Exhibit A

Newark

Sharpe James
Mayor

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Mr. Barker Hamill
Chief, Water Supply Element
N J D E P & E
Bureau of Safe Drinking Water
CN 426
Trenton, NJ 08625.

June 30, 1994

RE: PWS ID# 0714001. Corrosion optimization study report.

Dear Mr. Hamill:

Enclosed are two copies of the corrosion optimization study report for the City of Newark's Water System. This report was prepared after an extensive demonstration testing program conducted in house. The City recommends the use of sodium silicate as the optimal corrosion inhibitor to be fed at the Pequannock Treatment Plant.

A copy of this report is also being forwarded to the Townships of Bloomfiled and Belleville to whom we supply wholesale water.

The contact person for any inquiries on this report is Mr. Sanjeev Varghese, Principal Engineer, Hydraulics, who can be reached at 201-256-4965.

Very truly yours,

Daniel Berardinelli

Daniel Berardinelli, P.E.
Manager, Div. Water/Sewer Utility

sv hamill

encl: as above.
cc: Alvin Zach, P.E., Director, Engineering Department.
Andrew Pappachen, Supervising Engineer.
✓Anthony DeBarros, Principal Engineer, Hydraulics.

CITY OF NEWARK

Report
on

CORROSION OPTIMIZATION STUDY

Division of Water/Sewer Utility
1294 McBride Avenue
Little Falls, NJ 07424

June 1994

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1.0 INTRODUCTION

1.1 ABSTRACT

The Lead and Copper Regulation requires Corrosion Control Studies be performed by large Public Water Systems (PWS) who exceeded the lead or copper action levels (AL). The City of Newark's Water system exceeded the action level for lead during the initial two six-month monitoring periods.. The Corrosion Optimization Study Report the City of Newark was prepared after an extensive in-house study.

1.2 BACKGROUND

HISTORY

The City of Newark's water system is one of the largest and oldest systems in New Jersey State. Presently the System serves approximately 275,000 population in Newark and another 200,000 in various other municipalities. There are approximately 500 miles of water mains in the city's distribution system. Mains within the City are primarily made of cast iron and date back to the 1800's. Pipes recently installed have been made of ductile iron. There are approximately 50,000 water service connections and 40% of them have lead service lines. The water pressure in the general purpose supply system ranges from 40 to 110 psi. The City's water system is a complex network of reservoirs, water treatment plants, transmission lines and pumping stations. Although still predominantly a gravity fed system, the recent construction of new interconnections and pumping stations has provided the City with back up sources of supply from the Passaic Valley Water Commission, the City of Jersey City, the North Jersey District Water Supply Commission and the Elizabethtown Water Company.

The City of Newark has two main sources of water supply - the Pequannock System and Wanaque System (North Jersey District Water Supply Commission). The Pequannock Water System draws its water from the five storage reservoirs at the Pequannock watershed. The water system serves the South Ward, West Ward, part of the North Ward and Central Ward. It also serves the Township of Belleville and Bloomfield. Water in this system is treated in the new Pequannock Water Filtration Plant. The treatment consists of prechlorination, alum addition, high rate gulation, filtration and post chlorination. Typical raw water characteristics for the Pequannock system is given in Table 1. Water from the Pequannock Plant goes to an open balancing reservoir located at Cedar Grove. Water is sent through the Valley Road Rechlorination Plant where Sodium Hypochlorite is used as the disinfecting agent.

TABLE 1.1

Typical Raw Water Characteristics for Pequannock Water

CHARACTERISTICS	**RANGE**
Alkalinity (mg/l) as $CaCO_3$	22 - 35
pH	6.2 - 6.9
Turbidity (NTU)	1.0 - 2.5
Color (CU)	10 - 25
Hardness (mg/l) as $CaCO_3$	24 - 45
Iron (mg/l)	0.1 - 0.3
Sulfate (mg/l)	5 - 25
Silica (mg/l)	4.0
Manganese (mg/l)	0.01 - 0.06
Dissolved Inorganic Carbonates (DIC) mg/l as CaCO3	48-49
Chloride (mg/l)	6 - 32
Temperature °C	1 - 20

The City also serves water to the following Municipalities.

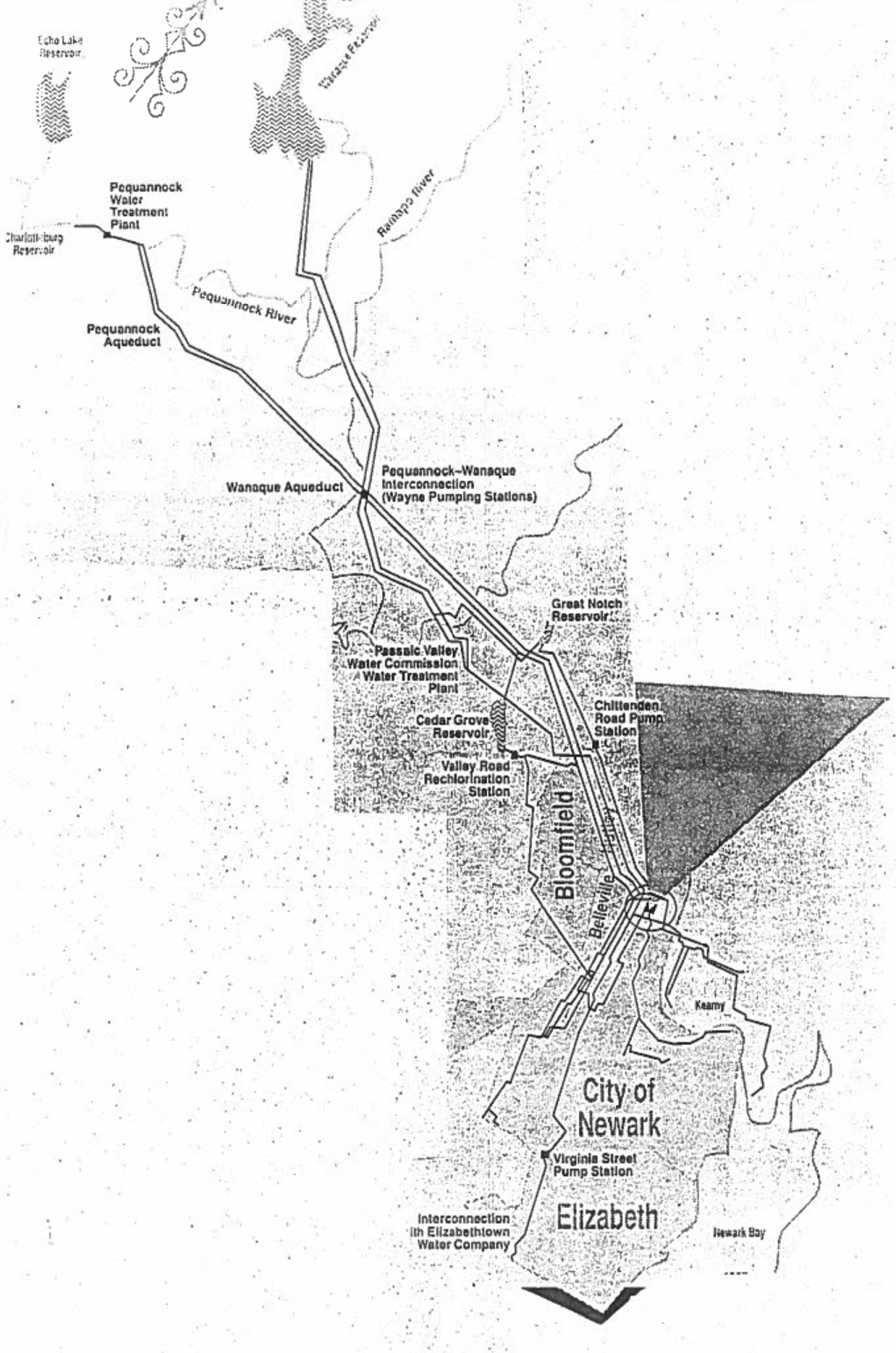
Table 1.2

System	Municipality	Average Daily Usage
Pequannock	Belleville	3.8 mgd*
Pequannock	Bloomfield	5.8 mgd*
Wanaque	City of Elizabeth	6.0 mgd*

*mgd- million gallons per day

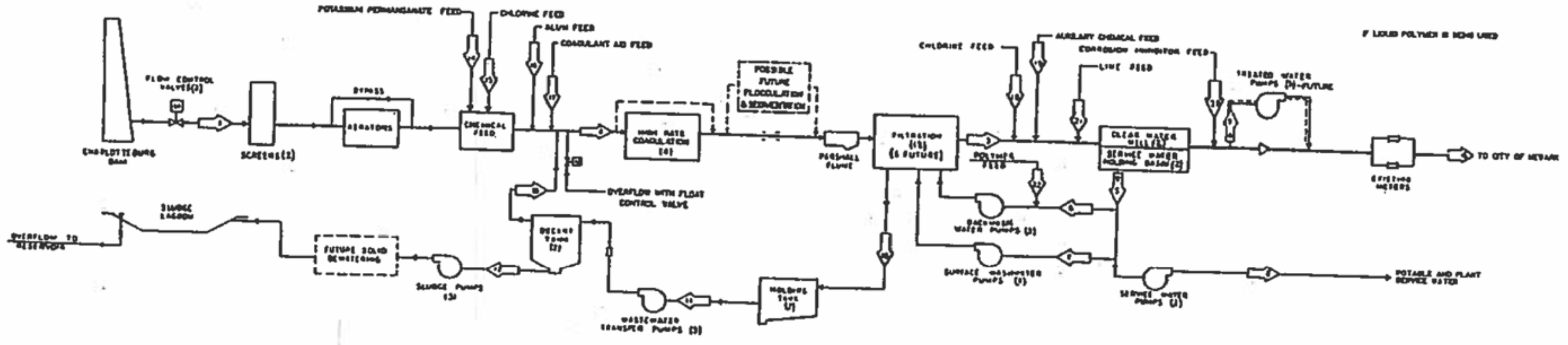
The second system, the Wanaque, serves Newark's East ward, part of the Central ward and part of the North Ward. It also serves the City of Elizabeth. The City of Newark owns a 40.5% share of water from the North Jersey District Water Supply Commission. Also the City is a participant in the Wanaque South Project and owns a 28.68% share. The primary transfer point from NJDWSC to Newark is at a regulator chamber located at the Belleville Reservoir site. The secondary transfer point is Newark's Wayne pumping station at which NJDWSC water is transferred to the Pequannock aqueducts. Raw water from the Wanaque Reservoir undergoes conventional surface water clarification/filtration at the NJDWSC's treatment plant. The water transferred at Wayne goes to the Cedar Grove open reservoir and get mixed with the Pequannock water.

Newark has an interconnection with NJDWSC at Wayne (Wayne Pump Station), with Passaic Valley Water Supply Commission and Jersey City at Chittenden Rd. Pumping Station, and with the Elizabethtown Water Company at Virginia St. pumping Station.


Echo Lake Reservoir
Wanaque Reservoir
Charlotteburg Reservoir
Pequannock Water Treatment Plant
Ramapo River
Pequannock River
Pequannock Aqueduct
Wanaque Aqueduct
Pequannock–Wanaque Interconnection (Wayne Pumping Stations)
Great Notch Reservoir
Passaic Valley Water Commission Water Treatment Plant
Chittenden Road Pump Station
Cedar Grove Reservoir
Valley Road Rechlorination Station
Bloomfield
Belleville
Kearny
City of Newark
Virginia Street Pump Station
Elizabeth
Interconnection ith Elizabethtown Water Company
Newark Bay

	MAIN SYSTEM (MGD)					PUMPING RATE (GPM)								CHEMICAL FEED RATE (GPM)								
FLOW THROUGH POINT Ⓧ	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
ULTIMATE PEAK FLOW:	137	146	140.5	136	8.5	30,000	1800	500	94,300	31,200	8100	600	8100	1257	10,000	488	303 20†	2485	18.8	30.1	360	133 13†
PRESENT PEAK FLOW:	80.3	88	84	80	4.5	30,000	1600	353	0	31,700	8100	400	8100	873.5	6945	130.5	210 15.3†	1705	13.0	20.5	303	133 13†
PRESENT AVERAGE FLOW:	53.5	50	53.3	37	2.8	30,030	4800	170	0	24,840	4050	200	4850	333	2406	68.4	61.5 26†	521	0.3	2.9	154.5	106 10.6†

† LIQUID POLYMER IS BEING USED



PROCESS SCHEMATIC

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HAZEN and SAWYER - CLINTON BOGERT ASSOCIATES
A JOINT VENTURE

CITY OF NEWARK

PEQUANNOCK WATER TREATMENT PLANT

OPERATION AND MAINTENANCE MANUAL

Sources of Lead

As is typical of most water treatment plants, the treated water leaving Newark's Pequannock Treatment Plant or NJDWSC's Wanaque treatment plant contains insignificant amounts of lead. During the initial and final monitoring periods at the point of entry, lead (Pb/Cu-POE) was below the method detection levels. Hence the source of lead in drinking water is from the lead service lines, lead solder and brass fixtures at the customer's end. Each of these sources respond differently to corrosion inhibitors.

The Initial Monitoring Program

Newark completed the two required six month initial monitoring programs in 1992-93 for lead and copper. Initial monitoring activities included a material survey of the distribution system, preparation of a sampling plan, sampling and testing and reporting the results to the State. The sampling was carried out at the City's high risk sites. Water quality parameters were also measured at different locations of the distribution system. The City exceeded the action level for lead during both sampling periods.

Lead corrosion control study
Initial and Final Monitoring Results
Lead Concentration Vs. Sample Number

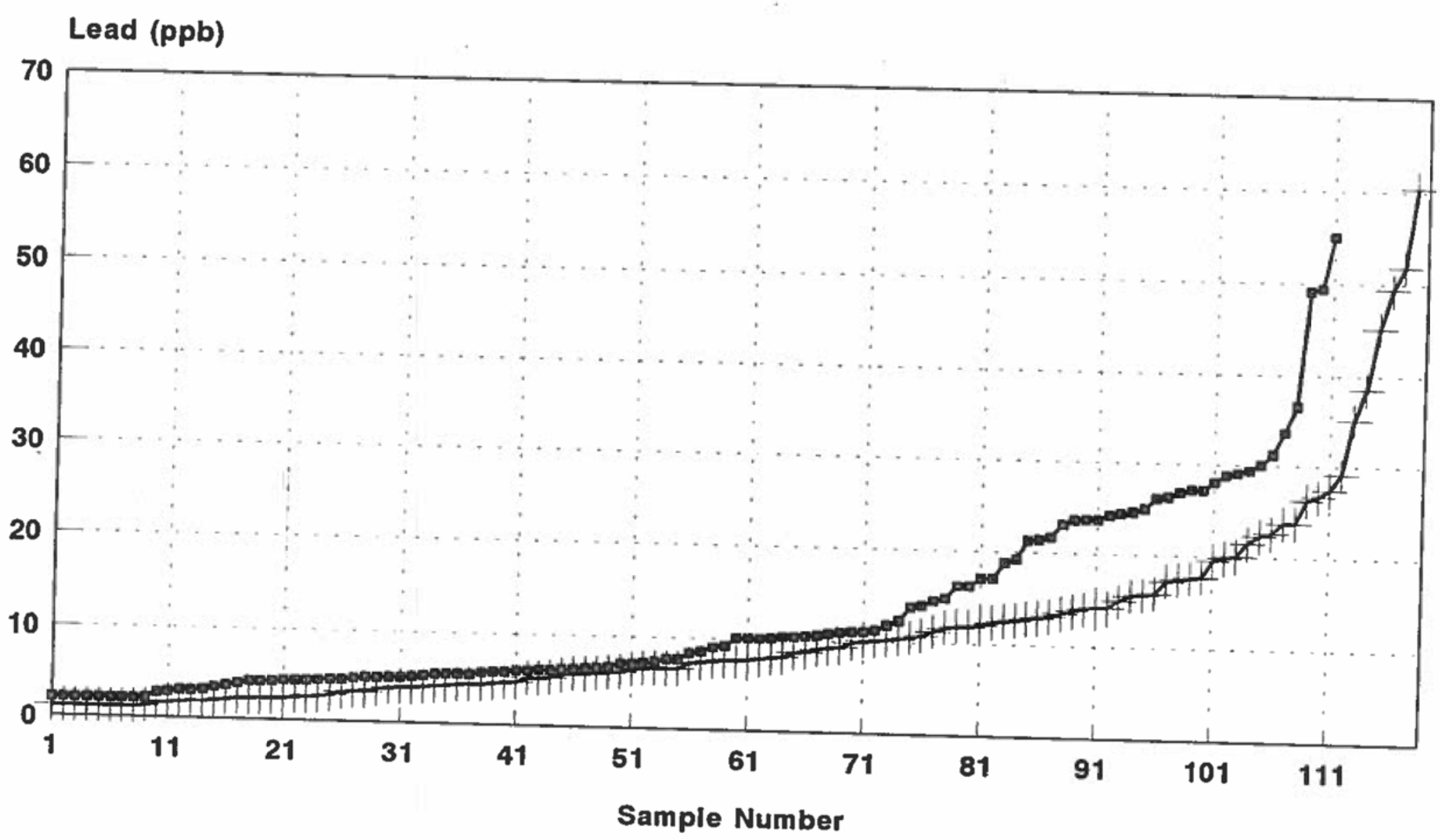


Figure 1.2

Lead corrosion control study
Initial and Final Monitoring Results
Copper Concentration Vs. sample Number

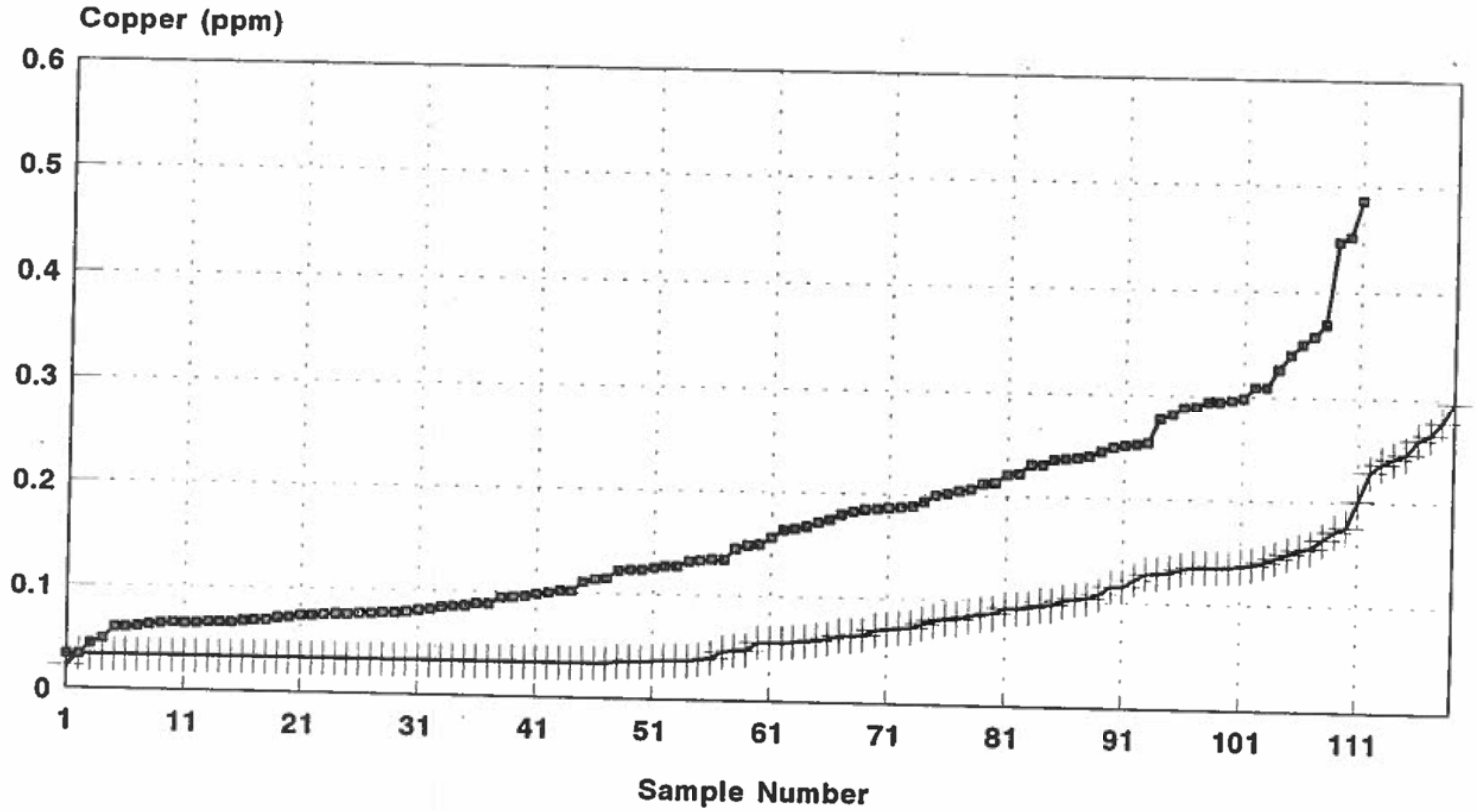


Figure 1.3

Copper Concentration Vs. Sample Number
Copper action level 1.3 mg/l

The results for copper analysis for both first round and second round sampling were well below the EPA action level. However, a higher concentration of copper was produced from first flush than water main samples, indicating considerable copper corrosion in the home plumbing.

Immediately after the initial monitoring sampling, the pH was raised to around 8.5 to study the effect of pH on the lead/copper leaching. As can be seen from the table below, pH did not make a significant change in the corrosion rate.

Table 1.3

Item	*Ist Monitoring*	*2nd Monitoring*
Lead (ppb)	27.1	22.6
Copper (ppm)	0.294	0.156

1.3 Preliminary Screening

Principle of Corrosion

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

1. Uniform Corrosion,
2. Concentration Cell Corrosion
3. Galvanic Corrosion.

Corrosion of drinking water distribution systems can result from any of the above mechanisms or combinations. Alterations of water quality characteristics by treatment can extensively reduce some corrosion activity. Corrosion control principally is intended to inhibit dissolution. The objective is to alter the water quality such that the chemical reactions between water supply and the pipe materials favor the formation of a protective layer on the interior of the pipe walls. Coincidental reduction of other corrosion activity may be accomplished when dissolution of lead and copper are minimized. Abrasion of piping materials is typically accelerated when corrosion by products, such as tubercles, are present in the distribution system.

The three treatment approach which generally exists for control of lead corrosion are:

1. Carbonate Passivation.

This refers to the modification of pH and alkalinity to induce the formation of a less soluble compound on the targeted pipe materials.

2. Carbonate Precipitation.

This refers to the adjustment of pH, alkalinity and calcium to affect the calcium carbonate system equilibrium such that a tendency for calcium carbonate precipitation results.

3. Corrosion Inhibitors.

This refers to application of special chemicals characterized by their ability to form metal complexes and thereby reduce corrosion. This method employs passivation of the metal surface as the means of corrosion control. The generally available corrosion inhibitors are ortho-Polyphosphates and silicates.

Carbonate Passivation & Carbonate Precipitation.

Newark's Pequannock system was actively experimented with using Carbonate Passivation and to some degree Carbonate Precipitation after the initial lead monitoring period during 1992-1993 when the system pH was maintained in the range of 8.5 - 8.8. However, 1993 final monitoring results for lead indicated that the strategy is not sufficiently effective. The pipe loop study also showed that pH control could reduce the corrosion rate by 10%, but this was not sufficient to meet the action level. Furthermore, carbonate passivation at higher pH is unlikely to provide significant improvement and could result in reduced disinfection, higher disinfection by-products formation and more customer complaints.

Corrosion Inhibitors

Two predominant forms of corrosion inhibitors are available for potable water treatment. These are phosphate and silicate based compounds. Somewhat different chemical mechanisms of corrosion control and water quality criteria are associated with the effective use of phosphate and silicate based inhibitors. However, both utilize passivation as the method of providing corrosion protection. A number of corrosion inhibitators are commercially available on the market. As a direct additive to the drinking water supply, phosphates and silicates are subject to ANSI/NSF standards.

Phosphate Inhibitors

Lead forms an orthophosphate solid of low solubility under typical drinking water conditions, which serves as the basis of corrosion control. Copper solubility is not affected by the addition of phosphates. The pH range across which the orthophosphate appears to be most effective is 7.4 to 7.8. At pH values much above 7.8 metal phosphates precipitate causing scale formation and hydraulic capacity loss. Low hardness water is well suited for the use of orthophosphate inhibitors.

The critical parameters in using orthophosphate in corrosion control treatment are a] maintaining a stable pH in the inhibitor's effective range throughout the distribution system and b] determining the inhibitors composition best suited for the specific water quality objectives and conditions and also c] applying the appropriate dosage to accommodate background orthophosphate demand as well as the corrosion control protection required. Phosphate based inhibitors are acidic in nature and the pH effect of their addition to the finished water must be considered in determining the suitability of their application.

As mentioned earlier phosphates are effective only over a constrained pH range. Maintaining that range throughout the distribution system is an important component of implementing a successful corrosion control program. Systems with poorly buffered water have to install treatment to stabilize pH in addition to installing a corrosion inhibitor system for reducing the lead leaching rate.

Phosphate inhibitors are available in a variety of compositions, including sodium orthophosphate, zinc orthophosphate, polyphosphates and poly-ortho blended phosphates. Each of these compounds has different formulations as to effective phosphate present. Polyphosphate revert (hydrolyze) back to orthophosphate with time resulting in an increase in orthophosphate ion. This reversion is dependent on the pH and available metal ions. Polyphosphates sometimes increase corrosivity of water and the EPA suggests that polyphosphates should be used with caution because "their effects may be viewed in the extreme sense as an uncontrolled toxicological experiment on the general population". Polyphosphates are not recommended for corrosion control purposes in general, although, their application may be beneficial for other water quality concerns. The principal use is to sequester dissolved cationic constituents and reduce their ability to precipitate either in the distribution system or in the water treatment plant. Ortho-Poly phosphate blends offers some of the benefits of both.

Silicate Inhibitor

The corrosion inhibition by silicates is not yet well understood. It is known that soluble silicates are effective, environmentally safe chemicals which have been used to protect metals from corrosive effects of water. They are classified as corrosion inhibitors because they can deposit protective films onto various metal surfaces and can isolate the metal from further corrosion attack. They do not contribute zinc or phosphorus to the treated water. The most common form of silicate in the water treatment is 3.22 weight ratio sodium silicates. The method of controlling corrosion attributed to silicates appears to be a combination of adsorption and formation of less soluble metal-silicates compounds. They are considered as anodic inhibitors, combining with the free metal released at anode site of corrosion activity and forming an insoluble metal silicate compound. This material crystallizes to form a protective barrier on the face of pipe walls.

Similar to the use of orthophosphate inhibitors, silicates also combine with other constituents in the delivered water besides the material targeted for protection. Therefore sufficient dosage has be applied to compensate for the consumption of silicate by other metals or cations.

1.4 Constraints

Water quality constraints

The implementation of corrosion control can affect other water quality goals. The Lead and Copper Rule requires the Newark consider water quality constraints in assessing alternative corrosion control treatment, specifically, how an alternative treatment may adversely affect the other water quality goals. EPA recommends that all water quality constraints affecting Newark's system be identified and considered in the selection of treatment.

The impact of alternative corrosion control treatment on regulatory compliance with existing and probable future federal and State drinking water requirements is complex. Water quality constraints associated with the following key regulatory actions were considered during the screening of corrosion control alternatives.

[a] *Surface Water Treatment Rule (SWTR)*

> Under this rule it is required that primary disinfection performance criteria be met. These criteria are pH dependent. Other conditions remaining the same, lesser inactivation of microbiological contaminants and improved corrosion control is achieved at higher pH.

[b] *Total coliform rule (TCR)*

> This rule requires the wholesale purchasers to meet minimum occurrence standards for the occurrence of total and fecal coliforms in distribution system samples. Increasing the pH decreases the disinfection efficiency of the secondary chlorine residual, which may, in turn increase microbiological growth. The addition of phosphate based inhibitors increase the phosphorous content of a system . Phosphorus is an essential nutrient for microorganisms.

[c] *Disinfectant and Disinfectant By-Products Rule (D-DBP)*

Disinfectant by-products are regulated under this rule. Adjusting pH upward will affect the formation of certain DBP's, most notably trihalomethanes and haloacetic acids. These contaminants exhibit negative response to pH adjustment.

[d] *Enhanced Surface water treatment rule*

This rule is expected to impose greater disinfection requirements for systems with poorer source water.

Other constraints

[a] *Excess algal growth in open reservoir*

Phosphates are an important nutrient for algae. The introduction of phosphates into open an reservoir might result in a rapid growth of algae in the reservoir. Hence the centralized use of a corrosion inhibitor is restricted to a non phosphate based chemical.

[b] *Sodium*

Sodium is a major constituent in drinking water. The current MCL for sodium in drinking water is 50 ppm. Sodium is associated with high blood pressure and heart disease. USEPA has suggested a guidance level of 20 mg/l in drinking water for the protection of at-risk population, the population comprised of people predisposed to hypertension.

Newark's system has approximately 10 ppm of sodium. At a typical dosage of Sodium Silicate, the amount of additional sodium is less than 3 ppm. Hence, Newark is not affected by the constraint relating to sodium.

[c] *Other*

As mentioned earlier, Newark has an open reservoir which stores treated water.

The reservoir is located in Cedar Grove, halfway between the distribution system and the treatment plant. The average detention time in this reservoir is 12 days. Hence, the centralized application of a phosphate is out of the question as it will cause major algae problems in the open reservoir. Another alternative application point is after the Cedar Grove reservoir. But Newark has interconnections with other municipalities before the reservoir and supplies water to those municipalities on a seasonal basis. The City might have an onerous condition imposed on itself if it was required to build a number of satellite inhibitor feeding stations to provide the required corrosion control for the Municipalities.

Consumer complaints regarding red water, dirty water, color and sediment may result from the action of inhibitor on existing corrosion by-products within the distribution system. The City's past experience with a phosphate-based inhibitor substantiate this fact. The City used a polyphosphate as a corrosion inhibitor in the mid 1980's for about 2 years. The inhibitor applied at the treatment plant reverted to up to fifty percent orthophosphate and was detected upon entry into the open reservoir . The City was forced to stop the application after two years because of numerous dirty water complaints from the customers and a severe algae problem in the open reservoir.

Use of zinc-based phosphates may cause problems to the POTWs having zinc or phosphate limits in their NJPDES permit, especially the Passaic Valley Sewerage Commission.

The application of phosphate-based inhibitors to a system with existing corrosion byproducts can result in depletion of disinfectant residuals within the distribution system. Also under certain conditions phosphate-based inhibitors may stimulate the bio-film in the system. If corrosion by-products are released after the use of inhibitors, coliforms may be detected more frequently and confluent growth is more likely.

2.0 BENCH SCALE TESTING

2.0 BENCH SCALE TESTING

From the results of the initial monitoring, it was determined that the practice of only adjusting the pH is insufficient to maintain lead concentrations below the first flush action level of 15 ppb in 90% or more of the samples. Therefore, a second phase of testing was undertaken to determine if alternative corrosion control treatment would be more effective in reducing lead concentrations. The specific objective of bench scale testing was to evaluate a wide range of feasible options (specifically required by the Lead/Copper Rule) and to identify the two or three best options for longer duration pilot testing.

2.1 Approach

Several approaches were considered for short term bench scale testing. A two cell corrosion test device was used . Raw water was fed into the first cell. Cleaned pre weighed metal coupons of mild steel were suspended in both cells so that contact with water would be maintained. All of the metal coupons were of identical size and shape. A corrosion inhibitor was applied to the water before it reached the second cell. The following is a list of inhibitors used in the testing.

1. Lime
2. Orthophosphate
3. Ortho-Poly Blended Phosphate
4. Silicate

In accordance with the manufacturer's recommendation a higher than normal dosage of orthophosphate, blended phosphates and silicate was used in the initial passivation period. A silicate dosage of 20 mg/l was used for the initial one month passivation period and an orthophosphate dosage of 1 mg/l was used for the first two weeks of passivation. After the passivation a lower dosage of 9 mg/l of silica was used. In the pH inhibitor cell a pH of about 8.5 to 9.0 was maintained. The performance of the corrosion inhibitors is based on a function of weight loss by the metal coupons under test conditions lasting one month.

2.2 Results

The results of the bench-scale testing were variable and did not clearly show one of the inhibitors to be more effective than the other in reducing corrosion.. Early results probably varied because the new metal coupons were corroding rapidly during the initial passivation period. In addition certain inhibitors were reacting with preformed corrosion products, which were still incompletely formed on the coupon surfaces during the initial passivation period. During the final weeks of testing all inhibitors started showing consistent results. All reduced corrosion to a degree . The least effective one was pH adjustment, which showed approximately a 15% reduction of lead leaching.

The following table shows the results of the bench scale testing.

Table 2.1

Inhibitor	Percentage Reduction	Remarks
pH Adjustment	15%	Insufficient inhibition to achieve desired lead reduction
Orthophosphate	50%	Showed lead reduction Cannot be used before the open reservoir/requires satellite feeding stations
Blended Phosphate	40%	Showed lead reduction Cannot be used before the open reservoir/requires satellite feeding stations
Silicate	45%	Showed lead reduction Can be used in the treatment plant

From the results of the bench scale testing the following alternatives were eliminated from further desk top evaluation.

1. pH-Alkalinity Adjustment.
2. Calcium Adjustment
3. Corrosion Inhibitors:
    a] Zinc Orthophosphate.
    b] Poly Phosphate.

The following alternative were further evaluated in the Desk Top or Pilot Testing:

1. Non Zinc Orthophosphate.
2. Ortho-Poly Blended Phosphate
3. Silicate.

3.0 PILOT TESTING

3.0 PILOT TESTING

The purpose of Corrosion control testing is to demonstrate the relative performance of alternative treatment approaches and identify the optimal treatment. In order to determine the relative performance of the alternative treatment approaches, a control condition must be clearly defined through out the testing period.

3.1 Flow-Through Testing Protocol

The use of a flow through testing method to evaluate the corrosion control performance is preferred since it more accurately simulates the house plumbing condition, which is the major source of lead in the City's case. Flow through testing refers to continuous or cycled flowing conditions through a testing apparatus. The solution is not recirculated. Typically, flow through testing is used to describe pipe rig operations where pipe loops and coupons are attached to a central manifold which distributes the test water to one or more corrosion testing units.

3.2 Selection of Chemquip's CHEMCORR-LP Pipe Loop.

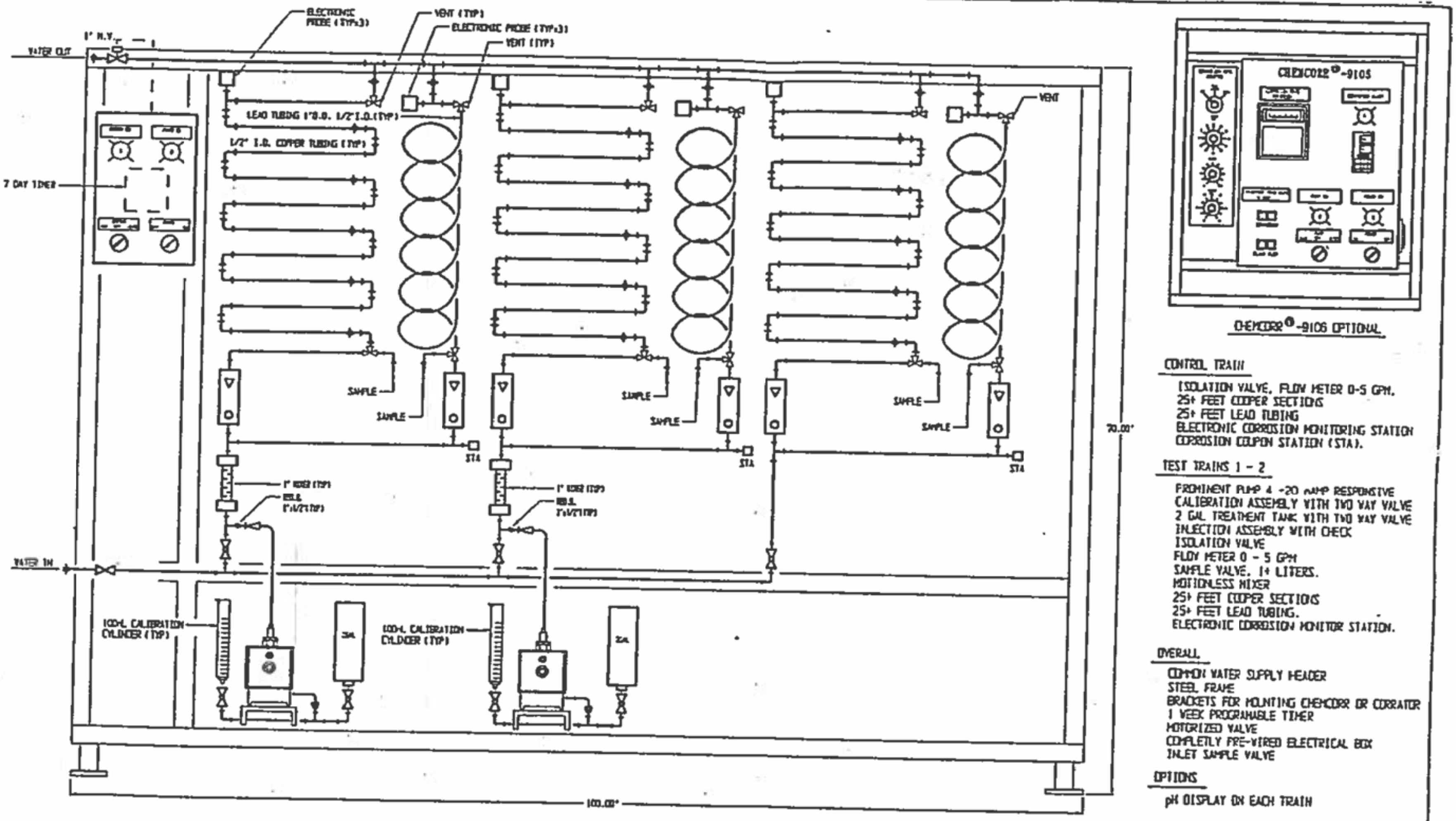
The City decided to use the Chemquip Corporation's CHEMCORR-LP Pipe Loop for the demonstration Testing after a study of available systems on the market. This is a pipe loop apparatus manufactured in accordance with AWWARF recommendations. It has 1/2" lead and copper loops and can study three corrosion conditions simultaneously. Finished water is directed to all the three trains. It simulates an eight hour dead leg condition using a timer, a motorized valve and a shut down device. This sample is a simulation of the first flush condition in homes. Flow is monitored and controlled through flow meters. Chemical treatment is monitored from treatment reservoirs and validated by 1000 ml calibration cylinders. Motionless mixers in the test trains insure complete mixing of the treatment chemicals when the water is flowing. A series of 25' of lead and copper lines in each train are available to detect changes in the corrosivity conditions over a period of time. The 25' allows exactly 1 liter of sample to be collected for each dead leg and sample is taken from each dead leg by means of a sample port and relief valve. A station is available on each train to provide electronic corrosion monitoring and readings are taken using corrosion rate probes.

Measurement of the corrosion rate is based upon the principle of corrosion. Corrosion is an electrochemical process whereby electrons flow from the anode to cathode in a conductive solution (water). As part of this electron migration, metal ions are liberated from anode to the conducting medium, water, and are transported to the cathode as the oxide form. Examples of this phenomena are lead oxide and ferric and ferrous oxides of iron, otherwise known as rust.

In this apparatus there are three principal ways of measuring the phenomena of corrosion. The first is by means of the metal ion in the solution. The second uses some pre-weighed coupons exposed for a fixed period of time, such as 30 days, and measures the weight loss over that time. The third type is the electronic corrosion rate. This uses the linear polarization technique and gives a read out in mils per year.

The same water is fed through all the three pipe loops. One loop of the three is kept as the control loop. CHEMCORR-LP can sense minute changes of water quality and can generate a response. It feeds the exact amount of inhibitor each time. The seasonal changes in the corrosion rate can be tracked accurately with this device.

During the testing finished water was sent through the pipe loop. Two of the pipe trains (each train contain one lead loop and a copper loop with lead solder) were used for corrosion control testing, where the third received no treatment and was used as a control loop. The corrosion control treatment schemes used by the two pipe train



CHEMCORR®-9106 OPTIONAL

CONTROL TRAIN

ISOLATION VALVE, FLOW METER 0-5 GPM.
25+ FEET COPPER SECTIONS
25+ FEET LEAD TUBING
ELECTRONIC CORROSION MONITORING STATION
CORROSION COUPON STATION (STA).

TEST TRAINS 1 - 2

PROMINENT PUMP 4 -20 mAMP RESPONSIVE
CALIBRATION ASSEMBLY WITH TWO WAY VALVE
2 GAL TREATMENT TANK WITH TWO WAY VALVE
INJECTION ASSEMBLY WITH CHECK
ISOLATION VALVE
FLOW METER 0 - 5 GPM
SAMPLE VALVE, 1+ LITERS.
MOTIONLESS MIXER
25+ FEET COPPER SECTIONS
25+ FEET LEAD TUBING.
ELECTRONIC CORROSION MONITOR STATION.

OVERALL

COMMON WATER SUPPLY HEADER
STEEL FRAME
BRACKETS FOR MOUNTING CHEMCORR OR CORRATOR
1 WEEK PROGRAMABLE TIMER
MOTORIZED VALVE
COMPLETLY PRE-WIRED ELECTRICAL BOX
INLET SAMPLE VALVE

OPTIONS

pH DISPLAY ON EACH TRAIN

NOTE:

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sets were determined through the bench scale testing and included three corrosion inhibitors, orthophosphate, blended phosphate and silicates. One liter samples were taken each week from each three trains (six loops) to measure the changes in metal concentration, orthophosphate, total phosphate, silicate, pH, alkalinity and hardness and several other parameters.

3.3 Treatment Schemes

Initially the pipe loop ran without any addition of corrosion inhibitors for approximately six weeks to generate corrosion in the newly installed pipes in the loop and to flush out any material debris attached to the interior of the pipe material. During this period samples were collected on a regular basis and the water quality was monitored. By the end of sixth week all the pipe loops attained a steady state condition (Stabilization) and results started showing similar qualities. The flow rate in each pipe was maintained at one gallon per minute (1 gpm) to simulate a flow in a typical household service line. Water samples were collected once a week in the morning after the water had been standing in the pipe for 8 hours and before the flow was resumed. This sample represented the first flush concentration expected from household service. The first flush samples were analyzed for temperature, pH, alkalinity, calcium hardness, lead, copper, orthophosphate, total phosphate and silicate.

3.4 Data Handling And Analysis

The USEPA guidance manual provides very little direction on techniques to use for evaluation of data from corrosion studies. Extensive laboratory studies and EPA experience indicate that most traditional techniques such as computation of averages and t-test for comparison of means are largely inadequate because of the highly variable and usually non-normal data. Changes in metal leaching and film formation caused complexity because metal dissolution is often non-linear with respect to time. Furthermore, metal levels in water to which consumers are exposed have not been shown to correlate well with surrogate measurements such as corrosion rates.

When comparing the difference in corrosion treatment using corrosion studies, metal concentration in the water are the parameters of concern. Under the Lead and

Copper rule, the treatment that minimizes corrosion is considered optimum. Therefore if the lead concentration in the water is the parameter being used as the most important factor to measure corrosion effectiveness, the treatment that gives the lowest lead levels in the water is considered the optimum one. To compare lead levels in the water between two treatments, assuming Wilcoxon Rank Test would be applied. And if the populations are independent the Wilcoxon Signed Rank Test would be applied. The Wilcoxin Signed Test is analogous to pairing the data between control and treatment.

Pipe loops constructed for corrosion studies of lead and copper leaching containing new materials will exhibit a decreasing trend in lead and or copper levels over time as materials age. These materials stabilize after a certain period of time if the incoming water quality is relatively consistent. This stabilization may indicate that the pipe material has reached equilibrium with respect to corrosion or a state where film formation or transition becomes very slow. It may respond similarly to the plumbing material in the system. While it may be of interest to evaluate the entire set of data generated from the study, it is more appropriate to use only those data which have reached stabilization while determining the impact of various treatments on lead levels. Stabilization can be determined by visual examination of the data or by calculating an estimated trend for the data.

When reviewing the distribution of the data generated from a corrosion study, the tendency of a researcher is to discard several of the very high levels as outlier, or values which are abnormalous. By discarding these values, the mean level of the data will be lowered and there will be less variation in the data. Discarding high levels may seem particularly attractive when comparing the differences in lead levels measured from a control pipe rack and treated pipe racks.

It is important to note, however, that lead levels at the tap also exhibit high lead levels occasionally. The occurrence of unusually high lead levels is the evidence of complex chemical and physical factors which impact upon the amount of lead which may leach into the water.

So in summary, the following procedures were followed in data handling for the City's corrosion optimization study. The data was checked to determine whether it followed the normal distribution using graphical techniques and numerical techniques. Then it was determined whether the data represented a stable population or whether there were still trends to chemistry evolution of the system. Appropriate comparison statistics at selected decision levels were made to the stabilized system. For normally distributed data, non parametric statistical procedures are used and for non normally distributed data Wilcoxin Signed Rank test was used.

3.5 Quality Assurance and Quality Control Program

Proper quality assurance and quality control procedures were followed during the testing program. Standing samples were taken every week and daily monitoring of water quality parameters was conducted for water supplied to the pipe rig.

Split samples were collected for metal analysis. Sample blanks and spikes were prepared by someone other than the chemist who was doing the analysis. All instruments were properly calibrated before the beginning of each metal testing period. Chemical feed rates were checked periodically to verify the feed rates. All sample handling procedures were followed for those required in the rule for metals and water quality parameters. The results were verified by comparing the results with that of an outside lab on a monthly basis.

3.6 Criteria for selecting optimum treatment

The following criteria were considered in its order of priority for selecting the optimum treatment.

1. *Performance:* Prime importance was given to the performance of the alternative treatment evaluated by the demonstration testing.

2. *Feasibility* of implementing the alternative corrosion control treatment.

3. Reliability features of the alternative treatment approaches based on treated water quality and full scale operational characteristics.

4. *Costs* associated with installation and operation, where alternative treatment have comparable performance.

3.7 Stabilization period
With no treatment

The same quality water was run through all the loops to achieve an equilibrium condition. After 4 weeks the loops started showing similar lead and other water quality characteristics.

The following table represents the initial and final results during that period.

Table 3.1

Loop I Results : Copper pipe with lead solder

No treatment : Initial Stabilization Period

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*	*Alkalinity ppm of CaCO3*	*pH*	*Hardness*
1	22	0.35	None	17.0	7.1	23.4
2	50.3	0.34	None	17.9	7.2	21.9
3	47.8	0.25	None	17.0	7.3	24.0
4	42.9	0.35	None	19.8	7.5	26.0
5	48.1	0.30	None	19.2	7.3	23.2
6	47.8	0.31	None	19.2	7.3	23.0

Table 3.2

Loop II Results : Lead Pipe

No treatment : Initial Stabilization Period

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*	*Alkalinity ppm of CaCO3*	*pH*	*Hardness*
1	490.0		None	17.0	7.1	23.4
2	378.0		None	17.9	7.2	21.9
3	420.0		None	17.0	7.3	24.0
4	373.0		None	19.8	7.5	26.0
5	437.0		None	19.2	7.3	23.2
6	437.0		None	19.2	7.3	23.2

Table 3.3

Loop III Results : Copper pipe with lead solder

No treatment : Initial Stabilization Period

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*	*Alkalinity ppm of CaCO3*	*pH*	*Hardness*
1	167.0	0.835	None	17.8	7.0	23.4
2	60.2	0.26	None	16.8	7.2	23.5
3	38.8	0.30	None	17.8	7.2	25.0
4	37.36	0.24	None	18.7	7.5	26.0
5	48.29	0.30	None	19.2	7.3	23.2
6	47.9	0.31	None	19.2	7.3	23.0

Table 3.4

Loop IV Results : Lead pipe

No treatment : Initial Stabilization Period

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*	*Alkalinity ppm of CaCO3*	*pH*	*Hardness*
1	422.0		None	17.0	7.1	23.4
2	-		None	17.9	7.2	21.9
3	350.2		None	17.0	7.3	24.0
4	374.2		None	19.8	7.5	26.0
5	430.0		None	19.2	7.3	23.2
6	428.5		None	19.2	7.3	23.0

Table 3.5

Loop V Results: Copper pipe with lead solder

No treatment : Initial Stabilization Period

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*	*Alkalinity ppm of CaCO3*	*pH*	*Hardness*
1	30.2	0.262	None	17.0	7.1	23.4
2	81.1	0.257	None	17.9	7.2	21.9
3	19.0	0.276	None	17.0	7.3	24.0
4	49.0	0.314	None	19.8	7.5	26.0
5	44.8	0.310	None	19.2	7.3	23.2
6	47.5	0.310	None	19.2	7.3	23.0

Table 3.6

Loop VI Results : Lead Pipe

No treatment : Initial Stabilization Period

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*	*Alkalinity ppm of CaCO3*	*pH*	*Hardness*
1	532.0		None	17.0	7.1	23.4
2	-		None	17.9	7.2	21.9
3	373.3		None	17.0	7.3	24.0
4	354.0		None	19.8	7.5	26.0
5	425.1		None	19.2	7.3	23.2
6	430.2		None	19.2	7.3	23.0

Lead corrosion control study

Initial Stabilization period-With no treatment

Lead results from lead pipe loops(II, IV & VI)

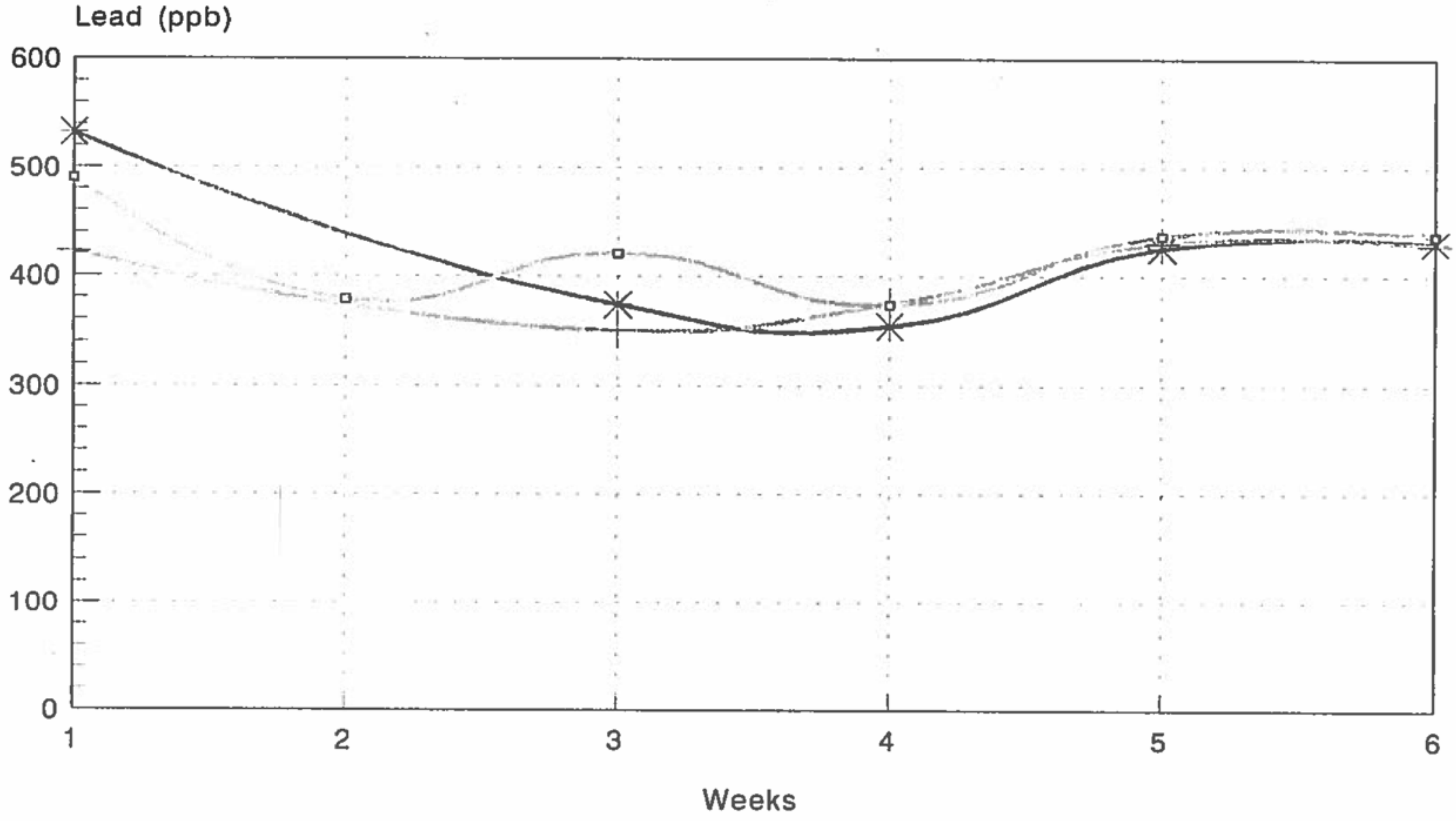


Figure 3.1

Corrosion control study
Initial Stabilization period-With no treatment
Lead results from Copper pipes with lead solder joints

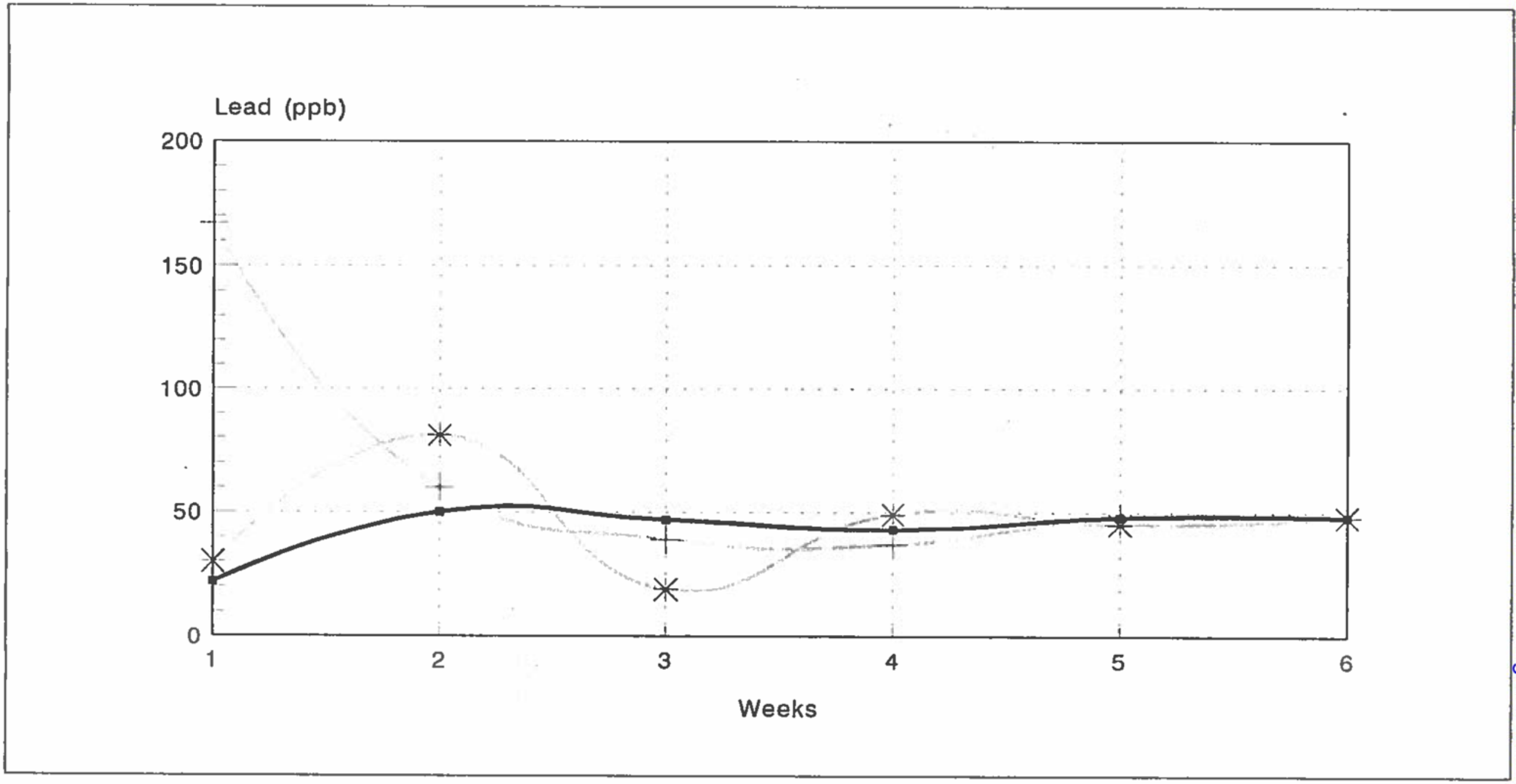


Figure 3.2

Copper with lead solder pipe loops-Lead Results

Lead corrosion control study
Initial Stabilization period-With no treatment
Copper results from Copper pipes with lead solder joints

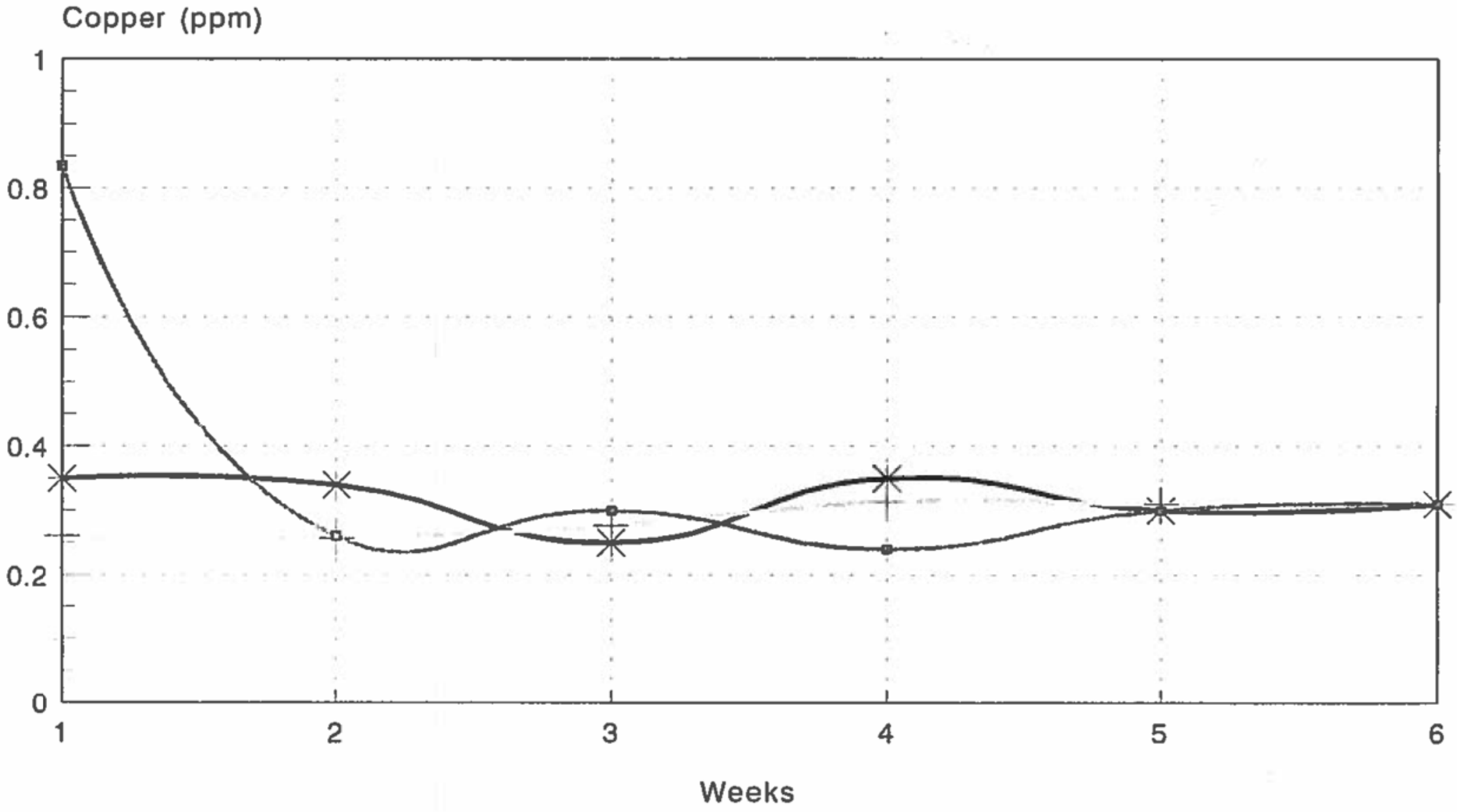
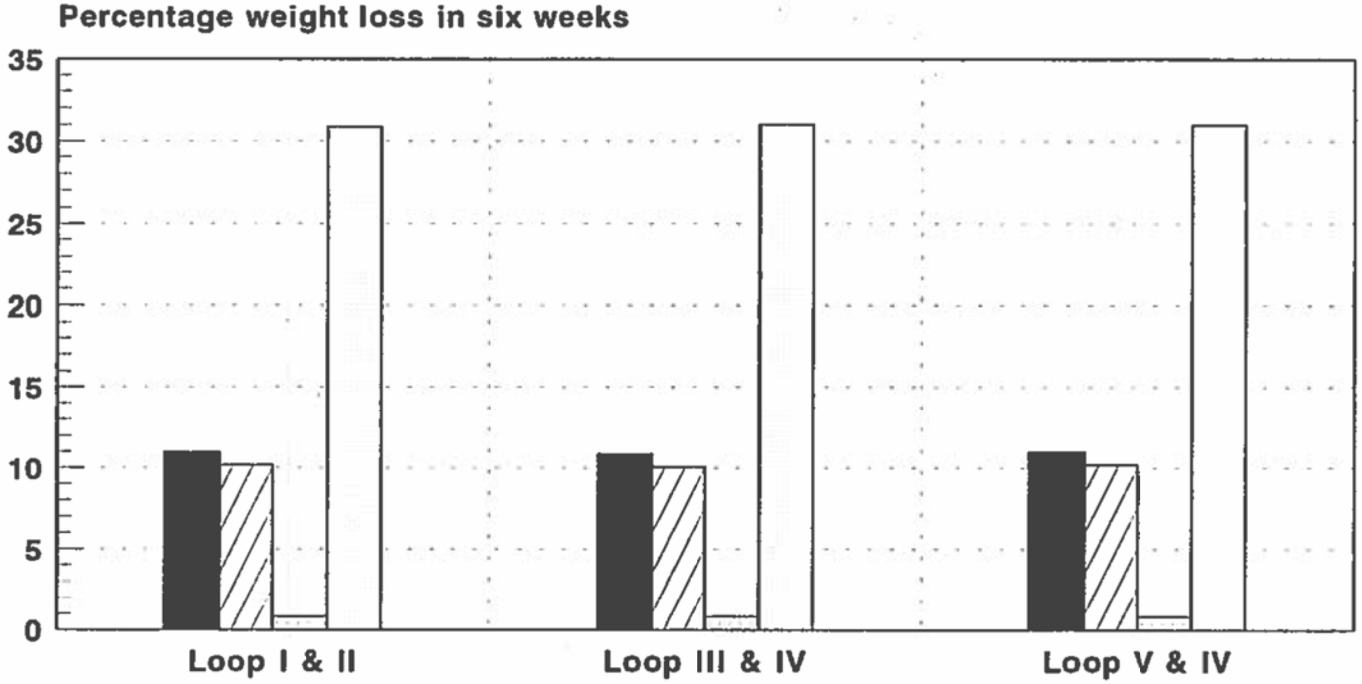


Figure 3.3

Copper with lead solder pipe loops-Copper Results

Lead corrosion control study
Pipe insert (coupons) Results
Comparison of coupon weight loss & Corrosion rate



	Loop I & II	Loop III & IV	Loop V & IV
Weight Loss(gms)	0.813	0.817	0.816
Corrosion rate	30.86	31.01	30.975

Figure 3.4

Initial Stabilization Period (with no treatment)

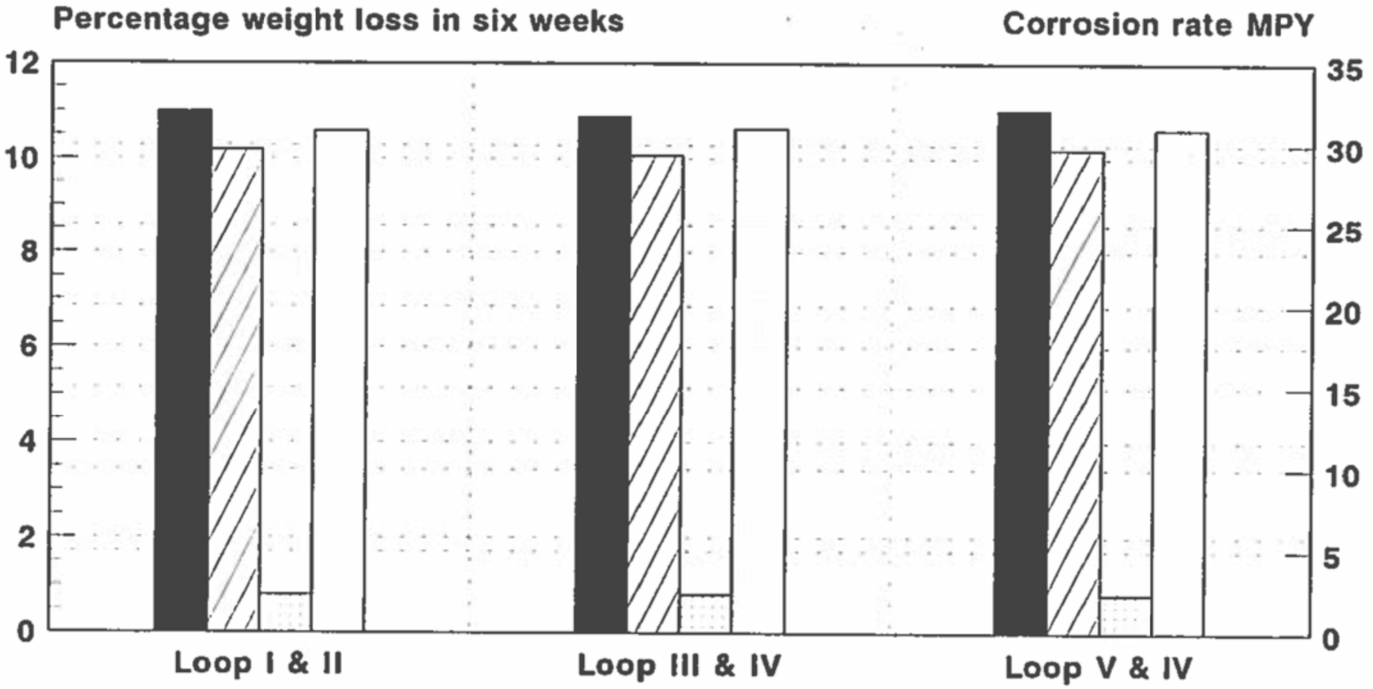
Table 3.7

Initial Pipe insert results (mild steel coupons)

No treatment : Initial stabilization Period (6 weeks)

Train	*Initial Weight (grams)*	*Final Weight (grams)*	*Percentage of Weight loss (%)*
Train 1	10.993	10.180	7.4%
Train 2	10.885	10.068	7.5%
Train 3	11.015	10.199	7.4%

Lead corrosion control study
Pipe insert (coupons) Results
Comparison of coupon weight loss & Corrosion rate



	Loop I & II	Loop III & IV	Loop V & IV
Weight Loss(gms)	0.813	0.817	0.816
Corrosion rate	30.86	31.01	30.975

Figure 3.4

■ Initial Wt.(gms) ▨ Final Wt.(gms) ░ Weight Loss(gms) □ Corrosion rate

Initial Stabilization Period (with no treatment)

City of Newark

3.8 Initial period with treatment

Orthophosphate was added as the inhibitor in the first loop for three months, silicate was added in the second train and the third train was kept as the control.

Following table is the summary of results from the first three months with treatment

Table 3.8
Loop I: Copper Pipe Loop with Lead Solder

Orthophosphate is added in this loop

Week	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*
7	137.0	0.009	1
8	31.3	0.190	1
9	13.64	0.078	1
10	36.7	0.264	1
11	75.0	0.227	1
12	32.0	0.0913	1
13	15.14	0.045	1
14	11.2	0.039	1
15	12.31	0.03	1
16	7.6	0.03	1
17	5.2	0.019	1
18	5.32	0.021	1
19	6.84	0.018	1
20	16.56	0.01	1

Week	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*
21	13.27	0.01	1
22	12.15	-	1
23	10.0	0.106	1
24	7.5	0.062	1
25	28.4	0.084	1
26		24.9	None
Stopped orthophosphate treatment on 26th week			

The following figure gives the graphical representation of the lead and copper concentration during that testing period of time.

Lead Corrosion control study
Loop I: Copper pipe with lead solder joints
With orthophosphate treatment

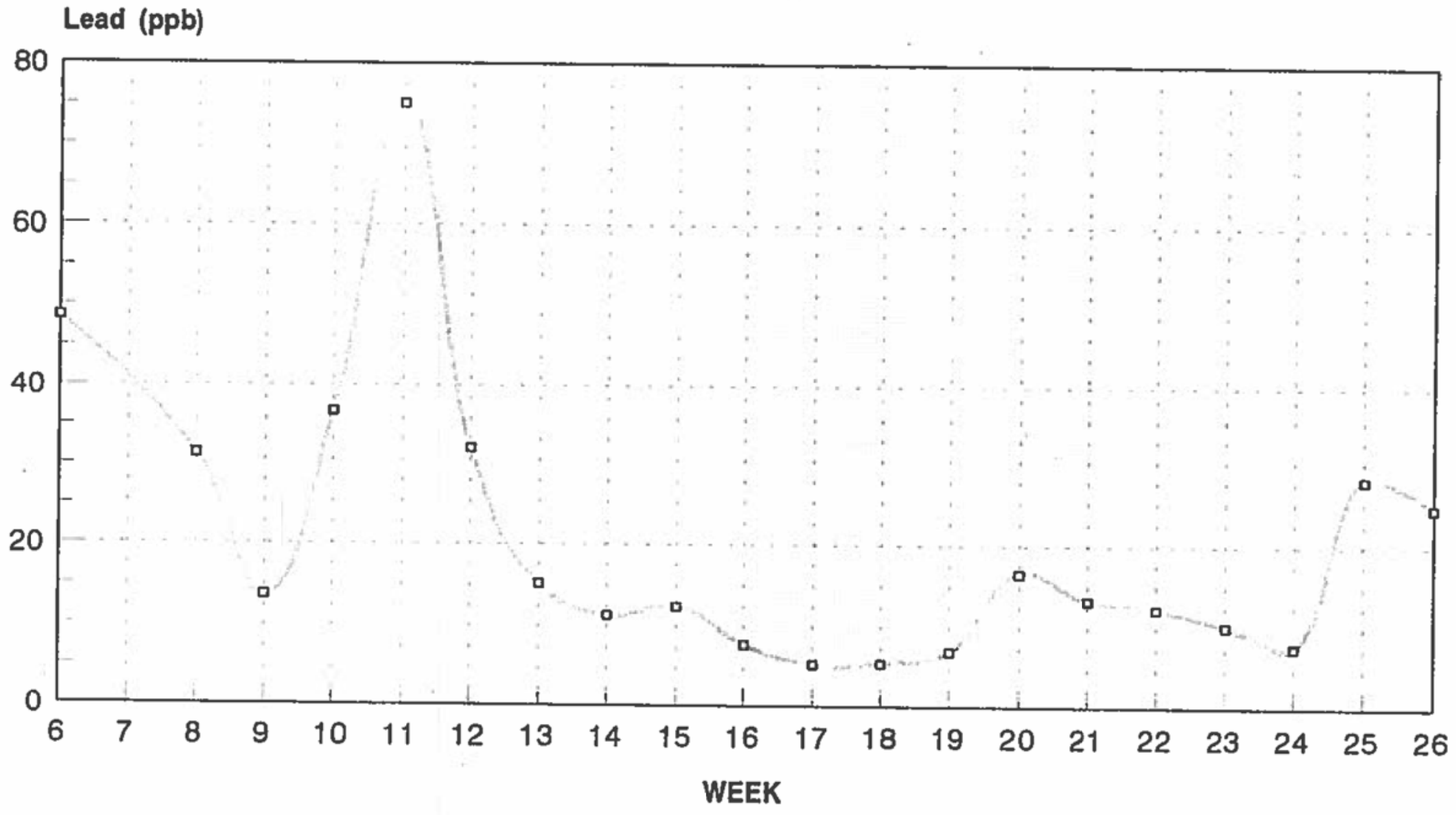


Figure 3.5

□ Loop I: Lead Results

Lead concentration in ppb vs. Weeks
Lead results from copper loop with lead solder treated with orthophosphate

Lead corrosion control study
Loop I: Copper pipe with lead solder joints
With Orthophosphate treatment

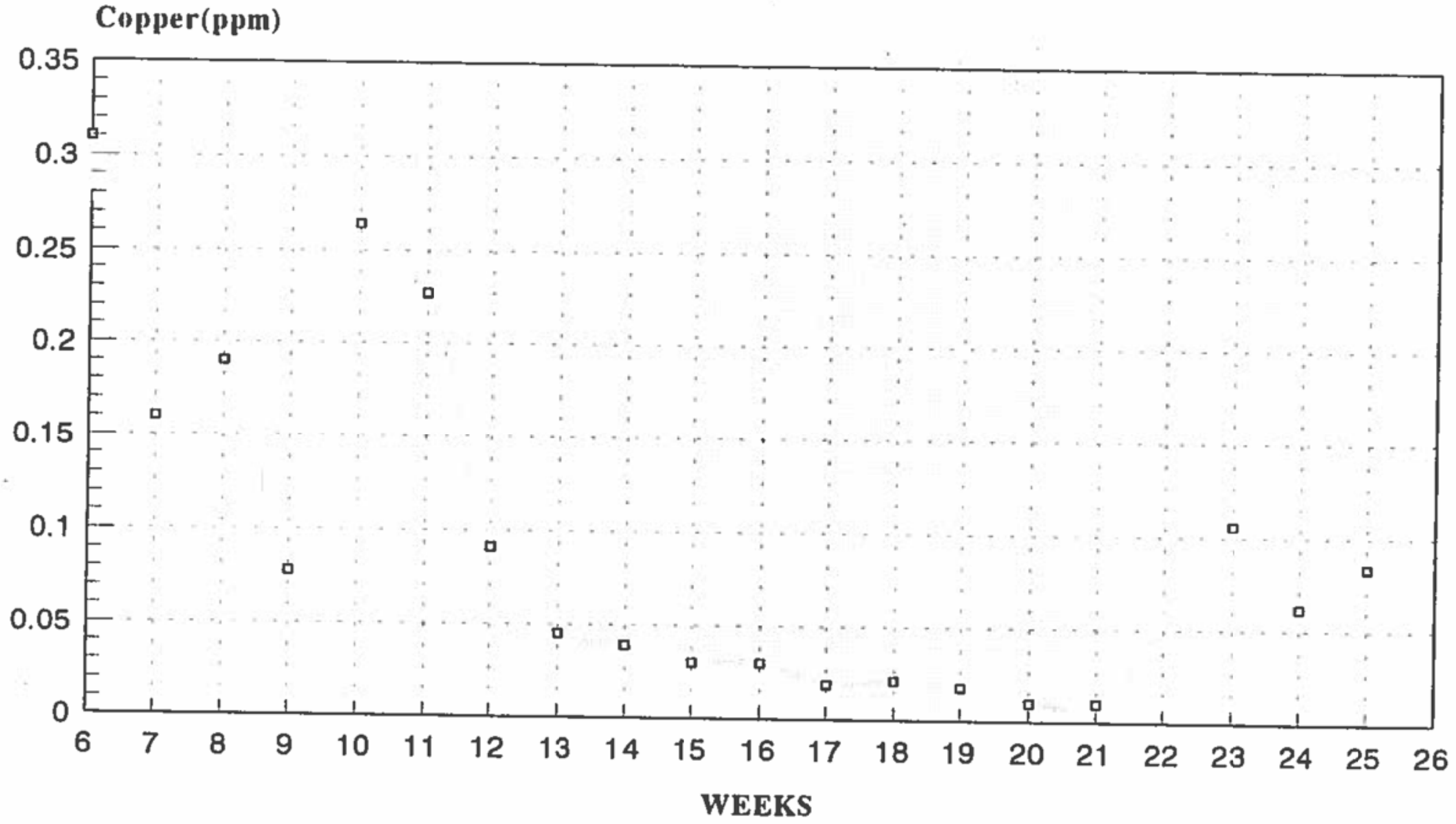


Figure 3.6

▫ Loop I: Copper results

Copper concentration in ppm Vs. Weeks
Copper results from copper pipe with lead solder joints

Table 3.9

Pipe Loop II: Loop with Lead pipe

With orthophosphatetreātment

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*
6	437.0		1
7	1232.0		1
8	-		1
9	1125.0		1
10	657.0		1
11	1290.0		1
12	248.0		1
13	848.0		1
14	508.0		1
15	92.0		1
16	216.0		1
17	145.0		1
18	99.0		1
19	70.0		1
20	-		1
21	64.0		1
22	102.0		1
23	135.0		1
24	202.0		1
25	233.0		1
26	210.0		None

Corrosion control study
Loop II: Lead Pipe
Lead results from lead pipe with orthophosphate treatment

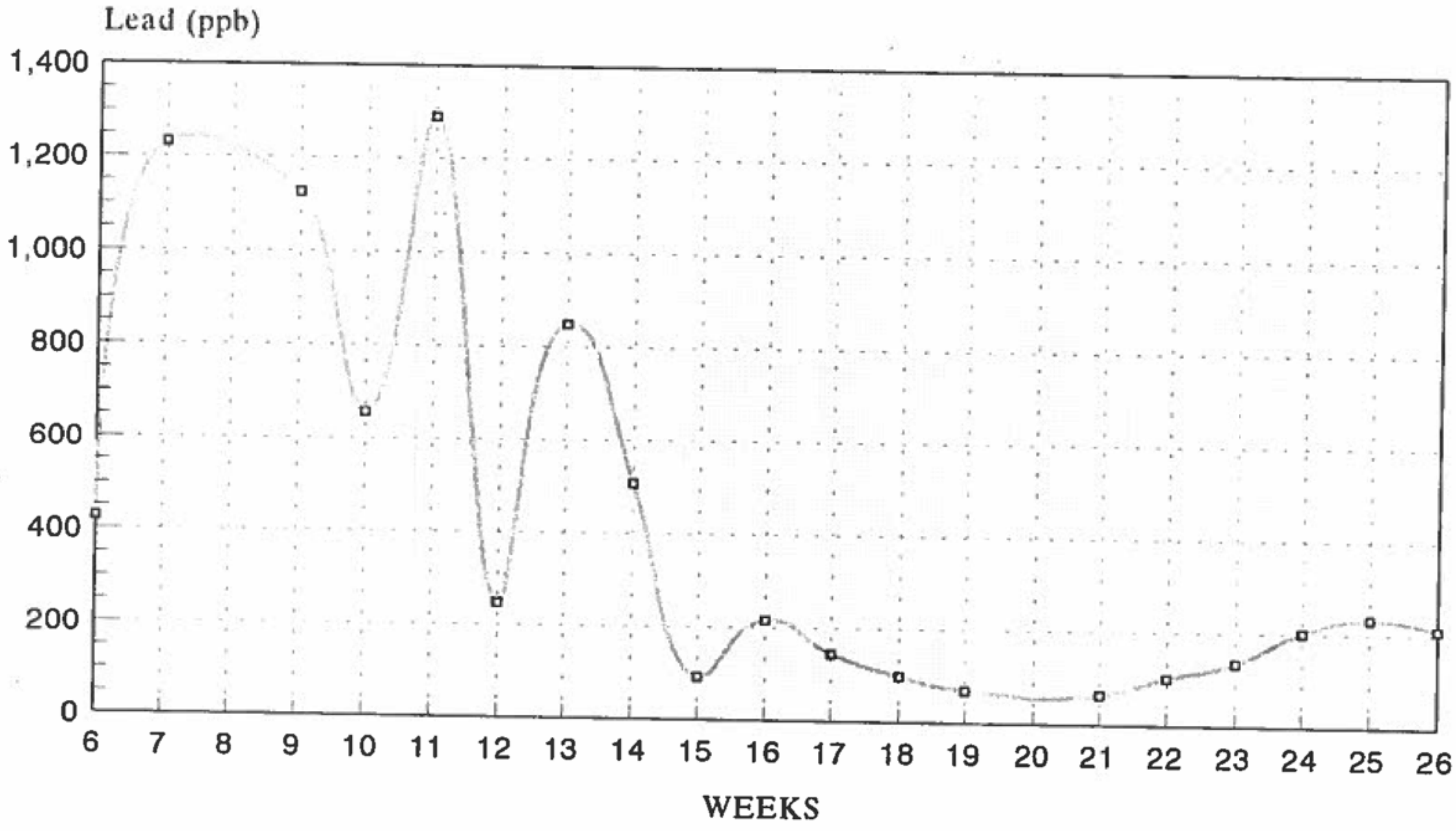


Figure 3.7

▫ Loop II: Lead Results

Lead concentration in ppb Vs. Weeks
Lead pipe with orthophosphate treatment

Table 3.10
Loop III: Copper pipe with Lead solder
With Silicate treatment

Week#	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm) as Si*
6		0.31	None
7	85.3	0.25	24
8	25.6	0.19	24
9	18.5	0.031	24
10	11.4	0.044	18
11	17.0	0.0323	18
12	23.6	0.018	18
13	12.89	0.023	18
14	15.1	0.018	12
15	6.7	0.022	12
16		0.016	12
17	10.6	0.0175	12
18	4.7	0.04	12
19	10.1	0.026	12
20	-	0.02	12
21	5.0	0.01	12
22	5.0		9
23	6.4	0.019	9
24	-	0.014	9
25	6.5	0.027	9
26	5.6	0.013	9
27	6.8	0.015	9

Week#	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm) as Si*
28	4.5	0.023	9
29	1.8	0.013	9
30	1.8	0.013	9
31	1.7	0.039	9
32	3.0	0.023	9
33	5.0	0.02	9
34	2.8	0.039	8
35	4.6	0.032	8
36	4.4	0.024	8
37	4.2	0.009	8
38	4.0	0.028	8
39	3.0	0.09	None

Following shows the graphical representation of the changes for above data

Lead corrosion control study
Loop III: Copper pipe with lead solder and with Silicate treatment
Lead results from copper pipe with lead solder joints and with Silicatetreatment

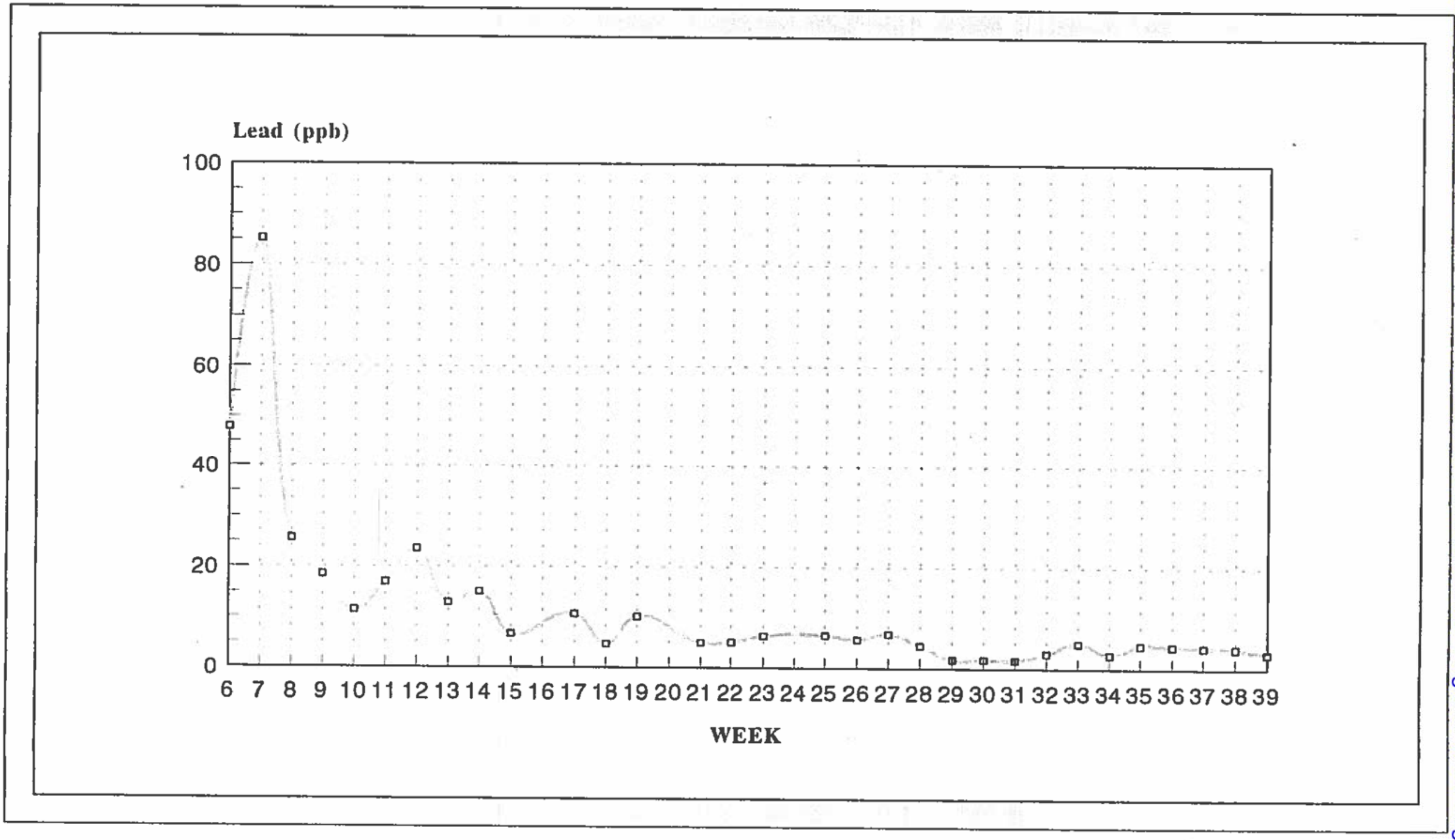


Figure 3.8

Lead concentration in ppb Vs. Weeks
Lead results from loop III treated with Sodium silicate

City of Newark

Corrosion control study
Loop III: Copper pipe with lead solder and with Silicate treatment
With Sodium Silicate treatment

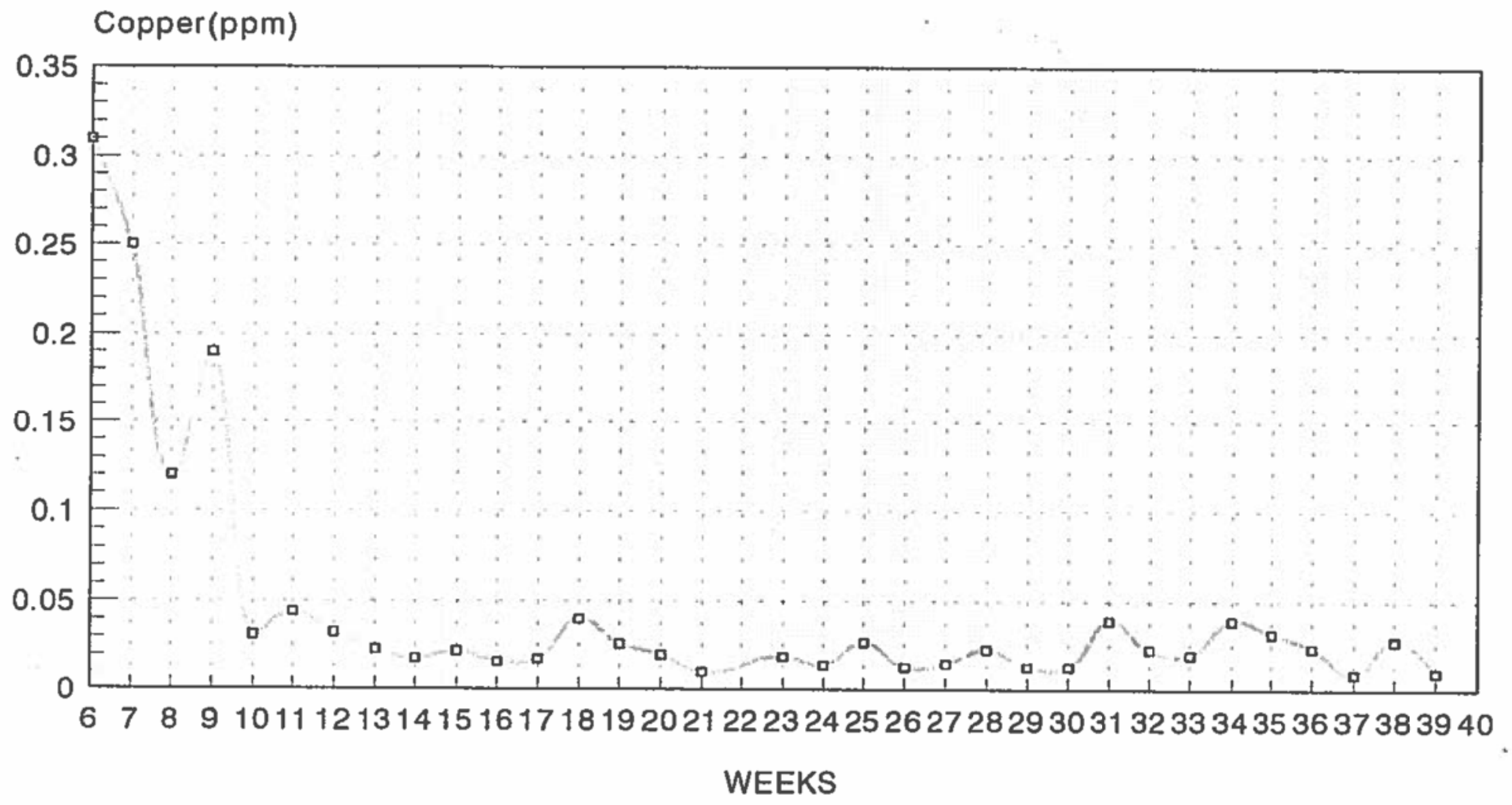


Figure 3.9

▫ Loop III:Copper Result

Copper Results in ppm Vs. Weeks
Copper pipe with Sodium Silicate as inhibtor

Table 3.11

Loop IV : Lead pipe loop

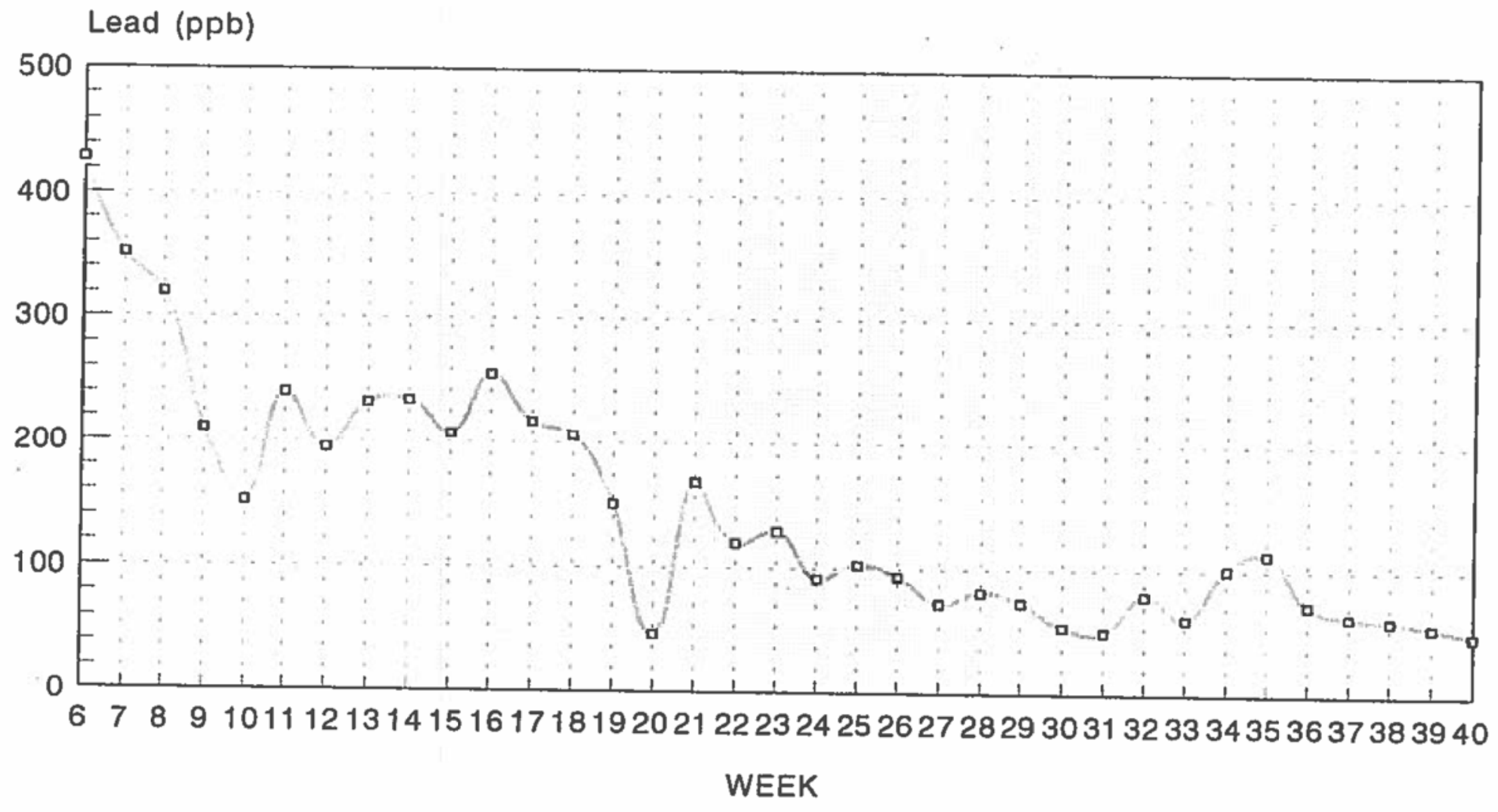
With Sodium Silicate treatment

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*
6	428.5		None
7	351.2		24
8	320.1		24
9	210.5		24
10	151.2		24
11	240.1		18
12	195.0		18
13	232.0		18
14	234.0		12
15	207.0		12
16	255.0		12
17	217.0		12
18	206.0		12
19	150.0		12
20	46.6		12
21	168.0		12
22	120.0		9
23	129.0		9
24	92.0		9
25	103.0		9
26	94.0		9
27	73.0		9

Week #	*Lead (ppb)*	*Copper (ppm)*	*Chemical Dosage (ppm)*
28	82.0	[redacted]	9
29	74.0	[redacted]	9
30	54.0	[redacted]	9
31	50.0	[redacted]	9
32	80.0	[redacted]	9
33	61.0	[redacted]	9
34	101.0	[redacted]	8
35	113.0	[redacted]	8
36	73.0	[redacted]	8
37	63.0	[redacted]	8
38	60.0	[redacted]	8
39	55.5	[redacted]	None
40	48.5	[redacted]	None

Please see the following graph

Corrosion control study
Loop IV: Lead Pipe
With Sodium Silicate treatment



Fifure 3.10

Lead concentration in ppb Vs. Weeks
Lead results from Soldium SIlicate treated lead pipe

City of Newark

Table 3.12

Loop V: Copper pipe with lead solder

Control loop (no treatment)

Week #	Lead (ppm)	Copper (ppm)	Chemical Dosage (Control Loop)
6	48.0	0.35	None
7	32.1	0.25	None
8	42.1	0.193	None
9	20.5	0.082	None
10	43.0	0.127	None
11	42.6	0.15	None
12	56.6	0.136	None
13	-	0.168	None
14	32.8	0.095	None
15	30.8	0.23	None
16	22.0	0.09	None
17	22.5	0.088	None
18	22.0	0.05	None
19	-	0.05	None
20	-	0.11	None
21	21.6	0.08	None
22	-	0.14	None
23	17.5	0.12	None
24	40.0	0.128	None
25	23.4	0.106	None
26	51.0	0.052	None
27	35.2	0.0577	None

Week #	Lead (ppm)	Copper (ppm)	Chemical Dosage (Control Loop)
28	18.0	0.064	None
29	15.1	0.168	None
30	15.1		None
31	38.4	0.045	None
32	34.5	0.05	None
33	104.7	0.129	None
34	24.1	0.125	None
36	29.1	0.06	None
37	52.1	0.07	None
38	24.6	0.07	None
39	24.6	0.08	None
40	24.0	0.08	None

The lead and copper concentration during the above period is shown in the following graphs

Corrosion control study
Loop V:Copper pipe with lead solder
With no treatment (Control loop)

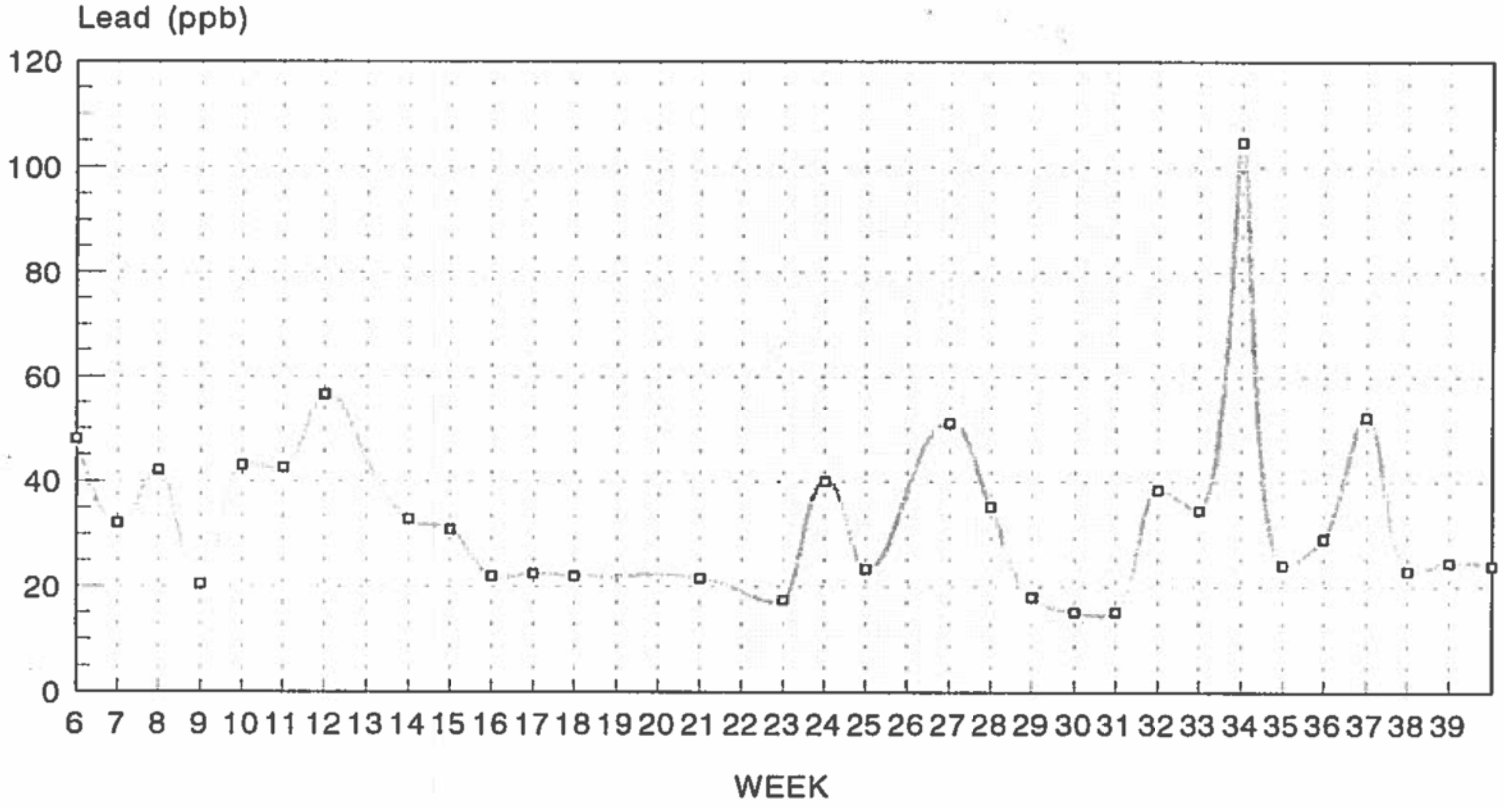


Figure 3.11

▫ Loop V: Lead Results

Lead results in ppb Vs. Weeks
Lead results from copper pipe with no treatment

Corrosion control study
Loop V: Copper pipe with lead solder and no treatment
Control loop with no treatment

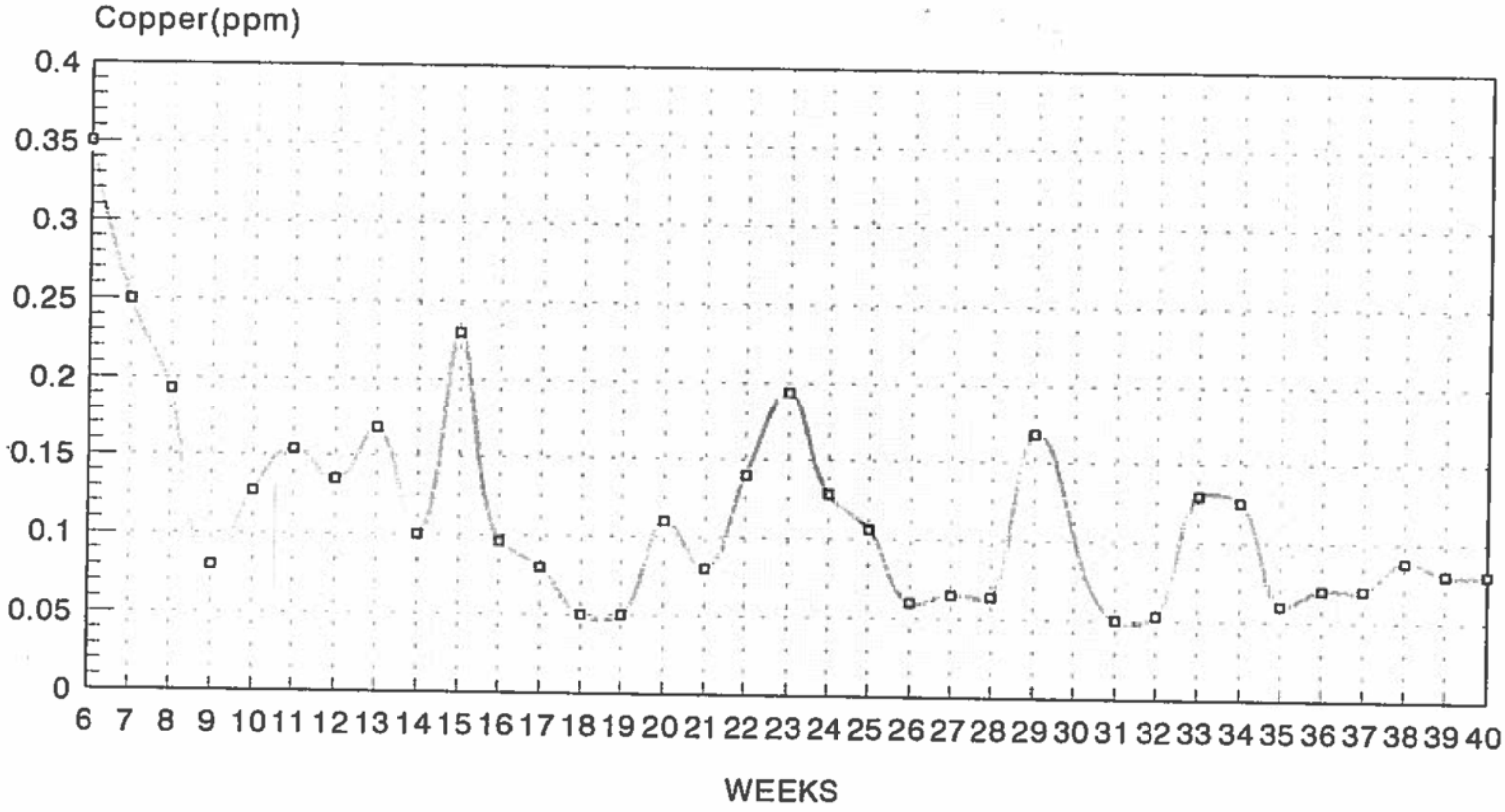


Figure 3.12

▫ Loop V: Copper results

Copper in ppm Vs. Weeks
Control loop

Table 3.13

Loop VI: Lead Pipe

Control loop (no treatment)

Week #	Lead (ppm)	Copper (ppm)	Chemical Dosage (Control Loop)
6	430.0		None
7	390.5		None
8	410.1		None
9	366.0		None
10	350.9		None
11	370.0		None
12	440.0		None
13	371.0		None
14	254.0		None
15	-		None
16	264.0		None
17	490.0		None
18	249.0		None
19	209.0		None
20	476.0		None
21	240.0		None
22	297.0		None
23	458.0		None
24	308.0		None
25	258.0		None
26	247.0		None
27	284.0		None

Week #	Lead (ppm)	Copper (ppm)	Chemical Dosage (Control Loop)
28	280.0	[redacted]	None
29	284.0	[redacted]	None
30	230.0	[redacted]	None
31	258.0	[redacted]	None
32	218.5	[redacted]	None
33	248.0	[redacted]	None
34	346.0	[redacted]	None
36	353.0	[redacted]	None
37	-	[redacted]	None
38	-	[redacted]	None
39	283.0	[redacted]	None
40	251.0	[redacted]	None

Please see the following graphs

Corrosion control study
Loop VI: Lead Pipe
Control loop with no treatment

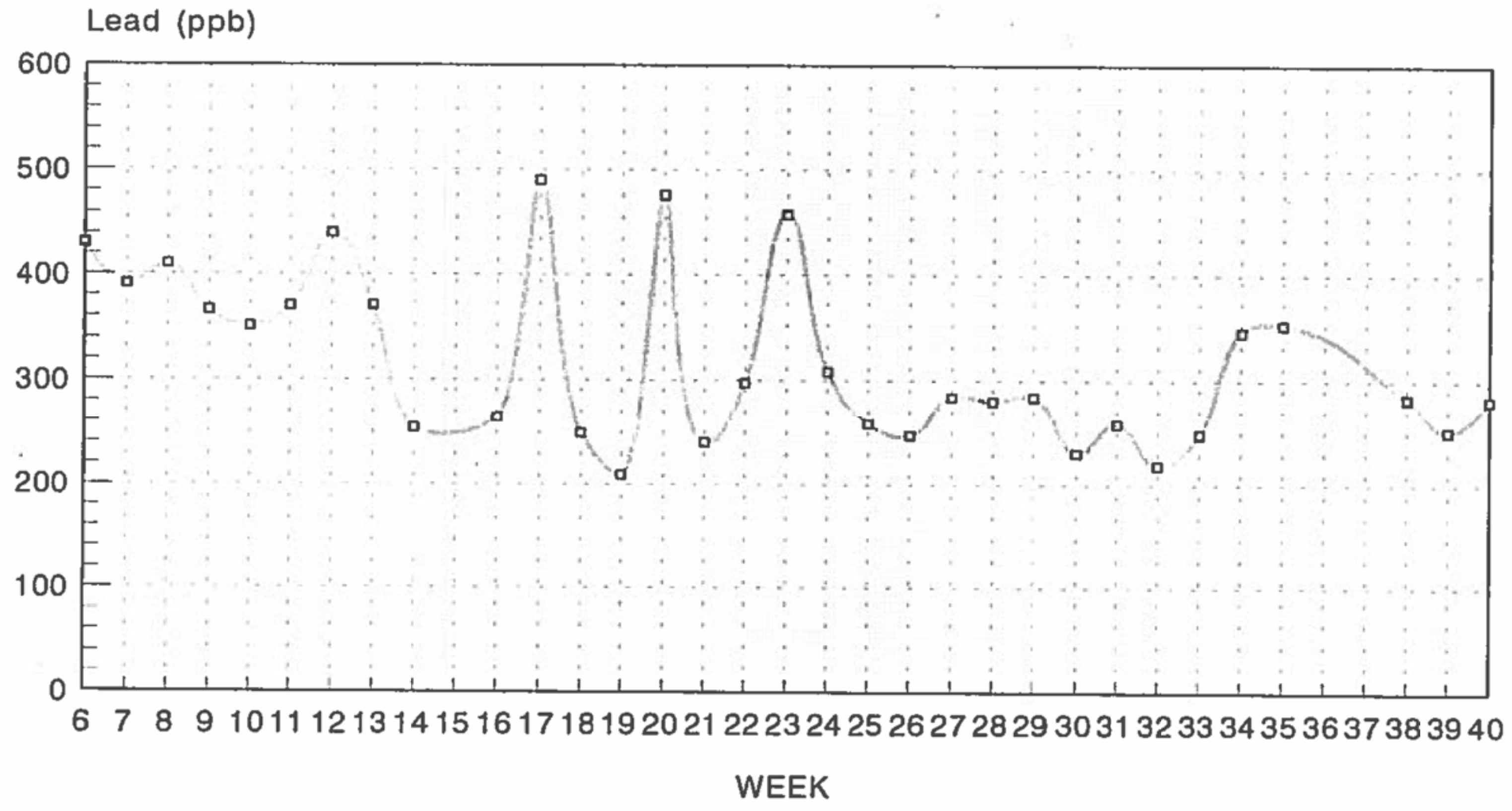


Figure 3.13

▫ Loop VI: Lead Results

Corrosion optimization study
Lead results from Copper pipes with lead solder
Lead results

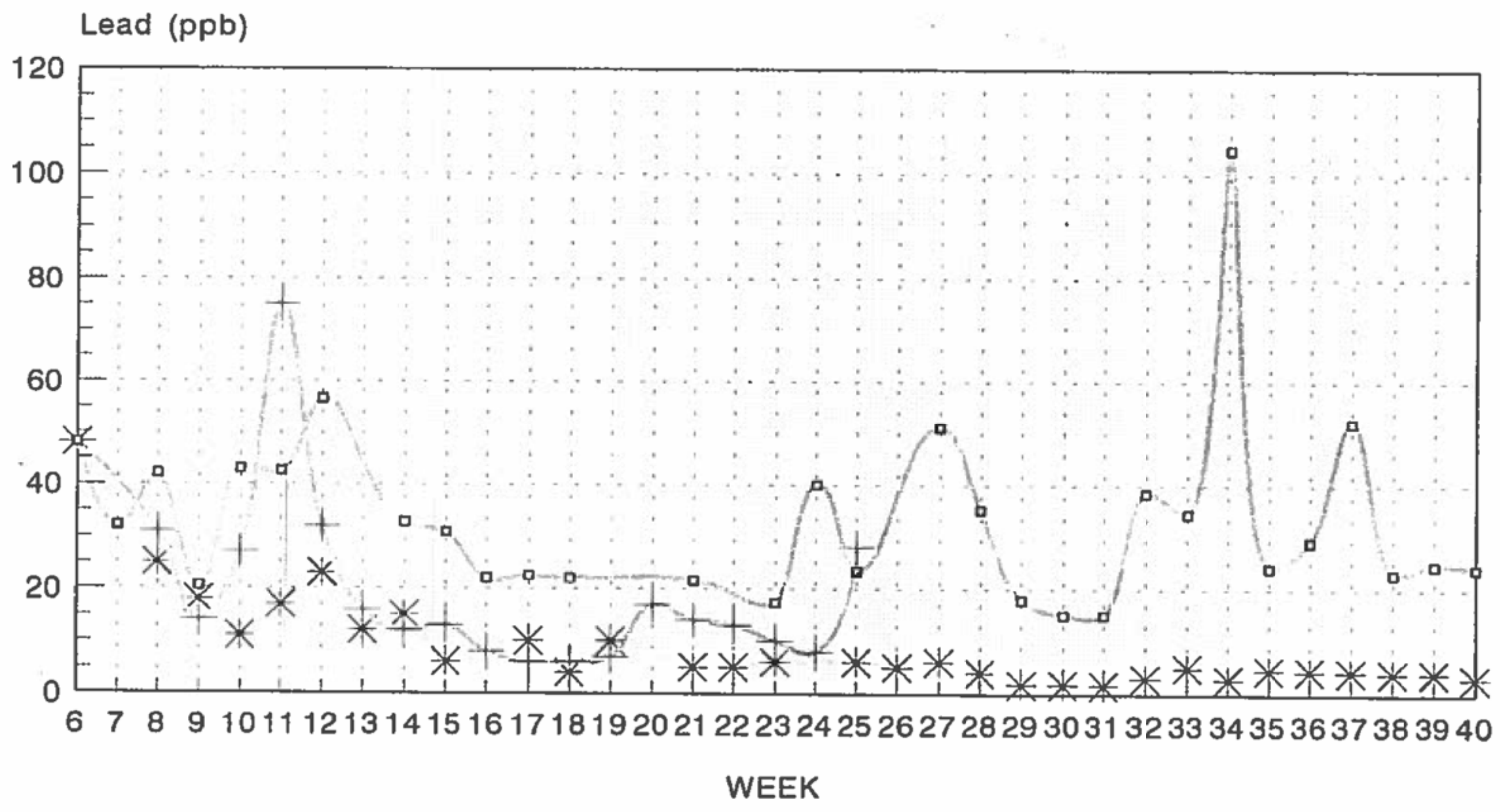


Figure 3.14

▫ Loop V:Control + Loop I:orthophosphate ✳ Loop III:silicate

Comparison of lead results in two treatment loops and control
Lead in ppb Vs. Weeks

Corrosion optimization study
Copper pipe with lead solder
Copper results

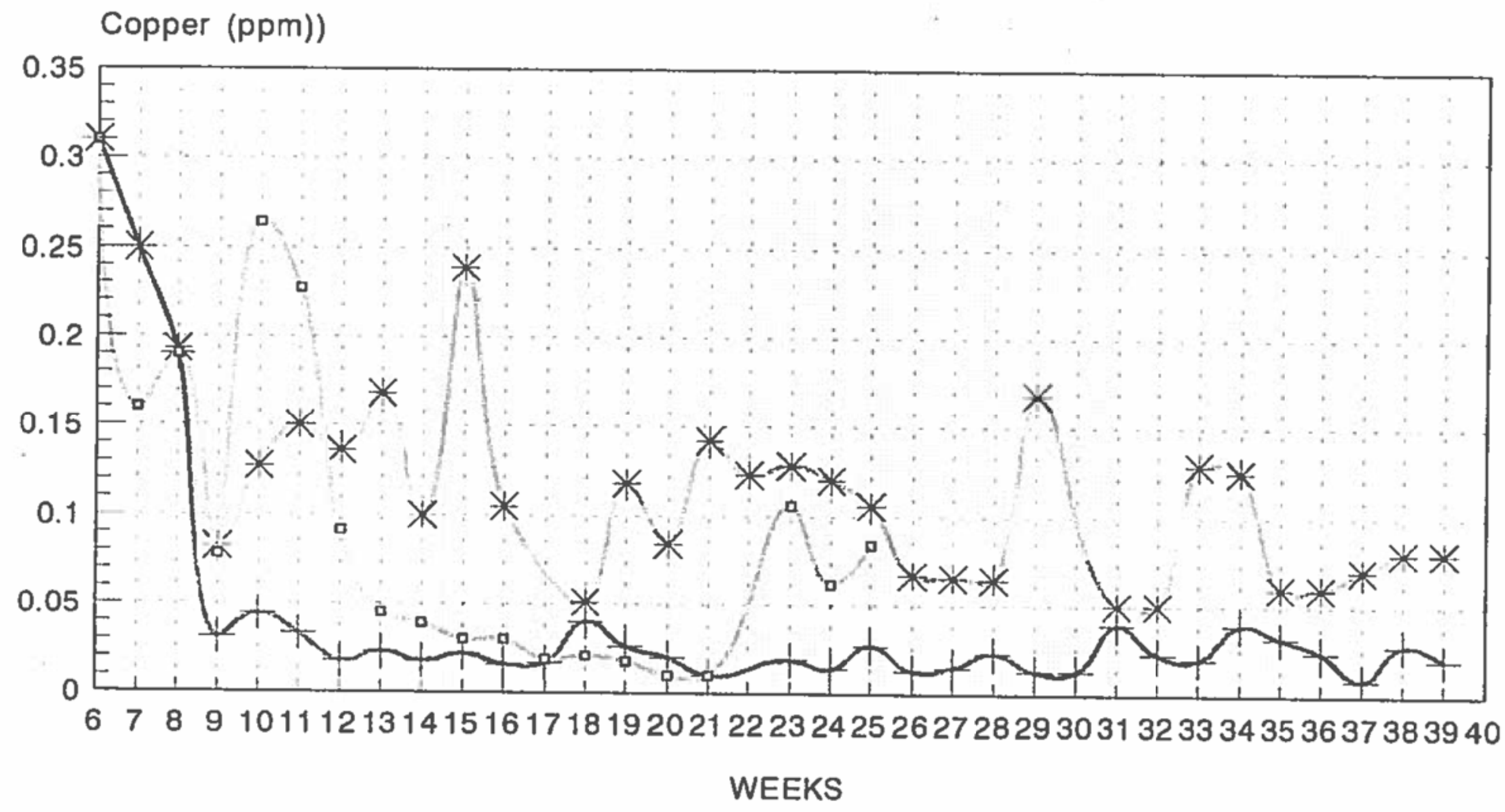
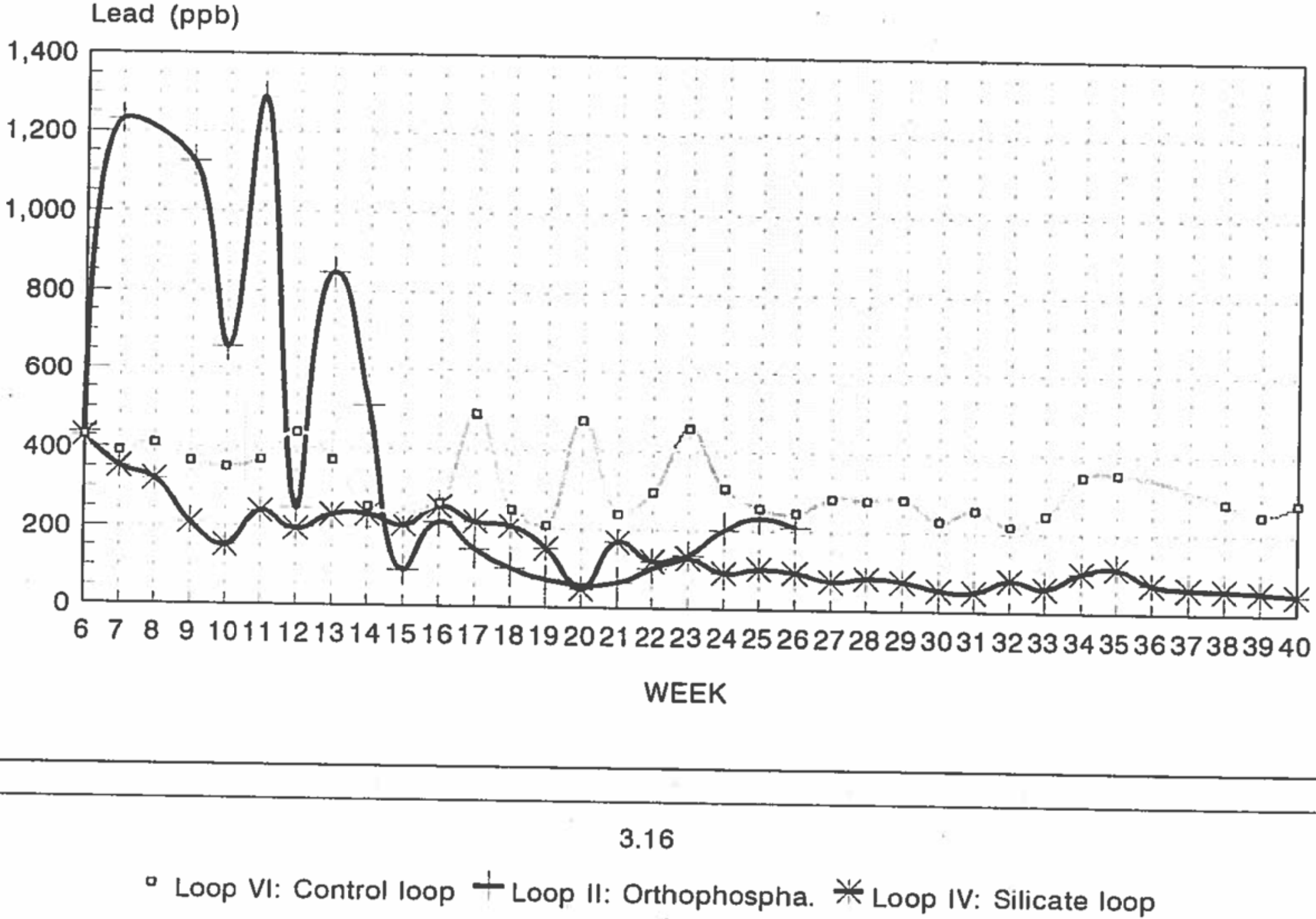


Figure 3.15

□ Loop I:Orthophosphate + Loop III:Silicate ✳ Loop IV: Control

Comparison of copper results in two treatment loops and control
Copper in ppm Vs. Weeks

Corrosion optimization study
Lead pipes loops
Lead results



3.16

Comparison chart with both treatment and control loop results
Lead in ppb Vs. Weeks

3.9 Final treatment period

After the 26th week, loop I & II orthophosphate testing was completed and the loop was cleaned and raw water was run through it until the 30th week. This was done to regenerate the initial condition and to free the loop for testing another chemical. During this time, all the results were monitored and once it started giving similar results as the control loop, a ortho-poly blended phosphate was added to the loop at a rate of 1 ppm (as ortho).

The results from that testing is tabulated in the following table.

Table 3.14

Loop I: Copper pipe with lead solder

With Ortho-Poly blended phosphate

Week #	Lead (ppb)	Copper (ppm)	Chemical Dosage ppm as ortho
26	35.5	0.02	None
27	45.0	0.061	None
28	32.4	0.10	None
29	35.0	0.08	None
30	14.5	0.15	1
31	12.5	0.09	1
32	10.9	0.085	1
33	9.6	0.045	1
34	8.8	0.03	1
35	24.5	0.019	1
36	7.5	0.029	1
37	6.5	0.035	1
38	6.0	0.04	1

Week #	Lead (ppb)	Copper (ppm)	Chemical Dosage ppm as ortho
39	5.8	0.035	1
40	12.3	0.03	1
41	5.2	0.025	1
42	6.8	0.03	1

Table 3.15

Loop II: Lead

With Ortho-Poly blended phosphate

Week #	Lead (ppb)	Copper (ppm)	Chemical Dosage ppm as ortho
26			None
27	158.5		None
28	220.0		None
29	285.5		None
30	235.0		1
31	250.0		1
32	145.5		1
33	130.0		1
34	210.0		1
35	120.0		1
36	98.5		1
37	75.0		1
38	66.3		1
39	108.5		1
40	98.5		1

Week #	Lead (ppb)	Copper (ppm)	Chemical Dosage ppm as ortho
41	66.3		1
42	58.5		1

Table 3.16

Loop V: Copper pipe with lead solder

Control loop (no treatment)

Week #	Lead (ppm)	Copper (ppm)	Chemical Dosage (Control Loop)
26	51.0	0.052	None
27	35.2	0.0577	None
28	18.0	0.064	None
29	15.1	0.168	None
30	15.1		None
31	38.4	0.045	None
32	34.5	0.05	None
33	104.7	0.129	None
34	24.1	0.125	None
36	29.1	0.06	None
37	52.1	0.07	None
38	24.6	0.07	None
39	24.6	0.08	None
40	24.0	0.08	None

Table 3.17
Loop VI: Lead Pipe
Control loop (no treatment)

Week #	Lead (ppm)	Copper (ppm)	Chemical Dosage (Control Loop)
26	247.0		None
27	284.0		None
28	280.0		None
29	284.0		None
30	230.0		None
31	258.0		None
32	218.5		None
33	248.0		None
34	346.0		None
36	353.0		None
37	-		None
38	-		None
39	283.0		None
40	251.0		None

The following pages shows the variation graphically.

Corrosion optimization study
Lead results from loop I and loop V
Blended phosphate loop Vs. Control loop

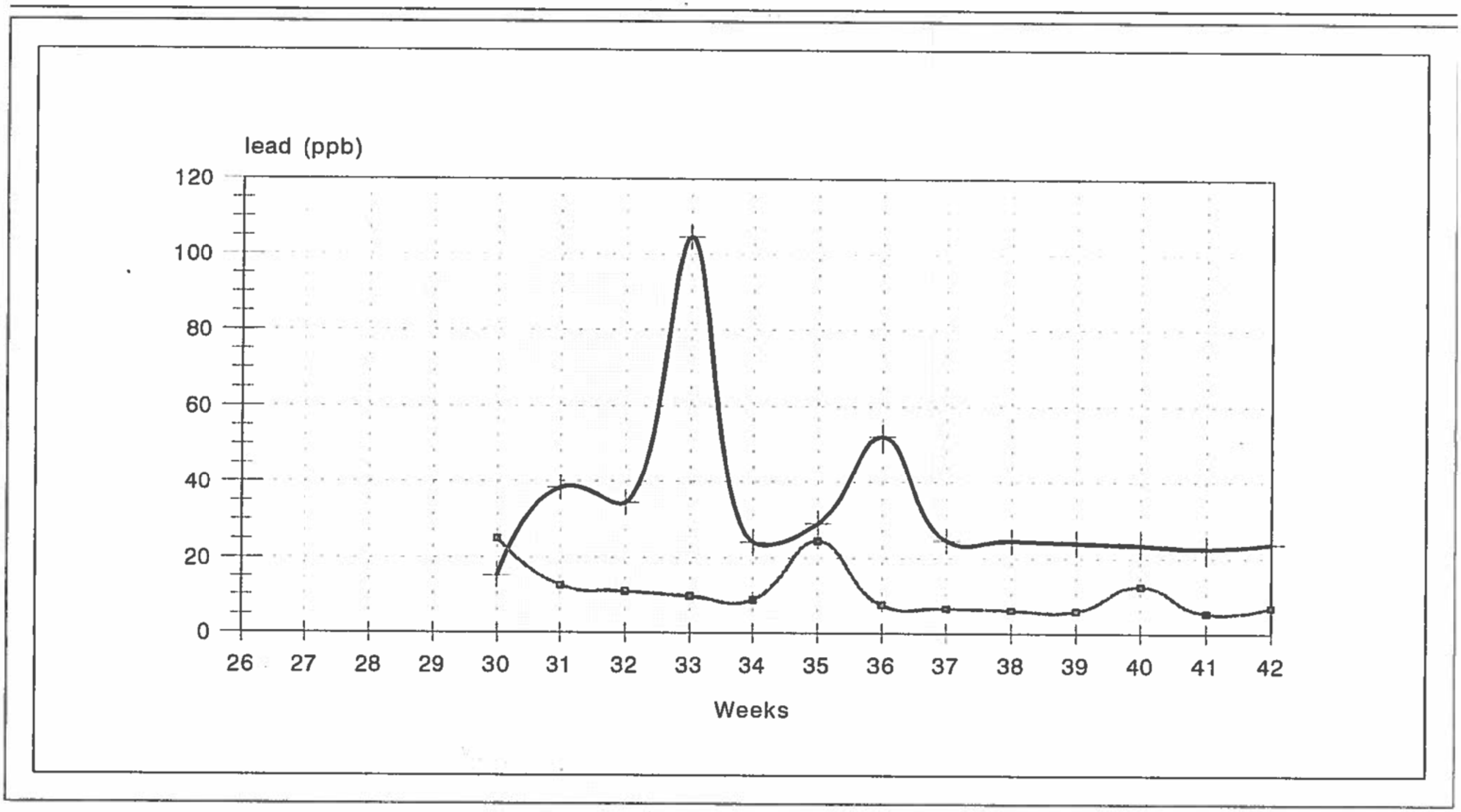


Figure 3.17

-□- Loop I: Blended phosp. ┼ Loop V: Control

Loop I is fed with blended phosphate and loop V is control
Copper pipe loops with lead solder joints

City of Newark

Corrosion optimization study
Copper results from loop I and loop IV
Blended phosphate loop Vs. Control loop

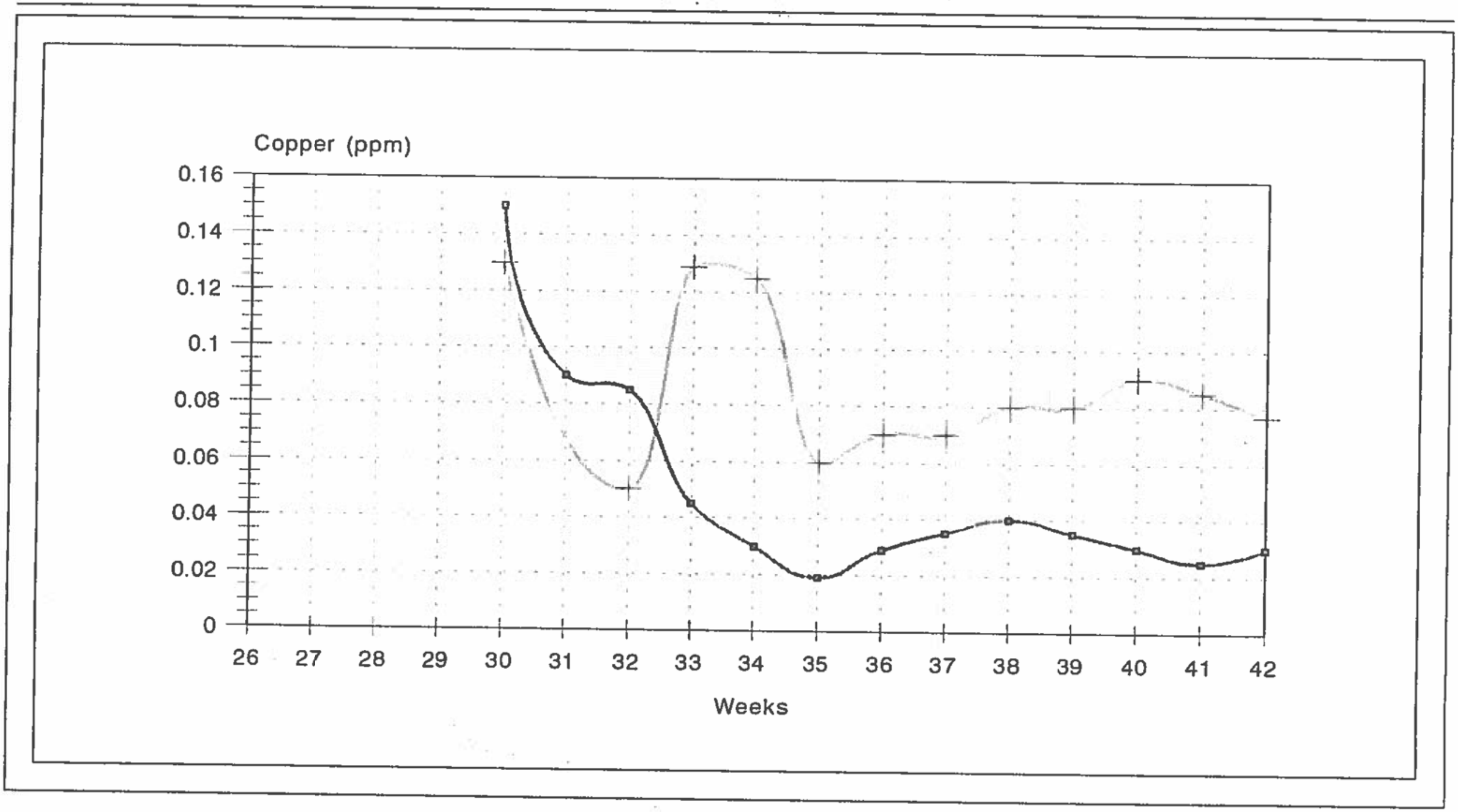


Figure 3.18

Loop I is fed with blended phosphate and loop V is control
Copper results from copper loop with lead solder

City of Newark

Corrosion optimization study
Lead results from loop II and loop VI (lead pipes)
Blended phosphate Vs. Control

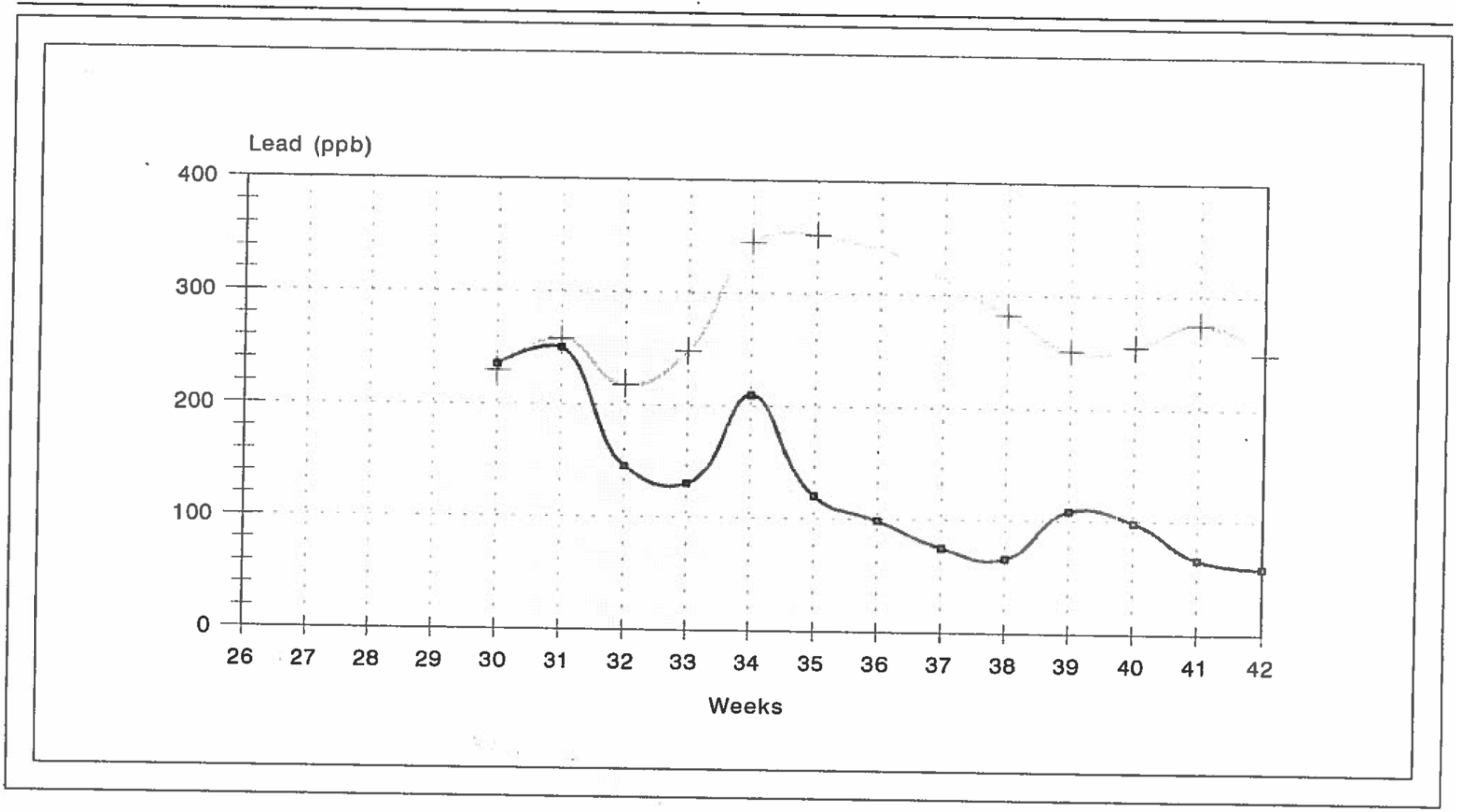


Figure 3.19

-□- Loop II: Blended phos. + Loop VI: Control

Loop II is fed with blended phosphate and loop VI is control
Lead results from lead pipe

Table 3.17a

Pipe insert (coupon) results

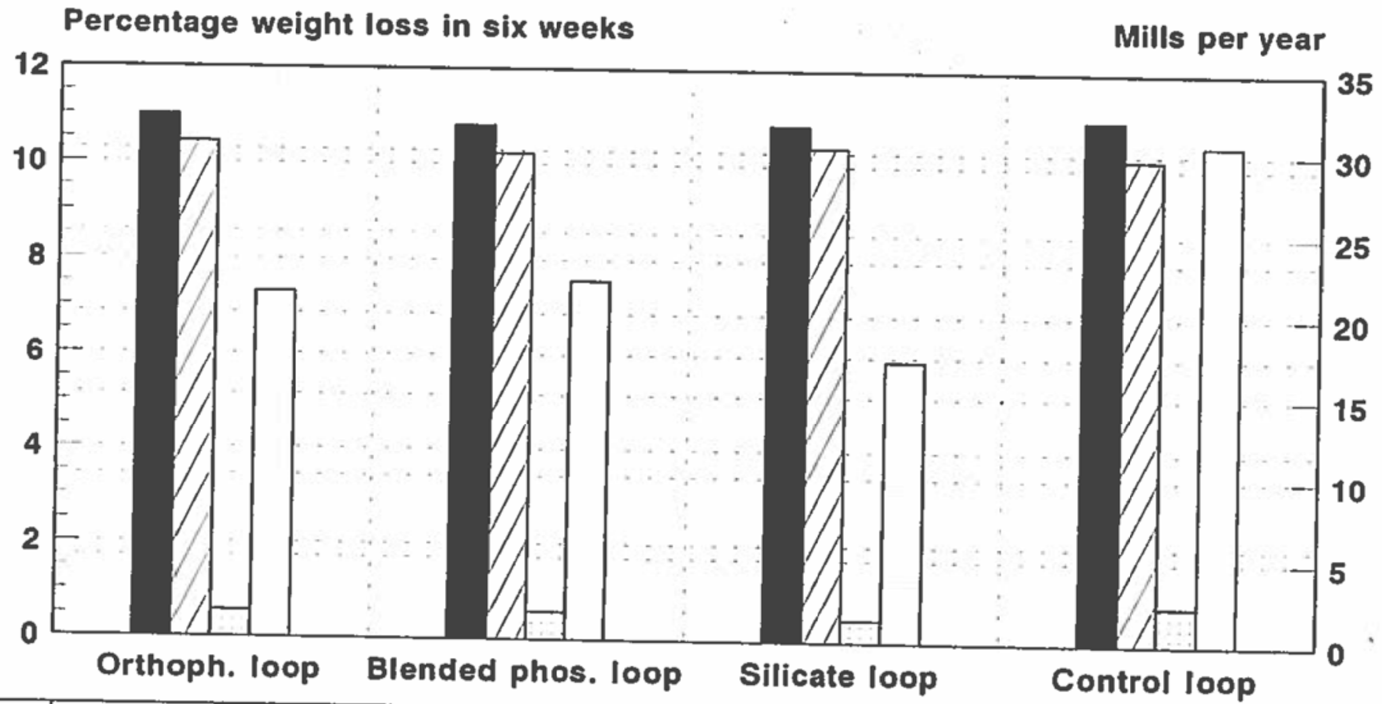
Location	Weight loss (gms)	Days	Corrosion rate (MPY)
Orthophosphate loop	0.561	49	21.29
Blended phosphate loop	0.595	49	22.58
Silicate loop	0.467	49	17.72
Control loop	0.806	49	30.595

Table 3.18

Average chemical feed rates and water quality characteristics by treatment alternatives for the pilot testing.

Treatment alternative	Water quality Characteristics mg/l			Chemical feed rate
	Ca Hardness	Alkalinity	pH	
Orthophosphate	37.0	31.0	7.4	1 ppm (ortho)
Blended phosphate	37.0	31.0	7.4	1 ppm (ortho)
Silicate	37.0	31.0	8.4	12 ppm

Lead corrosion control study
Pipe insert (coupons) Results
Comparison of coupon weight loss & Corrosion rates



	Orthoph. loop	Blended phos. loop	Silicate loop	Control loop
Weight Loss(gms)	0.561	0.581	0.467	0.806
Corrosion rate	21.294	22.05	17.27	30.59

Figure

■ Initial Wt.(gms) ▨ Final Wt.(gms) ░ Weight Loss(gms) ☐ Corrosion rate

Initial Stabilization Period (with no treatment)

City of Newark

4.0 COMPARISON OF ALTERNATIVES

4.0 COMPARISON OF ALTERNATIVES

4.1 Assessment of orthophosphate treatment:

Bench scale studies and the pilot plant studies showed that orthophosphate is effective effective in reducing lead corrosion from lead pipes and copper pipes with lead solder joints. However, addition of an orthophosphate in the Pequannock Water Treatment Plant is not desirable due to the potential for severe algal growth in the Cedar Grove open reservoir. If the City decides to feed this inhibitor after the reservoir, the City may need to build a number of satellite feeding stations which may involve substantial capital improvement and, hence, create a liability to the City's financial implication. Also, the City has reservation about using any phosphate in the system because of prior experience with a phosphate and the subsequent dirty water complaints that followed.

4.2 Assessment of Blended Phosphate:

Blended phosphate showed a lesser reduction of corrosion than the orthophosphate. Similar to orthophosphate, it also cannot be added at our Pequannock treatment plant. This product costs more than the orthophosphate, and to get the same ortho dosage more chemical will have to be added.

4.3 Asessment of Silicate:

Both bench scale and pilot plant studies showed that silicate is an effective corrosion inhibitor. Addition of silicate increases the pH of the water and, hence, the present lime dosage can be reduced. Another advantage is that silicate can be used at the treatment plant directly without building additional satellite feeding stations. The advantage of feeding at the treatment plant allows for better control over the chemical dosage. Silicates are also effective in controlling the condition of red water.

Algal (diatoms) growth in open reservoirs is usually associated with the presence of silica. Silica is an essential nutrient for diatoms, which are a type of algae. The ultimate effect of higher silica concentrations from silicates is not well understood. Both silica and phosphate are a must for the diatoms to grow. So an increase in silica will not increase the growth of diatoms because the other nutrient, phosphate, will be the controlling factor.

When water containing silica is heated in high pressure boilers, some silica vaporizes. Power generating utilities, in particular, and other industries use high pressure boilers to produce steam that is used to operate turbines. Silica vapors in the steam can condense onto turbine blades and cause permanent damage to the blades. There is a recommendation from the American Society of Mechanical Engineers (ASME) on the limit of silica concentration in water used in high pressure boilers. ASME recommends a limit of 20 mg/l silica concentration for boilers operating under high pressure (751-900 psi). Silica dosage reduction is not necessary, especially in the absence of condensing turbines. The silica dosage in the loop tested varied from 24 ppm to 8 ppm. The higher dosage of silica is required only in the early stage of the chemical treatment.

4.4 Overall assessment

Lead in lead pipe:

Throughout the test period sodium silicate produced the most consistent reduction in lead concentration. Over the term of the project lead concentrations were reduced by 65% with sodium silicate. This was slightly better than the orthophosphate treatment which reduced the lead concentration by about 60%. The lead reduction from orthophosphate treatment was inconsistent and the lead levels actually went up during the initial treatment period. Another notable phenomena was that in the orthophosphate and blended phosphate treatment loops, the mild steel pipe inserts pitted worse than the silicate loops and the water samples drawn from the loops were dirty and brownish. This evidence supports our earlier experience of phosphates and its aggressiveness. During the coldest months, lead leaching decreased in the control loop and there was only a slight reduction of lead leaching in all of the treatment loops. With the return of warmer water temperatures, the lead concentrations again increased in the control loops.

Lead in copper pipe with lead solder:

In this case, also, the most consistent results were obtained from the silicate loops. which produced almost a 60% lead reduction.

Copper in copper pipes with lead solder:

Copper results from copper pipe with lead solder is compared on the graph. It can be seen that all treatment chemicals achieved similar reductions of copper concentrations, well below that of the control loop and below the action level of 1.3 mg/l. Silicate produced a slightly lower concentration than the rest of the chemicals.

pH Variation:

Addition of sodium silicate in the silicate loop increased the pH in that loop. With a chemical dosage of 24 mg/l, the pH was 9.0 and with a chemical dosage of 8 mg/l the pH was 8.4. Minimal changes were noted in the ortho and blended phosphate loops.

4.5 Preliminary cost estimates

Unit capital cost and operational & maintenance costs associated with the several corrosion control alternatives are typically very similar. The key cost difference is attributable to the cost of the chemical and the dosage. As described earlier, the chemical cost for a blended phosphate would be more than for an orthophosphate. The blended phosphate showed a lesser lead reduction than the orthophosphate.

Table 4.1

Estimate of probable costs

Chemical	Chemical Cost $/Year	Capital Cost[1] ($)	Capital Cost ($/Year)	**Total Annual Cost ($)**
Blended phosphate[3]	750,000	2,500,000	250,000	1,000,000
Orthophosphate[3]	450,00	2,500,00	250,000	700,000
Silicate	750,000	400,000[2]	40,000	790,000

[1] Capital cost has been amortized over 20 years with an interest rate of 8%.

[2] The capital cost in this case is reduced because the Pequannock Treatment Plant is already equipped with the necessary corrosion inhibition feeding systems, including the storage tanks and pumps. Only minor alteration is required.

3. Orthophosphate and blended phosphate is deleterious to the operation of the Cedar Grove open balancing reservoir.

4.5 Performance comparison

Table 4.2

Corrosion Control Treatment Performance Ranking Matrix

Treatment Alternative	Performance Criteria		
	Metal Solubility		Weight Loss
	Lead	Copper	Mild Steel
Weighing factors	**.8**	**.2**	**1**
Orthophosphate	5	7	5
Blended phosphate	3	5	3
Silicate	7	7	7
Control	0	0	3
Interim performance Score			
Orthophosphate	4.0	1.4	5
Blended phosphate	2.4	1.0	3
Silicate	5.6	1.4	7
Control	0.0	0.0	3
Measurement techniques Weighing factor	**0.7**	**0.7**	**0.3**
Measurement scores			
Orthophosphate	2.8	0.98	1.5
Blended phosphate	1.68	0.7	0.9
Silicate	3.92	0.98	2.1
Control	0	0	0.9
Total Score			
Orthophosphate	5.28		
Blended phosphate	3.28		
Silicate	7.0		
Control	0.9		

4.6 Final Corrosion Control Treatment Selection Matrix

The factors selected to choose the best corrosion control chemical (inhibitor) are as follows:

1. **Performance:** Performance of alternative treatment techniques were evaluated for mitigating corrosion, based on the prioritization of (a) targeted material (b) measurement technique (c) confidence in testing program results. This was given the prime importance in the selection criteria.

2. **Feasibility & Reliability:** Feasibility of implementing corrosion control treatment and the reliability of alternative treatment approach based on treated water quality and full scale operational characteristics.

3. **Costs :** Costs associated with the installation and operation, where alternate treatment have comparable performance.

A decision matrix including each of the above factors was developed (shown below) and applied as the basis for the selection of optimum corrosion control treatment.

Table 4.3

Selection Matrix

Treatment Alternative	Corrosion control performance	Treatment reliability	Estimated costs	Total
Weighing factors	0.6	0.3	0.1	1
Orthophosphate	5	5	5	5.0
Blended phosphate	3	3	3	3.0
Silicate	**7**	**7**	**0**	**6.3**
Existing/Control	0	5	7	0.7

5.0 CONCLUSION

CONCLUSION

The objective of the study was to determine which of the possible corrosion control techniques would most effectively reduce lead and copper concentrations in the household service piping and plumbing. Even though the initial Lead and Copper Rule compliance monitoring results from Newark exceeded the lead action level, the compliance problem does not necessarily indicate an inadequate current corrosion control program. The study proved corrosion control studies of this nature are useful for comparing the effectiveness of the available various chemical treatments in reducing corrosion, but cannot predict how effective the treatment will be in meeting the lead and copper action levels in the distribution system. The following conclusions were reached:

> In lead pipes, Sodium Silicate treatment produced slightly better and more consistent results than orthophosphate. Blended phosphate produced the poorest results. Sodium silicate can be used centrally at the treatment plant and eliminate the requirement for satellite feeding stations.
>
> In copper pipes with lead solder joints, both orthophosphate and silicate produce a similar reduction level in lead. Orthophosphate increased the lead concentration during the initial stages of the treatment and showed inconsistent results. The silicate produced a more consistent reduction of lead than the orthophosphate.
>
> In copper pipe with lead soldered joints, the copper concentration were reduced by all three different treatment options. Orthophosphate developed a dirty water problem in the pipe loop because of its aggressiveness towards the mild steel coupons.
>
> Sodium silicate costs more than orthophosphate or blended phosphate. The total expense for sodium silicate treatment will be more than the other treatment options.

5.1 Recommendation

The City of Newark, after an extensive corrosion optimization study, recommends that sodium silicate be added at the Pequannock Treatment Plant to produce the optimal corrosion control treatment. The initial silicate dosage would be around 18 mg/l to 20 mg/l during the passivation period and this would be brought down to 8 mg/after the passivation period.

REFERENCES

1. Lead and Copper Rule Guidance Manual, Vol. I, By EPA.
2. Lead and Copper Rule Guidance Manual, Vol II, By EPA.
3. Lead control strategies, AWWA Research foundation.
4. Pipe loop testing at the Lowell water treatment plant by Leonard J. Mackoul, P.E..
5. Evaluation of Corrosion control Alternatives, By Bruce Johnson, Journal, NEWWA March '93.
6. PQ Soluble Silicates, Bulletin 37-3, By PQ Corporation.
7. Statistical procedures for corrosion studies, USEPA.
8. Sodium Silicate for the simultaneous control of lead, copper and iron based corrosion, By Jonathan C. Clement, Wright Pierce Engineers
9. Optimizing treatment plant performance while implementing corrosion control, By Bernard Rousseau, Pennick Water Works.
10. The effectiveness of bicarbonate/pH process as treatment for corrosion control, By Judith Ann Judge, Fitchburg Water Department.

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