Engineering Report

POTABLE WATER
Distribution System Analysis

Croton-on-Hudson (V)
Westchester County, NY

February 2007

THE Chazen COMPANIES

Prepared for:

Village of Croton-on-Hudson
One Van Wyck Street
Croton-on-Hudson, NY 10520

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1.0 INTRODUCTION

The Village of Croton-on-Hudson (Village) operates a public water supply system within Westchester County, permitted by the New York State Department of Health (PWS ID# NY5903425). The Village's main water source is a well field located on the bank of the Croton River, approximately 4,000 feet downstream from the New Croton Dam and spillway. Water is pumped directly from three (3) wells into the distribution system, which consists of a network of water mains, four storage tanks (reservoirs), well pumps, booster pump stations, and other water-related infrastructure. The village's total potable water storage capacity is 2.3 million gallons. The water withdrawn from the wells is disinfected with chlorine before it is sent into the distribution system. There are currently no restrictions on the use of the Village's water source.

1.1 Service Area Description

The Village water system supplies 7,606± users. Water use is primarily for residences, but also for businesses and industries, with 2,500± service connections. During 2005, the total amount of water withdrawn from the aquifer was approximately 400 million gallons. The daily average volume of water treated and pumped into the distribution system was 1.1-million gallons per day. Approximately 91% of the total water supplied was billed directly to consumers. The balance, or unaccounted for water, went to firefighting, hydrant use, leaks in the distribution system, and unauthorized use.

The Village's service area is divided into two operational zones: the larger lower zone, which includes the older center of the Village, and an upper zone serving a relatively new area of development of the Village. The lower zone is supplied directly from the source wells and from the North Highland above-grade storage tank. The upper zone is supplied from the Hessian Hills tank and a tank located within the Hudson Nation Golf Course, which are both fed by the North Highland booster pump station located adjacent to the North Highland tanks.

The Village supplies water to the golf course, which has a substantial water demand, due primarily to irrigation requirements during the summer, through the North Highland booster pump station via the upper village distribution zone. Figure 1 presents an aerial map of the Village showing the major components of the water system.

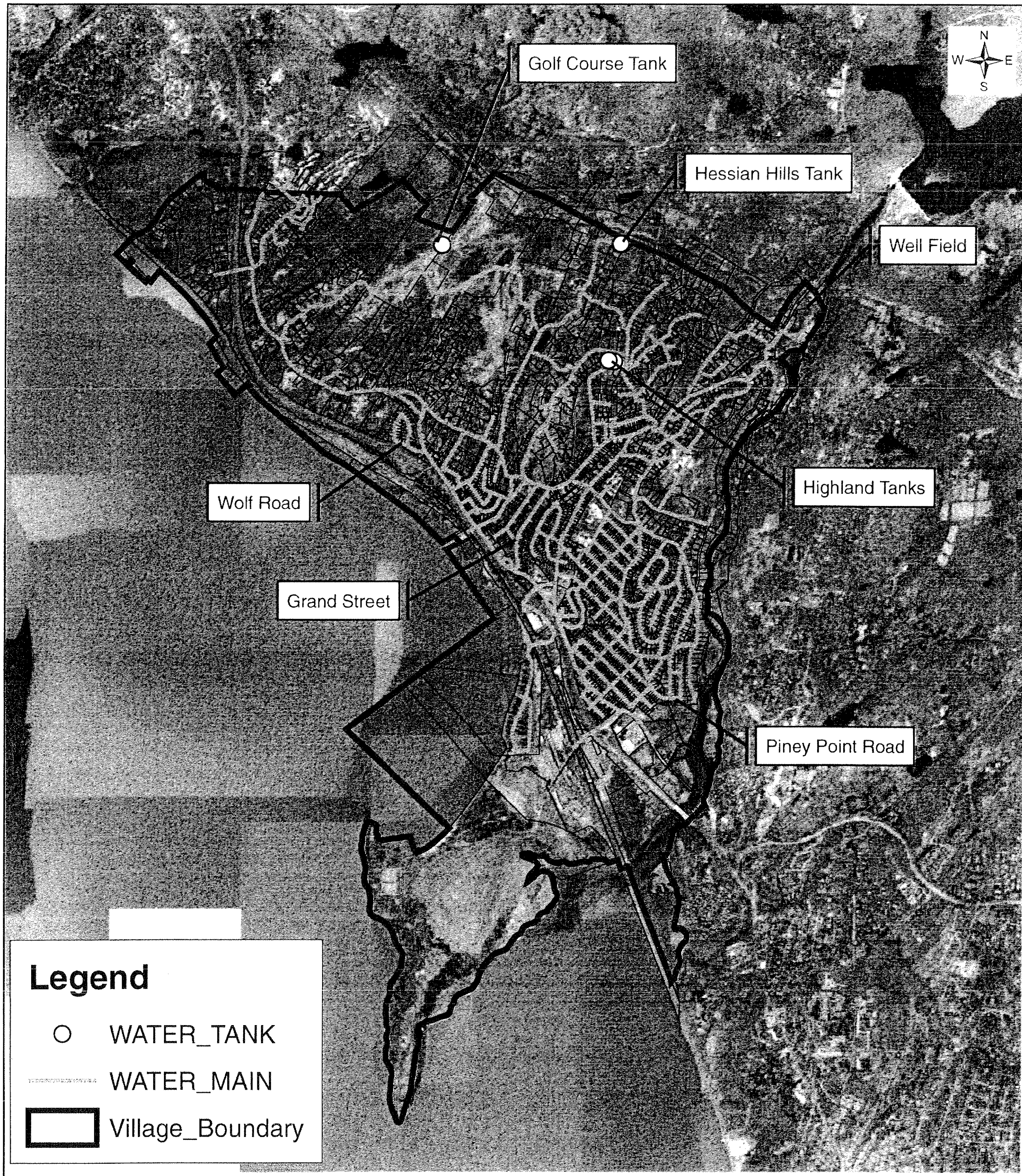

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FIGURE 1 - LOCATION MAP
Village of Cronton-on-Hudson
Westchester County, New York

NYS Office of Technology 2004 Orthophoto Data

Created by: Sharon Froedden
Date: January 2006
Scale: 1 in equals 3,001 ft
Project #: 40408.00

1.2 Distribution System Description

The Village's water distribution system is comprised of a mixture of pipe materials, of varying age, as is typical of older systems that have been expanded over a period of time. The distribution mains within the system are unlined cast iron and cement-lined ductile iron pipe. Lesser quantities of water distribution mains in the system are galvanized steel. Service connections are generally galvanized steel or copper pipe.

The oldest distribution pipes are generally located in the lower water service area, which includes the older areas of the Village. As indicated by the Village Water Department staff, this lower portion of the distribution system has the highest rate of "brown" water complaints.

There are four water storage tanks used to maintain system pressure and provide fire protection flow within the distribution system. Two of the tanks (the above-grade North Highland Tank and the Hessian Hills Tank) provide the majority of usable storage capacity in the system. The below-grade North Highland Tank volume is sustained by use of an altitude valve located on the pipe connecting the tank to the lower service area, and the below-grade tank is used primarily to supply the North Highland booster pump station, which is used to supply the northern portion of the Village, the Hessian Hills tank, and the Golf Course Tank.

Table 1: Schedule of Storage Tanks

Tank ID	Volume (mg)	Effective Tank Depth (ft.)	Operating Range (ft.)	Tank Description
N. Highland, Above-grade	1.25	24	18-23	Steel Tank, Welded
N. Highland, Below-grade	0.40	15	9-15	Concrete Tank
Hessian Hills	0.50	15	10-13	Concrete Tank
Golf Course	0.15	30	17-25	Glass-coated Steel, Bolted

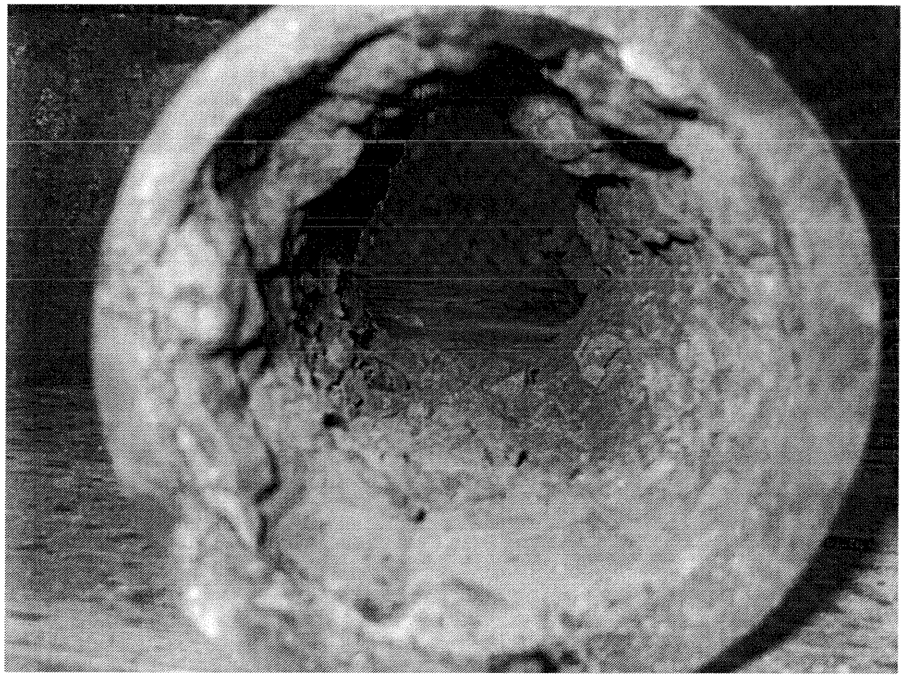

Figure 2 - Unlined cast iron pipe, with effects of corrosion shown, taken from within the Harmon Water Main Replacement Project area in the Village, 2005

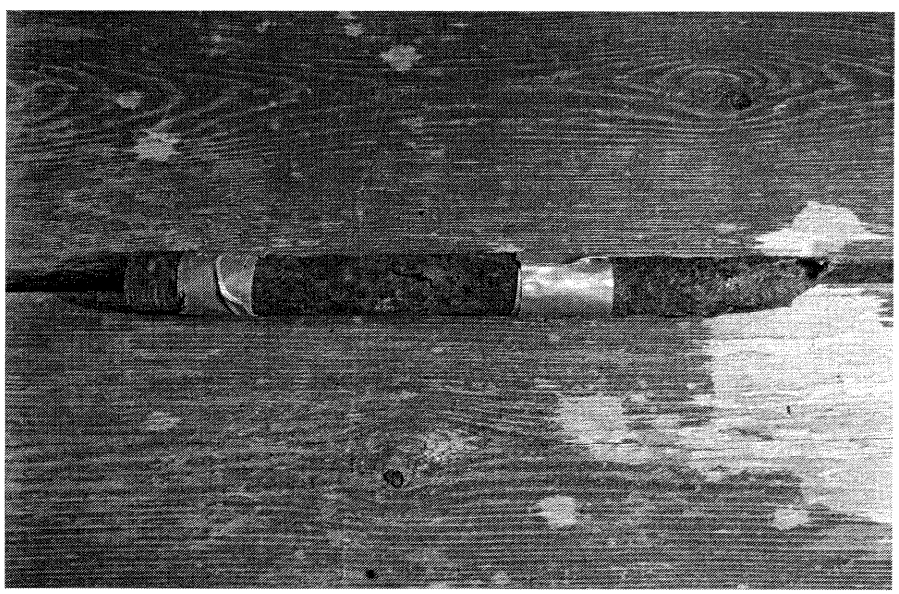

Figure 3 – Galvanized steel water service pipe with corrosion hole in center of picture, encountered during the Harmon Water Main Replacement Project area in the Village, 2005

2.0 SAMPLING PROGRAM

2.1 Sampling Program Description

The Village Water Department regularly performs the requisite sampling at the specified time intervals, as stipulated in NYSDOH Part 5, Subpart 5-1, *Public Water Systems,* for the Village water supply system. The results of the regularly mandated sampling are presented in a summary format in the Annual Report of the Village Department of Water, last issued for testing done through December 2005.

In addition to sampling required by NYSDOH, the Village has acquired and analyzed additional samples from the water supply wells and locations within the distribution system to support this evaluation effort. Comprehensive tabular results for the sampling conducted under this project are presented in tables located in Appendix A.

Also, The Chazen Companies (TCC) performed field measurements of several water quality parameters within the Village's above-ground North Highland and Hessian Hills water storage tanks.

A brief summary of each sampling parameter is presented in the sections below. The sampling parameters at the wellhead sites are summarized in Table 2 below. Individual sampling parameters are discussed here:

- Alkalinity plays a complex role in corrosion of pipes. The alkalinity concentration affects the stability of dissolved and solid species within the water, the kinetics of reactions, and, importantly, is an indication of water's ability to resist changes in pH.

- Lower pH values ($pH<7$, acidic) indicate that the water can be more corrosive and may result in a water system having more difficulty in complying with the EPA Lead and Copper Rule (LCR). Acidic water causes an increase in leaching of lead and copper from the walls of service lines and indoor plumbing.

- Total Dissolved Solids (TDS) are an indicator of the mineral content in a water supply and can be a factor in corrosion rates at very high or very low concentrations.

- Turbidity is a measure of the clarity of a water supply. Higher turbidity values indicate cloudy, less acceptable water and the presence of solids and/or dissolved materials.

- Dissolved oxygen (DO) will occur in any water body exposed to the atmosphere. Because groundwater supplies are not exposed to significant concentrations of free oxygen, the initial DO concentration of water pumped directly out of wells is nearly zero. Through the distribution process the dissolved oxygen concentration can be expected to increase. Oxygen is then available for a great many chemical and biological reactions that may occur, including corrosion processes.

- Oxidation-Reduction Potential (ORP) is also sometimes referred to as redox potential. It basically indicates the potential for a specific type of chemical reaction to occur. There are many common redox reactions, such as rusting of metal. Disinfection of water by use of chlorine is also a redox reaction, and therefore, the presence of chlorine, particularly in the form it takes (HOCl) at lower (acidic) pH levels will result in higher redox potentials. A "neutral" redox potential is a value of approximately 250 mV. Higher redox values indicate the presence of more oxidizing agents, and lower redox values indicate the presence of reducing agents.

- The presence of metals in the water supply is not unexpected, particularly for ground water. However, elevated concentrations may be indicative of distribution system pipe issues and a corrosion-favorable environment.

- Temperature has an impact on the rate of chemical reactions and the likelihood of biological activity. The higher the temperature, the more rapidly reactions will occur.

- Specific conductivity is interrelated to TDS. Water having a high TDS concentration will also likely have a high specific conductivity.

Table 2: Sampling Parameters

Sampling Parameter	Units
Alkalinity as Calcium Carbonate ($CaCO_3$)	mg/L(1)
pH	pH Units
Total Dissolved Solids (TDS)	mg/L
Dissolved Oxygen (DO) (6)	mg/L
Oxidation-Reduction Potential (ORP) (7)	mV(2)
Physical Parameters	
Turbidity	NTU(3)
Metals	
Calcium (Ca)	mg/L
Iron (Fe)	mg/L
Magnesium (Mg)	mg/L
Manganese (Mn)	mg/L
Dissolved Metals	
Iron (Fe)	mg/L
Manganese (Mn)	mg/L
Field Parameters	
Temperature	° C(4)
Specific Conductivity	µS/cm(5)

(1) milligrams/Liter
(2) milliVolts
(3) Nephelometric Turbidity Units
(4) degrees Centigrade
(5) microSiemens per centimeter
(6) Dissolved Oxygen sampled at storage tanks
(7) ORP sampled at storage tanks

2.1.1 Supply Well Sampling

The Village collected samples at the wells and within the water distribution system on May 9, June 16, July 21, August 11, and September 15, 2005.

The Village Water Department collected the supply well samples at each well prior to the water entering the distribution system. Therefore, the sample results indicate the well water quality, rather than the quality in the distribution system.

2.1.2 Distribution System Sampling

The three (3) distribution system samples were collected from fire hydrants located at Grand Street, Piney Point Road, and Wolf Road, as shown on Figure 1.

The Village Water Department collected samples within the distribution system on the same dates as the well sampling (May 9, June 16, July 21, August 11, and September 15, 2005). The constituents listed in Table 2 were also analyzed for the samples taken from the distribution system.

2.1.3 Tank Water Quality Measurements

Field water quality measurements from within the North Highland above-grade and Hessian Hills storage tanks were made by TCC on October 6 and November 3, 2005. The goal of this effort was to develop a vertical profile of water quality for specific parameters through the full depth of the tanks. Although the plan was to take measurements from all four tanks, it was determined after evaluating the available tank access points with the Village Water Department, that two of the tanks would not be suitable. The below-grade North Highland Tank was inaccessible for measurements, and the Golf Course tank was isolated from the rest of the water distribution system by a one-way direction of flow valve. Therefore, only the above-grade North Highland tank and the Hessian Hills tank would be evaluated.

The above-grade North Highland Tank had two man-way access hatches, one on the southwest side where the tank is exposed to environmental changes in temperature, and one on the northeast side, which is partially buried into the hill. Because these two accesses points are horizontally separated by approximately 75 feet, and exposed to differing levels of environmental temperature change, field measurements were made at both locations to determine if there were also horizontal variations in water quality.

Field measurements collected within the tanks included: temperature, specific conductivity, dissolved oxygen, and pH. In addition, the oxidation-reduction potential (ORP) was also measured in the two tanks. The ORP indicates the potential for a particular type of chemical reaction to occur in which one species loses elemental oxygen and a second species acquires the oxygen; corrosion processes are one of these reactions. Disinfection by chlorine is another such reaction.

2.2 Sampling Program Results

A complete set of the sampling results (include a well sample result table and distribution sample result table) are presented in the tables included in Appendix A. Sampling results are discussed in the sections below.

2.2.1 Wellhead Sampling

The Village Water Department collected samples from the supply wells on the five (5) dates noted above, which were analyzed for the parameters listed in Table 1.

In general, sampling results at the wells indicates that the Village water supply is of a good quality. The raw water pH value is nearly optimal, alkalinity is on the low side, and total dissolved solids are well within the recommended limit. The concentration of metals and dissolved metals are well within applicable limits.

The water temperature indicated for the supply well samples is slightly higher then average. A higher temperature will increase the rate of chemical reactions within the distribution system; some of which are inevitably corrosion reactions.

2.2.2 Distribution System Sampling

The Village Water Department collected samples within the water distribution system on the same five (5) dates that the supply wells were sampled. As with the supply well samples, the distribution system samples were also analyzed for the parameters listed in Table 2.

Sample results from the distribution system have similar values to those from the wells, except a higher concentration of iron was observed at the Piney Point Road and Wolf Road sampling points. At Wolf Road, iron concentrations greater than 4 mg/L were obtained, while even higher concentrations were found on Piney Point Road. The maximum allowable concentration of iron is 0.3 mg/L. Higher iron concentrations directly influence the discoloration of water. The Water Department has an on-going flushing program to minimize discolored water. As the replacement of pipes continues, the Water Department should re-evaluate the location and frequency of flushing.

These higher iron concentrations found within the distribution system, which are higher than those indicated in the Wellhead samples, are indicators of corrosion occurring within the distribution system pipes. Tuberculation from the inner wall of the pipes (as shown in Figure 2) is likely being conveyed through the system. A higher flow velocity within the pipe causes turbulent flow, particularly within the more heavily tuberculated pipes, which can cause oxidized iron to be scoured from the pipe surface and conveyed through the system.

2.2.3 Tank Water Quality Measurements

TCC staff made field water quality measurements of two of the Village's water storage tanks on October 6th and November 3rd of 2005. Sampling was done at both access points on the above-grade North Highland Tank. Data was collected at two (2) foot increments of depth from the water surface to the bottom of the tanks.

Field water quality measurements at the Hessian Hills Tank yielded no unexpected results. Measurements were all within the normally expected ranges.

Field water quality measurements from the above-grade North Highland Tank yielded some observations of interest. The dissolved oxygen (DO) concentration in the tank is unusually low and drops with increased depth within the tank, for the October sampling event, only. Appendix B includes tabular data summary as well as graphs of some variables of interest for the above-grade North Highland Tank.

The redox potential (ORP) in the above-grade North Highland Tank also varies significantly with depth; initially ORP increases with depth, and then ORP drops sharply near the bottom of the tank. One possible reason for this is that chemical processes are occurring in the tank until available DO is depleted. This may be an indication of excessive water age or stagnation in the water tank.

Some horizontal variation was observed within the above-grade North Highland Tank. Most notably, the ORP was approximately 10% higher at Sample Point 2 (the southwest portion of the tank). There were also less pronounced differences between the water temperature and dissolved oxygen measurements from the two sampling points within the North Highland Tank. These differences may be an indication of incomplete mixing in the tank, or a result of the differences in exposure to environmental temperature changes between the exposed and buried portions of the tank.

3.0 RECOMMENDATIONS

3.1 Corrosion Control Program

It is recommended that a corrosion control program be initiated. The addition of a corrosion control chemical to the distribution system would aid in the reduction of brown-water events and also reduce lead concentrations in the distribution system. The 2005 annual report of the Village Department of Water indicates that the 90th percentile lead concentration is nearing the allowable limit.

The Village would benefit by being pro-active regarding lead concentrations. If a violation occurs, the Village would be required to implement a corrosion control program and would also be required to sample for lead far more often than currently required. The cost of additional sample collection and analyses for lead and copper would be significant.

3.1.1 Corrosion Control Program Description

When considering a corrosion control program for a water system, the first step is to evaluate the existing physical and chemical condition of the system. For the Village water system, the physical condition of the distribution pipes is the primary cause of the current system quality problems, and the ongoing replacement of system piping will resolve the majority of the current issues.

Some water quality issues are a result of the type of service piping used by individual customers. Corrosion inhibitors will aid in the reduction of metals leaching from customer service connections.

Chemically, as noted above, the quality of the Village supply is good. The pH and alkalinity are both slightly lower than optimal. However, the difference from optimal for these parameters did not play a significant role in the current condition of the distribution system. In addition, it is not recommended that additives to modify pH or alkalinity be considered at this time. Once the older portion of the distribution piping is replaced, the current pH and alkalinity levels will be well within the acceptable range. The replacement of the unlined pipe with cement-lined ductile iron pipe will also cause a slight increase in the pH and alkalinity of the water, as the water comes in contact with the cement lining.

Chemical additives have been used to aid in corrosion control of drinking water systems for more than 50 years. Additives used are phosphates, silicates, or phosphate-silicate blends. Commonly used additives include:

1. Phosphates
    a. Orthophosphates
    b. Molecularly dehydrated polyphosphates
    c. Bimetallic phosphates
    d. Phosphate blends
2. Silicates
3. Phosphate-silicate blends

It is proposed to add a form of liquid zinc orthophosphate $[Zn_3(PO_4)^2]$ to the water supply. Zinc orthophosphate is classified as a bimetallic phosphate. The zinc and orthophosphate will both bind to the inner wall of the pipe and, to some degree, isolate the pipe from the water. The zinc orthophosphate, which comes in a liquid form suspended in a weak sulfuric or hydrochloric acid solution, would be injected into the distribution system at a point near the well field.

Zinc orthophosphate is a commonly used chemical for corrosion control. There are many slightly different blends, which are usually proprietary. It has no deleterious health effects. The form of zinc orthophosphate proposed to be added to the water supply is NSF (formerly National Sanitation Foundation) approved and will be readily acceptable to regulators reviewing the proposed corrosion control program.

As with all the corrosion control chemicals noted above, the zinc orthophosphate displays a synergistic effect in the distribution system. Studies have suggested that the zinc forms carbonate compounds at cathodic sites on the pipe wall, while the phosphate forms other compounds located at anodic sites. This initial treatment phase during which the isolating layer of the additive between the pipe surface and the water forms is termed passivation.

Bimetallic compounds are less soluble than other forms of phosphates and may perform better at lower concentrations. While other corrosion control chemicals would also improve the system water quality, the combination of familiarity to regulating agencies and good performance at low concentrations make the zinc orthophosphate a good choice for treating the Village water supply.

Initially, while passivation is occurring, it is recommended by the chemical supplier to add the zinc orthophosphate at a slightly higher concentration to facilitate the initial coating formation (passivation) within the water distribution piping. The distribution system will be monitored, and after an initial period the dosage rate will be decreased to the lowest level necessary to maintain the coating. Based on the data available, the dosage rate during the passivation phase is estimated to be 5 mg/l; and the maintenance dosage rate is estimated at 3 mg/l.

A Material Safety Data Sheet (MSDS) for zinc orthophosphate is included in Appendix D of this report. The MSDS states that the additive is 16% zinc chloride and 38% Orthophosphoric Acid.

Formulation:

Zinc Chloride: $ZnCl_2$

Orthophosphoric Acid: H_3O_4P

At 16% of 5 mg/L, zinc chloride makes up 0.8 mg/L of the additive. By atomic weight, the zinc is 48% of the total zinc chloride molecule weight. Therefore, at a 5 mg/L dosage, 0.38 mg/L is zinc. As 1 mg/L is nearly equal to 1 part per million (ppm), for every million gallons of water used there will be 0.38 gallons of zinc added at the passivation dosage. When the dosage is reduced to 3 mg/L, the zinc content will be reduced to 0.23 gallons (a quart) per million gallons of water.

3.1.2 Corrosion Control Limitations

Corrosion control additives can be expected to limit corrosion of pipes and the leaching of copper and lead into the water column. However, corrosion is a complex process, influenced by many factors. Particularly for pipes already having severe tuberculation, it cannot be guaranteed that a corrosion control additive will completely eliminate brown-water events.

The addition of a corrosion control additive to the water supply causes favorable changes to the system with respect to the water condition. The additive also can have less favorable impacts on other important water quality parameters, most notably the pH and chlorine residual. These parameters will require additional monitoring during the early implementation of a corrosion control program.

3.1.3 Long-term Monitoring Requirements

The addition of a corrosion control additive requires more careful monitoring of the distribution system water quality. Some items of concern include:

1. pH – addition of the proposed corrosion control additive results in a minor reduction in the pH value. That is, the addition of the additive results in slightly more acidic water. More acidic water has impacts on many other aspects of water quality. If otherwise untreated, an increase in the acidity of the water increases the lead and copper leaching into the water supply. Alkalinity present in the water supply can act as a buffer to limit changes in the pH.

   The pH value also has some bearing on the efficacy of the corrosion control program. The corrosion control additive works best for a pH in the range of 7.2-7.6. Lower pH values reduce the efficiency of the additive. Higher pH values can cause the zinc to precipitate. If the zinc precipitates, it may be observed by the consumer. Consumer complaints would be likely if zinc were to precipitate from the water supply. In addition, water users utilizing filtration processes may experience clogging of filtration devices. As it is proposed to start the corrosion control program with a higher than required concentration of the additive, it will be crucial for the Water Department to monitor the water pH throughout the entire distribution system.

   It is not anticipated that the pH in the distribution system will vary significantly from the optimal range noted above. At this time it is not proposed to use a second additive to boost the pH. However, this should be re-evaluated after initial post-corrosion control program initiation sample data is available.

2. The addition of the corrosion control additive may also require that the disinfection dosage be modified. The additive will cause the chlorine residual to drop slightly. However, the slight drop in pH discussed above also will cause an increase in the more beneficial form of chlorine, increasing the efficiency of the disinfection process. The Water Department will also need to carefully monitor the chlorine residual throughout the system.

3.1.4 Corrosion Control Costs

At this conceptual stage the probable cost of implementing a corrosion control system is difficult to accurately predict. A bench test of the

Village's water with various corrosion control additives could be completed to initially identify the most effective additive and dose.

The capital costs associated with the implementation of a corrosion control system would include the purchase and installation of flow-paced metering pumps and chemical storage units. Additionally, if the Village's well field meters can not provide an output signal compatible with the metering pumps, a new meter will need to be purchased. The corrosion control additive is somewhat vulnerable to lower temperatures, and it would be recommended that the building in which this system is housed be maintained at a temperature above 50° F.

The corrosion control system might be housed in the existing Water Department office located at the Village's well field. This building is in close proximity to the main transmission line leading to the water distribution system. This existing building is heated and has existing electrical power. However, the compatibility of the corrosion control system with the current use of this building needs to be evaluated with regard to available space, safety, floodplain and other potential issues.

Alternately, the Village could erect a small equipment building across the service road from the Water Department's well field office to house the metering pump and chemical storage units. This would require the additional expense of the equipment building and the extension of electrical power for both the metering pump and a unit heater. The building would need to be above the 100-year flood elevation, which is in the process of being revised upwards by FEMA.

Operation and maintenance costs would include the cost of the corrosion control additive, electrical power costs, additional monitoring costs, preventative equipment maintenance, and periodic repairs. Initially, the estimated chemical cost would be approximately $30/day. Once the initial coating of the pipe interiors has occurred, as determined through system monitoring, the chemical concentration would be reduced and the chemical cost lowered to an estimated $20/day. The other operational costs would be approximately equal to the chemical cost.

Table 3: Conceptual Corrosion System Cost

	Using Existing Building	New Equipment Building
Equipment Capital Costs(1)	$30,000	$30,000
Equipment Housing (2), (4)	$80,000*	$150,000*
Annual O & M Costs	$21,900	$21,900

(1) Does not include a new flow meter

(2) Modifications to existing building or new equipment building with power

(3) *Flood plain review study by FEMA and NYSDOH review may effect cost substantially

3.2 North Highland Storage Tank

Based on the water quality measurements taken from within two of the Village's storage tanks, combined with anecdotal information obtained from the Village Water Department, it appears that the above-grade North Highland Tank may be experiencing excessive water age or stagnation. The water quality measurements indicate the water quality in the above-grade tank varies with depth. Additionally, the Water Department indicated that during periods in the summer the water temperatures in the lower portion of the water distribution system, which are feed from the North Highland Tank, become elevated. This suggests that there is insufficient mixing of the water held in the tank, which has an exposed southern face. This raises the water temperature.

The potential for stagnation in this tank is further confirmed by a review of the available design drawings for the above-ground North Highland Tank, the general plan of which is included in Appendix C. The tank, designed in 1964, has a single 12" diameter inlet/outlet pipe located in the southwest portion of the tank. This combined with the large storage volume relative to daily demand limits the amount of mixing that would be expected under normal operation. It has been shown in other studies that, without thorough mixing, the water within even moderate sized storage tanks can become stagnant under normal operation. Then, during a period of high peak demand such as a fire flow, water main break, or heavy irrigation flow, the stagnant water can be released into the distribution system, creating a period of reduced water quality and increased customer complaints.

As a follow up to this initial evaluation the Village should consider operational and/or equipment modifications to the above-ground North Highland Tank to address apparent water stagnation problems.

- According to the Village Water Department, the last time the North Highland above-ground tank was inspected was reportedly more than 10 years ago. Since this tank is over 40 years old and has not been inspected recently, the Village should consider having the interior of the North Highland Tank inspected to determine its condition and estimated remaining service life. Based on the tank inspection findings, preventative maintenance such as cleaning or coating repairs may be necessary. Although no measurement of thickness was made, a sediment layer was noted during the storage tank water quality measurement exercise. This sediment layer may be agitated during periods of high demand, potentially re-suspending solids into the water distribution system.

- The Village should alter the level controls in the tank to vary the water storage volume, reducing the age of water stored within the tank. However, since the storage volume in the tank is dictated by fire protection requirements, the Village Water Department has indicated there is minimal ability to fluctuate the tank level.

- An evaluation of the feasibility of modifying the inlet/outlet pipe configuration to promote water circulation in the tank. Conceptually, this may include installing an extended inlet/outlet pipe equipped with a series of oriented uni-directional diffuser ports that would project across the floor of the tank. This type of a retrofit has been shown to promote mixing within existing tanks during normal operation.

- As an alternate to a modification of the inlet/outlet pipe, the Village should evaluate the option of installing a recirculation line from the North Highland booster pump station to the northeast portion of the tank to allow for periodic mixing. A control unit could divert flow into the North Highland Tank after receiving a high level cutoff at the end of a fill cycle for the Hessian Hills tank. This would provide a minimal level of burst mixing in the tank to improve water quality. Alternately, a separate recycling pump could be added to help keep the larger North Highland Tank "fresh".

3.3 Distribution System Maintenance

There are also several alternatives available to the Village that may both extend the service life of the water distribution system and reduce the frequency of "brown" water complaints. A detailed evaluation of the potential of these maintenance alternatives is beyond the scope of this project, therefore, only a brief description of the alternatives that may be considered by the Village in the future is presented.

Mechanical cleaning physically cleans the interior surfaces of pipe to remove buildup that results from either sedimentation or corrosion. Mechanical cleaning can be accomplished using a series of "pigs" or shaped scrubbers placed in the water main and driven by upstream water pressure to scrub the inside of the pipes. Pigs may be launched, and recovered, from disassembled fire hydrants

Another form of mechanical cleaning utilizes a chain of metal scrappers that are either pushed through a pipe hydraulically, or pulled through a pipe using a winch. Metal scrappers can remove large amounts of heavy solids in a single pass, however, both type of scrapper require that an entry and exit point be cut into the water main.

Chemical cleaning uses a liquid cleaning agent, targeted to the type of deposits found in a pipe, to dissolve and breakdown the solids. To use chemical cleaning; a section of water main is isolated and the cleaning solution introduced and allowed to react for a period of typically 24 hours. The section of line is then flushed at high velocity to remove the dissolved and suspended solids.

Surface applied pipe lining is typically used following a program of heavy cleaning to remove severe corrosion in order to minimize the reoccurrence of corrosion. Once the pipe section has been cleaned, the pipe can be lined with cement or epoxy lining, the linings are usually spun cast to the interior of the pipe, providing a corrosion resistant coating that can extend the life of pipe. Due to the many factors that can affect project costs, including age, condition, and location of the pipe, surface applied linings must be evaluated for cost effectiveness on a project specific basis. Historically, surface lining is not a cost effective alternative for water mains less than 8 inches in diameter.

Alternately, if a pipe section has a high leakage rate, a structural lining system such as fold-and-form or cured-in-place pipe lining might be considered. These systems differ in how the lining works with the existing pipe to improve structural integrity and eliminate leaks, but the installation method is very similar. A section of pipe is removed and the lining is introduced into the pipe, then the lining is formed to the inside of the original pipe using steam or hot water. Typically the minor loss of interior pipe diameter is compensated by the lower friction losses associated with the lining materials (PVC, HDPE, or Epoxy resins.)

3.4 Distribution System Functional Improvements

Periodic improvements are required to maintain a water distribution systems functional capacity, or its ability to adequately serve current and future demands. In certain instances, such as when distribution piping is beyond it's expected service life and does not have the capacity to meet current or future needs, phased pipe replacement should also be considered as a viable alternative. This is presently being done in the Harmon section of the Village, where aged, undersized portions of the distribution system are being replaced to improve both the quality and quantity of water provided to this neighborhood.

In addition to periodic replacement of functionally obsolete portions of the distribution system, the Water Department should implement a program to eliminate all dead-end pipe runs, as is currently being planned for the dead end of Wayne Street. Dead end sections are prone to water quality problems, due to the lack of circulation and are also more vulnerable to service interruptions, as there is only one supply point. By looping, or connecting dead end section to other nearby distribution piping, water is allowed to constantly flow through the piping and minimize the potential for water quality issues related to stagnation. Looping would also allow these dead end sections to be served from multiple points, which could be used to maintain service during repairs or maintenance activities.

3.5 Distribution System Modeling

It also would be advisable for the Village Water Department to develop a computer-simulation model of the entire water supply system. A model of the system is a valuable tool that can assist in the planning, operation and maintenance of a water system. These models can be used to determine the potential impacts of a proposed modification, identify impacts of maintenance activities, identify potential problems within the system by comparing actual monitoring data to predicted results, and help optimize water quality by modeling water age and concentrations within the system.

A distribution system model would assist in the evaluation of the effect of the above-ground North Highland tank being temporarily out of service, and other similar system alterations. In addition, it is possible that future Homeland Security requirements may require that additional information about the distribution system kinetics be available. Computer software can assist in evaluating chemical decay rates within the distribution system.

Appendix A:
Summary of Village Water Sampling Results

Village of Croton-on-Hudson
Potable Water Distribution System Analysis
Table A-1: Field sampling results

Location	1A - Grand St.				
Date	5/9/2005	6/16/2005	7/21/2005	8/11/2005	9/15/2005
Chemistry Parameters					
Alkalinity as CaCO3 (mg/l)	110	108	NA	109	106
pH (pH Units)	7.1	7.33	NA	7.48	7.59
Total Dissovled Solids (mg/l)	188	296	NA	238	249
Physical Parameters					
Turbidity (NTU)	<1	<0.200	NA	<0.200	<0.200
Metals					
Calcium (mg/l)	36.0	37	NA	38	34
Iron (mg/l)	0.06	<0.050	NA	<0.050	<0.050
Magnesium (mg/l)	12.5	12	NA	12	9.7
Manganese (mg/l)	0.018	<0.0050	NA	0.014	0.010
Dissolved Metals					
Iron (mg/l)	<0.060	<0.050	NA	<0.050	<0.050
Manganese (mg/l)	<0.010	<0.0050	NA	<0.0050	<0.0050
Field Parameters					
Temperature (°C)	11.9	NA	15.8	19.8	19.5
Conductivity	435	NA	464	450	450

NOTES:
NA - Not Analyzed
All samples were collected by the Village of Croton-on-Hudson Water Department

Village of Croton-on-Hudson
Potable Water Distribution System Analysis
Table A-1: Field sampling results

Location	2A - Piney Point				
Date	5/9/2005	6/16/2005	7/21/2005	8/11/2005	9/15/2005
Chemistry Parameters					
Alkalinity as CaCO3 (mg/l)	110	103	NA	112	110
pH (pH Units)	7.3	7.36	NA	7.48	7.6
Total Dissovled Solids (mg/l)	196	234	NA	243	214
Physical Parameters					
Turbidity (NTU)	1.2	51.00	NA	60.0	55
Metals					
Calcium (mg/l)	33.6	37	NA	38	33
Iron (mg/l)	0.586	33	NA	46	37
Magnesium (mg/l)	12.5	11	NA	11	9.2
Manganese (mg/l)	0.024	0.13	NA	0.10	0.088
Dissolved Metals					
Iron (mg/l)	<0.060	1.1	NA	1.0	<0.050
Manganese (mg/l)	0.012	<0.0050	NA	0.0080	0.017
Field Parameters					
Temperature (°C)	13.6	NA	21.4	24.0	22.0
Conductivity	438	NA	461	459	450

NOTES:
NA - Not Analyzed
All samples were collected by the Village of Croton-on-Hudson Water Department

Village of Croton-on-Hudson
Potable Water Distribution System Analysis
Table A-1: Field sampling results

Location	3A - Wolf Road				
Date	5/9/2005	6/16/2005	7/21/2005	8/11/2005	9/15/2005
Chemistry Parameters					
Alkalinity as CaCO3 (mg/l)	110	108	NA	112	118
pH (pH Units)	7.3	7.37	NA	7.46	7.59
Total Dissovled Solids (mg/l)	184	256	NA	256	222
Physical Parameters					
Turbidity (NTU)	<1	7.6	NA	3.50	1.00
Metals					
Calcium (mg/l)	33.6	42	NA	38	33
Iron (mg/l)	0.23	4.2	NA	1.2	0.31
Magnesium (mg/l)	11.5	13	NA	12	9.6
Manganese (mg/l)	0.012	0.057	NA	0.15	0.0470
Dissolved Metals					
Iron (mg/l)	<0.060	0.015	NA	<0.050	<0.050
Manganese (mg/l)	<0.010	0.0078	NA	0.0067	0.0076
Field Parameters					
Temperature (°C)	13.9	NA	21.6	22.6	22.6
Conductivity	429	NA	463	459	454

NOTES:
NA - Not Analyzed
All samples were collected by the Village of Croton-on-Hudson Water Department

Village of Croton-on-Hudson
Potable Water Distribution System Analysis
Table A-1: Field sampling results

Location	AA-Well #1				
Date	5/9/2005	6/16/2005	7/21/2005	8/11/2005	9/15/2005
Chemistry Parameters					
Alkalinity as CaCO3 (mg/l)	100	103	NA	106	105
pH (pH Units)	7.1	7.48	NA	7.65	7.63
Total Dissovled Solids (mg/l)	184	214	NA	262	240
Physical Parameters					
Turbidity (NTU)	<1	0.300	NA	<0.200	<0.200
Metals					
Calcium (mg/l)	34.4	33	NA	35	31
Iron (mg/l)	0.107	<0.050	NA	<0.050	<0.050
Magnesium (mg/l)	13.0	11	NA	11	9.2
Manganese (mg/l)	<0.010	<0.0050	NA	<0.0050	<0.0050
Dissolved Metals					
Iron (mg/l)	<0.060	<0.050	NA	<0.050	<0.050
Manganese (mg/l)	<0.010	<0.0050	NA	<0.0050	<0.0050
Field Parameters					
Temperature (°C)	9.6	NA	17.1	19.5	21.8
Conductivity	415	NA	439	446	438

NOTES:
NA - Not Analyzed
All samples were collected by the Village of Croton-on-Hudson Water Department

Village of Croton-on-Hudson
Potable Water Distribution System Analysis
Table A-1: Field sampling results

Location	BB-Well #3				
Date	5/9/2005	6/16/2005	7/21/2005	8/11/2005	9/15/2005
Chemistry Parameters					
Alkalinity as CaCO3 (mg/l)	94.0	106	NA	101	102
pH (pH Units)	7.1	7.38	NA	7.50	7.5
Total Dissovled Solids (mg/l)	186	257	NA	231	234
Physical Parameters					
Turbidity (NTU)	<1	<0.200	NA	<0.200	<0.200
Metals					
Calcium (mg/l)	33.6	39	NA	35	32
Iron (mg/l)	<0.060	<0.050	NA	<0.050	<0.050
Magnesium (mg/l)	15.8	11	NA	10	9.0
Manganese (mg/l)	0.018	0.019	NA	0.0320	0.0380
Dissolved Metals					
Iron (mg/l)	<0.060	<0.050	NA	<0.050	<0.050
Manganese (mg/l)	0.018	0.019	NA	0.023	0.026
Field Parameters					
Temperature (°C)	11.3	NA	19.5	21.5	21.8
Conductivity	424	NA	455	447	445

NOTES:
NA - Not Analyzed
All samples were collected by the Village of Croton-on-Hudson Water Department

Village of Croton-on-Hudson
Potable Water Distribution System Analysis
Table A-1: Field sampling results

Location	CC-Well #4				
Date	5/9/2005	6/16/2005	7/21/2005	8/11/2005	9/15/2005
Chemistry Parameters					
Alkalinity as CaCO3 (mg/l)	116	120	NA	121	115
pH (pH Units)	7.1	7.28	NA	7.37	7.47
Total Dissovled Solids (mg/l)	194	261	NA	256	246
Physical Parameters					
Turbidity (NTU)	<1	<0.200	NA	<0.200	<.200
Metals					
Calcium (mg/l)	40.0	44	NA	<5.0	37
Iron (mg/l)	<0.060	<0.050	NA	<0.050	<0.050
Magnesium (mg/l)	15.8	13.0	NA	12	10
Manganese (mg/l)	0.018	0.0083	NA	0.0077	0.0074
Dissolved Metals					
Iron (mg/l)	<0.060	<0.050	NA	<0.050	<0.050
Manganese (mg/l)	0.018	<0.0050	NA	<0.0050	0.0057
Field Parameters					
Temperature (°C)	10.8	NA	13.6	15.2	16.7
Conductivity	448	NA	458	457	453

NOTES:
NA - Not Analyzed
All samples were collected by the Village of Croton-on-Hudson Water Department

Appendix B:
Field Water Quality Measurements

Village of Croton-on-Hudson
Potable Water Distribution System
Above Ground Tank Sampling Results for October 6, 2005

Weather - (Central Park Obs.)
High 77, Low 64, hazy sun

North Highlands Above Ground Tank - Sampling Point No. 1

Water Elevation at Time of Sampling: 22.9'

	Depth in Feet (approximate)										
Parameter	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
Temp °C	19.82	19.66	19.43	19.05	18.79	18.74	18.74	18.73	18.73	18.72	18.71
mS/cmC	0.41	0.41	0.41	0.407	0.408	0.407	0.407	0.407	0.407	0.407	0.405
DO mg/L	6	4.96	3.35	1.02	0.22	0.85	0.76	0.52	0.63	0.63	0.69
pH	7.59	7.49	7.40	7.28	7.27	7.27	7.26	7.26	7.27	7.28	7.31
ORP	452.6	465.1	474.8	498.7	542	554.6	533.5	514.3	523.7	512.6	442.7

North Highlands Above Ground Tank - Sampling Point No. 2

Water Elevation at Time of Sampling: 22.9'

	Depth in Feet (approximate)										
Parameter	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
Temp °C	19.75	19.62	19.5	18.91	18.81	18.77	18.75	18.73	18.72	18.70	18.45
mS/cmC	0.409	0.409	0.408	0.407	0.407	0.407	0.407	0.407	0.407	0.407	0.403
DO mg/L	5.90	5.22	3.47	1.36	0.49	1.00	0.48	0.99	0.91	0.98	0.90
pH	7.56	7.52	7.42	7.32	7.31	7.31	7.32	7.31	7.32	7.34	7.39
ORP	502.1	516.9	532.3	593.2	573.9	576.9	585.7	583.9	587.1	555.1	508.9

Hessian Hills Tank Water Elevation at Time of Sampling: 11'

	Depth in Feet (approximate)			
Parameter	**6**	**8**	**10**	**12**
Temp °C	18.59	18.59	18.59	18.66
mS/cmC	0.407	0.407	0.407	0.408
DO mg/L	7.37	8.01	9.54	12.50
pH	7.40	7.42	7.45	7.49
ORP	411.8	410.4	407.8	404.0

Village of Croton-on-Hudson
Potable Water Distribution System
Above Ground Tank Sampling Results for October 6, 2005

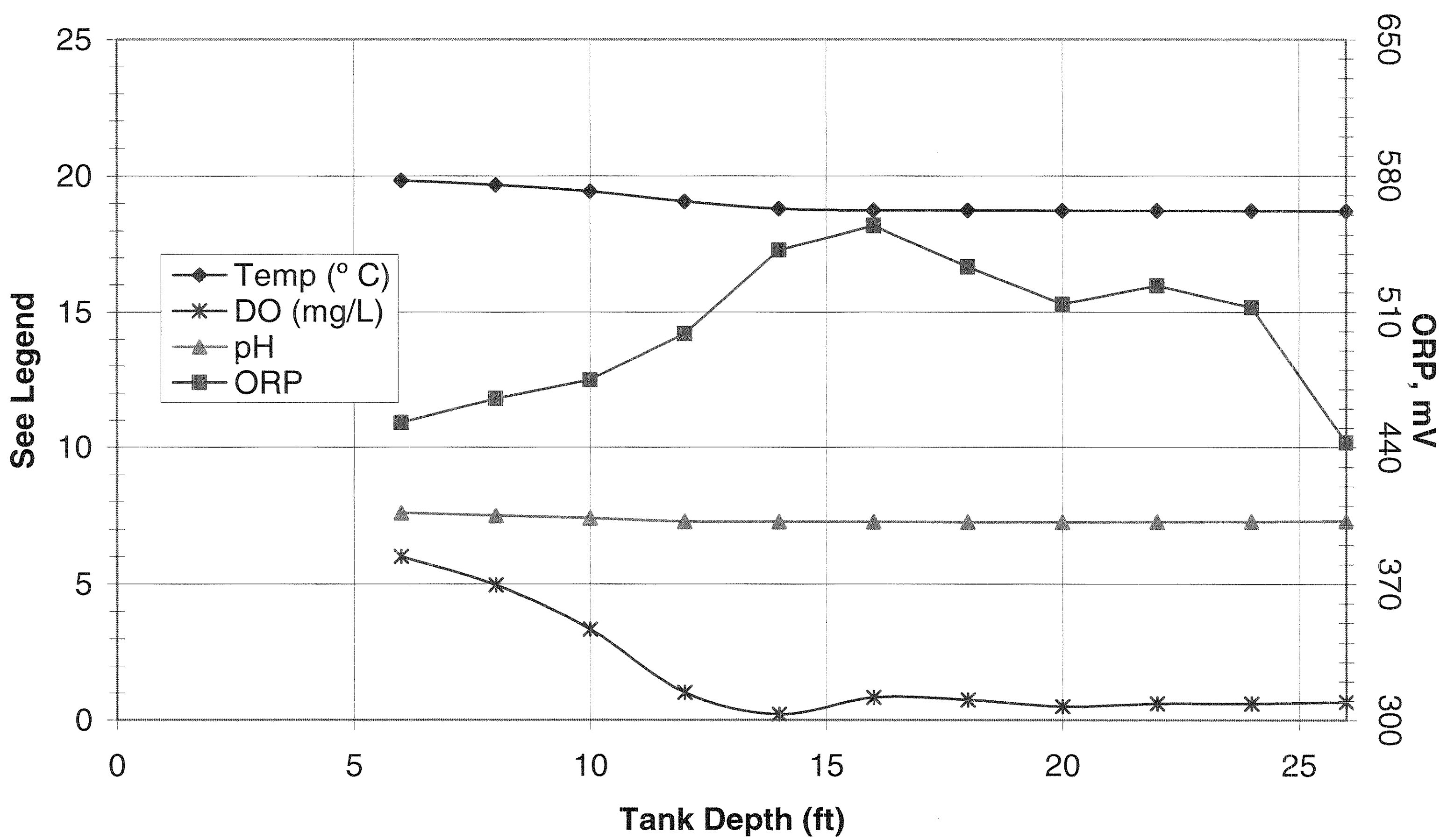

Figure A-1: Graphical sampling results. North Highlands above-ground Tank, Sampling Point: #1, Sampling Date: 10/6/05

Village of Croton-on-Hudson
Potable Water Distribution System
Above Ground Tank Sampling Results for October 6, 2005

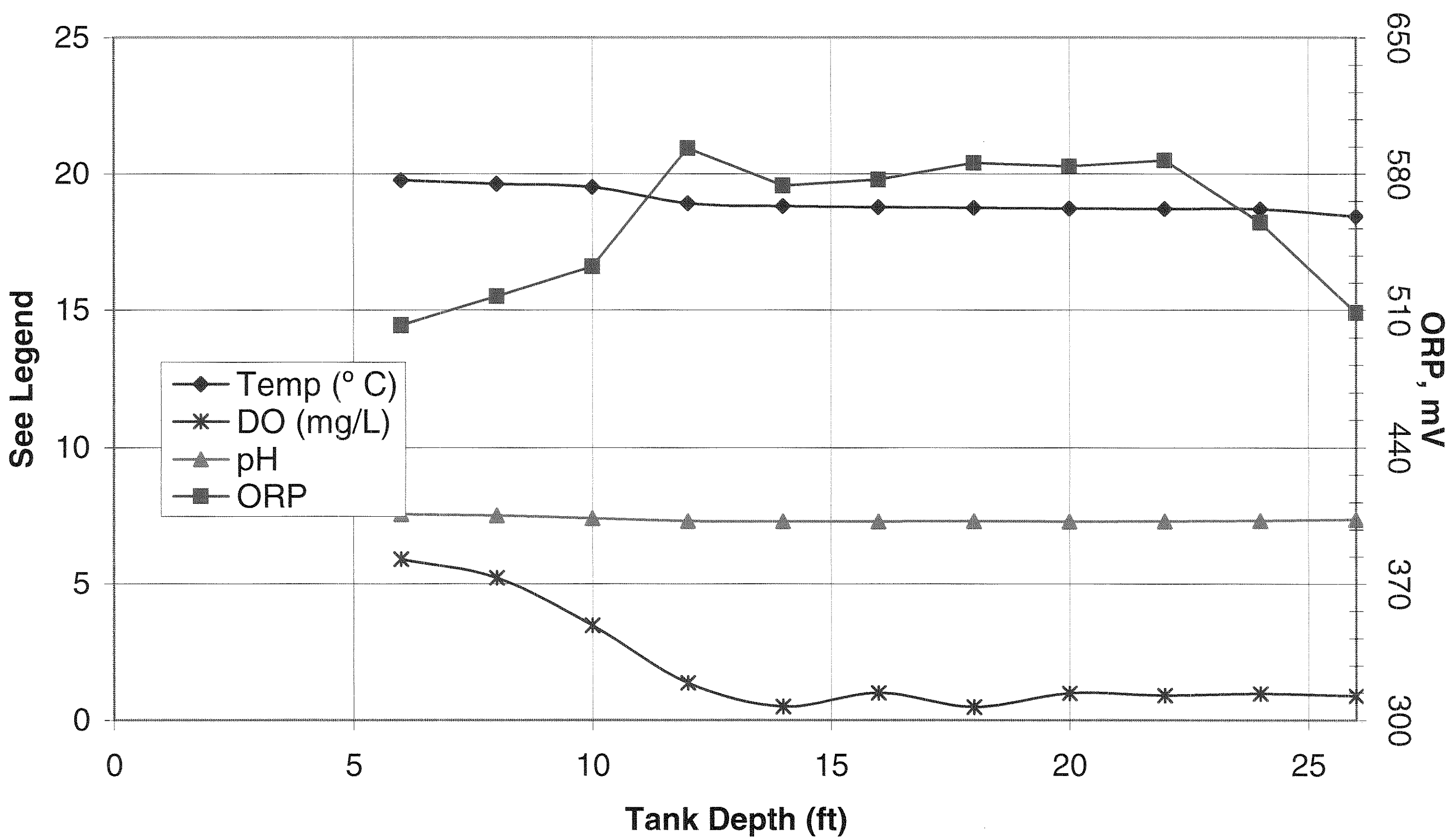

Figure A-2: Graphical sampling results. North Highlands above-ground tank, Sampling Point #2, Sampling Date: 10/6/05

Village of Croton-on-Hudson
Potable Water Distribution System
Above Ground Tank Sampling Results for November 3, 2005

Table A-3: Tank Sampling Results for November 3, 2005

Weather - (Central Park Obs.)
High 65, Low 46, hazy sun

North Highlands Above Ground Tank - Sampling Point No. 1

Water Elevation at Time of Sampling: 21.5'

	Depth in Feet (approximate)										
Parameter	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
Temp °C	15.90	15.89	15.90	15.90	15.90	15.90	15.89	15.89	15.82	15.85	15.82
mS/cmC	0.426	0.426	0.426	0.426	0.426	0.426	0.426	0.426	0.428	0.425	0.426
DO mg/L	3.21	3.23	3.23	3.23	3.24	3.23	3.24	3.24	3.26	3.34	3.34
pH	7.71	7.71	7.71	7.72	7.71	7.71	7.70	7.69	7.69	7.67	7.66
ORP	417.0	457.3	448.5	432.7	415.8	401.9	382.3	359.5	329.1	343.4	351.0

North Highlands Above Ground Tank - Sampling Point No. 2

Water Elevation at Time of Sampling: 21.5'

	Depth in Feet (approximate)									
Parameter	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
Temp °C	15.92	15.90	15.90	15.90	15.90	15.90	15.89	15.86	15.86	15.25
mS/cmC	0.426	0.426	0.426	0.426	0.426	0.426	0.426	0.424	0.425	0.426
DO mg/L	3.20	3.20	3.21	3.21	3.23	3.25	3.28	3.32	3.56	X
pH	7.69	7.66	7.68	7.68	7.69	7.69	7.76	7.67	7.68	7.68
ORP	512.4	508.3	499.3	484.7	485.4	478.2	454.2	435.6	435.4	432.3

Hessian Hills Tank Water Elevation at Time of Sampling: 10.7'

	Depth in Feet (approximate)				
Parameter	**0**	**6**	**8**	**10**	**12**
Temp °C	15.84	15.84	15.84	15.84	15.81
mS/cmC	0.430	0.429	0.429	0.428	0.429
DO mg/L	4.07	4.08	4.09	4.18	4.37
pH	7.75	7.76	7.76	7.77	7.77
ORP	374.7	376.0	377.0	376.7	364.4

Village of Croton-on-Hudson
Potable Water Distribution System
Above Ground Tank Sampling Results for November 3, 2005

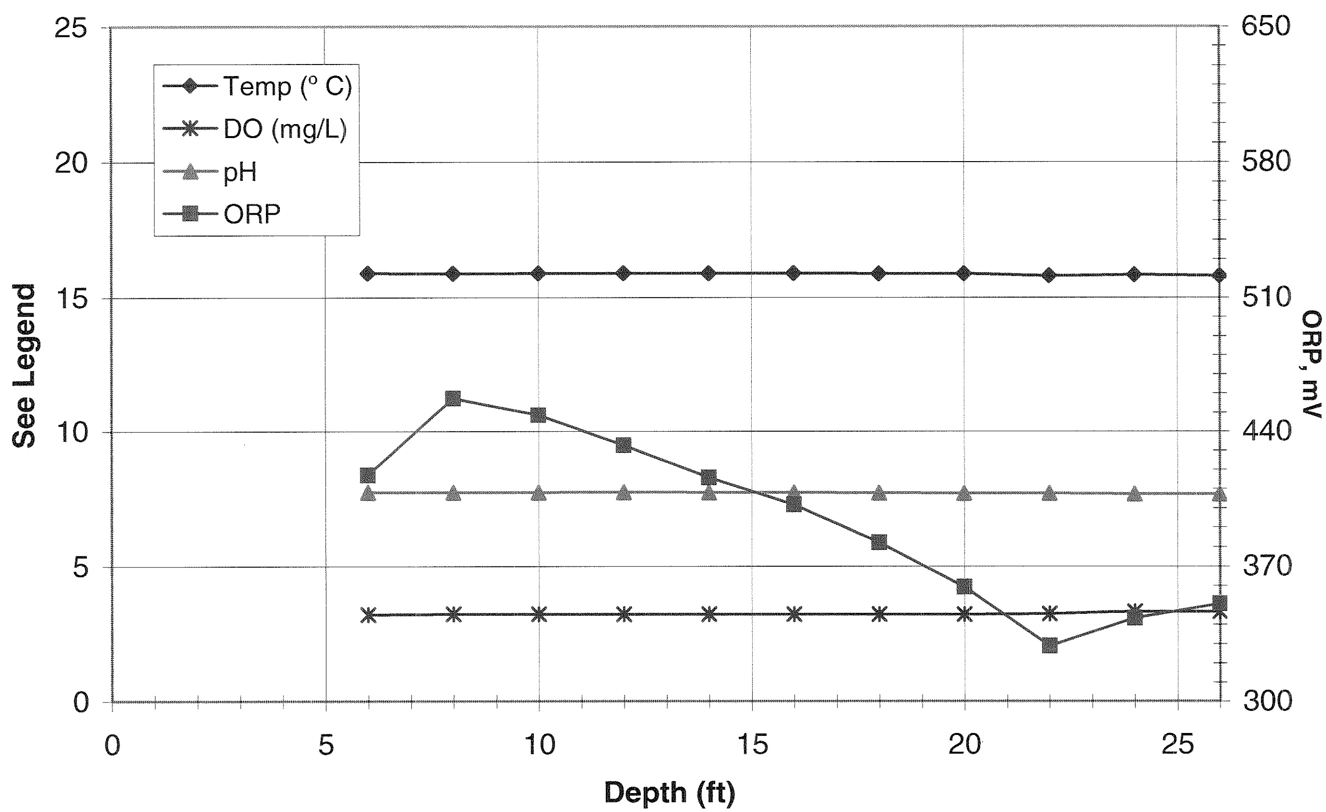

Figure A-3: Graphical sampling results. North Highland above ground tank, Sampling point #1, Sampling date:11/3/05

Village of Croton-on-Hudson
Potable Water Distribution System
Above Ground Tank Sampling Results for November 3, 2005

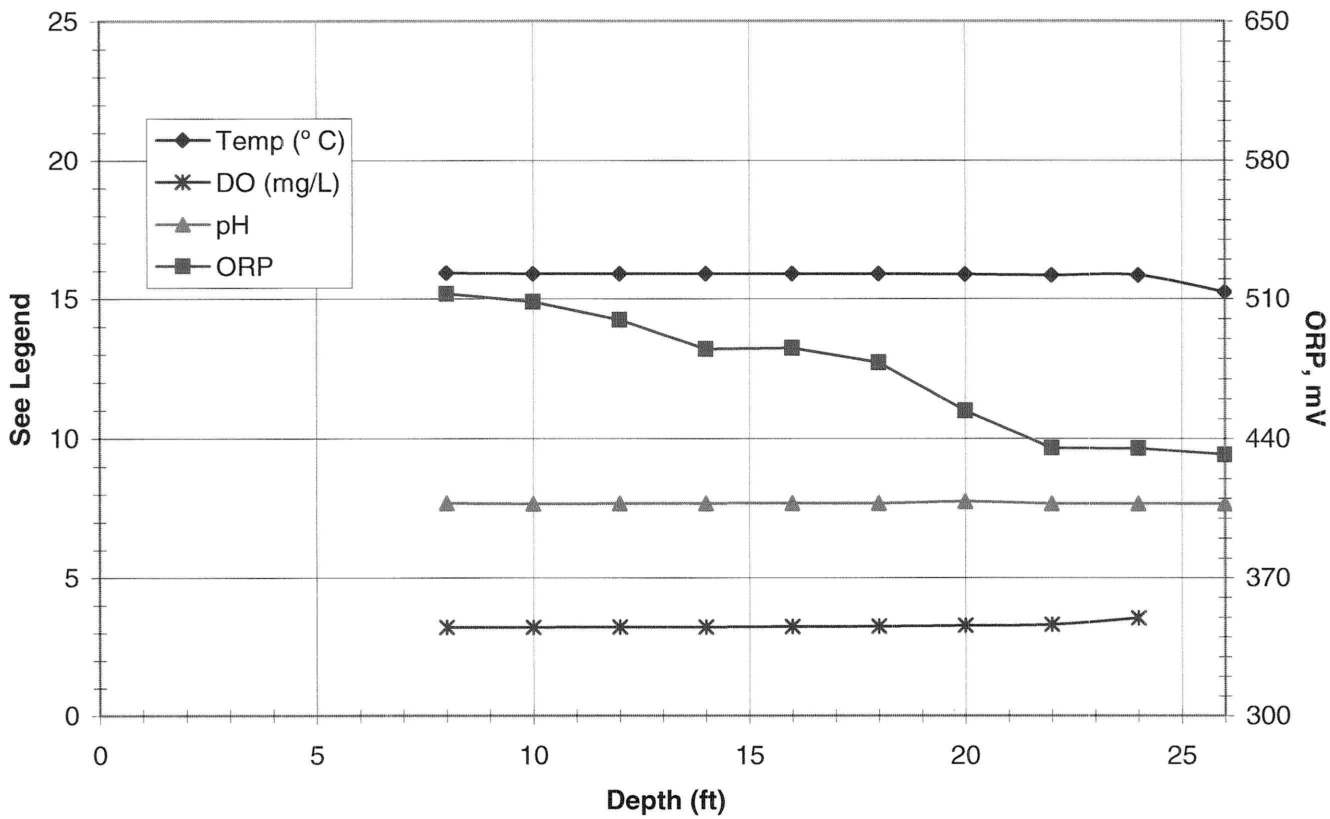

Figure A-4: Graphical sampling results. North Highlands above-ground tank, Sampling point #2, Sampling date: 11/3/05

Appendix C:
General Plan of Highland Tank Site

Appendix D: Zinc Orthophosphate MSDS

Sweetwater Technologies
P.O. Box 1473, Temecula, CA 92593
Telephone (909) 676-2443 FAX (909) 676-2913

Material Safety Data Sheet

Section I - Identification

Trade Name: CP 837	**CAS Number:** 7779-90-0
Chemical Name and Synonyms: Zinc Orthophosphate	
Chemical Name: Acidic Liquid	**Formula:** $Zn_3(PO_4)_2$

Section II - Hazardous Ingredients

Component	%	TLV-TWA
Zinc Chloride	16	1 mg./m3
Orthophosphoric Acid	38	

Section III - Physical Data

Boiling Point (C)	> 100C	**Specific Gravity**	1.37 - 1.45
Vapor Pressure (mm Hg)	Similar to water	**Percent Volatile by Volume**	
Vapor Density (Air = 1)	Similar to Water	**Evaporation Rate**	Similar to Water
Solubility in Water	Infinite	**pH Neat**	<1
Appearance and Odor:	Colorless to light green or amber, slight to no odor, clear with no appreciable suspended matter.		

Section IV - Fire and Explosion Data

Flash Point Method: None	**Flammable Limits** N/A	**LEI** N/A	**UEL** N/A

Extinguishing Media: Not flammable

Special Fire, Hazard, and Fire Fighting Procedures: A self-contained breathing apparatus should be worn by fire fighting personnel.

Section V - Reactivity Data

Stability: Stable	**Hazardous Polymerization:** Will not occur	**Conditions to Avoid:** Treat as an acidic solution.

Incompatability, Materials to Aviod: Metals, strong caustic materials.	**Hazardous Decomposition Products:** Hydrogen chloride

Section VI - Health Hazard Data

Threshold Limit Value (TWA):	None established
Symptoms of Overexposure:	Irritation similar to a burn
Primary Routes of Entry:	Skin
Toxicity Information:	None Established

Emergency First Aid Procedures

Skin: Immediately wash skin thoroughly with soap and water.

Eyes: Flush with copious amounts of water for 15 minutes. Call a physician.

Ingestion: Administer large amounts of water to the victim. Call a physician.

Inhalation: Move victim to an uncontaminated area and administer oxygen if necessary. Avoid breathing mists and vapors. Call a

Section VII - Special Protection Information

Respiratory Protection (Specify Type): A NIOSH approved respirator is recommended.

Ventilation: Area should be well ventilated.	**Protective Gloves:** Rubber
Eye Protection: Chemical splash goggles	**Other Protective Equipment:** Eye bath and safety shower

Section VIII - Spill or Leak Procedure

Steps to be taken in case material is released or spilled:	Dike spill area and cover with soda ash or other absorbent material. Follow all local, state, and federal laws in disposal of in an appropriate manner.
Waste Disposal Method:	In accordance of all local, state, and federal regulations

Section IX - Special Precautions

Precautions to be taken in handling and storing: Avoid contact with eyes, skin, and inhalation of mists.

Date of Issue: 4/11/97	**Supercedes:**	**Prepared by:** Tiffany Tierney