and alkalinity must be measured at a minimum once every two weeks at the entry point to the distribution system, and two samples must be collected every six months from a minimum of 10 distribution system sites. In addition, chemical dosages must be reported when alkalinity adjustment is part of corrosion control treatment. Systems that remain within the State specified water quality parameter ranges for two consecutive six-month monitoring periods may reduce monitoring to two samples every six months from 7 distribution system sites. Monitoring may be reduced further to annually after three years of maintaining the State specified water quality parameter ranges. There is no reduced monitoring for the entry point to the distribution system.

To determine whether tap lead levels are above or below action levels, and whether continued public education is mandated, Bellingham will be required to conduct two consecutive six-month monitoring rounds following installation of corrosion control treatment. Because systems are given two years to install treatment, the first round does not begin until January 1997. Monitoring will include lead and copper tap sampling at a minimum of 60 Tier 1 sites (plus additional sites to include consecutive systems). The second round occurs between July and December 1997 and also requires 60 Tier 1 sites to be sampled for lead and copper. It is recommended that Bellingham target the same homes that were sampled during Rounds 2 and 4 of initial full-scale monitoring. Between January and June 1998, the State will specify the Water Quality Parameter Values for Bellingham's optimal corrosion control treatment. Two six-month monitoring rounds follow this determination by the State, consisting of the same sites sampled previously for lead and copper. If Bellingham meets the lead and copper action levels or maintains the DOH-specified optimal corrosion control treatment for two consecutive 6-month periods, tap sampling may be reduced to annually to 30 Tier 1 sites. Systems maintaining water quality parameter values for six consecutive 6-month monitoring periods (3 years) may reduce lead and copper tap sampling to 30 Tier 1 sites once every 3 years.

Bellingham will need to meet the required monitoring as outlined above; however, those requirements do not address control of the soda ash feed process. Bellingham currently measures and records the pH level of the water entering the distribution system continually and calculates a daily average pH. Alkalinity is measured twice per month. To help maintain a relatively consistent finished water pH reporting level, it is recommended that Bellingham continue monitoring pH on this basis. However, the frequency for monitoring alkalinity should be increased to at least once per week.

8.1.2 Recommended Implementation Monitoring

Construction of the new reservoir, combined with corrosion control treatment, could have varying effects on distribution system water quality as discussed previously. Water distribution systems are delicate in the balance they maintain between physical conditions such as flow rates and direction; chemical parameters such as pH and chlorine residuals; and microbiological organisms including coliform and heterotrophic plate count bacteria. Piping scales have developed over many decades of use, especially in old unlined cast iron mains prevalent in Bellingham and some consecutive systems. Since Bellingham has already installed what is considered optimal corrosion control treatment, the two-year treatment installation and implementation period (1995 and 1996) provided in the LCR would be an opportune time to conduct additional non-regulatory monitoring in the distribution system. The purpose of this recommended approach is to allow time for evaluation of the following areas of potential concern: 1) lead and copper levels at the tap; 2) bacteriological quality and disinfectant residual levels in the distribution system; 3) disinfection-by-product levels; 4) CT compliance status; 5) water quality effects associated with the new 16.5 MG reservoir; and 6) customer response including consecutive systems and wastewater treatment impacts. The recommended implementation strategy is shown in Exhibit 8-1.

Based on the results of implementation monitoring data, a further adjustment to above or below pH = 8 may or may not be useful. If 90th percentile lead levels remain less than or equal to 0.015 mg/L and monitoring indicates that all other parameters are in compliance with existing and possible future regulations, Bellingham is optimized and should maintain water quality conditions.

If 90th percentile lead levels are less than or equal to 0.015 mg/L, but one or more of the other 6 criteria are a major problem, Bellingham should consider reverting to pH 7.6–7.8. If 90th percentile lead levels are greater than 0.015 mg/L and there are no major problem in other areas, Bellingham should consider further increasing pH levels. It is important to note that Bellingham could still conceivably exceed an action level but remain in compliance with the LCR as long as state-specified water quality parameters are maintained and corrosion control treatment is optimized.

8.2 Timing

This report needs to be submitted to DOH by the required deadline of June 30, 1994. If approval is obtained, Bellingham should begin collecting the additional data to verify that optimal corrosion control treatment has been realized. DOH has indicated that the two rounds of regulatory follow-up monitoring can be conducted at any time during the two-year implementation period, if Bellingham wishes to proceed ahead of schedule. However, routine and reduced monitoring cannot be conducted until the State has specified water quality parameter ranges. It is Bellingham's objective to have any additional equipment that may be necessary for control or feed installed by the January 1, 1997 deadline.

8.3 Redundancy

Although not specifically required by the Lead and Copper Rule, providing redundant feed systems will improve Bellingham's ability to comply with the Rule. For Bellingham, this may involve installation of additional piping and control mechanisms. Bellingham already maintains duplicate soda ash feed systems however, additional quality control verification measures may be required based on the redundancy requirements which will be determined by EPA and DOH.

8.4 Costs

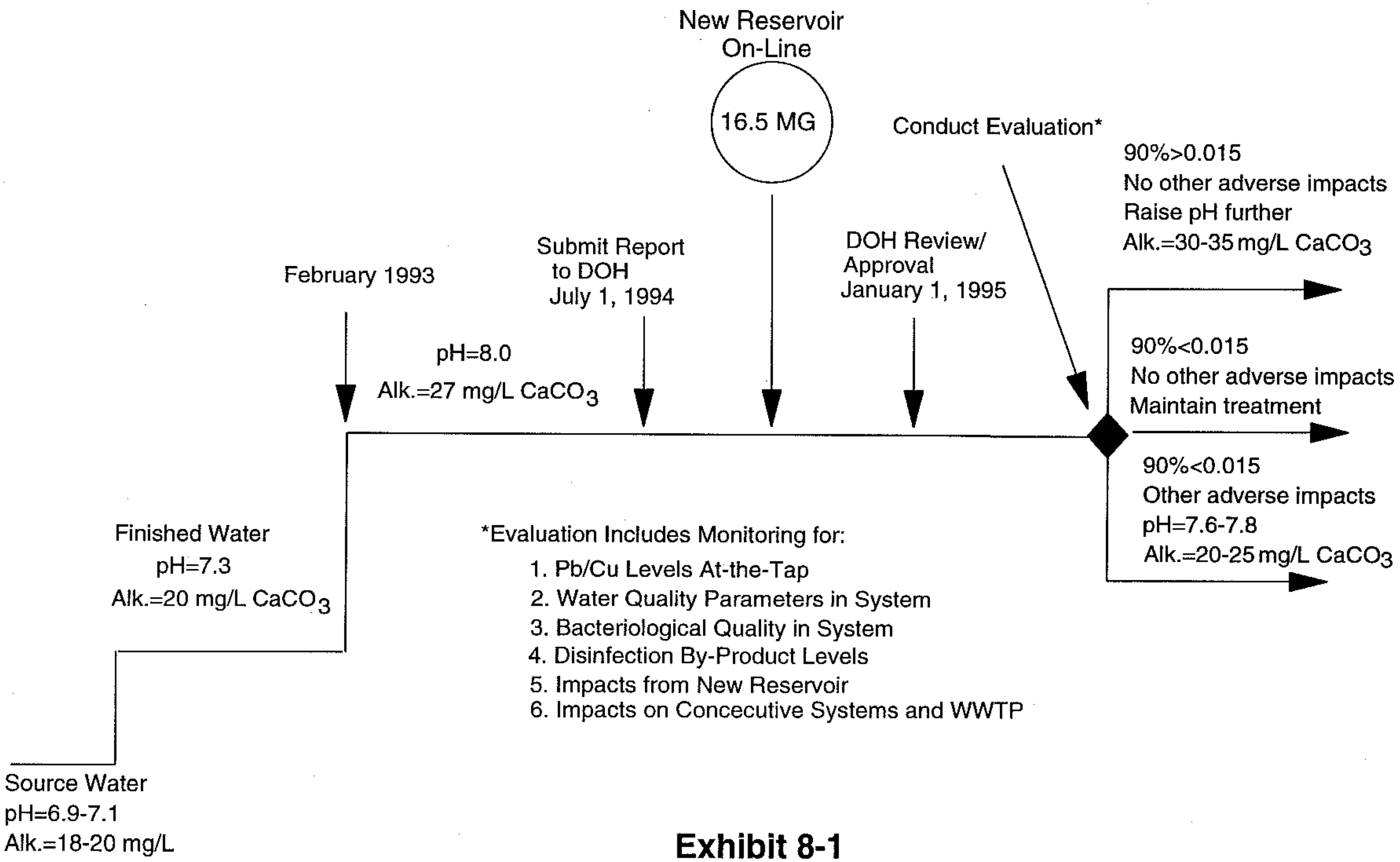
The costs for implementing Bellingham's corrosion control treatment strategy were calculated for capital, chemical, and O&M expenditures. These costs are summarized in Table 8-1.

Table 8-1
Estimated Costs for pH/Alkalinity Adjustment as Corrosion Control Strategy

	Average Cost*
Chemical Cost	$48,000/year
O&M Cost	$11,000/year
Capital Cost	potentially $15,000**

* *Costs are for planning purposes only; ±30%. Average daily flow assumed to be 11 mgd, dosage assumed to be 12–15 mg/L of soda ash.*

** *Additional capital expenditures may be necessary to supply complete corrosion control treatment redundancy capabilities.*



*Evaluation Includes Monitoring for:

1. Pb/Cu Levels At-the-Tap
2. Water Quality Parameters in System
3. Bacteriological Quality in System
4. Disinfection By-Product Levels
5. Impacts from New Reservoir
6. Impacts on Concecutive Systems and WWTP

Exhibit 8-1
City of Bellingham
Suggested Implementation Strategy

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Appendix A

Consecutive Systems Sampling Plan for the Lead and Copper Rule

FINAL

CITY OF BELLINGHAM

CONSECUTIVE SYSTEMS SAMPLING PLAN FOR THE LEAD AND COPPER RULE

BACKGROUND

The City of Bellingham uses water from Lake Whatcom as its sole source of drinking water. Water is diverted from the Middle Fork of the Nooksack River to Lake Whatcom via a pipeline. The City draws approximately 45 MGD from Lake Whatcom of which 33 MGD is received by Georgia Pacific Corporation, and 12 MGD is treated at the Bellingham Water Filtration Plant and distributed to customers.

Water treatment is accomplished by prechlorination, coagulation and flocculation with addition of alum and cationic polyelectrolytes by rapid mix. Direct filtration is achieved using six mixed media gravity filters. Peak treatment capacity is about 33 MGD. Plant clearwell capacity is one million gallons. A 16 million-gallon reservoir has been designed to meet requirements of the Surface Water Treatment Rule. Chlorine gas is used for disinfection with a target residual of 0.6 mg/L free chlorine leaving the plant. Soda ash is added to the clearwell for pH adjustment with a target pH of 7.3 leaving the plant. The City is considering raising target pH to 8.0 for corrosion control purposes.

Lake Whatcom provides soft, low alkalinity water typical of a Cascade range surface supply. Raw pH averages 7.1 with alkalinity of 19 mg/L and hardness of 21 mg/L. Average raw water turbidities are 0.45 NTU, and the average temperature is 12.1 degrees Celsius.

Finished water enters the distribution system with an average pH of 7.3, and an average alkalinity of 21 mg/L with hardness at 22 mg/L. Average treated water turbidity is 0.05 NTU.

RATIONALE FOR A CONSOLIDATED MONITORING PLAN FOR LEAD AND COPPER

The City of Bellingham has exceeded the Environmental Protection Agency's action limit for lead at the 90th percentile for two monitoring periods. As a result, Bellingham is committed to conducting a corrosion control study and instituting treatment to optimize corrosion control.

The City of Bellingham distributes water to several water districts and associations. Five of these are small systems and one is medium sized. The City has recently acquired three small systems, and may take in the remaining five small consecutive systems in the next five years. Since the City will be responsible for corrosion control treatment for consecutive systems, it would be beneficial to consolidate sampling for the lead and copper rule to provide a representative database from which to evaluate corrosion control techniques.

A consolidated sampling plan will benefit Class A medium and small systems by reducing effort and cost. With the assistance of a large system which has some experience under the rule, smaller systems can better ensure compliance with requirements of the regulation. The proposed reduction in sample sites for the small and medium sized consecutive systems far exceeds the requirement for a large system with the same population.

Under this plan, responsibilities for elements of the rule's requirements will be outlined. Failure to comply with requirements of the consolidated monitoring plan will carry the same penalties as if the utility were individually out of compliance with the Lead and Copper Rule 40 CFR 141.86. Conditions of the plan and the interlocal agreement will be terminated upon approval of corrosion control treatment by the State and follow-up monitoring. Participation by consecutive systems will be voluntary.

RESPONSIBILITIES UNDER THE CONSOLIDATED LEAD AND COPPER MONITORING PLAN

Materials Evaluation:

Each system will be responsible for providing all available information regarding materials in their distribution system. Of special concern are any lead components such as lead piping, lead service connections and, lead goosenecks. Systems will be asked to provide the building code for household plumbing in place between 1983 and 1988.

Sample Site Selection:

Each system will be prescribed a required number of tier-one sample sites. These are homes built between 1983 and 1988, with copper plumbing and lead solder. Consecutive systems will be asked to provide addresses for tier-one sites in their area. In addition to sampling for lead and copper, the rule requires sampling for water quality parameters at representative points within the distributions system. The system may be asked to assist Bellingham personnel in sample site investigation and selection.

Resident Contact:

Consecutive systems may be asked to assist Bellingham personnel in contacting sample site residents.

Bottle/Sample Delivery:

Consecutive systems may be asked to assist in bottle and sample delivery.

Sample Collection:

Residents will be instructed in proper sampling techniques for lead and copper tap samples. Consecutive systems may be asked to collect samples for water quality analysis.

Source Water Monitoring:

The City of Bellingham will be responsible for collection and analysis of source water samples from Lake Whatcom.

Sample Analysis:

All lead and copper samples will be analyzed by a certified commercial laboratory. Water quality samples will be analyzed at the City of Bellingham's Water Laboratory. The City will bear the cost of sample analysis.

Reporting:

The City of Bellingham will prepare and report results for the consolidated system to the State. A copy of results will be provided to each system.

Public Notification/Education:

Systems will be required to distribute public notification materials supplied by the City of Bellingham to their customers according to the Lead and Copper Rule. The City will provide public service announcements and press releases as required.

Lead Service Line Replacement:

Each consecutive system will be responsible for removal of lead piping or lead service lines within their distribution system.

RESPONSIBILITIES OF THE CITY OF BELLINGHAM

In addition to the responsibilities assigned above, the City of Bellingham will:

design a consolidated sampling plan that fulfills the requirements of the Lead and Copper Rule.

coordinate the consolidated sampling effort for the required sampling periods, including post corrosion control implementation monitoring.

undertake a corrosion control study for drinking water distributed by the City of Bellingham to consecutive systems as required by the Lead and Copper Rule.

implement corrosion control measures at Bellingham's Water Filtration Plant for water delivered to customers and to consecutive systems to optimize corrosion control as prescribed by the State. The City of Bellingham will provide optimization of corrosion control to the extent that corrosion is due to the quality of water supplied by the City, and not due to the character of materials or other factors within the consecutive system itself.

WATER DISTRICTS CONSECUTIVE TO THE CITY OF BELLINGHAM

This is a list of the Class A systems consecutive to Bellingham that are included in the consolidation proposal. "# Samples Required" represents the number of samples required under the Lead and Copper Rule, should the system conduct its own program. Systems with an asterisk have been newly acquired by the City of Bellingham.

System Name	Population	Services (#)	System Size	# Samples Required	
				Lead/ Copper	WQ
City of Bellingham	60,000		Large	60	10
*Telegraph Rd. Water Assn.		25	Small	5	1
*Van Wyck		112	Small	10	2
*Water District #16		86	Small	5	1
Baker-James Water Assn.	150	48	Small	5	1
Glen-Cove Water Co-op	155	21	Small	5	1
Water District #2 (Marine Dr. to Marietta)	1,646	501	Small	20	2
Water District #7 (Britton Rd. to Toad Lake)	1,200	356	Small	10	2
Water District #9	120	52	Small	5	1
Water District #10	5,435**	1,999	Medium	40	3

Total population served: 65,488

Total sample # required under individual systems plan 145 23

** Only the Geneva area of Water District #10 is served by Bellingham water. Geneva accounts for half of the service; population and sample requirements are calculated accordingly.

SAMPLE PLAN FOR CONSOLIDATED SYSTEMS

System Name	Population	Services (#)	System Size	# Samples Required	
				Lead/ Copper	WQ
City of Bellingham	60,000		Large	60	10
Baker-James Water Assn.	150	48	Small	3	1
Glen-Cove Water Co-op	155	21	Small	3	1
Water District #2 (Marine Dr. to Marietta)	1,646	501	Small	10	1
Water District #7 (Britton Rd. to Toad Lake)	1,200	356	Small	5	1
Water District #9	120	52	Small	3	1
Water District #10	5,435**	1,999	Medium	10	1
Total proposed sample sites				94	16

Since the requirement for monitoring of small systems does not begin until July 1993, it will be assumed that samples collected before the July deadline will be counted toward the requirement.

CONSOLIDATED SAMPLE PLAN CHECKSHEET

Name of Utility: ______________________________
Mailing Address: ______________________________
Telephone #: ______________________________
DOH System ID#: ______________________________
Contact Name: ______________________________
Number of Service Connections: ______________________________
Population Served: ______________________________
Average Daily Flow: ______________________________

1. Do you have any records of the materials composing mains, service connections and household plumbing within your distribution system? Please attach information. Please estimate percentage of each material used in your system.

2. Please estimate the number of single family residences constructed in your service area between 1982-1988. ________
   Are water hookup records available for these homes? ________
   Please include addresses for these homes.

3. Do you have record of the following water quality parameters for your system?

   a) Average pH: ______________________
   b) Average Alkalinity: ______________________
   c) Average Hardness: ______________________
   d) Average Temperature: ______________________
   e) Average Conductivity: ______________________

4. Please include the locations of your coliform monitoring sites.

Does your utility wish to be included in the Consolidated Lead and Copper Monitoring plan for Bellingham and its consecutive systems? ______________

Signature: ______________________________ Date: ______________

Title: ______________________________

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PUBLIC WORKS OPERATIONS

INTERLOCAL AGREEMENT
CITY OF BELLINGHAM - WATER DISTRICT NO.2
CONSOLIDATED WATER SAMPLING PLAN FOR LEAD AND COPPER

WHEREAS, the City of Bellingham (City), provides water to various water districts and associations in Whatcom County; and,

WHEREAS, any treatment of water which occurs at the City Water Treatment Plant affects all those to whom water is provided; and,

WHEREAS, under present Federal and State requirements, all districts or associations regardless of size are required to comply with the Environmental Protection Agency's (EPA) Lead and Copper Rule (40 CFR 141.86); and,

WHEREAS, in order to monitor and begin treatment of system corrosion, a comprehensive program of water sampling by all those to whom the City supplies water will yield the broadest and most reliable data base possible; and,

WHEREAS, the Water District No.2 ("District") and the City wish to enter into this interlocal agreement, pursuant to RCW 39.34,

NOW, THEREFORE, IT IS MUTUALLY AGREED AS FOLLOWS:

1. In order to carry out a consolidated monitoring plan which will be approved by the Environmental Protection Agency (EPA),
   (a) the City will conduct, according to protocol it has developed, water sampling and testing at selected locations within the District; and,
   (b) the District agrees to permit such testing of its customers and system, and will abide by the provisions of the City's protocol, attached hereto as Exhibit A and incorporated by this reference.

2. The District agrees to participate in reasonable sampling and testing activities as from time-to-time requested by the City.

3. The City is not responsible for and need not correct any anomalies discovered or otherwise existing in the District's system.

4. Failure by the District to comply with requirements of the consolidated monitoring plan will subject it to the same penalties imposed by EPA or the State as if the District were individually deemed to be out of compliance with EPA's Lead and Copper Rule.

5. The City may terminate this Agreement upon failure by the District to comply with any provision of this Agreement. In any event, this Agreement will terminate upon approval by the Washington State Department of Health (acting on behalf of EPA) of the City's corrosion control optimization program.

6. Each party agrees to assume liability for and hold the other harmless as to claims arising out of its own activities in connection with this Agreement and, in the event of concurrent negligence, to share proportionately in any settlement or judgment to that effect.

IN WITNESS WHEREOF, this Agreement is duly executed as follows:

Date: March 22 1993

WATER DISTRICT NO.2

John D. Coulthurst
Manager

John D. Coulthurst

Date: Apr. 8, 1993

CITY OF BELLINGHAM

Paula Beatty for
Attest: Lynn Carpenter
Finance Director

Tim Douglas
Tim Douglas, Mayor

Departmental Approval:

John M. Garner
Public Works

Approved as to form:

Richard N. Little, Jr.
Office of the City Attorney

Appendix B
Typical Information Collected from Monitoring Sites

Sample Number	Address	Year Built	Zone	WQ Site	LEAD (mg/L)	COPPER (mg/L)	Main Main	Interior Plumbing	Aerator removed	Pb SOLDER Tested	Pb SOLDER e present	Fixture
001B-9205	408 Fieldston		Southside	Larrabee	0.02		Cast Iron	Copper	Yes	yes	yes	Chrome plated Brass
001t-9202	408 Fieldston		Southside	Larrabee	0.008	0.32		Copper		no		Chrome plated Brass
002K-9202	1913 22nd St.		Southside	Larrabee	0.005	0.31	Cast Iron	Copr	Yes	yes	yes	Chrome plated Brass
003K-9202	1876 Governor	1985	Yew	Padden Res	0.002		Ductile Ir	PVC	Yes	no		Chrome plated Brass
004K-9202	211 Morey Ave	1983	Sunset Heights	Sunset Heights Res	0.008	0.19	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
005K-9203	1919 Governor	1986	Yew	Padden Res	0.026	0.43	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
005k-9204	1919 Governor	1986	Yew	Padden Res	0.015	0.47		Copper		no		Chrome plated Brass
006K-9203	2619 Lynn St.	1984	Gravity	Eldridge & Lindbergh	0.006	0.41	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
007K-9203	610 W.Maryland	1985	Gravity	Eldridge & Lindbergh	0.004	0.24	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
008K-9203	2811 Niagra St.	1984	Dakin	Whatcom Falls Res	0.004	0.11	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
009K-9203	3847 Idaho	1983	Gravity	Whatcom Falls Res	0.022	0.26	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
009k-9204	3847 Idaho	1983	Gravity	Whatcom Falls Res	0.012	0.22		Copper		no		
010K-9203	618 Willow Ct.	1986	Southside	Larrabee	0.005	0.37	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
011B-9203	3408 Lindsay Av	1985	Southside	Padden Res	0.006	0.20	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
012K-9203	2711 Fir	1983	Dakin	Dakin Reservoir	0.003	0.05	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
013K-9203	2512 King	1986	Gravity	Alabama & Woburn	0.007	0.20	Cast Iron	Copper	yes	yes	no	Chrome plated Brass
014K-9203	911 Nevell	1987	Gravity	Sehome Res	0.007	0.11	Ductile Ir	Copper	yes	no	no	Chrome plated Brass
015K-9203	3559 Ridgemont	1984	40th St	40th St. Res	0.017	0.43	Ductile Ir	Copper	yes	no	no	Chrome plated Brass
015k-9204	3559 Ridgemont	1984	40th St	40th St. Res	0.012	0.10	Ductile Ir	Copper		no		Chrome plated Brass
015K-9303					0.013	0.044		Copper		no		
016K-9203	2620 Henry St.	1984	Gravity	Eldridge & Lindbergh	0.001	0.15	Cast Iron	Copper	yes	no	no	Chrome plated Brass
017K-9203	1013 W. Toledo	1984	Yew	Alabama & Woburn	0.004	0.14	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
018K-9203	2312 St. Clair	1984	Dakin	Alabama & Woburn	0.002	0.10	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
019K-9203	1211 Franklin	1987	Gravity	Sehome Res	0.003	0.04	Ductile Ir	Copper	yes	no	no	Chrome plated Brass
020K-9203	3631 Home	1984	Gravity	BAC	0.002	0.13	Ductile Ir	Copper	no	yes	yes	Chrome plated Brass
021K-9203	3616 Home Rd.		Gravity	BAC	0.002	0.17	Ductile Ir	Copper	Yes	yes	yes	Chrome plated Brass
022K-9203	2516 Orleans St	1983	Gravity	Alabama & Woburn	0.004	0.01	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
023K-9203	110 34th St.	1983	Southside	Sehome Res	0.001	0.15	Ductile Ir	Co[illegible]r	yes	yes	yes	Chrome plated Brass
024K-9203	211 Bayside Rd.	1984	Southside	Larrabee	0.011	0.28	Ductile Ir	C[illegible]	yes	yes	yes	Chrome plated Brass
025K-9203	1325 Welling Rd	1986	N. Lake Whatcom	Northshore Drive	0.042	0.30	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
025k-9204	1325 Welling	1986	N. Lake Whatcom	Northshore Drive	0.046	0.19		Copper		no		
026K-9203	4881 Samish Way	1984	40th St	Padden Res	0.001	0.25	Ductile Ir	Copper	yes	yes	no	Chrome plated Brass
027K-9203	3910 Wilkin St	1983	40th St	Padden Res	0.001	0.28	Cast Iron	Copper	no	yes	yes	Chrome plated Brass
028K-9203	3429A Redwood	1988	Gravity	Eldridge & Lindbergh	0.001	0.51	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
029K-9203	2804 Niagara St	1984	Dakin	Alabama & Woburn	0.012	0.24	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
030K-9203	421 S. Clarkwoo	1988	Southside	Larrabee	0.001	0.52	Ductile Ir	Copper	yes	yes	no	Chrome plated Brass
031B-9203	1712 Edwards St	1985	Gravity	Upper Yew Res	0.01	0.380	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
032K-9203	1206 Gambier Av	1985	Southside	State & Berry	0.012	0.22	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
033K-9203	3001 Vining St.	1986	Dakin	Whatcom Falls Res	0.001	0.13	Cast Iron	Copper	yes	yes	no	Chrome plated Brass
034K-9203	119 N 34th	1986	Southside	Sehome Res	0.004	0.17	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
035K-9203	2731 Michigan	1983	Dakin	Alabama & Woburn	0.006	0.46	Cast Iron	Copper	yes	no	no	Chrome plated Brass
036K-9203	2906 Cherrywood	1983	Gravity	Eldridge & Lindbergh	0.03	0.210	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
036k-9205	2906 Cherrywood		Gravity	Eldridge & Lindbergh	0.043	0.21		Copper	yes	no		Chrome plated Brass
037k-9203	520 20th St.	1987	Sunset Heights	Sunset Heights Res	0.009	0.58	Ductile Ir	Copper	y	y	y	Chrome plated Brass
038K-9203	1203 24th St.	1984	Southside	State & Berry	0.018	0.23	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
038k-9205	1203 24th Stree		Southside	State & Berry	0.015	0.35		Copper	yes	no		Chrome plated Brass
038K-9303					0.046	0.045		Copper		no		
039K-9203	1261 Xenia	1985	Dakin	Alabama & Woburn	0.001	0.050	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
040B-9203	2400 40th St.	1987	40th St	Padden Res	0.023	0.62	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
040B-9205	2400 40th Stree		40th St	40th St. Res	0.016	0.580		Copper	yes	no		Chrome plated Brass
041K-9203	209 S.Garden Te	1986	Sunset Heights	Sunset Heights Res	0.042	0.52	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
042K-9203	1894 Governor R	1985	Yew	Padden Res	0.012	0.450	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
043k-9205	3418 Lindsay Av	1987	40th St	40th St. Res.	0.004	0.15	Ductile Ir	Copper	yes	no		Chrome plated Brass
044B-9203	4441 Northwest	1987	Gravity	BAC	0.003	0.20	Asbestos c	[illegible]r	y	yes	yes	Chrome plated Brass
045K-9203	1442 Greenville	1983	N. Lake Whatcom	Northshore Drive	0.009	0.24	Ductile Ir	Copper	yes	yes	yes	Chrome plated Brass
046k-9204	2488 Yew St. Rd	1983	Yew	Lower Yew Res	0.015	0.41	Ductile Ir	Copper	y	y	y	Chrome plated Brass
046k-9205	2488 Yew St. Ro		Yew	Upper Yew Res	0.013	0.44		Copper	yes	no		Chrome plated Brass

Sample Number	Address	Year Built	Zone	WQ Site	LEAD (mg/L)	COPPER (mg/L)	Main Main	Interior Plumbing	Aerator removed	Pb SOLDER Tested	Pb SOLDER present	Fixture Fixture
047k-9204	1737 Electric A	1983	Dakin	Clearwell	0.002	0.10	Cast Iron	Copper	n	n		Chrome plated Brass
048K-9204	709 Willow Ct.	1986	Southside	Larrabee	0.011	0.36		Copper	yes	yes	yes	Chrome plated Brass
049k-9204	1119 Nevada St.	1984	Gravity	Whatcom Falls Res	0.013	0.15	Cast Iron	Copper	y	y	y	Chrome plated Brass
050k-9204	134 Soundview R	1983	Southside	Larrabee	0.01	0.410	Ductile Ir	Cop	y	y	y	Chrome plated Brass
051k-9104	2535 Queen St.	1986	Gravity	Alabama & Woburn	0.001	0.04	Cast Iron	Copper	y	y	y	Chrome plated Brass
052k-9204	412 Arbutus Pla	1987	Southside	Larrabee	0.001	0.55	Ductile Ir	Copper	y	y	y	Chrome plated Brass
053K-9204	2819 Niagara St	1984	Dakin	Dakin Reservoir	0.003	0.04	Ductile Ir	Copper	yes	7yes	yes	Chrome plated Brass
054k-9204	1463 Iron St.	1984	Gravity	Alabama & Woburn	0.003	0.13	Ductile Ir	Copper	y	y	n	Chrome plated Brass
055k-9204	4682 Aldrich Ro	1986	Gravity	Foster Reservoir	0.034	0.27	Ductile Ir	Copper	y	y	y	Chrome plated Brass
056k-9204	933 Northshore	1983	Dakin	Dakin Reservoir	0.002	0.14	Cast Iron	Copper		y	y	Chrome plated Brass
057k-9204	1872 Governor R	1984	Yew	Padden Res	0.023	0.45	Ductile Ir	Copper	yes	no		Chrome plated Brass
058k-9204	1011 Racine Str	1985	Yew	Alabama & Woburn	0.008	0.25	Ductile Ir	Copper	yes	no		Chrome plated Brass
059k-9205	129 34th Street	1983	Gravity	Sehome Res	0.002	0.15	Cast Iron	Copper	yes	y	yes	Chrome plated Brass
060k-9205	1502 40th Stree	1986	40th St	40th St. Res	0.01	0.430	Cast Iron	Copper	y	n		Chrome plated Brass
061b-9205	3565 Ridgemont	1986	40th St	40th St. Res	0.02	0.470	Ductile Ir	Copper		y	y	Chrome plated Brass
062k-9205	1502 38th Stree	1983	40th St	40th St. Res	0.02	0.300	Cast Iron	Copper	y	y	y	Chrome plated Brass
062K-9303	1502 38th	1983	40th St	40th St. Res	0.015	0.052		Copper		no		
063k-9205	1022 14th Stree	1986	Southside	State & Berry	0.017	0.44	Ductile Ir	Copper	y	y	y	Chrome plated Brass
064k-9205	1724 Northshore	1984	Dakin	Northshore Drive	0.003	0.22	Cast Iron	Copper	yes	yes	yes	Chrome plated Brass
065K-9202	311 E. North	1983	Gravity	BAC	0.013	0.43	Ductile Ir	Copper	y	yes	no	Chrome plated Brass
066k-9205	3100 Saint Clai	1988	Dakin	Dakin Reservoir	0.002	0.07	Cast Iron	Copper	yes	yes	no	Chrome plated Brass
068b-9205	2831 Flint Stre	1985	Dakin	Dakin Reservoir	0.042	0.16	Cast Iron	Copper		yes	yes	Brass
070K-9211	3786 Brownsvill	1985	N. Lake Whatcom	Northshore Drive				Copper		yes	no	
098K-9302	2408 Mill Ave	1983	Southside	Sunset Res	0.001	0.00		Copper	no	yes	yes	Chrome plated Brass
099K-9302	2496 Yew St	1983	Yew	Lower Yew Res	0.003	0.10		Copper	no	no		Chrome plated Brass
100K-9303	4265 King Ave	1957	WD 9		0.005	0.073		Copper	yes	yes	yes	Chrome plated Brass
101K-9303	1407 Holly Cour	1987	Gravity	Dakin Reservoir	0.005	0.014		Copper	yes	no		Brass
102K-9303	1511 Mt. Baker	1937	Van Wyck		0.001	0.002		Copper	yes	no		Chrome plated Brass
103K-9303	4307 King Ave.	1940	WD 9		0.006	0.080		Cop	yes			Chrome plated Brass
104K-9303	2409 Walnut St	1985	Gravity	Eldridge & Lindbergh				Copper	yes	no		Chrome plated Brass
105K-9303	2620 Iron St	1984	Gravity	James St. Res	0.002	0.002		Copper	yes	yes	no	Chrome plated Brass
107B-9303	5101 E. Nortle	1983	Dakin	Dakin Reservoir				Copper		no		Chrome plated Brass
1082G-1092	4104 York St	1983	Geneva	Alabama & Woburn				Copper	yes	no		Chrome plated Brass
108K-9303	2508 Franklin	1984	Gravity	Alabama & Woburn	0.001	0.002		Copper	yes	no		Chrome plated Brass
109K-9303	3577 Ridgemont	1986	Gravity	40th St. Res	0.004	0.130		Copper		no		
110K-9303	2505 Fir	1986	Dakin	Dakin Reservoir	0.004	0.002		Copper	yes	yes	no	
111K-9303	606 13th St.	1987	Southside	State & Berry	0.011	0.220		Copper	yes	yes	yes	Chrome plated Brass
112K-9303	3601 Seely St	1987	Gravity	Dakin Reservoir	0.003	0.053		Copper	yes	yes	no	Chrome plated Brass
113K-9303	27 Shorewood Dr	1986	Southside	Larrabee	0.003	0.020		Copper	yes	yes	no	Chrome plated Brass
116K-9303	3812 York St	1987	Gravity	Eldridge & Lindbergh				Copper	yes	no		Chrome plated Brass
117K-9303	407 S. Clarkwoo	1987	Southside	Larrabee	0.022	0.091		Copper	yes	no		Chrome plated Brass
118K-9303	512 Linden Road	1986	Southside	Larrabee	0.008	0.084		Copper	yes	no		Chrome plated Brass
119K-9303	2730 Birchwood	1986	Gravity	Eldridge & Lindbergh	0.002	0.002		Copper	yes	yes	yes	Chrome plated Brass
121K-9303	1825 Mt. Baker	1988	Van Wyck		0.002	0.016		Copper	yes			Chrome plated Brass
122K-9303	1230 Mt. Baker	1970	WD 2		0.001	0.024		Copper	yes			Chrome plated Brass
123K-9303	1465 Mt. Baker	1955	Van Wyck		0.006	0.002		Copper	yes			Chrome plated Brass
124K-9303	2616 Huntington .	1986		Northshore Drive	0.003	0.003		Copper				
125K-9303	1727 Mt. Baker	1984	Van Wyck					Copper	yes	no		Chrome plated Brass
125K-9303	1727 Mt. Baker	1984	Van Wyck					Copper	yes	no		Chrome plated Brass
126K-9303	662 Clark Rd.	1986	Southside	Larrabee	0.001	0.002		Copper	yes			Chrome plated Brass
127K-9303	2100 Samish Way	1987	Gravity	Padden Res	0.004	0.160		Copper	yes	no		Chrome plated Brass
128K-9303	923 36th	1987	40th St	40th St. Res	0.005	0.034		Copper	yes			Chrome plated Brass
129K-9303	1121 W. Racine	1987	Gravity	Alabama & Woburn	0.002	0.020		Copper	yes			Chrome plated Brass
130B-9303	410 S. Clarkwoo	1987	Southside	Larrabee	0.009	0.054		Copp				Chrome plated Brass
131K-9303	700 Fieldston	1985	Southside	Larrabee	0.004	0.049		Copp	yes			Chrome plated Brass
132K-9303	2633 Birchwood	1986	Gravity	Eldridge & Lindbergh	0.005	0.024		Copper				Chrome plated Brass
133K-9303	1475 E. Bakervi	1986	Baker-James		0.001	0.002		Copper	yes	no		Chrome plated Brass

Sample Number	Address	Year Built	Zone	WQ Site	LEAD (mg/L)	COPPER (mg/L)	Interior Plumbing	Aerator removed	Pb SOLDER Tested	Pb SOLDER present	Fixture Fixture
134K-9303	3226 Locust Ave	1985	WD 2		0.003	0.054	Copper	yes			Chrome plated Brass
135K-9303	3191 Locust Ave	1961	WD 2		0.003	0.002	Copper	yes			Chrome plated Brass
136K-9303	3903 E. Cliffsi	1955	WD 2		0.001	0.002		yes	no		Chrome plated Brass
137K-9303	3874 Cliffside	1957	WD 2		0.002	0.002	Copper	yes	no		Chrome plated Brass
138K-9303	4144 James St R	1936	Baker-James				Copper	yes	no		Chrome plated Brass
139K-9303	3947 Cliffside	1959	WD 2		0.003	0.016		yes			Chrome plated Brass
140K-9303	1796 Bayon Rd	1902	WD 2		0.001	0.002	Copper	no			Chrome plated Brass
141K-9303	955 Marine Driv		WD 2		0.001	0.012		yes	no		Chrome plated Brass
142K-9303	1423 Marine Dr.		WD 2		0.006	0.030	Copper				Chrome plated Brass
143K-9304	1520 Hillsdale	1983	WD 7				Copper	yes	no		Chrome plated Brass
144K-9303	1496 Island Vie	1957	WD 2				Copper	yes	no		Chrome plated Brass
145K-9303	3661 Britton Rd	1985	Gravity	James St. Res	0.009	0.056	Copper	yes	no		Chrome plated Brass
146K-9303	1611 Euclid Ave	1989					Copper		no		Chrome plated Brass
147K-9303	773 Telegraph R	1968	Telegraph Rd				Copper	yes	no		Chrome plated Brass
148K-9304	1864 Emerald La	1983	WD 7				Copper	yes	no		Chrome plated Brass
149K-9303	3315 McAlpine	1963	WD 2		0.003	0.002	Copper	yes	no		Chrome plated Brass
150K-9303	3520 McAlpine D		WD 2		0.004	0.002	Copper	yes	no		Chrome plated Brass
151K-9303	1589 Bayon Rd	1983	WD 2		0.008	0.069	Copper	yes	no		Chrome plated Brass
152K-9303	1801 Lake Crest	1986	Gravity	Clearwell			Copper	yes	no		Chrome plated Brass
153K-9303	4351 Gooding Av	1992	WD 9				Copper	yes	no		Chrome plated Brass
155K-9303	1118 W. Racine	1987	Gravity	Clearwell			Copper	yes	no		Chrome plated Brass
156K-9303	1614 Euclid Ave	1929	Glen Cove				Copper	yes	no		Chrome plated Brass
157K-9303	1701 Euclid	1968	Glen Cove				Copper		no		Chrome plated Brass
158K-9303	1552 Hillsdale	1983	WD 7				Copper	yes			Chrome plated Brass
159K-9303	3839 Cindy Lane	1983	WD 7				Copper	yes	no		Chrome plated Brass
160K-9303	920 36th St	1985	40th St	40th St. Res			Copper	yes	no		Chrome plated Brass
161K-9303	3978 Britton Rd	1985	WD 7				Copper	yes	no		Chrome plated Brass
162K-9303	3792 Brownsvill	1985	WD 7				Copper	yes	no		Chrome plated Brass
163K-9303	3867 Gala Loop	1983	WD 7				Copper	yes	no		Chrome plated Brass
164K-9303	3765 Brownsvill	1982	WD 7				Copper	yes	no		Chrome plated Brass
165K-9304	1008 38th St	1987	40th St	40th St. Res			Copper	no	no		Chrome plated Brass
166K-9304	318 Willow Ct.	1985	Southside	Larrabee			Copper	yes	no		Chrome plated Brass
167K-9304	704 Fieldston R	1986	Southside	Larrabee			Copper	no			Chrome plated Brass
168K-9304	4256 Rural Ave	1956	WD 2				Copper	yes	no		Chrome plated Brass