

**Final Report**  
**on the**  
**Corrosion Control Study**  
**for the**  
**New York City Water Supply System**

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**D E P**

New York City  
Department of Environmental Protection  
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March, 1993

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## **FORWARD TO FINAL REPORT**

The previous report entitled **Interim Report on the Corrosion Control Study for the New York City Water Supply System** (March 16, 1992) provided an account of the first six months of research aimed at determining the best course of water treatment for controlling lead and copper corrosion from plumbing in New York City buildings.

For each course of treatment subjected to study, attention was given to data revealing water quality trends for lead and copper levels analyzed in first draw drinking water samples. Discussed were how these trends were influenced by: 1) changes in raw water quality conditions, 2) changes in the manner in which the experimental system was operated, or 3) the manner in which the City's water supply system was operating.

In several circumstances, experimental data revealed an anomalous result or contradictory trend unable to be fully explained at the time the **Interim Report** was completed. Further investigations have revealed that, in most instances, an experimental flaw (either procedural or equipment-related) was found to be the cause; and was subsequently corrected during the final phase of research evaluation. For example, it is believed that poor hydraulics in the experimental system explains the previously observed discrepancies in the effectiveness of the calcium-based (blended) orthophosphate treatment methods in comparative testing at pH 7.0 and pH 7.5.

For the purpose of providing concise and relevant findings, further explanations for the observed experimental variances encountered during the course of this study were omitted from this report. That such variance did exist, and was unavoidable in most instances, has not undermined the integrity of the study or the ability to draw proper conclusions from the research work described herein.

In developing the **Final Report**, all existing data and information from the corrosion control investigations was vigorously reevaluated and reformatted. Erroneous data and statistical outliers were discarded so that conclusions on the effectiveness of different treatment methods could be more clearly discerned.

The result is a more straightforward assessment of the effectiveness of various courses of treatment for controlling lead and copper in New York City's drinking water.

Rocco A. Mastronardi, P.E.  
March 5, 1993

## **EXECUTIVE SUMMARY**

Public health implications of lead in first draw quantities of residential drinking water and the need to reduce the copper content of sewage sludge have resulted in the implementation of a corrosion control study by the New York City Department of Environmental Protection, Bureau of Water Supply and Wastewater Collection.

Utilizing a unique pipe rack system, incorporating both U.S. Army Construction Engineering Research Laboratory (CERL) loop and American Water Works Association Research Foundation (AWWARF) loop designs, corrosion control studies were implemented on May 3, 1991 and completed on July 10, 1992.

This report provides the results of the corrosion control studies for the purpose of satisfying the requirements of the STIPULATION AND ORDER between the City of New York and the New York State Health Department and providing support for the design and construction of interim corrosion control facilities proposed under the Sludge Management Program.

As recommended herein, the most suitable water treatment option for controlling lead and copper levels in the City's drinking water has been determined to be the addition of a blended orthophosphate formulation at a minimum dosage, following passivation, of 1.0 ppm as phosphate with sufficient sodium hydroxide (caustic soda) addition to establish a distribution system pH of between 7.0 and 7.5. Utilizing this treatment has resulted in average lead reductions of over 80 percent in first draw samples from lead coil piping, copper reductions of over 70 percent in first draw samples from copper coil piping, and reductions in lead joined copper piping of over 65 percent and over 70 percent for lead and copper respectively.

When utilizing the blended orthophosphate treatment at a pH of 7.5, corrosion rates for lead and copper, monitored in accordance with ASTM procedures, were found to be reduced from "severe" (without treatment) to "minimal" and "mild" ratings respectively.

## CORROSION THEORY

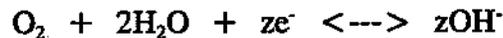
A tenet of elementary physics holds that all things in nature seek their lowest energy level. The corrosion of a metal surface in contact with drinking water occurs because the corrosion products are at a lower free energy level than the metal surface itself. This difference in free energy, manifested as an electrochemical potential, serves as the driving force for the reaction.

Corrosion is an electrochemical process that requires an anode, a cathode and an electrolyte to proceed. Theory states that anodic and cathodic sites are distributed throughout a pipe surface due to differences in crystal lattice structure or other imperfections in the metal. Drinking water, since it contains ions, serves as the electrolyte.

At the interface between a metal surface and drinking water there exists a potential difference due to the tendency of the metal to go into equilibrium with its dissolved state. This can be generically written as:



This equation indicates that the metal corrodes, or is converted to an oxidized form, as the reaction goes to the right. This "anodic" reaction is coupled with a set of "cathodic" reactions, which consume the liberated electrons, such as the reduction of oxygen:



Theoretically, these reactions will continue until an equilibrium condition is established, at which time no further corrosion occurs.

The goal of chemical treatment for corrosion control is to interrupt the entire process by placing a barrier to the movement of ions to and from anodic and cathodic sites on a metal surface. This barrier can be established by either: 1) altering the solution chemistry of the oxidized species (the  $\text{Metal}^{z+}$ ) to form an insoluble precipitate which acts as a passivating film or 2) precipitating a completely different chemical species which will create a passivation film by "locking" onto the anodic or cathodic locations.

## LEAD CONTROL STRATEGIES

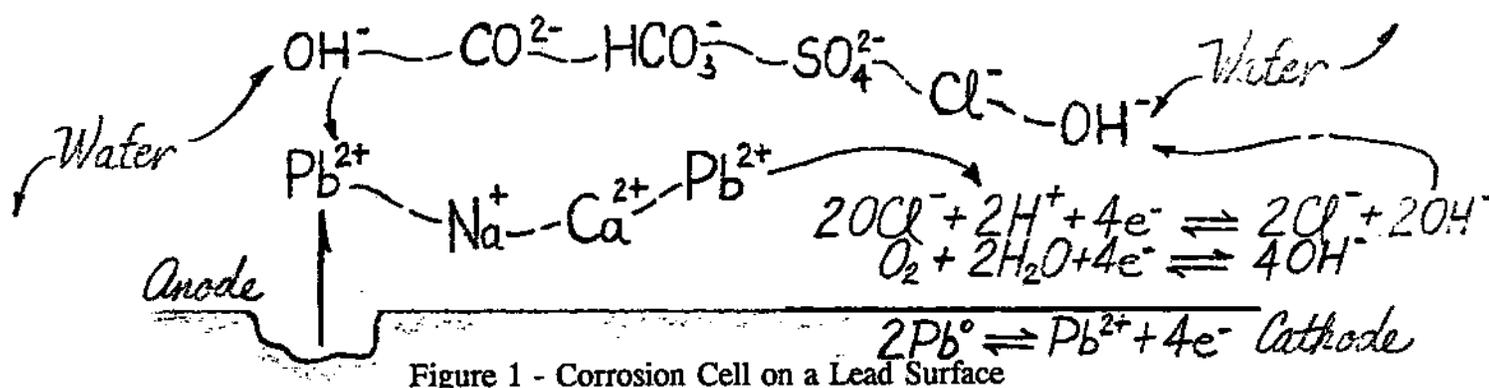
### Introduction

While it is necessary for the City to reduce the copper content of sewage sludge, the mobilization of lead from plumbing and service line sources is the major corrosion concern of the Bureau of Water Supply and Wastewater Collection. Since the water treatment strategies that can be used to control lead in drinking water have also been shown to adequately address copper corrosion, this discussion will primarily focus on the nature and control of lead solubility.

### Important Water Quality Characteristics in NYC Drinking Water

The concentration of lead in first draw drinking water results from the previously described corrosion reactions and the solution chemistry of the resulting oxidized lead species,  $Pb^{2+}$ . Figure 1 is a diagram of a corrosion cell for a lead surface.

The most important factors influencing lead corrosion are the physical and chemical characteristics of the potable water that is in contact with the lead-bearing materials. The parameters which appear to have the greatest influence are: pH, dissolved inorganic carbonate or DIC (which is based on total alkalinity), and temperature. Oxidant concentrations, such as dissolved oxygen and chlorine, play less of a role in lead corrosion than they do in the corrosion of steel, cast iron and ductile iron piping material. <sup>(1)</sup>



### pH

The pH of water is defined as the negative log of the hydrogen ion ( $H^+$ ) concentration. As a measuring device, it can be used to determine the relative presence of hydroxide ions based upon the equilibrium equation:



As Figure 1 indicates, the hydroxide ion plays an important role in corrosion, forming as a result of the reduction of various oxidants at cathodic sites. Hydroxide ions in solution can participate in the complexation of the oxidized lead species,  $Pb^{2+}$ , thereby forming insoluble

precipitates such as hydrocerussite,  $Pb_3(CO_3)_2(OH)_2$ . Altering the presence or availability of hydroxide ion via pH manipulation will, therefore, impact the corrosion process.

From a treatment perspective, the effectiveness of corrosion inhibitors is pH dependent. The optimum pH for polyphosphates is generally considered to be in a pH range of 6 to 7. With zinc addition, the pH range is increased to about 7.5. Orthophosphate inhibitors are also pH sensitive, with the most favorable results in the pH range of 6.5 to 7.5 for ferrous metals; however, for lead and zinc the optimum pH is higher, in the range of approximately 7.5 to 8.5.

### Dissolved Inorganic Carbonate (DIC)

Dissolved inorganic carbonate is not a commonly used water quality parameter. DIC is the total concentration of all dissolved inorganic carbonate species, including carbonic acid, bicarbonates, carbonates, and carbonate complexes and ion pairs. The formation of effective carbonate films (usually one of the solid basic lead carbonates with mineral names like hydrocerussite or plumbonacrite) depends on both DIC and pH levels. DIC can be calculated from total alkalinity, pH temperature and ionic strength. The dominant factors are pH and total alkalinity. DIC is typically expressed in mg C/L.

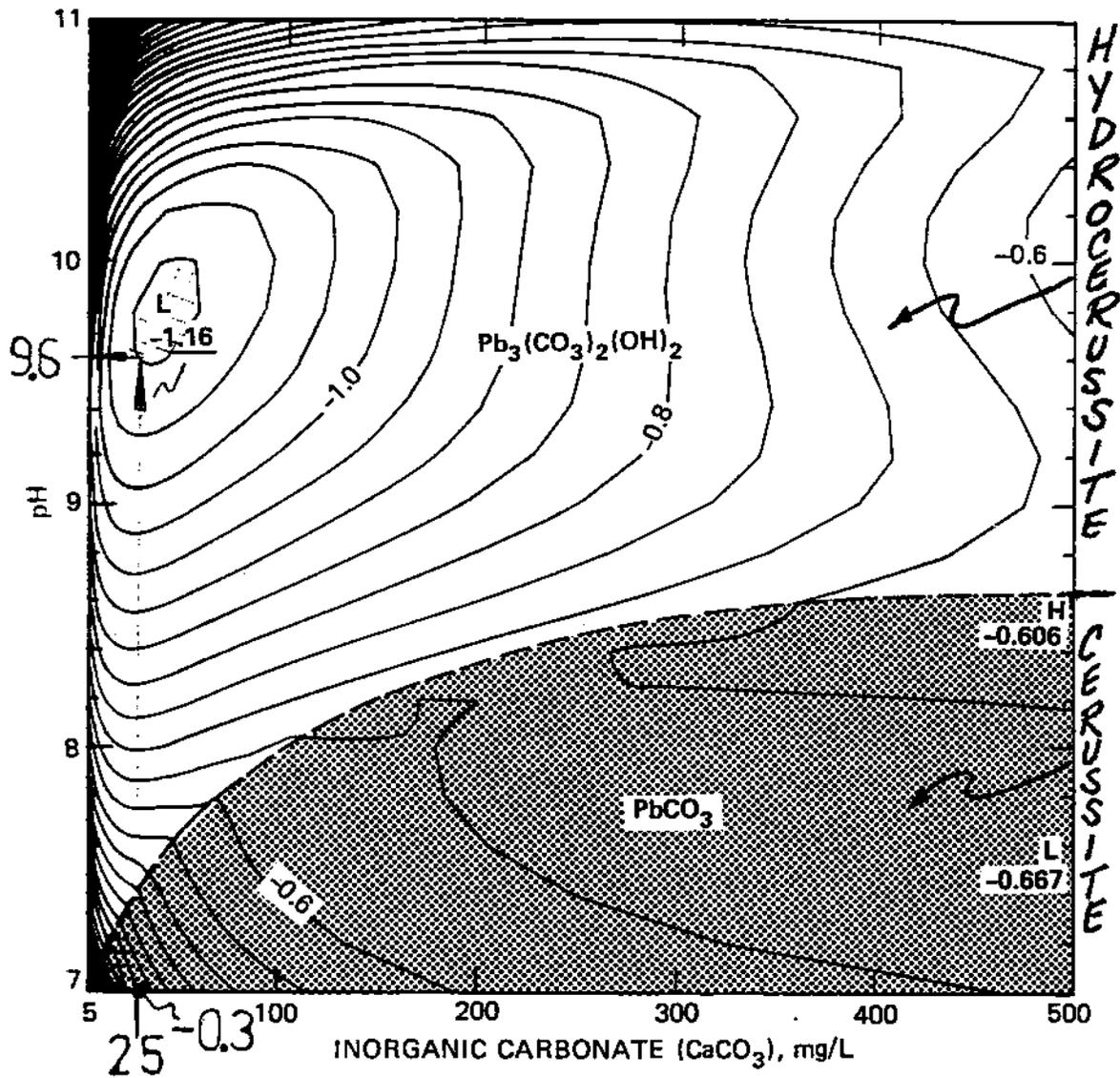
### Temperature

Water temperature can be an important factor in corrosion. Generally, the oxidation and diffusion rates of metals increase with temperature. Temperature is also important in affecting the solubilities of various solids that could form passivating films on pipe. Some solids increase in solubility as temperature increases: some decrease. The relationships are usually very non-linear as well.

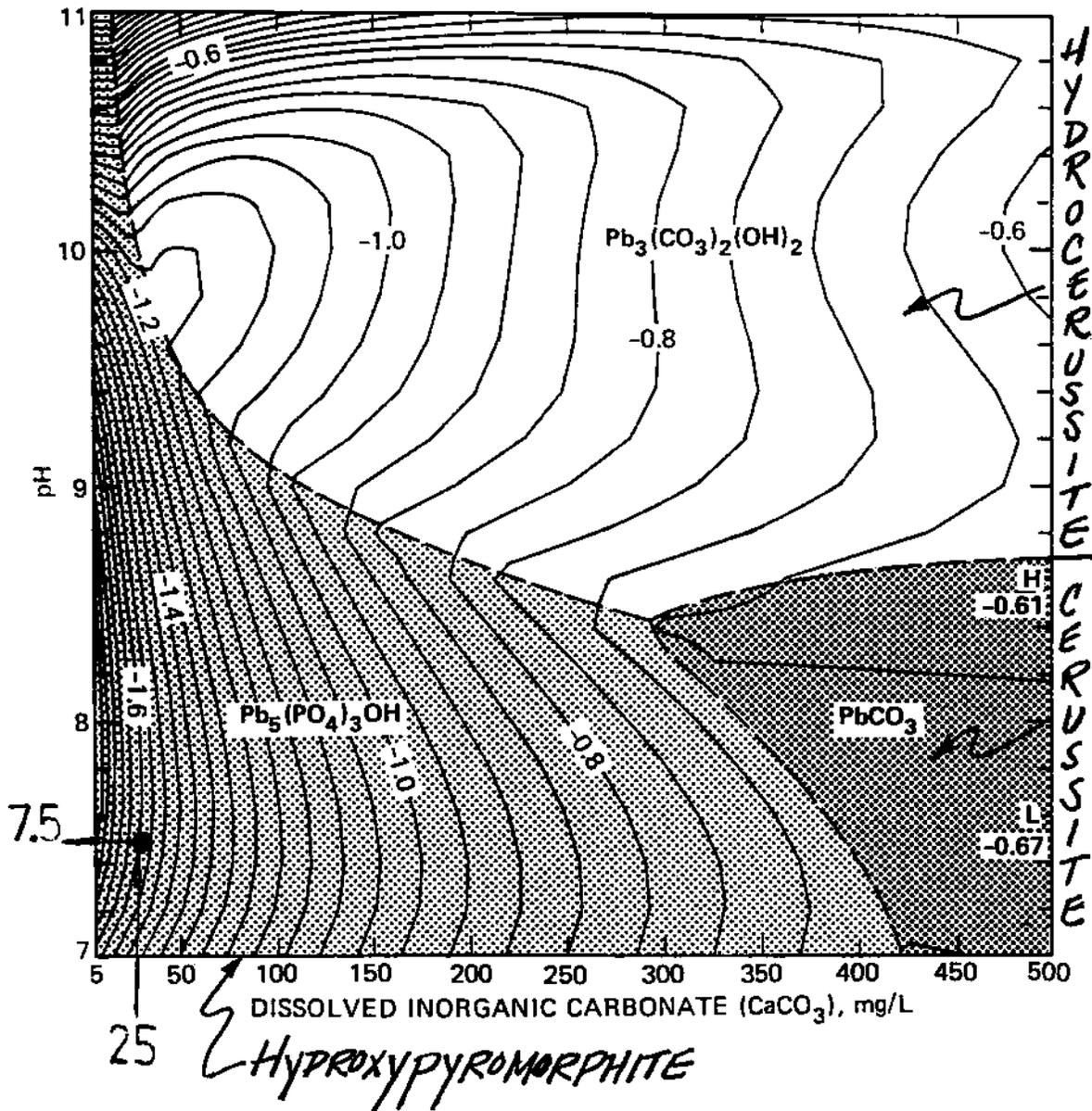
### Solution Chemistry of Lead

The corrosion of lead can be restricted by the formation of relatively insoluble films (passivating films) on the surface of the lead-bearing material. These films result from the complexation of oxidized lead by various ions or molecules in the water such as hydroxide ( $OH^-$ ), carbonate ( $CO_3^{2-}$ ), orthophosphate ( $PO_4^{3-}$ ), and polyphosphates. Some important passivating deposits that have been identified include  $Pb_3(CO_3)_2(OH)_2$  (hydrocerussite),  $Pb_{10}(CO_3)_6(OH)_6O$  (plumbonacrite),  $PbCO_3$  (cerussite), and  $PbO_2$  (plattnerite, a  $Pb^{4+}$  oxide). The forms of lead orthophosphate solids, which may be less soluble than hydrocerussite, have been defined as  $Pb_5(PO_4)_3OH$  (hydroxypyromorphite) and  $Pb_3(PO_4)_2$  (tertiary lead phosphate).

Understanding the formation and behavior of lead complexes has generally been accomplished by using chemical solubility models. With these models, simple systems can be simulated and the controlling solids identified and evaluated theoretically. Much work remains to be done in understanding the real world behavior of lead and lead complexes in



**FIGURE 2** A Contour Diagram of Lead(II) Solubility in a Pure System With Varying Hydrogen Ion and Carbonate Species Concentrations, at 25°C and  $I = 0.005$  mol/L (The boundary line position between the domains of the lead solids is approximate. Concentration units are Log (mg Pb/L). Local high and low points are marked "L" and "H", respectively.)



**FIGURE 3** A Contour Diagram for Lead(II) Solubility in a System Having 0.5 mg PO<sub>4</sub> /L Orthophosphate, With Varying Levels of pH and DIC, at 25°C and I = 0.005 mol/L (Solid phase domain boundary lines are approximate. Concentration units are log (mg Pb/L). Local high and low points are indicated.)

+ Ionic strength was determined from the average of:

$$I = (\text{avg. specific conductance}) \times (1.6 \times 10^{-5}), \text{Langelier (1936)}$$

$$I = (\text{avg. total dissolved solids}) \times (2.5 \times 10^{-5}), \text{Kemp (1971)}$$

For illustrative purposes an assumption is made that, due to various water quality considerations and space considerations, the maximum distribution system pH attainable is 7.5. At the previously established DIC concentration of 25 mg/L, the intersection contour line is -1.6, whose inverse log gives a lead level of 0.025 mg/L. Having started, on Figure 2, with an initial lead level of 0.50 mg/L, this gives a theoretical lead reduction of 95%. Even allowing for the ideality of the model, this example clearly shows the beneficial and practical influence of orthophosphate addition in controlling lead solubility.

*polyphosphate addition.*<sup>(2)(3)</sup> The addition of polyphosphates to control lead, particularly in the form of proprietary polyphosphate corrosion inhibitors, has become a controversial area. Despite the large economic investment made by the producers of commercially available formulations there exists a lack of published, peer-reviewed, scientific research concerning the differences between ortho- and polyphosphates relative to the formation of metallic precipitates and corrosion films in potable waters. It is known that polyphosphates revert back to orthophosphate *in-situ*. The rate and extent of this reversion has not been quantified since detailed chemical data and surface compound analyses have been almost universally absent from existing reports. The issue is further complicated by the lack of understanding by many users of the chemical of the differences between ortho- and polyphosphates, making interpretation of reported corrosion control experiences difficult.

Polyphosphates have long been used as a sequestering agent for iron and manganese, particularly for water utilities which rely on impounded surface water supplies, and have been proven effective at inhibiting iron and steel corrosion. However, experimentation to date has shown that the use of polyphosphate inhibitors for the purpose of controlling lead corrosion may actually increase the solubility of lead in plumbing systems and therefore entails considerable uncertainty and risk.

In light of the above and experimental time restrictions polyphosphates were subject to limited, but sufficient, experimentation in the corrosion control studies for the Bureau..

## DESIGN OF THE CORROSION CONTROL STUDY

### The Pipe Rack System

A total of 8 pipe rack assemblies were constructed for the Bureau's corrosion control study at Uptake Chamber No. 2 of Hillview Reservoir to receive water from the Catskill/Delaware supply. Each pipe rack consists of four (4) United States Army Construction Engineering Research Laboratory (USA-CERL) design and three (3) American Water Works Association Research Foundation (AWWA-RF) design loops.

### CERL Loops

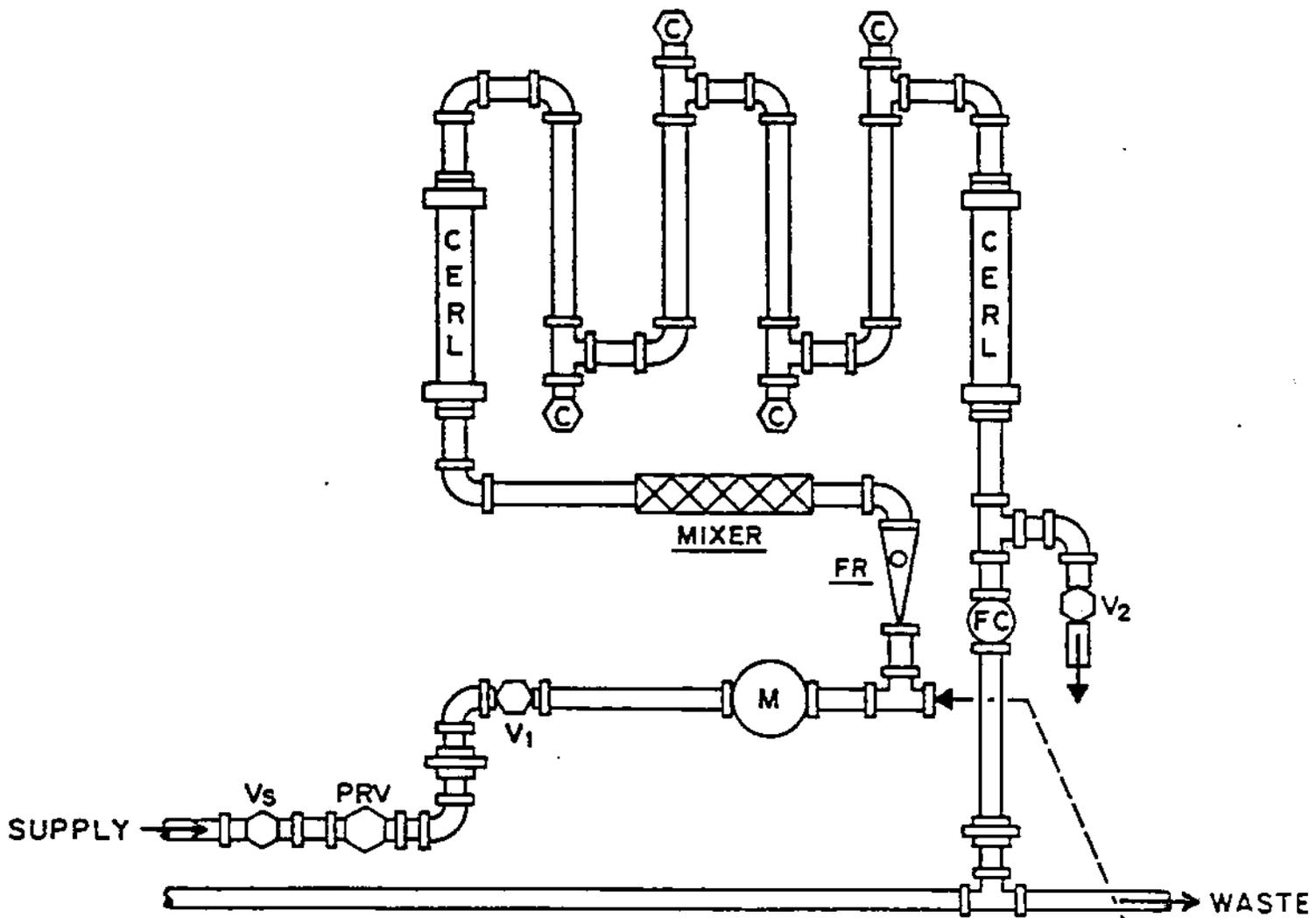
The diagram of a typical CERL loop unit is shown in Figure 4. A given pipe rack incorporates a section with four such units in series. Each CERL unit consists of four pipe segments and four coupon specimens of distribution system materials (one each of lead, copper, galvanized steel and mild steel) for a total of sixteen coupon and sixteen pipe segments per rack. This number of specimens allows for the testing of various pipe materials at varied durations of exposure during the study period. Both coupon and pipe specimens are included so that any differences in corrosion occurring on pipe walls could be compared to the corrosivity of the bulk water. The corrosion rate determination will be based on weight loss of the pipe insert of metal coupon performed according to ASTM Standard Method D-2688-83.

Pipe segments are designed into the CERL loop via the pipe sleeve method shown in Figure 5. The specimens are each 3 inches long and exposed a surface area of 10.25 inches to the water.

The metal coupons, each 1/2 inch x 3 inch x 1/16 inch, are mounted on a PVC plug by means of a teflon stem which allow the coupons to protrude into the middle of the pipe. They are all installed in the CERL loop oriented in the same direction relative to the flow of water through the loop.

### AWWA-RF Loops

AWWA-RF loops were fabricated in general accordance with the design shown in Figure 6. These loops consisted of a lead coil 45 feet x 1 inch ID, a copper coil 60 feet x 1/2 inch ID, and a copper coil soldered at 20 joints with 50/50 tin/lead solder, 60 feet x 1/2 inch ID. Flow can be cut-off and the AWWA-RF isolated from the CERL Loops by closing valves. Figure 7 is a schematic of the New York City pipe rack system.



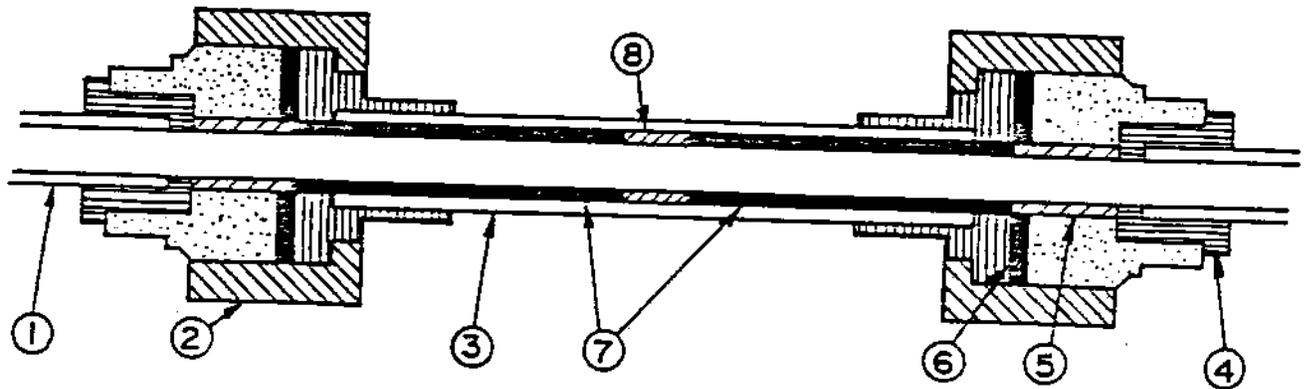
**MATERIAL LISTING**

- MIXER - STATIC
- V<sub>s</sub> - MAIN WATER SUPPLY SHUT-OFF VALVE
- PRV - PRESSURE REGULATING VALVE
- V<sub>1</sub> - TEST LOOP ISOLATION VALVES
- FC - FLOW RATE CONTROLLER, PVC, 3GPM
- FR - ROTAMETER, 0-5 GPM
- M - WATER METER, TOTALIZING
- C - CORROSION CUPONS
- CERL - PIPE SPECIMENS
- V<sub>2</sub> - SAMPLE VALVE, 1/4"
- PIPE & FITTINGS - 3/4", SCH. 40. PVC



FIGURE 4

-SCHEMATIC OF USA-CERL PIPE LOOP SYSTEM



- ① 3/4" PVC SERVICE LINE
- ② 1" UNION, PVC, SOCKET TYPE
- ③ 1 x 10" PIPE NIPPLE, PVC, SCH. 40
- ④ 1 x 3/4" REDUCING BUSHING, PVC, SOCKET
- ⑤ 3/4" PVC SPACER, SCH. 40, O.D. REDUCED 0.015"
- ⑥ UNION GASKET
- ⑦ CORROSION SPECIMENS, 3/4", O.D. REDUCED 0.030", MACHINED FROM SCH. 40 GALVANIZED STEEL OR STEEL PIPE
- ⑧ 3/4 x 2" SPECIMEN SEPARATOR, PVC, SCH. 40, O.D. REDUCED 0.015"

FIGURES  
CROSS-SECTION OF USA-CERL CORROSION TESTER

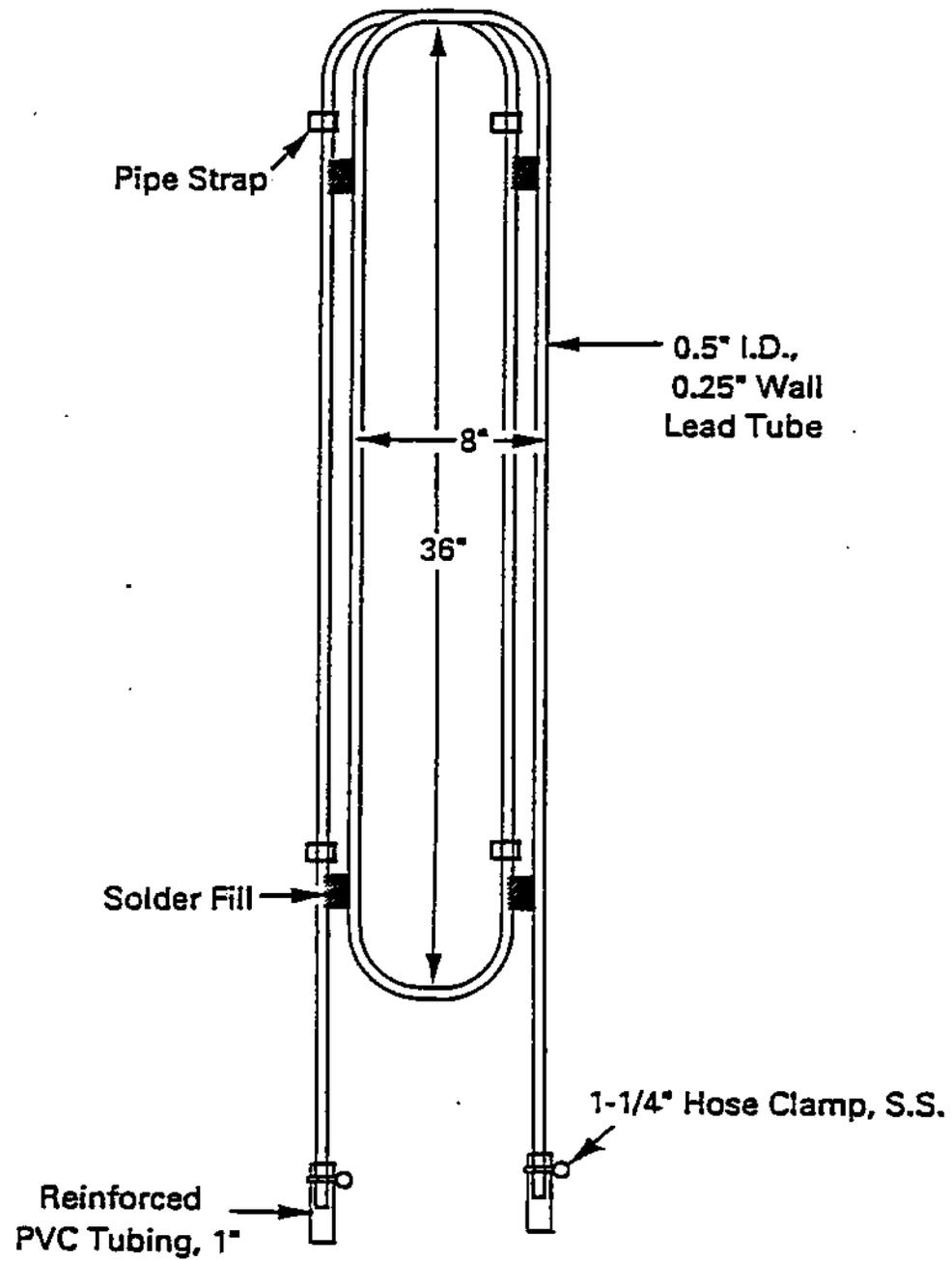


FIGURE 6

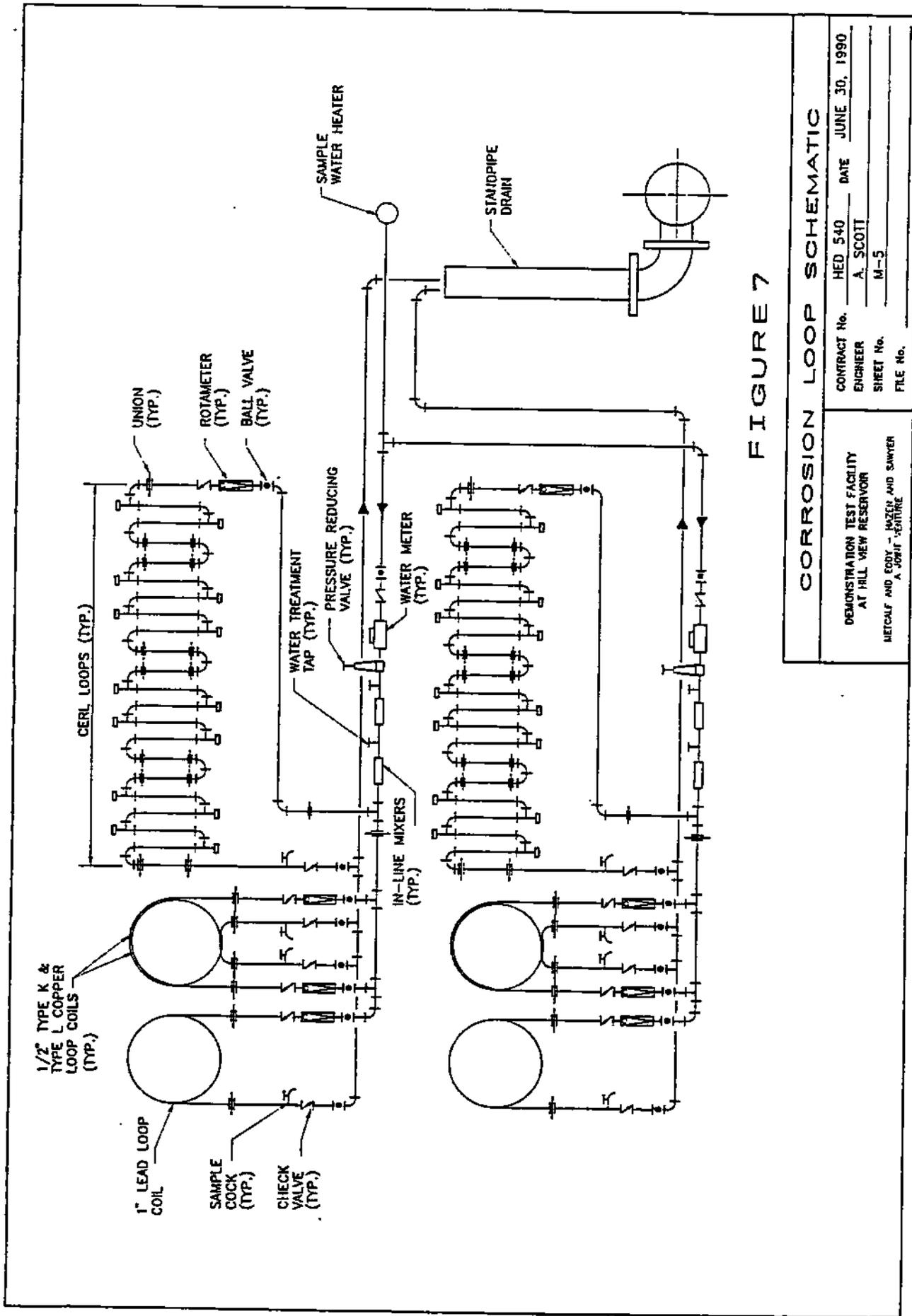


FIGURE 7

<b>CORROSION LOOP SCHEMATIC</b>	
CONTRACT No. HED 540	DATE JUNE 30, 1990
ENGINEER A. SCOTT	SHEET No. M-5
FILE No.	
DEMONSTRATION TEST FACILITY AT HILL VIEW RESERVOIR METCALF AND EDDY - HAZEN AND SAWYER A JOHN F. DEUTER	

## Experimental Protocol

As stated previously, eight pipe racks were operated for analyzing the Catskill/Delaware water supply, utilizing Kensico effluent water taken prior to caustic addition at Hillview Reservoir as the control in accordance with the following treatment alternatives:

- (Pipe Rack No. 1: Raw water control loop)
- Pipe Rack No. 2: caustic soda - pH 7.5
- Pipe Rack No. 3: zinc orthophosphate - pH 7.0
- Pipe Rack No. 4: zinc orthophosphate & caustic soda - pH 7.5
- Pipe Rack No. 5: blended orthophosphate - pH 7.0
- Pipe Rack No. 6: blended orthophosphate & caustic soda - pH 7.5
- Pipe Rack No. 7: blended polyphosphate - pH 7.0
- Pipe Rack No. 8: blended polyphosphate with silicate - pH 7.0

In accordance with recommendations made by the AWWA-RF Pipe Loop Project research contractor, total water flow through the pipe rack was set at 5 gpm. The CERL loop sections received 2 gpm and the 3 AWWA-RF pipe coils each received 1 gpm.

### CERL loops

During the course of the study, one set of four pipe segments and four coupons were extracted from each pipe rack every three months from the date of passivation for corrosion rate analysis.

### AWWA-RF Loops

On a bi-weekly basis thereafter, flow through the AWWA-RF coils was manually stopped for an overnight period and resumed no sooner than 16 later at which time first draw water samples were taken. Based on evaluation of historical pipe loop studies, this sampling frequency was to allow for better than 10% accuracy and 95% confidence relative to potential variability for sampling results for lead and copper.<sup>(4)</sup>

In addition to lead and copper, analyses for the following water quality parameters were also undertaken during the initial months of the study:

pH	temperature	hardness	total dissolved solids
HPC	total coliform	trihalomethanes	iron
zinc	calcium	sodium	magnesium
turbidity	color	sp. conductance	chlorine
residual	dissolved oxygen	alkalinity	

With the exception of total trihalomethanes\*, no changes of significance were observed for the above listed parameters as analyzed in first draw samples from the respective pipe racks. They were eventually eliminated from the sampling program, with the study primarily focusing on lead and copper as the analytes of concern.

\* Total trihalomethanes appeared to average a 10 ug/L (ppb) increase in phosphate treatments utilizing caustic soda addition on the basis of two (2) sampling events for each of the treatment methods studied.

## **RESULTS OF THE CORROSION CONTROL STUDY**

### **Catskill/Delaware Water Supply**

The combined Catskill/Delaware water system provides 90% of the city's average daily consumption of 1,500 million gallons per day from supplies which are softer and less alkaline, though not considerably, than those of the Croton. For this reason, eight pipe racks were constructed at Hillview Reservoir so that an optimum corrosion control treatment strategy, which could be applied to both systems, could be determined.

Since Catskill and Delaware source waters are normally combined at Kensico Reservoir in Valhalla, NY, the Hillview pipe racks were constructed to receive Kensico effluent water from the Delaware Aqueduct in Uptake Chamber No. 2. During the course of the study, however, the mode of operation for the Catskill/Delaware system changed with the Delaware Aqueduct being placed on a complete by-pass of Kensico on October 1. Delaware water was also intermittently sent to the West Branch of the Croton Reservoir due to subsequent episodes of high turbidity or aeration. From the point of view of the corrosion control study, these operational and associated raw water quality changes did not appear to affect the overall results of the study. A more thorough discussion and evaluation of water quality results and the impact of corrosion control treatment is provided in following section.

### **Water Quality Results-Lead and Copper Reductions**

The models utilized for determining the reductions of lead and copper in first draw drinking water were the American Water Works Association-Research Federation (AWWA-RF) design coils described earlier. Results of first draws from the lead (Pb), copper (Cu), and jointed-copper (Jt.-Cu) coils receiving different types of treatment (Pipe Racks Nos. 2 through 8) were compared to those of the Catskill/Delaware control loop (Pipe Rack No. 1). Reductions were determined on a relative basis and are shown graphically in Figures 8 through 11.

#### **Lead Reduction**

Figure 8 shows average lead reductions in first draws from the 45 ft. x 1 in. ID lead coil after 16 hours detention for the one year period of study. The effectiveness of each treatment method is ranked as follows:

- (1) Pipe Rack No. 4: zinc orthophosphate & caustic soda - pH 7.5; 89% avg. reduction
- (2) Pipe Rack No. 2: caustic soda - pH 7.5; 80% avg. reduction
  - Pipe Rack No. 5: blended orthophosphate - pH 7.0; 80% avg. reduction
  - Pipe Rack No. 6: blended orthophosphate & caustic soda - pH 7.5; 80% avg. reduction
- (3) Pipe Rack No. 3: zinc orthophosphate - pH 7.0; 71% average reduction

Given the non-ideality of the experimental lead-water matrix system, these results correspond well with the theoretical prediction of lead reduction provided earlier.

### Copper Reduction

Figure 9 shows percent copper reductions in first draws from the 60 ft. x 1/2 in. ID copper coil after 16 hours detention for the one year period of study. The effectiveness of each treatment method is ranked as follows:

- (1) Pipe Rack No. 5: blended orthophosphate - pH 7.0; 88% avg. reduction
- (2) Pipe Rack No. 4: zinc orthophosphate & caustic soda - pH 7.5; 84% avg. reduction
- (3) Pipe Rack No. 2: caustic soda - pH 7.5; 64% avg. reduction
- (4) Pipe Rack No. 3: zinc orthophosphate - pH 7.0; 47% avg. reduction
- (5) Pipe Rack No. 6: blended orthophosphate & caustic soda - pH 7.5; 43% avg. reduction

### Lead and Copper Reductions in jointed copper pipe

Figures 10 and 11 show the percent reductions of lead and copper, respectively, in first draws from the 60 ft. x 1/2 in. ID copper piping with 25 sweated 50/50 lead-tin solder joints. The effectiveness of each treatment method is ranked as follows:

For lead (due to joints):

- (1) Pipe Rack No. 5: blended orthophosphate - pH 7.0; 67% avg. reduction
- (2) Pipe Rack No. 6: blended orthophosphate & caustic soda - pH 7.5; 65% avg. reduction
- (3) Pipe Rack No. 3: zinc orthophosphate - pH 7.0; 58% avg. reduction
- (4) Pipe Rack No. 4: zinc orthophosphate & caustic soda - pH 7.5; 50% avg. reduction
- (5) Pipe Rack No. 2: caustic soda - pH 7.0; no reduction  
(In fact, concentrations of lead increased in first draws from this loop.)

All of the effective treatments (3, 5, & 6) for lead resulted in first draws from this coil at or below the action level of 0.015 mg/L.

For copper:

- (1) Pipe Rack No. 4: zinc orthophosphate - pH 7.0; 87% avg. reduction
- (2) Pipe Rack No. 5: blended orthophosphate - pH 7.0; 81% avg. reduction
- (3) Pipe Rack No. 6: blended orthophosphate & caustic soda - pH; 71% avg. reduction
- (4) Pipe Rack No. 2: caustic soda - pH 7.0; 70% avg. reduction
- (5) Pipe Rack No. 3: zinc orthophosphate & caustic soda - pH 7.5; 49% avg. reduction

# Avg. Lead Reductions in 45' Solid Lead Coil

## Catskill/Delaware Supply - One Year Study

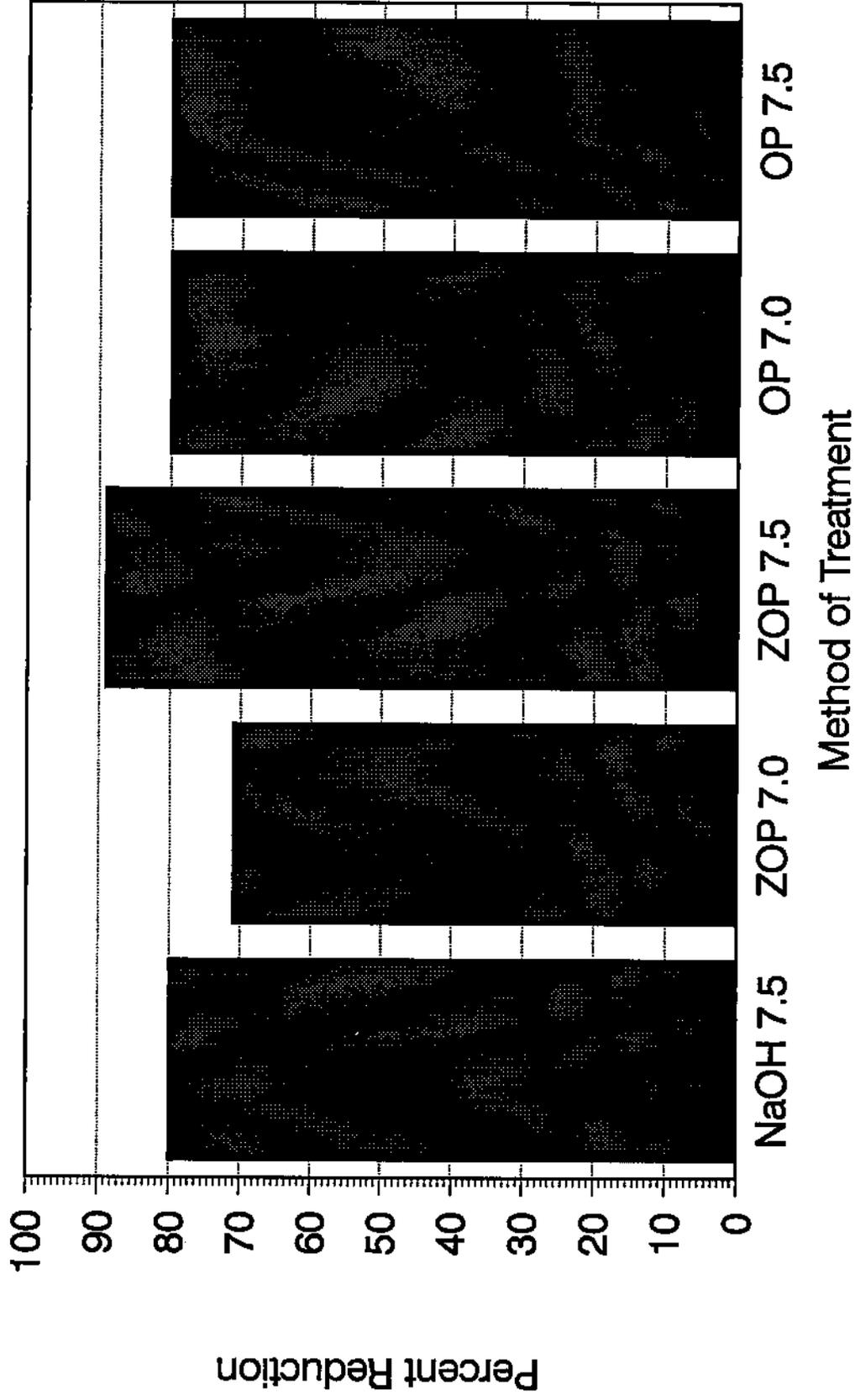


Figure 8 Average Phosphate Dosage: 1.0 ppm

# Avg. Copper Reductions in 60' Solid Copper Coil

## Gatskill/Delaware Supply - One Year Study

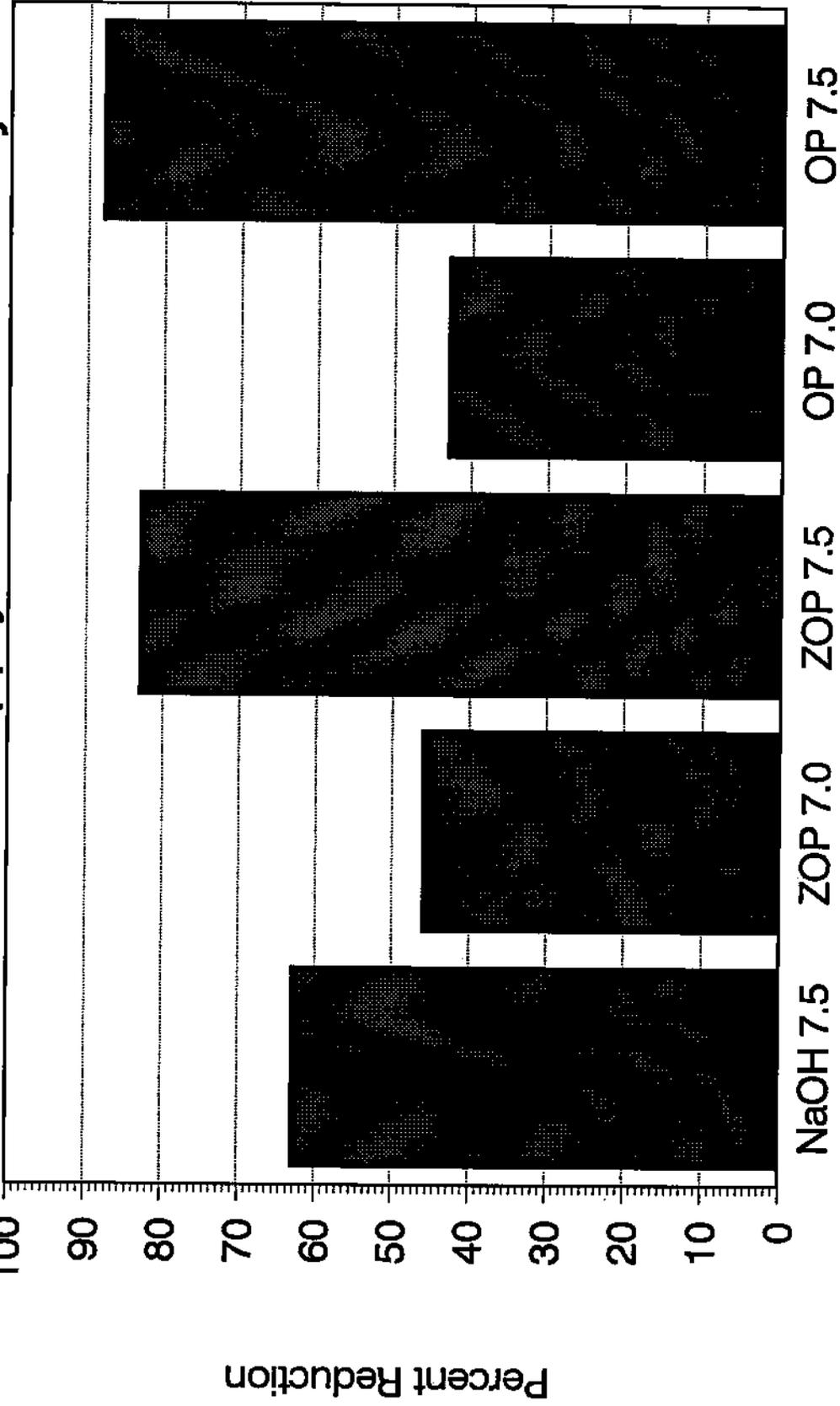


Figure 9  
Average Phosphate Dosage: 1.0 ppm

# Avg. Copper Reductions in 60' Jointed Copper Coil

## Catskill/Delaware Supply - One Year Study

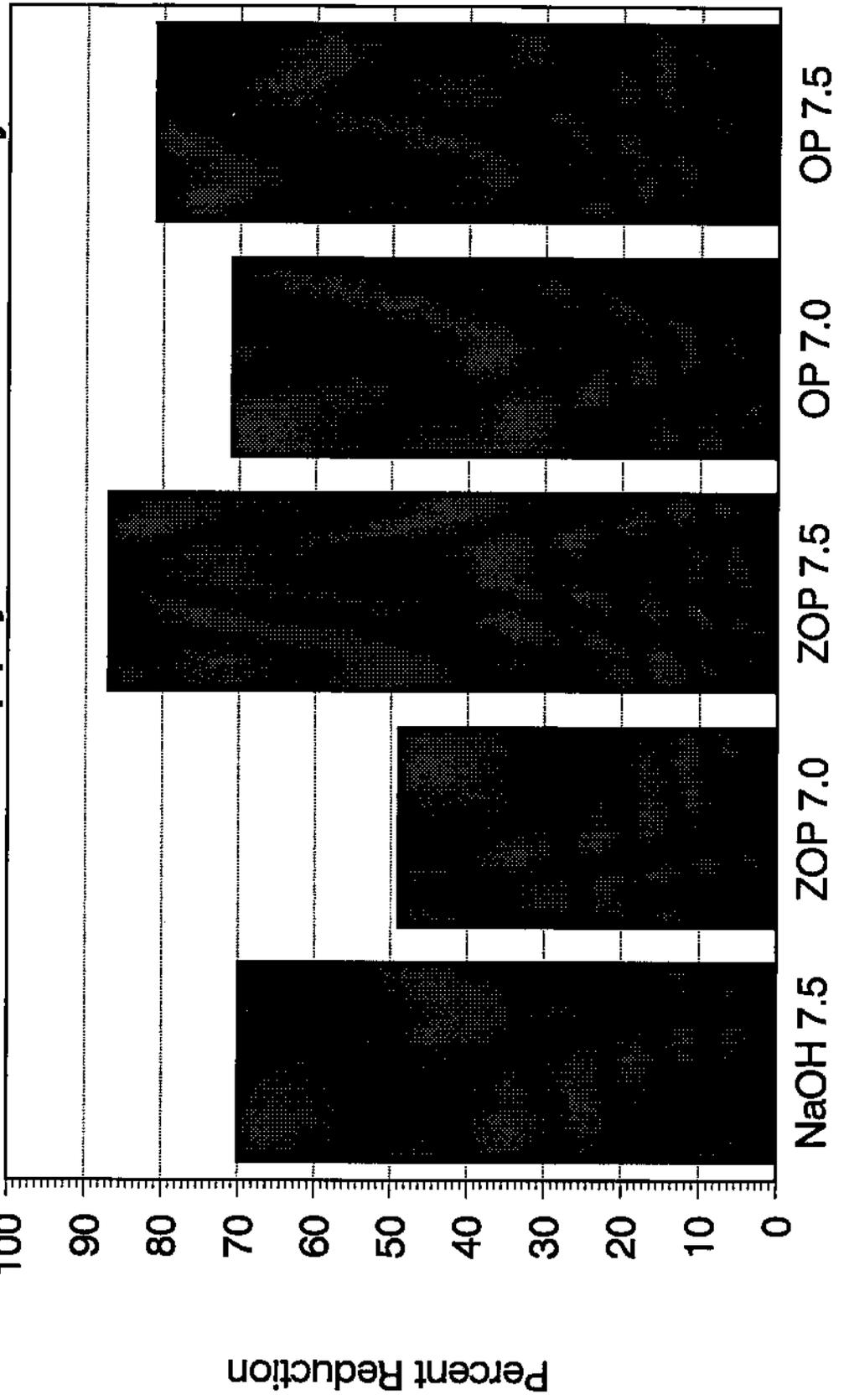


Figure 11  
Average Phosphate Dosage: 1 ppm

# Avg. Lead Reductions in 60' Jointed Copper Coil

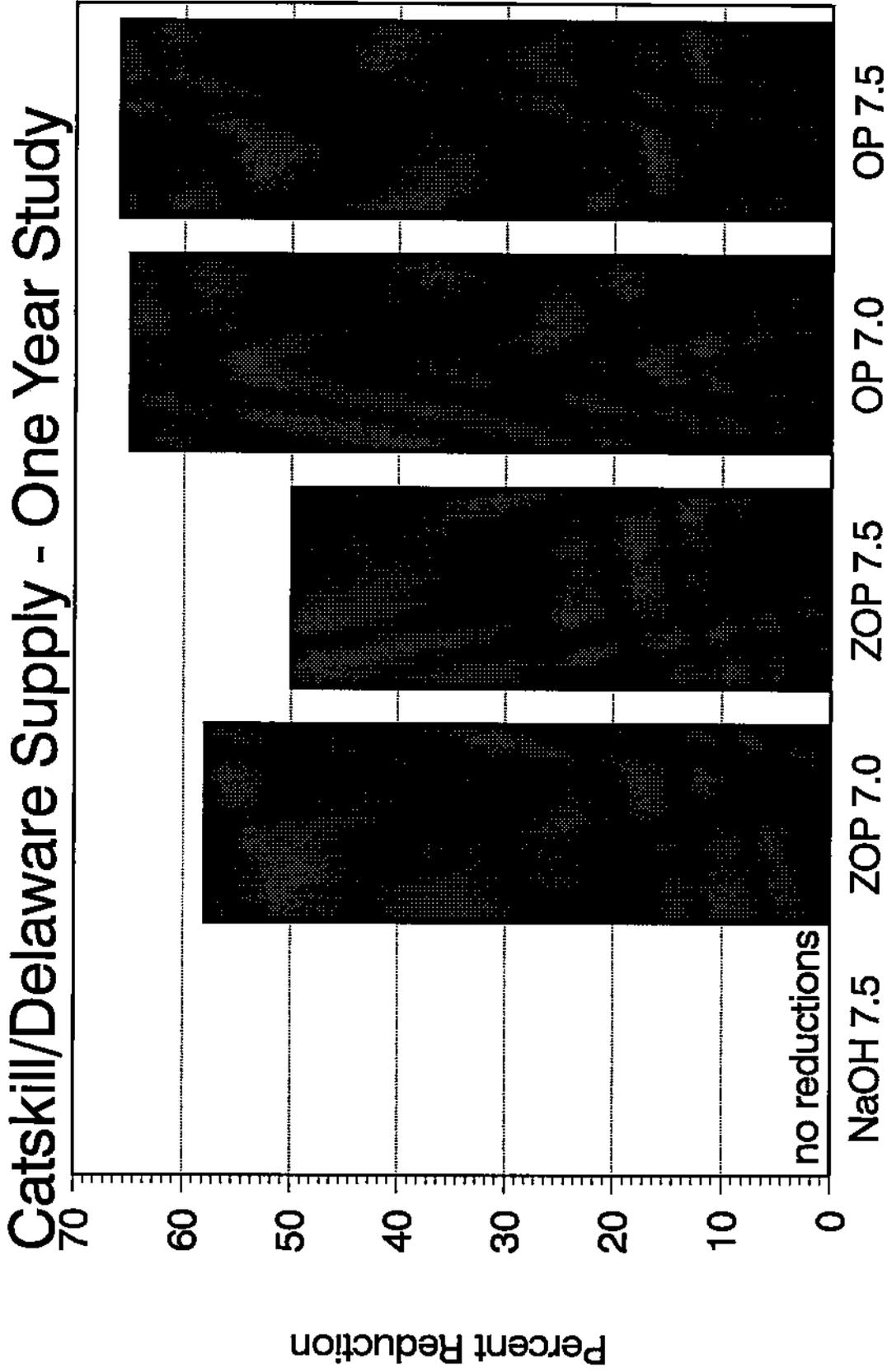


Figure 10 Average Phosphate Dosage: 1.0 ppm

## Water Quality Ratings

The water quality ratings on treatment effectiveness for lead and copper reduction are as follows:

- (1) Pipe Rack No. 6 - blended orthophosphate & caustic, pH 7.5
- (2) Pipe Rack No. 4 - zinc orthophosphate & caustic, pH 7.5
- (3) Pipe Rack No. 5 - blended orthophosphate, pH 7.0
- (4) Pipe Rack No. 2 - caustic soda (NaOH), pH 7.5
- (5) Pipe Rack No. 3 - zinc orthophosphate, pH 7.0

## Corrosion Loss Rates-Results of Quarterly Testing

### Coupon Specimens

Figures 12 through 15 are bar graphs depicting corrosion loss rates for metal coupon specimens removed from the pipe racks every quarter during the course of the respective treatments. Evaluation of corrosion was performed according to ASTM Standard Method D-2688-83 and evaluated based on the following criteria:

Steel & Galvanized Steel	Lead & Copper	Evaluation
0 - 2 mpy	0.0 - 0.2 mpy	Minimal corrosion
2 - 5 mpy	0.2 - 0.5 mpy	Mild corrosion
5 - 10 mpy	0.5 - 1.0 mpy	Moderate corrosion
> 10 mpy	> 1.0 mpy	Severe corrosion

Compared to the Control, the figures suggest that all of the orthophosphate-based treatments and one blended polyphosphate treatment provide some measure of improved corrosion resistance for steel and galvanized steel surfaces. It is upon the target metals of lead and copper, however, that the most significant improvements are seen. The effectiveness of each treatment method corroborates the data obtained from the water quality analyses of first draws from the lead and copper (and copper-jointed) coils. Once again, the orthophosphate treatments that employ caustic addition for pH adjustment to 7.5 appear to give the most favorable corrosion rate reductions for these metals.

### Pipe Insert Specimens

The results obtained from pipe insert specimens, shown in Figures 16 through 19, show a considerably different picture for reduced corrosion rates on steel and galvanized steel surfaces. This is, no doubt, due to the effect of erosion velocities on the pipe wall as compared to the corrosivity of the bulk solution. Where shear velocity serves to apparently dominate the impact of corrosion inhibitors for steel and galvanized steel, there may be increased bulk transport of inhibitor species to the pipe wall which reduces the corrosion rates of lead and copper to a greater extent in comparison to the analyses provided by the coupon specimens. As industry-wide experience would suggest, the blended polyphosphate inhibitor of Loops 7 & 8 provides the best results for steel and galvanized steel protection, but offers little in the way of corrosion inhibition for lead and copper. It is assumed that protection for the target metals comes by way of in-situ reversion of the polyphosphate to orthophosphate.

# Corrosion Rate Data

Catskill/Delaware Supply - 3 Month Specimens

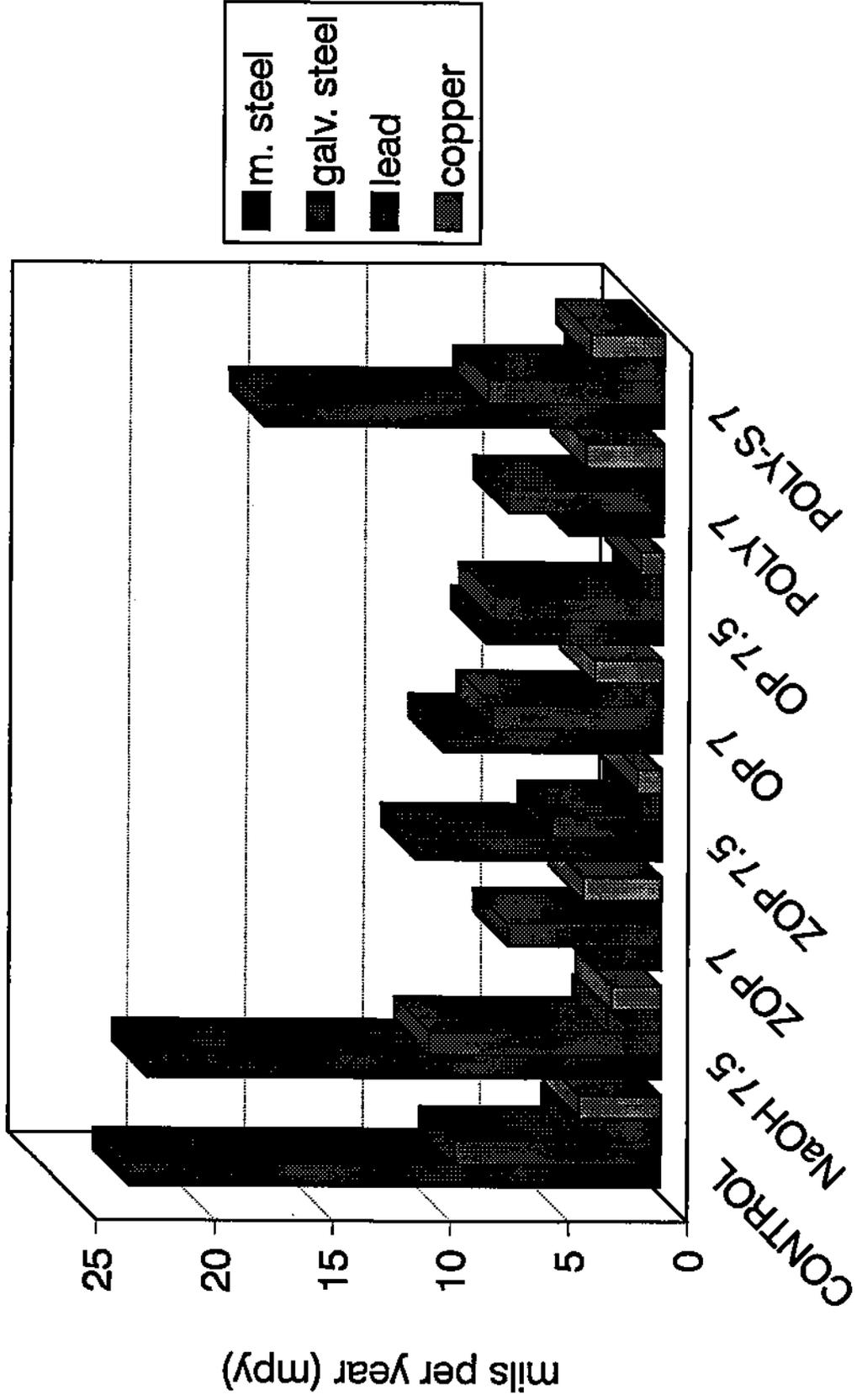


Fig. 12 Coupon Loss Rate for each Method of Treatment

# Corrosion Rate Data

Catskill/Delaware Supply - 6 Month Specimens

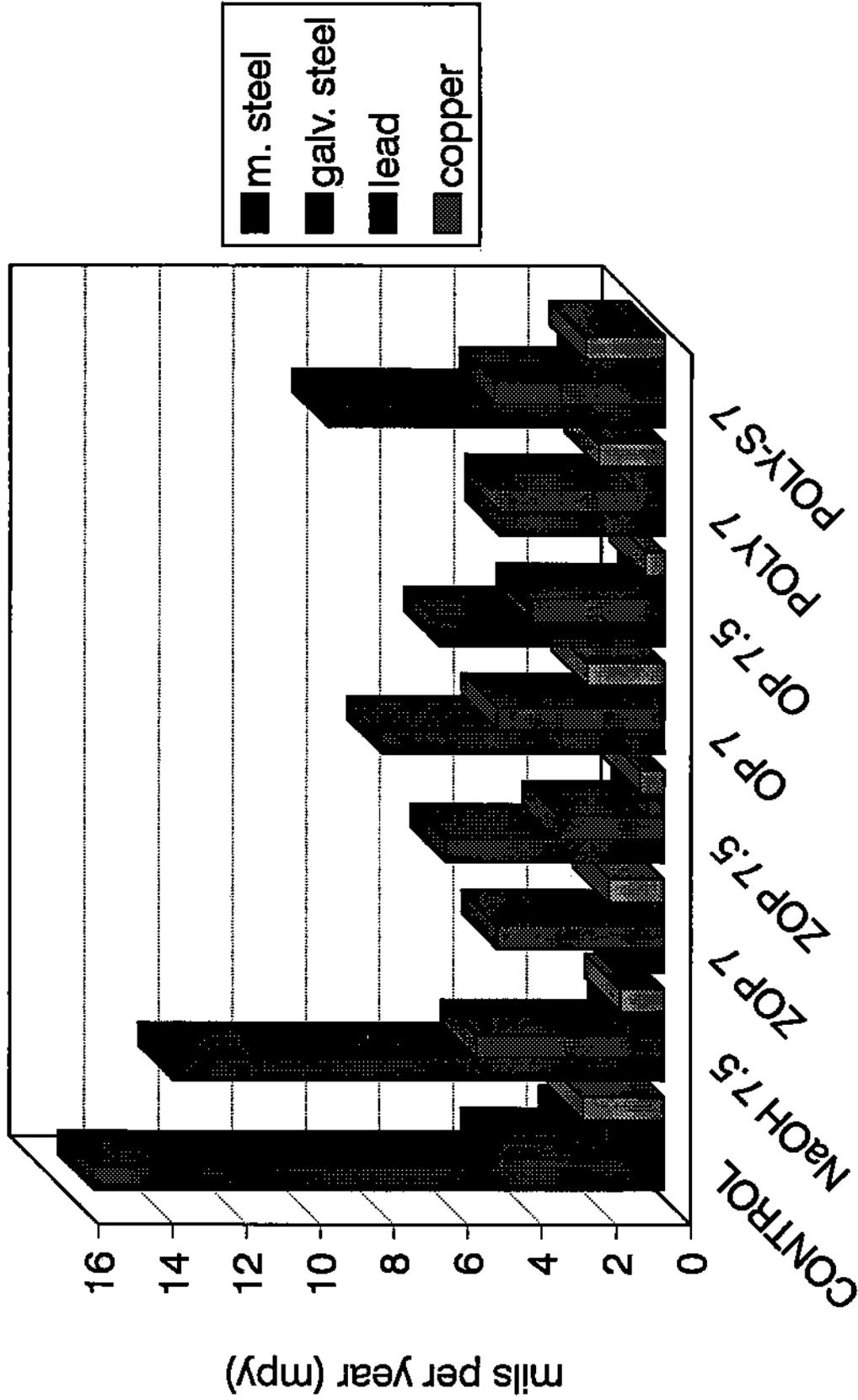


Fig. 13 Coupon Loss Rate for each Method of Treatment

# Corrosion Rate Data

Catskill/Delaware Supply - 9 Month Specimens

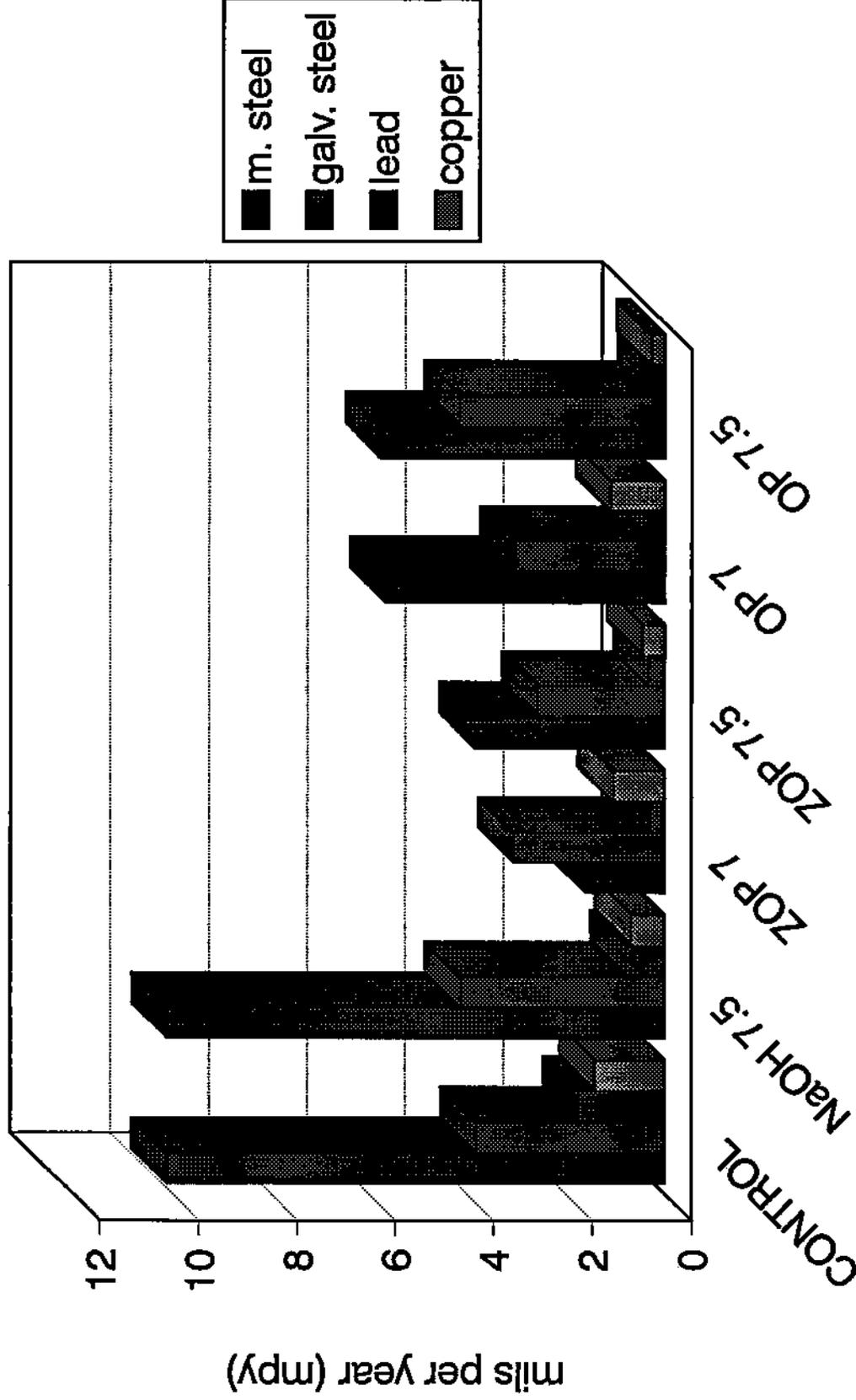


Fig. 14 Coupon Loss Rate for each Method of Treatment (polyphosphate treatments 9&10 suspended)

# Corrosion Rate Data

Catskill/Delaware Supply - 12 Month Specimens

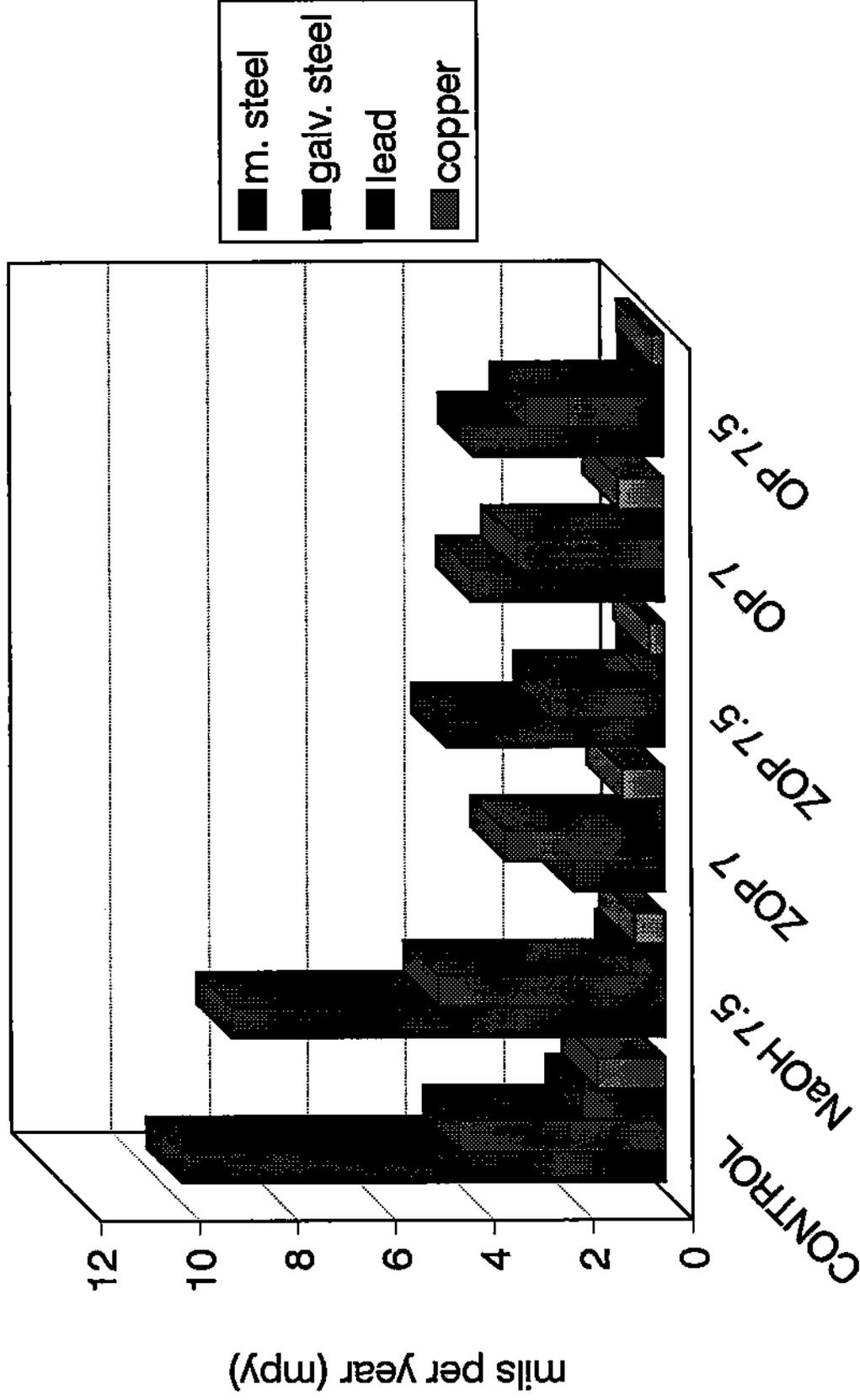


Fig. 15 Coupon Loss Rates for each Method of Treatment (polyphosphate treatments 9&10 suspended)

# Corrosion Loss Data

Catskill/Delaware Supply - 3 Month Specimens

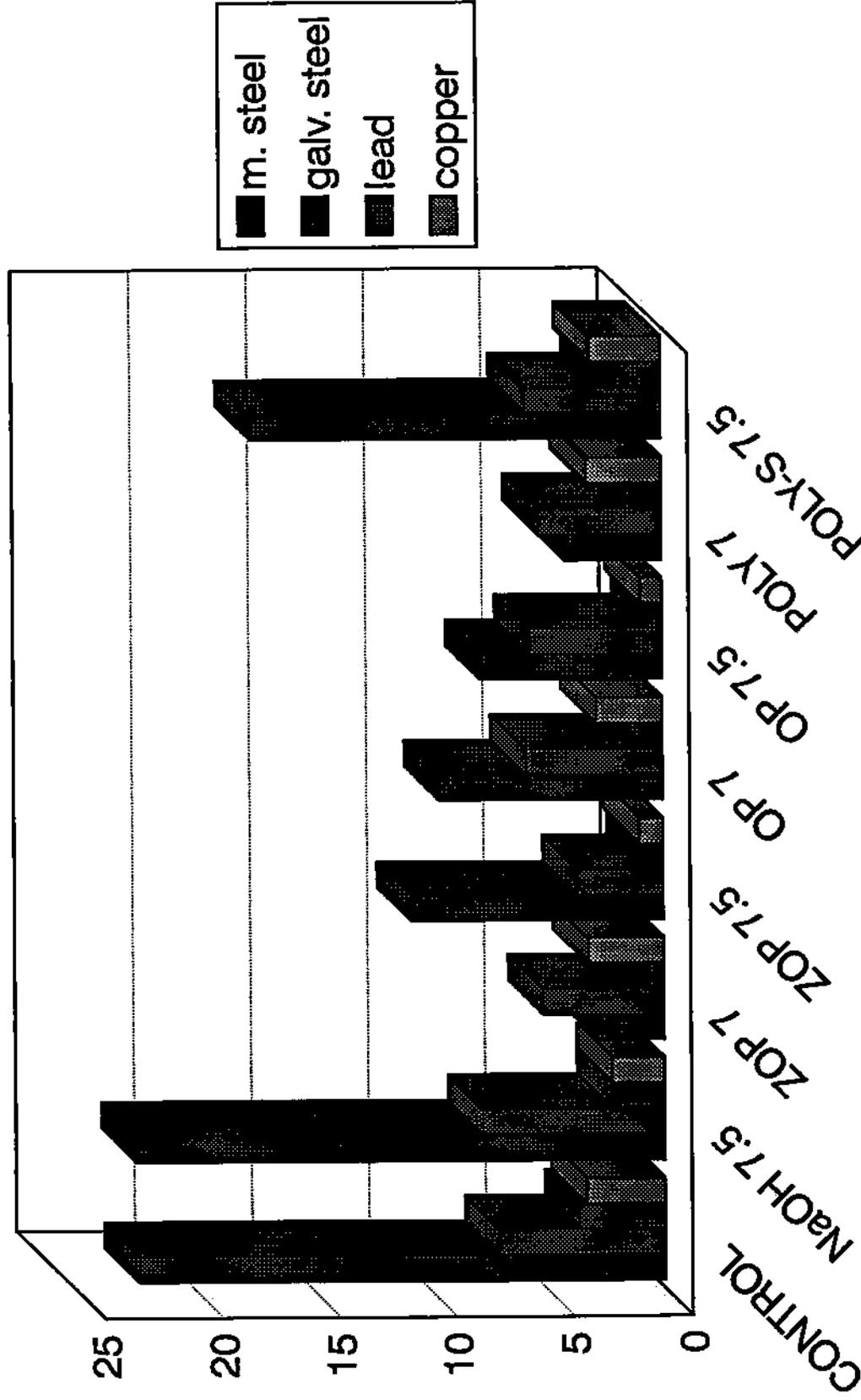


Fig. 16 - Pipe Insert % Loss for each Method of Treatment

# Corrosion Loss Data

Catskill/Delaware Supply - 6 Month Specimens

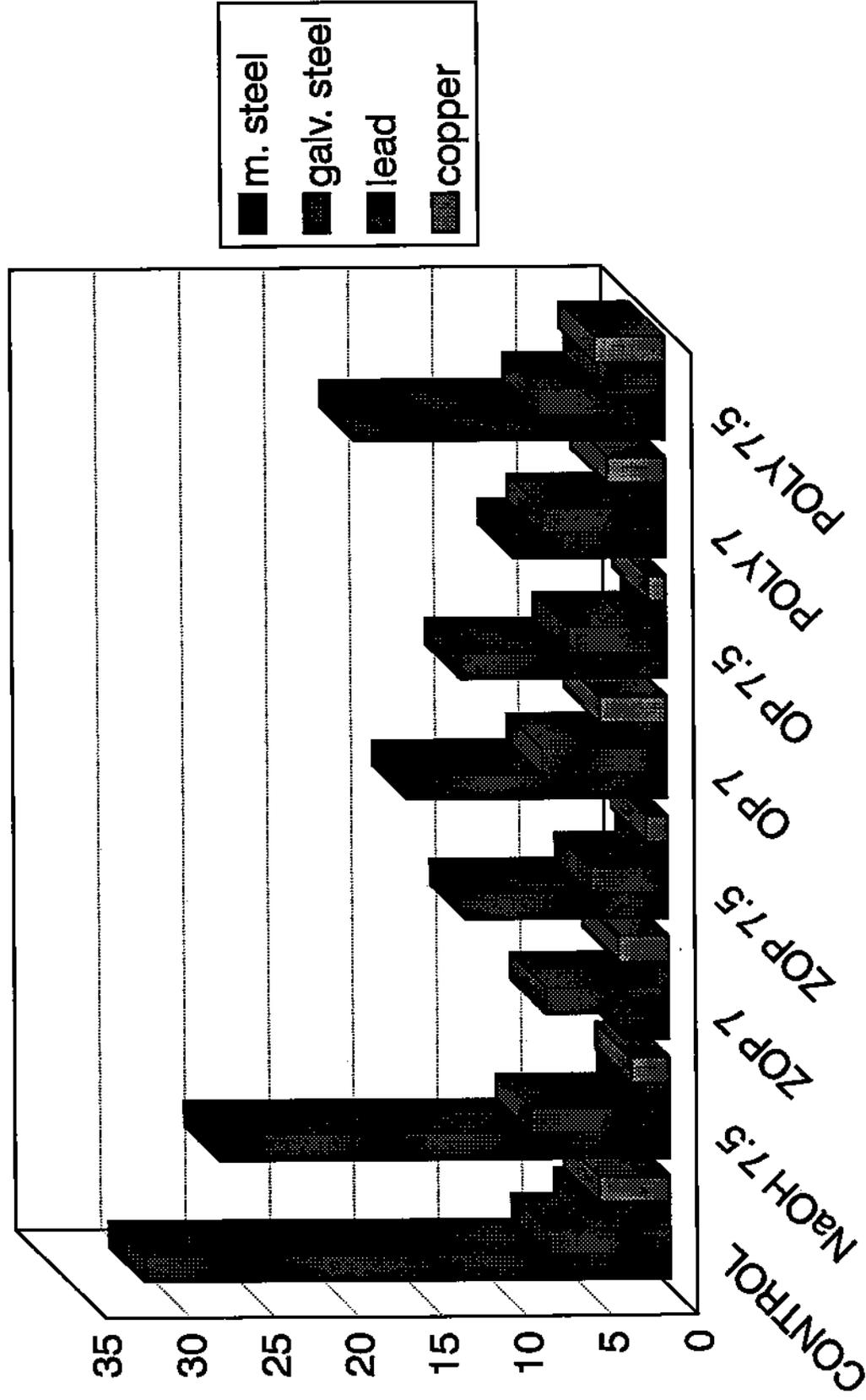


Fig. 17 - Pipe Insert % Loss Rate for each Method of Treatment

# Corrosion Loss Data

Catskill/Delaware Supply - 9 Month Specimens

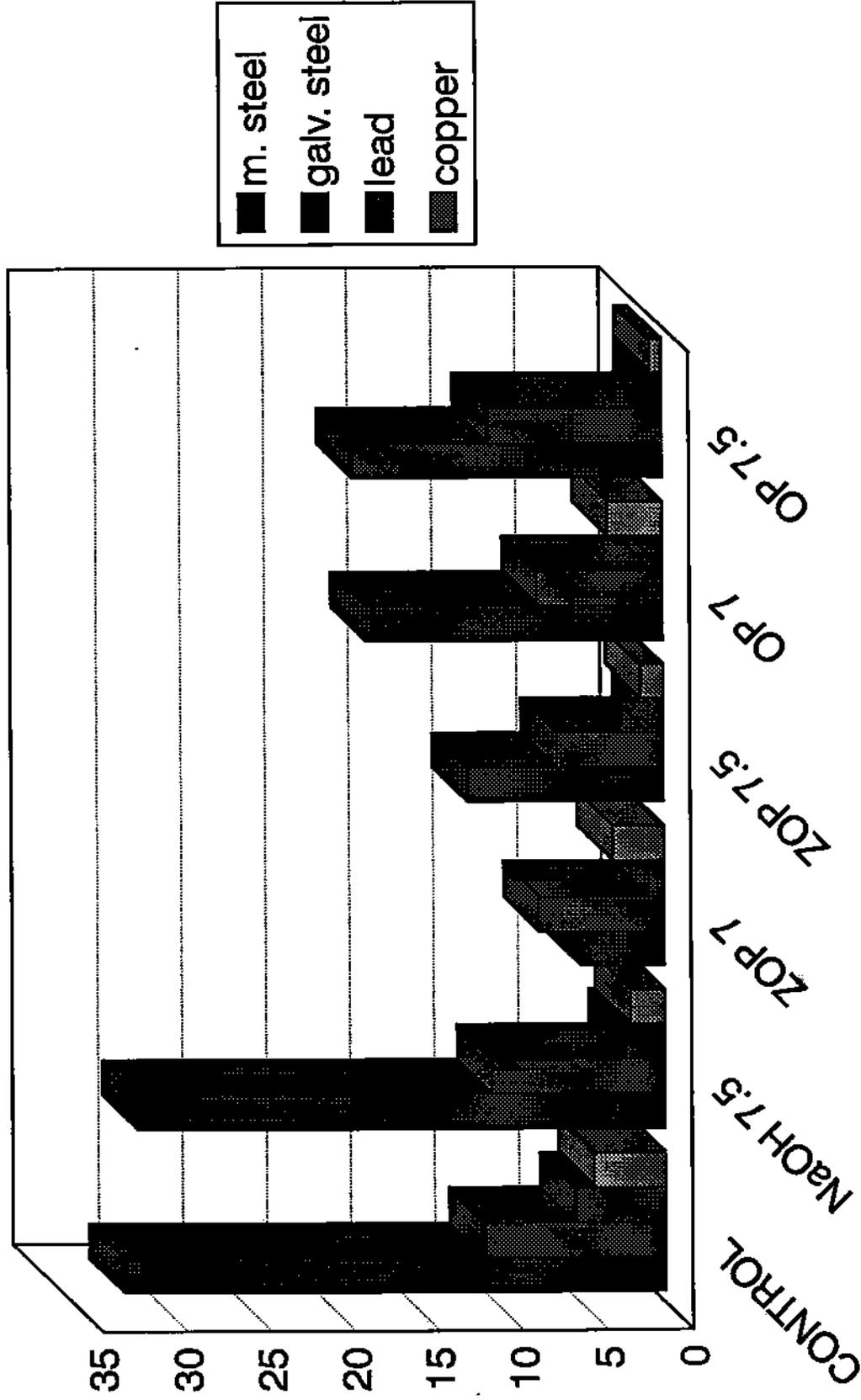


Fig. 18 - Pipe Insert % Loss for each Method of Treatment (polyphosphate treatments 9&10 suspended)

# Corrosion Loss Data

Catskill/Delaware Supply - 12 Month Specimens

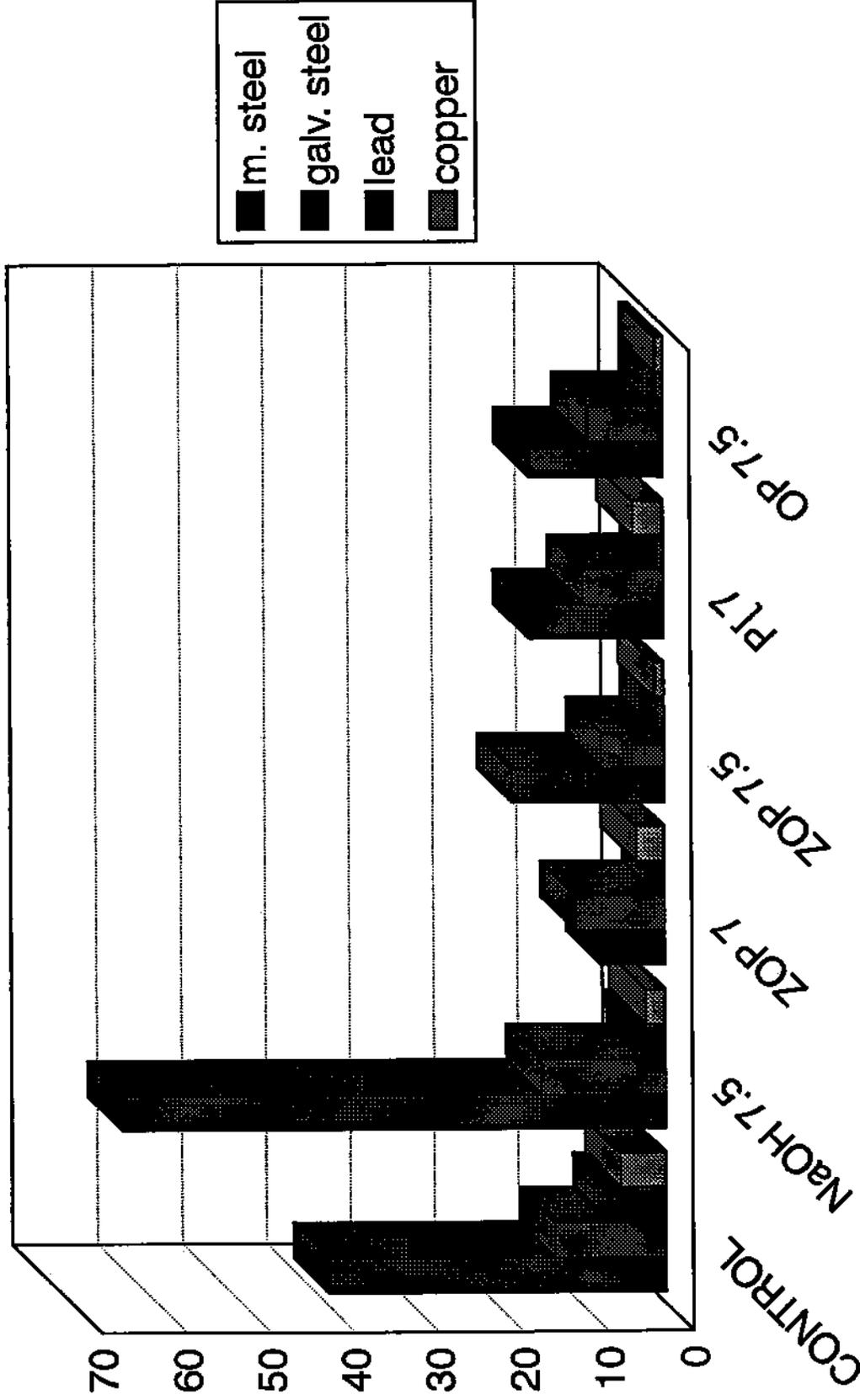


Fig. 19 - Pipe Insert % Loss Rate for each Method of Treatment (polyphosphate treatments 9&10 suspended)

## Corrosion Reduction Ratings

The ratings on treatment effectiveness for reduction of lead and copper corrosion rates based upon both coupon and pipe insert specimens is as follows:

First six months ( includes polyphosphate treatments):

- (1) Pipe Rack No. 6 - blended orthophosphate & caustic, pH 7.5
- (2) Pipe Rack No. 3 - zinc orthophosphate, pH 7.0  
Pipe Rack No. 5 - blended orthophosphate, pH 7.0
- (3) Pipe Rack No. 4 - zinc orthophosphate & caustic, pH 7.5
- (4) Pipe Rack No. 2 - caustic soda, pH 7.5
- (5) Pipe Rack No. 7 - blended polyphosphate, pH 7.0
- (6) Pipe Rack No. 8 - blended polyphosphate with silicate, pH 7.0

Second six months:

- (1) Pipe Rack No. 6 - blended orthophosphate & caustic, pH 7.5
- (2) Pipe Rack No. 4 - zinc orthophosphate & caustic, pH 7.5
- (3) Pipe Rack No. 5 - blended orthophosphate, pH 7.0
- (4) Pipe Rack No. 3 - zinc orthophosphate, pH 7.5
- (5) Pipe Rack No. 2 - caustic soda, pH 7.5

## Overall Performance Ratings for Treatment Methods

The following ratings for treatment effectiveness are based on the combined results of the water quality data and corrosion loss rate data as given above:

- (1) Pipe Rack No. 6 - blended orthophosphate & caustic, pH 7.5
- (2) Pipe Rack No. 4 - zinc orthophosphate & caustic, pH 7.5
- (3) Pipe Rack No. 5 - blended orthophosphate, pH 7.0
- (4) Pipe Rack No. 3 - zinc orthophosphate, pH 7.0
- (5) Pipe Rack No. 2 - caustic soda, pH 7.5

## ASSESSMENT OF CORROSION CONTROL TREATMENT METHODS

### Adjustment of pH to 7.5 with caustic soda

A review of the water quality results for reductions in first draw samples of lead and copper from their respective appurtenances (Figures 9 & 10) may at first suggest that increased caustic dosage on the Catskill/Delaware supply is a viable interim corrosion control option. However, the study to date has also indicated that increasing hydroxide alkalinity ( $\text{pH} > 7$ ) may further stimulate galvanic corrosion in copper pipe joined with a high-lead solder. In such circumstances, copper surfaces will be protected, but this will be achieved at the expense of the lead joint, resulting in increased concentrations of lead in first draw samples from such plumbing systems. Upon inquiry, this theory was supported by a prominent researcher in the field of lead corrosion control.<sup>(6)</sup>

Since the plumbing systems of newer homes, constructed with copper tubing utilizing sweated solder joints of high lead content, have been targeted as high risk for lead contamination, this course of treatment warrants further study and is not recommended as a long-term solution.

A review of the corrosion rate evaluations (Figures 12-14) also suggests that higher levels of caustic (alone) may encourage the dissolution of iron and zinc cladding from galvanized steel.

### The use of zinc orthophosphate corrosion inhibitors

Theory states that, in forming a passivation film, the orthophosphate radical can bond with a variety of available cations (i.e.  $\text{Ca}^{2+}$ ,  $\text{Fe}^{2+}$ , etc.) to establish a barrier over anodic and cathodic regions of a corrosion cell. A greater chance exists in bonding with whichever cation appears in the greatest concentration at these metal surface sites. Zinc-bearing phosphate corrosion inhibitors have generally been acknowledged as the most effective passivation film formers. The inclusion of zinc provides a more rapid establishment of a passivation film due to, it is believed, the strong ionic bond formed with the orthophosphate or phosphate radical.<sup>(6)</sup>

Evaluation of the water quality and corrosion rate test results indicate that the use of zinc orthophosphate treatment on Catskill/Delaware water is most effective when utilized at a pH of 7.5. While significant lead reductions are achieved at a pH of 7.0, copper loss rates appear to be more influenced by the increased hydroxide alkalinity provided by a pH elevation to 7.5.

A drawback to the use of zinc orthophosphate treatment for the City's water supply has been the concern that allowable levels of zinc in wastewater sludge may be exceeded. Currently, a projected maintenance dosage of zinc orthophosphate inhibitor at 2.5 ppm as product will result in adding a minimum 0.20 ppm of zinc (and 0.63 ppm of orthophosphate) to the wastewater stream once passivation has been established. While the test results clearly show reductions in the corrosion rates of galvanized steel surfaces, it is not clear how this reduction in zinc corrosion will balance against zinc addition from a corrosion inhibitor.

Based upon the forestated, and concerns about public acceptance of a zinc-bearing orthophosphate treatment method (reductions of lead and copper notwithstanding), it is recommended that an alternative orthophosphate corrosion inhibitor (without zinc) be considered.

#### **The use of blended orthophosphate corrosion inhibitors**

Due to a recognition of concerns about using a zinc-bearing phosphate additive, water treatment chemical manufacturers have developed inhibitor formulations which effectively replace the role of zinc as a predominant divalent cation available for passivation film formation. The basic film established on metal surfaces with the blended orthophosphate additive employed in this study is believed to be calcium orthophosphate based upon the prevalence of naturally occurring divalent calcium ion in the City's water supply.

Evaluation of the water quality and corrosion rate test results indicate that the use of blended orthophosphate treatment on Catskill/Delaware water is somewhat more effective than zinc orthophosphate at reducing lead and copper levels at a pH of 7.0. This includes reductions to or below the action level of 0.015 mg/L in the AWWA-RF jointed copper coil model.

When utilized at a pH of 7.5, the data clearly indicates that blended orthophosphate almost outperforms every other treatment method subjected to study with respect to lead reduction.

## **RECOMMENDATION FOR CORROSION CONTROL TREATMENT**

The purpose of this report has been to present the results obtained from the Corrosion Control Study undertaken by the Bureau of Water Supply and Wastewater Collection and, based upon these results, provide a recommendation for a long-term lead and copper corrosion control measure for the City's drinking water.

This treatment measure will serve to: (1) establish compliance with the STIPULATION AND ORDER between the City of New York and the New York State Department of Health concerning quantities of lead in first draw samples of drinking water, and (2) assist the City in establishing compliance with the ORDER ON CONSENT imposed by the New York State Department of Environmental Conservation, banning the disposal of wastewater sludges at sea, by reducing the copper content of wastewater sludges so that alternative sludge management options can be implemented.

Based upon the evaluation of the data provided in this report and the discussions contained herein, the following measures are recommended:

1. Upon completion of the Interim Corrosion Control Facilities under Task 27 of the City's Sludge Management Program, corrosion inhibitor feed for passivation should commence utilizing the calcium-based blended orthophosphate additive with sufficient caustic soda addition to maintain a pH of between 7.0 and 7.5 in the City's distribution system. In order to guard against any unforeseen disturbance of distribution system water quality, the passivation dosage should be the lowest recommended which is 5 ppm of the orthophosphate inhibitor formulation as product and should continue until a residual of 1.35 ppm of orthophosphate is obtained at the ends of the distribution system for at least 48 consecutive hours. Following passivation, a continuous maintenance dosage of 2.5 ppm as product (0.90 as orthophosphate) is to be applied.
2. On-line distribution system optimization of this treatment may be necessary if, during (or after) the course of passivation, sampling for lead levels in first draw drinking water and copper in digested wastewater sludges should not reveal the desired reductions. Steps to optimize treatment would include gradually increasing the maintenance dosage or increasing caustic dosage to maintain a higher pH.
3. The operation of the pipe racks at Hillview Reservoir should continue so that a thorough evaluation of other commercially available and recently developed blended orthophosphate products may be undertaken. This will enable the City to pre-qualify various specialty chemical suppliers blended orthophosphate products and establish performance specifications for future contract and procurement purposes.

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- (1) American Water Works Association Research Foundation, Lead Control Strategies, prepared by Economic and Engineering Services, Inc., Bellevue, WA in association with Illinois State Water Survey, Champaign, IL, 1990.
- (2) *ibid.*
- (3) Holm, Thomas R. & Schock, Michael R., "Potential Effects of Polyphosphate Products on Lead Solubility in Plumbing Systems", Journal American Water Works Association, Vol. 83, No. 7, pp. 76 - 82, July 1991.
- (4) Attachment to Professional Correspondence from Gregory J. Kirmeyer, P.E., Economic and Engineering Services, Inc., Bellevue, WA to Charlotte Dery, Water Quality Manager, New York City Department of Environmental Protection, New York, NY. "Statistical Background for Sampling Program Design". November 2, 1990.
- (5) Schock, Michael R., A Personal Communication, 1991.
- (6) Hatch, G. B., "Reducing Corrosion in Domestic Systems: Polyphosphate Inhibitors in Potable Water", Materials Protection, pp. 31 - 35, November, 1969.

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American Water Works Association Research Foundation & DVGC - Forschungsstelle, Internal Corrosion of Water Distribution Systems, Cooperative Research Report, 1985.

Evans, Herbert, Chesterfield County Water Authority, Chesterfield, VA, A personal communication, 1992.

Caldwell, Quana, Director of Laboratories, City of Atlanta Department of Water Supply, Atlanta, GA, A personal communication, 1992.

Belcher, Harvey, Technical Director, Shannon Chemical Corporation, Malvern, PA, A personal communication, 1991.

## **APPENDIX A**

\*\*\*\*\* DICALK \*\*\*\*\*  
PROGRAM TO CALCULATE THE CONCENTRATION OF DIC  
OR TOTAL ALKALINITY, GIVEN pH, I, AND  
TEMPERATURE PLUS TALK OR DIC.

INCLUDE DECIMAL POINTS IN ALL ENTRIES.

ENTER IONIC STRENGTH, OR [CNTRL-Z] [CR] TO STOP.  
0.001

ENTER TEMPERATURE IN CELCIUS.  
13.0

ENTER THE pH FOR THE CALCULATION.  
7.0

IF YOU WISH TO INPUT TOTAL ALKALINITY AND COMPUTE DIC  
ENTER 'D' OR 'd':

IF YOU WISH TO INPUT DIC AND COMPUTE TOTAL ALKALINITY  
ENTER 'A' OR 'a':  
d

THE DISSOLVED INORGANIC CARBONATE CONCENTRATION IS:

2.6238E-04 mol/l  
3.031 mg C/L  
25.261 mg CaCO<sub>3</sub>/L

\*\*\*\*\*

D I C A L K

INTERACTIVE VERSION

PROGRAM TO COMPUTE DISSOLVED INORGANIC CARBON FROM TOTAL ALKALINITY AND PH (FOR A GIVEN I AND TEMP), OR TO COMPUTE THE TOTAL ALKALINITY AT A GIVEN PH FROM DIC INPUT.

WRITTEN IN JUNE, 1988 BY M. SCHOCK, BY MODIFICATION OF DELTAPH.

\*\*\*\*\*

```

COMMON /A/I,TEMP,PH,KW,CK1,CK2,F0,FM,FD
REAL NEWPH,I,IFS2,IFS3,KW
CHARACTER*1 FLAG
WRITE(0,800)
10 WRITE(0,810)
   READ(0,940,END=60) I
   WRITE(0,820)
   READ(5,940,END=60) TEMP
   WRITE(0,830)
   READ(0,940,END=60) PH
   WRITE(0,840)
   READ(0,950) FLAG
   IF (FLAG.EQ.'A'.OR.FLAG.EQ.'a') CALL ALKCOMP
   IF (FLAG.EQ.'D'.OR.FLAG.EQ.'d') CALL DICCOMP
   GO TO 10
60 STOP

```

```

800 FORMAT(1X,' ***** DICALK *****',/,/, 'PROGRAM TO CALCULATE THE',
1' CONCENTRATION OF DIC',/,/, 'OR TOTAL ALKALINITY, GIVEN PH, I, AND
2' ',/,/, 'TEMPERATURE PLUS TALK OR DIC',/,/, 'INCLUDE DECIMAL POINTS',
2' IN ALL ENTRIES.',/,/)
810 FORMAT(/, ' ENTER IONIC STRENGTH, OR [CNTRL-Z] [CR] TO STOP.')
820 FORMAT(/, ' ENTER TEMPERATURE IN CELSIUS: ')
830 FORMAT(/, ' ENTER THE PH FOR THE CALCULATION.')
840 FORMAT(/, ' IF YOU WISH TO INPUT TOTAL ALKALINITY AND COMPUTE DIC',
1' ',/, ' ENTER "D" OR "d";',/,/, ' IF YOU WISH TO INPUT DIC AND ',
2' COMPUTE TOTAL ALKALINITY,',/,/, ' ENTER "A" OR "a": ')
940 FORMAT (G10.0)
950 FORMAT (A1)
END

```

..... COMPUTES DIC FROM ALKALINITY INPUT.

```

SUBROUTINE DICCOMP
COMMON /A/I,TEMP,PH,KW,CK1,CK2,F0,FM,FD
REAL I,IFS2,IFS3,KW

```

..... ALKALINITY IS CONVERTED FROM 'MG/L AS CaCO3' TO 'MEQ/L' CONCENTRATION UNITS.

```

WRITE(0,900)
READ(0,910) TALK
ALKEQ=TALK/(100.089E+03/2.E0)
CALL TCOR
CALL GAMMA
CALL KCOR

```

..... THE CARBONATE SPECIATION IS DERIVED FROM THE INPUT  
C..... PH, I, TEMP, AND ANALYZED TOTAL ALKALINITY

```
SMH=1E1**(-PH-FM)
SMOH=KW/SMH
D=((SMH*SMH)+(CK1*SMH)+(CK1*CK2))
IFS2=SMH*CK1/D
IFS3=CK1*CK2/D
DIC=(ALKEQ+SMH-SMOH)/(IFS2+2E0*IFS3)
```

..... TEST FOR THE PLAUSIBILITY OF THE PH AND TOTAL  
C..... ALKALINITY COMBINATION INPUT.

```
IF(DIC.LT.0) WRITE (6,930)
DIC2=DIC*12.011E+03
DIC3=DIC*100.089E+03
WRITE (6,920) DIC,DIC2,DIC3
900 FORMAT(/,' ENTER THE TOTAL ALKALINITY AS mg CaCO3/L:')
910 FORMAT(G10.0)
920 FORMAT(/,' THE DISSOLVED INORGANIC CARBONATE CONCENTRATION IS:',
1 /,1PE11.4,' mol/l',/,0PF8.3,' mg C/L',/,1X,f8.3,' mg CaCO3/L')
930 FORMAT(1X,' *** WARNING ***',/,1X,' DIC IS NEGATIVE. YOUR',
1' COMBINATION OF PH AND ALKALINITY',/,1X,' IS IMPLAUSIBLE.',
2' CHECK YOUR ANALYSES.')
RETURN
END
```

..... COMPUTES TOTAL ALKALINITY FROM DIC INPUT.

```
SUBROUTINE ALKCOMP
COMMON /A/I,TEMP,PH,KW,CK1,CK2,F0,FM,FD
CHARACTER*1 FLAG
INTEGER UFLAG
REAL I,IFS2,IFS3,KW
WRITE (0,850)
READ (0,860) UFLAG
WRITE (0,900)
READ (0,910) DIC
IF(UFLAG.EQ.1) DIC=DIC/12.011E+03
IF(UFLAG.EQ.2) DIC=DIC/100.089E+03
CALL TCOR
CALL GAMMA
CALL KCOR
```

..... THE CARBONATE SPECIATION IS DERIVED FROM THE INPUT  
..... PH, I, TEMPERATURE AND ANALYZED DISSOLVED INORGANIC CARBONATE  
..... CONCENTRATION.

```
SMH=1E1**(-PH-FM)
SMOH=KW/SMH
D=((SMH*SMH)+(CK1*SMH)+(CK1*CK2))
IFS2=SMH*CK1/D
IFS3=CK1*CK2/D
ALKEQ=DIC*(IFS2+(2*IFS3))+SMOH-SMH
```

..... TEST FOR THE PLAUSIBILITY OF THE PH AND TOTAL  
..... ALKALINITY COMBINATION INPUT.

```
IF(ALKEQ.LT.0) WRITE (6,930)
WRITE(0,940) ALKEQ,ALKEQ*(100.089E+03/2.)
```

```

850 FORMAT(/, ' ENTER YOUR INPUT UNITS FOR DIC: 1 = mg C/L; 2 = mg Ca
1 'CO3/L; 3 = mol/L:')
860 FORMAT(I1)
900 FORMAT(/, ' ENTER THE DIC CONCENTRATION:')
910 FORMAT(G10.0)
920 FORMAT(/, ' THE DISSOLVED INORGANIC CARBONATE CONCENTRATION IS: ',
1 /, 1pe11.4, ' mol/l', /, 0pf8.3, ' mg C/L', /, f8.3, ' mg CaCO3/L')
930 FORMAT(1X, ' *** WARNING ***', /, 1X, 'TALK IS NEGATIVE. YOUR',
1 ' COMBINATION OF PH AND DIC', /, 1X, ' IS IMPLAUSIBLE.',
2 ' CHECK YOUR ANALYSES.')
940 FORMAT(/, ' TOTAL ALKALINITY = ', 1PE11.3, ' eq/L or ', 0pf8.3,
1 ' mg CaCO3/L')
RETURN
END

```

```

.... SUBROUTINE TO CALCULATE THE ACTIVITY
.... COEFFICIENTS FOR UNCHARGED, MONOVALENT
.... AND DIVALENT IONS .

```

```

SUBROUTINE GAMMA
COMMON /A/I, TEMP, PH, KW, CK1, CK2, F0, FM, FD
REAL I, KW

```

```

.... TEMPERATURE EFFECTS ON DEBYE-HUCKEL SOLVENT CONSTANTS
.... COPIED FROM THE USGS PROGRAMS WATEQ AND WATEQF. ONLY
.... THE TERMS FOR TEMP < 100 C WERE KEPT.

```

```

T=TEMP+273.15
S1=374.11-TEMP
S2=S1**(1E0/3E0)
S3=SQRT((1.0+0.1342489*S2-3.946263E-03*S1)/(3.1975E0-.3151548E0*S2
1-1.203374E-3*S1+7.48908E-13*S1**4))
IF (T.LT.373.15) GO TO 20
C1=5321E0/T+233.76E0-T*(T*(8.292E-7*T-1.417E-3)+.9297E0)
GO TO 30
20 C1=87.74E0-TEMP*(TEMP*(1.41E-6*TEMP-9.398E-4)+.4008E0)
30 CONTINUE

```

```

.... COMPUTATION FROM THE DAVIES EQUATION FOR MONO AND DIVALENT
.... IONS. ACTIVITY COEFFICIENTS ARE CALCULATED IN
.... LOG FORM.
.... THE EQUATION FOR UNCHARGED SPECIES IS THAT USED BY THE WATEQ
.... PROGRAMS.

```

```

C1=SQRT(C1*T)
AA=18248.14E02*S3/C1**3
F0=0.1*I
FM=-(AA*((SQRT(I)/(1+SQRT(I)))-0.3*I))
FD=4.*FM
RETURN
END

```

```

.... CALCULATES KW, K1 AND K2 FOR THE SAMPLE TEMPERATURE.
.... CARBONATE K'S ARE FROM PLUMMER AND BUSENBERG.

```

```

SUBROUTINE TCOR
COMMON /A/I, TEMP, PH, KW, CK1, CK2, F0, FM, FD
REAL KW, I
T=TEMP+273.15E0
KW=35.3944-0.00853*T-5242.39/T-11.8261*ALOG10(T)

```

```
CK1=-356.3094-0.06091964*T+21834.37/T+126.8339*ALOG10(T) -  
11684915./(T*T)  
CK2=-107.8871-0.03252849*T+5151.79/T+38.92561*ALOG10(T) -  
1563713.9/(T*T)  
RETURN  
END
```

..... CORRECTS KW, K1 AND K2 FOR IONIC STRENGTH.  
C.....

```
SUBROUTINE KCOR  
COMMON /A/I,TEMP,PH,KW,CK1,CK2,F0,FM,FD  
REAL KW,I  
CK1=1.E1** (CK1+F0-FM-FM)  
CK2=1.E1** (CK2-FD)  
KW=1.E1** (KW-2*FM)  
RETURN  
END
```

## **APPENDIX B**

	<u>Catskill- Delaware</u>	<u>Croton</u>	<u>USEPA NYS DR</u>	<u>AWWA GOALS</u>
Temperature °F	33-70	33-69		
Turbidity (JTU)	0-10	0-45		
Color (su)	0-35	1-70	1 <sup>5</sup> 15 <sup>6</sup>	0.1 3
Taste & Odor			Odor = 3 <sup>6</sup>	None
Nitrogen (mg/l)				
Free Ammonia	.006 - .144	.01 - .16		
Total Albuminoid	.02 - .28	.02 - .28		
Nitrite	.000 - .006	.000 - .006		
Nitrate	.03 - .60	.03 - .40	45	45
Oxygen Consumed (mg/l)	0.8 - 3.9	1.7 - 7.9		
Carbon Dioxide (mg/l)	0.8 - 6.0	2.3 - 7.3 <sup>4</sup>		
Dissolved Oxygen (mg/l)	9.4 - 18.4	8.7 - 15.9 <sup>4</sup>		
pH (Hydrogen ion conc)	6.1 - 7.9	6.8 - 7.9	6.5 - 8.5 <sup>6</sup>	
Bacteria/ml	0-200	0-400 <sup>3</sup>		
Total organisms (su/ml)	15-1485	15-3420		
Amorphous Matter (su/ml)	275-1750	100-1600	500 <sup>6</sup>	200
Total Solids (mg/l)	24-69	72-177		
Fixed Solids (mg/l)	9-50	44-122		
Spec. Cond. (MGhos)	50-95	140-220		
LAS (mg/l)	.00 - .08	.00 - .40		
Radiochemical Levels				
Alpha po/L	.00 - .38	.00 - .42	15	
Beta pa/L	0-98.7	0.0 - 85.7		
Chloride (mg/l)	-3.5 - 16	10.8 - 35.0		
Alkalinity as CaCO <sub>3</sub> (mg/l)	4-23	20-50		
Hardness as CaCO <sub>3</sub> (mg/l)	8-24	49-88		
Ca as CaCO <sub>3</sub> (mg/l)	4.2 - 18.8	18.0 - 46.5		
Mg as CaCO <sub>3</sub> (mg/l)	3.2 - 8.5	15.0 - 32.0		
Calcium as Ca	-1.0 - 7.5	7.2 - 19.0		
Magnesium as Mg	.96 - 1.7	4.0 - 8.0		
Carbonate mg/l	.00 - .00	.00 - .00		
Cyanide mg/l	.000 - .009	.000 - .013		
Fluoride mg/l	.05 - 1.45	.05 - 1.50		
Iodide mg/l	.00 - .01	.00 - .02		
Phosphate mg/l	.00 - .25	.01 - .25		
Silica as SiO <sub>2</sub> mg/l	.05 - 4.0	2.0 - 8.0		
Sulfate mg/l <sup>2</sup>	-5.0 - 16	10.5 - 32.0	250 <sup>6</sup>	250
Aluminum mg/l	.00 - .11	.00 - .26		0.05
Arsenic mg/l	.000 - .002	.000 - .001	0.35	0.05
Barium mg/l	.02 - .18	.03 - .74	1.0	1.0
Boron mg/l	.00 - .25	.00 - .29		
Cadmium mg/l	.00 - .00	.00 - .00	0.01	0.01
Chromium +6 mg/l	.00 - .01 <sup>2</sup>	.00 - .03 <sup>2</sup>	0.05 <sup>6</sup>	0.05
Copper mg/l	.01 - .18 <sup>2</sup>	.00 - .84 <sup>2</sup>	1 <sup>6</sup>	0.2
Iron mg/l	.01 - .35	.01 - .58	0.3 <sup>6</sup>	0.05
Manganese mg/l	.00 - .17	.00 - .35	0.05 <sup>6</sup>	0.01
Mercury hg/l	.001 - .001 <sup>1</sup>	.001 - .001 <sup>1</sup>	0.002	
Potassium mg/l	.30 - 2.00	.30 - 4.4		
Phenol mg/l	.000 - .015	.000 - .005		
Lead mg/l	.00 - 0.05	.00 - .05		
Sodium mg/l	-1.7 - 5.4	4.5 - 12.		
Selenium mg/l	.001 - .010	.001 - .008	0.01	0.01
Silver mg/l	.000 - .30	.000 - .032	0.05	0.05
Strontium mg/l	.00 - .06	.01 - .12		
Zinc mg/l	.00 - .12	.01 - .09	5	1.0

NOTES:

1. No data available for 1968 and 1969.
2. Maximum during copper sulfate treatment on infrequent occasions.
3. No data available for 1968.
4. No data available for 1972.
5. No data available for 1973.
6. Preliminary Secondary Standards of USEPA.

TABLE II-2  
RANGE OF WATER QUALITY CHARACTERISTICS  
1968 - 1975

R. Mastroianni

RANGE AND AVERAGE OF DRINKING WATER QUALITY CHARACTERISTICS OF THE CATSKILL - DELAWARE AND CROTON SUPPLIES FROM RESPECTIVE POINTS IN THE NEW YORK CITY DISTRIBUTION SYSTEM FOR THE YEAR 1989

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CHEMICAL AND MICROBIOLOGICAL ANALYSES REQUIRED BY USEPA NDH REGULATIONS

Constituent	USEPA Primary Standards (MCL)	M.D.L. (1)	Catskill - Delaware System		Croton System	
			Range	Average	Range	Average
Arsenic	0.05 mg/l	0.04 mg/l	ND (2)	ND	ND	ND
Barium	1 mg/l	0.05 mg/l	<0.05 - 0.08 mg/l	<0.05 mg/l	<0.05 - 0.07 mg/l	<0.05 mg/l
Cadmium	0.010 mg/l	0.003 mg/l	ND	ND	ND	ND
Chromium	0.05 mg/l	0.005 mg/l	ND	ND	ND	ND
Lead	0.05 mg/l	0.005 mg/l	ND	ND	ND	ND
Mercury	0.002 mg/l	0.001 mg/l	ND	ND	ND	ND
Nitrate (as N)	10 mg/l	0.10 mg/l	0.17 - 0.53 mg/l	0.34 mg/l	<0.10 - 0.53 mg/l	0.31 mg/l
Selenium	0.01 mg/l	0.005 mg/l	ND	ND	ND	ND
Silver	0.05 mg/l	0.01 mg/l	ND	ND	ND	ND
Fluoride	1.4 - 2.4 mg/l	0.10 mg/l	0.10 - 1.18 mg/l	1.00 mg/l	0.50 - 1.27 mg/l	1.02 mg/l
Turbidity (3)	1 NTU	-	0.4 - 3.4 NTU	0.9 NTU	0.3 - 3.2 NTU	0.9 NTU
Coliform Bacteria (4)	<1 CFU/100ml (mean)	-	-	<1 CFU/100ml	-	<1 CFU/100ml
Endrin	0.2 ug/l	0.1 ug/l	ND	ND	ND	ND
Lindane	4 ug/l	0.1 ug/l	ND	ND	ND	ND
Methoxychlor	100 ug/l	0.5 ug/l	ND	ND	ND	ND
Toxaphene	5 ug/l	1.0 ug/l	ND	ND	ND	ND
2,4 - D	100 ug/l	0.5 ug/l	ND	ND	ND	ND
2,4,5 - TP Silvex	10 ug/l	0.1 ug/l	ND	ND	ND	ND
Total Trihalomethanes	100 ug/l	-	14 - 55 ug/l	27 ug/l	32 - 87 ug/l	51 ug/l

RANGE AND AVERAGE OF DRINKING WATER QUALITY CHARACTERISTICS OF THE CATSKILL - DELAWARE AND CROTON SUPPLIES FROM RESPECTIVE POINTS IN THE NEW YORK CITY DISTRIBUTION SYSTEM FOR THE YEAR 1989

continued

CHEMICAL ANALYSES REQUIRED BY USEPA NDM REGULATIONS

Constituent	USEPA Secondary Standards (MCL)	M.D.L. (1)	Catskill - Delaware System		Croton System	
			Range	Average	Range	Average
Chloride	250 mg/l	-	7.5 - 14.0 mg/l	9.7 mg/l	22.5 - 50.0 mg/l	32.0 mg/l
Color	15 color units	-	3 - 18 C. Units	6 C. Units	3 - 23 C. Units	8 C. Units
Copper	1 mg/l	0.01 mg/l	<0.01 - 0.13 mg/l	0.03 mg/l	<0.01 - 0.17 mg/l	0.05 mg/l
Corrosivity (5)	Non corrosive	-	Langelier Index -3.29 to -2.05	-2.72	Langelier Index -1.75 to -1.01	-1.43
Dissolved Solids	500 mg/l	-	39 - 72 mg/l	53 mg/l	126 - 179 mg/l	152 mg/l
Foaming Agents	0.5 mg/l	0.01 mg/l	(MB-LAS) ND (2)	ND	(MB-LAS) ND	ND
Iron	0.3 mg/l	0.01 mg/l	0.01 - 0.15 mg/l	0.05 mg/l	0.03 - 0.22 mg/l	0.07 mg/l
Manganese	0.05 mg/l	0.01 mg/l	<0.01 - 0.10 mg/l	0.02 mg/l	0.01 - 0.18 mg/l	0.08 mg/l
Odor	3 T.O.N.	-	0, 1A-2A, 10C-30C, 10Ch-20Ch, 1Cs, 1Cm, 10f, 1E, 1M-4M, 1V-2V.	-	0, 1A, 10C-30C, 10Ch-20Ch, 1Cs, 1Cm, 10f, 1E.	-
pH	6.5 - 8.5	-	6.7 - 7.3	-	6.8 - 7.5	-
Sulfate	250 mg/l	-	7.6 - 12.5 mg/l	9.7 mg/l	13.2 - 19.7 mg/l	15.8 mg/l
Zinc	5 mg/l	0.01	<0.01 - 0.08 mg/l	<0.01 mg/l	<0.01 - 0.09 mg/l	0.02 mg/l

RANGE AND AVERAGE OF DRINKING WATER QUALITY CHARACTERISTICS OF THE CATSKILL - DELAWARE AND CROTON SUPPLIES FROM RESPECTIVE POINTS IN THE NEW YORK CITY DISTRIBUTION SYSTEM FOR THE YEAR 1989

continued

CHEMICAL ANALYSES NOT REQUIRED BY USEPA NDW REGULATIONS

Constituent	M.D.L. (1)	Catskill - Delaware System		Croton System	
		Range	Average	Range	Average
Alkalinity as CaCO3	-	9.0 - 13.0 mg/l	10.6 mg/l	40.0 - 57.2 mg/l	46.5 mg/l
Aluminum	0.010 mg/l	<0.010 - 0.120 mg/l	0.037 mg/l	<0.010 - 0.050 mg/l	0.021 mg/l
Beryllium	0.003 mg/l	ND (2)	ND	ND	ND
Boron	-	0.02 - 0.12 mg/l	0.06 mg/l	0.03 - 0.14 mg/l	0.07 mg/l
Carbon Dioxide	-	1.1 - 3.3 mg/l	2.0 mg/l	1.8 - 6.6 mg/l	3.9 mg/l
Calcium as CaCO3	-	13.30 - 19.50 mg/l	15.84 mg/l	42.00 - 65.00 mg/l	50.73 mg/l
Calcium as Ca	-	5.30 - 7.60 mg/l	6.32 mg/l	16.80 - 26.00 mg/l	20.28 mg/l
Chemical Oxygen Demand	-	1.2 - 5.4 mg/l	3.1 mg/l	4.0 - 11.6 mg/l	7.1 mg/l
Cyanide	0.02 mg/l	ND	ND	ND	ND
Dissolved Oxygen	-	9.2 - 12.1 mg/l	10.6 mg/l	6.4 - 13.4 mg/l	10.5 mg/l
Hardness as CaCO3	-	16.0 - 26.4 mg/l	20.1 mg/l	58.0 - 82.0 mg/l	75.3 mg/l
Iodide	0.01 mg/l	ND	ND	ND	ND
Lithium	0.01 mg/l	ND	ND	ND	ND
Magnesium as CaCO3	-	4.50 - 9.05 mg/l	6.22 mg/l	22.60 - 41.10 mg/l	29.16 mg/l
Magnesium as Mg	-	1.10 - 2.20 mg/l	1.51 mg/l	5.00 - 10.00 mg/l	7.10 mg/l
Nickel	0.05 mg/l	ND	ND	ND	ND
Nitrogen-Ammonia	0.03 mg/l	ND	ND	ND	ND
Nitrogen-Nitrite	0.001 mg/l	0.001 - 0.004 mg/l	0.001 mg/l	0.001 - 0.006 mg/l	0.002 mg/l
Phenol	0.001 mg/l	ND	ND	ND	ND
Phosphate	0.02 mg/l	0.02 - 0.13 mg/l	0.03 mg/l	0.02 - 0.08 mg/l	0.04 mg/l
Potassium	-	0.45 - 1.30 mg/l	0.69 mg/l	1.40 - 3.80 mg/l	1.91 mg/l
Silica (Silicon Dioxide)	-	2.1 - 3.8 mg/l	2.6 mg/l	3.6 - 5.8 mg/l	4.9 mg/l
Sodium (6)	-	3.70 - 7.20 mg/l	5.77 mg/l	11.4 - 19.4 mg/l	15.50 mg/l
Specific Conductance	-	61 - 98 umhos/cm	80 umhos/cm	184 - 268 umhos/cm	235 umhos/cm
Strontium	0.05 mg/l	ND	ND	<0.05 - 0.09 mg/l	<0.05 mg/l
Temperature	-	33 - 74 °F	-	33 - 79 °F	-
Total Organic Carbon	-	1.1 - 4.5 mg/l	2.3 mg/l	2.4 - 5.4 mg/l	3.6 mg/l

RANGE AND AVERAGE OF DRINKING WATER QUALITY CHARACTERISTICS OF THE CATSKILL - DELAWARE AND CROTON SUPPLIES FROM RESPECTIVE POINTS IN THE NEW YORK CITY DISTRIBUTION SYSTEM FOR THE YEAR 1989

continued

MICROBIOLOGICAL ANALYSES NOT REQUIRED BY USEPA NOW REGULATIONS

Constituent	Catskill - Delaware System		Croton System	
	Range	Average	Range	Average
Amorphous Matter	625 - 1125	878	750 - 1125	897
Heterotrophic Plate Count (48 hrs. at 35 °C)	<1 - 3988 CFU/ml	9 CFU/ml	<1 - 1397 CFU/ml	17 CFU/ml
Plankton Organisms	25 - 1110 A.S.U.	347 A.S.U.	45 - 3580 A.S.U.	735 A.S.U.

FOOTNOTES

- (1) M.D.L. is the Minimum Detection Limit.
- (2) N.D. is Not Detected at M.D.L..
- (3) USEPA turbidity MCLs are for entry points only. They are 1 NTU for a monthly average and 5 NTU for a two-consecutive-day average. The values listed under Catskill-Delaware and Croton Systems encompass both entry and distribution points.
- (4) TNTC's cannot be included in the City-Wide Coliform (mean) calculation. The actual City-Wide Coliform mean in the distribution system is 0.01, number of samples with >4/100ml coliform is 5, and percentage of samples with >4/100ml coliform is 0.06.
- (5) If the Langelier Index (L.I.) is zero, water is chemical balance, if L.I. is a plus quantity, scale forming tendencies are indicated, and if L.I. is minus quantity, corrosive tendencies are indicated.
- (6) There is no current MCL for sodium. Water with sodium concentrations of more than 20 mg/l and 270 mg/l should not be used for drinking by persons in severely and moderately restricted sodium diets, respectively.