Appendix H

In-Situ Chemical Oxidation Report, 93B and 95 Maple Avenue

GEI Consultants

Geotechnical
Environmental and
Water Resources
Engineering

Report on In-Situ Chemical Oxidation Treatment

93B and 95 Maple Avenue

Haverstraw, New York
Site ID 3-44-0449

Submitted to:
Orange and Rockland Utilities, Inc
500 Route 208
Monroe, NY 10950

Submitted by:
GEI Consultants, Inc.
455 Winding Brook Drive
Glastonbury, CT 06033
860-368-5300

March 31, 2006

Project 040600-1008

John A. Ripp
Principal

Table of Contents

Table of Contents (cont.)

Tables

Figures

Appendices

Table of Contents (cont.)

J:\WPROC\Project\O&R\93B\93B IRM\93B ISCO Project\Final Report on In-Situ Chemical Oxidation Treatment 3-31-06.doc

Executive Summary

As part of the Interim Remedial Measures (IRM) conducted at the former Haverstraw manufactured gas plant (MGP) site in the Village of Haverstraw, New York, GEI Consultants, Inc. (GEI) was contracted by Orange and Rockland Utilities, Inc. (O&R) to conduct an in-situ chemical oxidation (ISCO) treatment on soils beneath a warehouse/office building and adjacent property located at 93B and 95 Maple Avenue, respectively, in Haverstraw.

GEI subcontracted Xpert Design and Diagnostics, LLC (XDD), a vendor with experience in the design and application of ISCO technology, to develop and apply the treatment. The ISCO treatment using sodium persulfate was conducted on three occasions in March 2004, January 2005, and March 2005.

The ISCO treatments were performed in accordance with Section III of the Administrative Order on Consent (AOC Index #D3-0001-98-03) between O&R and the New York State Department Environmental Conservation (NYSDEC). In order to achieve an unrestricted use designation for the property at the completion of the IRM, the NYSDEC and the New York State Department of Health (NYSDOH) set a cleanup target of 25 parts per million (ppm) total polycyclic aromatic hydrocarbons (PAHs) in soils that are attributable to the former MGP site. Thus 25 ppm was the remedial objective and cleanup target for the ISCO treatment.

The warehouse/office building is adjacent to a former subsurface gas holder foundation that had been excavated during an IRM (the holder IRM) conducted in late 2003 and early 2004. During the holder IRM, a seam of tar was observed in soils adjacent to the warehouse/office building. In September and October 2003, concurrent with the holder IRM, nine soil borings were drilled through the floor of the building and on the 95 Maple Avenue property to collect soil samples for PAH analysis. Based on the validated analytical results, the average total PAH concentration in the soils was 1,275 ppm. Total PAH concentrations ranged from 0.04 to 3,650 ppm.

An ISCO treatment Work Plan was developed and approved by the NYSDEC. The Work Plan included twelve borings that were drilled prior to the first ISCO treatment (in March 2004) to establish pre-injection soil concentration baseline conditions, and allow for installation of injection wells. (Note, an assumption was made that the baseline soil concentrations would not be significantly different than the soil concentrations measured earlier in 2003). However, the soil analytical results were not available until after the first ISCO treatment was completed.

The first application (March 2004) of chemical oxidant was designed to destroy total average PAH concentrations in the range of 1,200 ppm (based on the soil data generated in September and October 2003). The analytical results of the baseline soil samples showed the average total PAH concentration at 3,133 ppm (with individual sample results as high as 7,543 ppm). Subsurface soil analytical confirmation samples collected after the first ISCO injection event had total PAHs ranging from 1.5 ppm to 6,122 ppm with the average total PAH concentration at 1,514 ppm. As such, the first ISCO treatment was designed for lower concentrations than were measured during the baseline analysis and it failed to reduced total PAHs to anywhere near the target cleanup level.

After a review of the results of the first injection event and with approval from the NYSDEC, a second ISCO treatment Work Plan was developed. Additional soil samples were collected in June 2004 to account for the apparent high variability in concentrations of PAHs. These additional soil samples were collected from new borings that also were completed as injection wells. The second ISCO treatment design was based on reducing the maximum concentrations of total PAHs by individual sub-areas of the treatment site. Seven sub-areas were delineated. In addition, the second treatment event was divided between two separate injections (event 2 and event 3) separated by approximately 6 weeks. In event two, 6414 gallons of oxidant and catalyst were applied and 6914 gallons of oxidant and catalyst were applied in the third event.

Groundwater monitoring conducted during and after all three treatment events confirmed that the oxidant was well distributed across the treatment zone and that active reactions were occurring in the subsurface soils. Confirmation soil sampling conducted after event 3 indicated that a wide range of total PAHs still remained under the site. The average concentration of total PAHs in the soils was 1,970 ppm. Total PAH concentrations ranged from 41 ppm to 9,774 ppm.

The results of the ISCO treatment at the Haverstraw MGP site failed to achieve the soil cleanup target of 25 ppm total PAH. Mean concentrations of soil PAHs were calculated throughout the project and the means did not significantly change over time. The standard deviation of three groupings of soil sample results suggests that the mean values are not representative of the heterogeneity of the soils which were impacted by MGP NAPL. Only through an analysis of mass of PAHs by individual sub-area, can some degree of PAH reduction be observed. For the second and third treatment event combined a mass reduction of 60% was estimated.

Consequently, the failure of the ISCO treatment at Haverstraw appears to be a function of mass transfer limitations that prevented oxidant from reaching all the PAHs in the soil pores. Additional study of ISCO technology is required to understand how it can be successfully

applied to MGP sites that have both dissolved phase PAHs in groundwater and separate phase NAPL in soil.

1. Introduction

In the winter of 2004, GEI Consultants, Inc. (GEI) retained Xpert Design and Diagnostics, LLC (XDD) of Allentown, Pennsylvania to perform an in-situ chemical oxidation (ISCO) treatment on manufactured gas plant (MGP) impacted soils located at 93B and 95 Maple Avenue in the Village of Haverstraw, New York. The site location is presented in Figure 1. The ISCO treatment was part of an Interim Remedial Measure (IRM) GEI conducted under contract with Orange & Rockland Utilities, Inc (O&R), the responsible party for the former gas plant site. Third parties own the 93B and 95 Maple Avenue properties.

The IRM initially involved the excavation, removal, and off-site treatment of a subsurface gas holder foundation, its contents and other remaining holder structural materials (the holder IRM). In addition, impacted soils surrounding and beneath the former holder foundation were excavated, removed and disposed of off-site. The New York State Department of Environmental Conservation (NYSDEC) designated this work as Phase I of Operable Unit 1 (OU-1). It was completed in the spring of 2004.

During the Phase I, OU-1 holder IRM, a seam of non-aqueous phase liquid (NAPL) was observed under a warehouse/office building adjacent to the holder foundation. Therefore, the IRM was expanded to include the application of ISCO treatment to the subsurface soils under the warehouse/office building and the adjacent property. NYSDEC designated the ISCO work as part of the Phase II IRM for OU-2. The IRM was performed in accordance with Section III of the Administrative Order on Consent (AOC Index #D3-0001-98-03) between O&R and the NYSDEC.

This report describes the activities and results associated with the application of the ISCO treatments at the site. It summarizes the basis of design, the injection events, and performance monitoring. It discusses the results of the ISCO treatment relative to the project objectives. It is based in part on the two Draft Oxidant Injection Summary Reports (July 7, 2004 and June 7, 2005) provided to GEI by XDD.

1.1 Report Organization

This report is organized in seven sections. Section 2.0 describes the Project Objectives. Section 3.0 presents the Approach and Project Overview. Section 4.0 describes Pre-injection Characterization Activities. Section 5.0 provides the Oxidant Injection Summary. Analysis and Discussion is presented in Section 6.0. Conclusions are presented in Section 7.0.

2. Project Objective

The objective of the OU-1 Phase I IRM was to obtain an unrestricted land use designation from the NYSDEC and the New York State Department of Health (NYSDOH) for the property located at 93B Maple Avenue in Haverstraw, New York. To do so it was necessary to excavate the holder foundation and surrounding impacted soil, including soils containing polycyclic aromatic hydrocarbons (PAHs) above a specified concentration, and free-phase tar NAPL that were attributed to the former MGP site.

As stated in NYSDEC's July 10, 2002 letter to O&R (Appendix A), if the IRM achieved the cleanup target of 25 parts per million (ppm) total polycyclic aromatic hydrocarbons (PAHs) in soils that are attributable to the former MGP site, NYSDEC and NYSDOH would approve unrestricted residential land use for the 93B Maple Avenue site and adjacent parcels following completion of the IRM. A successful implementation of the IRM would constitute the final remedy for the site.

The OU-1 IRM did meet the clean-up criteria and a Record of Decision (ROD) for OU-1 was issued by the NYSDEC in March 2005. Since an unrestricted residential use designation was desired for the soils around and beneath the warehouse/office building, the cleanup objective for the OU-2, ISCO treatments was also 25 ppm total PAHs in soil. Therefore, the objective of the ISCO treatments was to reduce total PAH concentrations beneath the warehouse/office building and adjacent subsurface soils to 25 ppm or less.

3. Approach and Project Overview

The impacted area subject to ISCO treatment was delineated by GEI during a subsurface investigation in which nine borings were drilled and sampled under the 93B warehouse/office building and southeast of the building on the 95 Maple Avenue property. This investigation was conducted concurrently with the holder IRM in September and October of 2003. The impacted area was defined to be approximately 30 feet by 45 feet, with the largest area located underneath the building. Figure 2 presents the site configuration, the warehouse/office building, and the locations of the nine borings installed in September and October of 2003. Drilling/boring services were provided by Prosonic Corporation (Marietta, Ohio).

NAPL was present in a seam of fine to medium sand within a 2-foot thick zone that varied in depth from 8 to 14 feet below ground surface (bgs). The NAPL consisted of MGP oil and tar. A silty clay layer was present beneath the impacted fine to medium sand unit. The silty-clay layer limited the vertical migration of the MGP residuals. The depth of water in the impacted area was approximately seven feet bgs. Subsurface soil samples from the nine borings were collected to determine total PAH concentrations in the treatment area. The average total PAH concentration was approximately 1,275 ppm in the area where the NAPL was observed. The soil analytical results are presented in Table 1. Severn-Trent Laboratories in Shelton, Connecticut performed all laboratory analytical services.

The chemical constituents of the NAPL in the impacted area included PAHs, and benzene, toluene, ethylbenzene and xylene (BTEX) compounds. These compounds present a potential source of leachable constituents to groundwater.

The first ISCO treatment was designed as one event, with the oxidant injection staggered across twelve injection wells, to reduce the average total PAH concentration from approximately 1,200 ppm to 25 ppm. However, following completion of the first injection, baseline soil analytical data for samples collected just prior to the first injection revealed that PAH concentrations were significantly higher than the first injection event was designed to address. As such, the initial injection event was designed based on PAH concentrations that were not representative of the target treatment area soils and therefore it failed to achieve the target cleanup level.

Subsequent confirmation soil characterization revealed the presence of "hot spots" and significant variability in the subsurface PAH concentrations. In June and July of 2004 after discussions with NYSDEC and O&R, thirteen additional injection wells were installed, soil samples were collected and analyzed and a supplemental Work Plan was developed for

additional ISCO treatment. Upon approval of a supplemental Work Plan GEI mobilized for the second treatment event.

The second and third injection events used 18 injection wells over two intervals: one in January and the other in March of 2005.

Groundwater was sampled both during and after each injection event to evaluate the persistence of the oxidant in the subsurface and to gauge when confirmatory soil sampling should be preformed. Confirmatory soil sampling was performed by GEI approximately six weeks after the third injection event.

This report describes the three treatments; the first in the spring of 2004, the second and third in January and March of 2005, respectively. Separate Work Plans (January 7, 2004 and November 22, 2004, respectively) were submitted to and approved by the NYSDEC for each event. Appendix A provides copies of the approval letters (January 20, 2004 and November 30, 2004, respectively) from the NYSDEC.

4. Pre-Injection Characterization Activities

4.1 Event 1 Pre-Injection Activities

September/October 2003 Geoprobe® Investigation

The first data set used to characterize the nature and magnitude of MGP tar impacts in the subsurface soils on 93B and 95 Maple Avenue was generated during the OU-1 Phase I IRM of the holder foundation on 93B Maple Avenue. The purpose of the investigation was to delineate the extent of MGP impacted soils first observed in the east sidewall of the holder excavation which were thought to extend beneath the warehouse/office building. GEI sampled beneath the warehouse/office building and on a small portion of the 95 Maple Avenue property on September 30, October 1 and 2, 2003.

The investigation consisted of nine Geoprobe® borings (GP-41 through GP-49), as presented in Figure 2. Four borings (GP-41, GP-42, GP-43 and GP-44) were advanced from locations inside the building. The vertical depth of the borings was about 17.5 to 20 feet below the floor slab. All these borings extended through the MGP impacted zone and into the clay confining unit.

Because the office area of the building was inaccessible, GP-43 and GP-44 were advanced from the warehouse portion of the building using a 45 degree angle directional boring. MGP impacted material was encountered in Geoprobe® borings GP-42 and GP-43 at a vertical depth of about 12.3-14.4 feet (see Appendix B for the Boring Logs). Five additional vertical Geoprobe® borings (GP-45, GP-46, GP-47, GP-48 and GP-49) were advanced on the 95 Maple Avenue property to depth from 10 to 15 feet bgs. MGP impacted material was encountered at Geoprobe® boring locations GP-45, GP-46 and GP-49 at a vertical depth of about 5.5-8 feet. Note, the ground surface on 95 Maple Avenue is at a lower elevation than the elevation of the building floor slab and the MGP impacted soils were found to be close to the same elevation across the entire treatment area.

Average total PAH concentrations were calculated for those soils collected in zones where MGP impacted material was encountered. The average total PAH concentration was 1,275 ppm based on five samples (see Table 1). Samples from GP-42 (19-20), GP-43 (16-17) and GP-45 (14-15) were not used in the calculation because they were collected below the MGP impact zone. The range of total PAH concentrations from these borings, again within the MGP impact zone, was 9.1 ppm to 3,650 ppm. The first in-situ chemical oxidation treatment

event was designed by XDD to treat an average concentration of 1,200[1] ppm total PAHs and not the maximum concentration of 3,650 ppm.

March 2004 Baseline Soil Sampling and Injection Well Installation

On March 23, 24 and 25, 2004 XDD and GEI oversaw the installation of 12 Geoprobe® borings (Borings B-1/IW-1 through B-12/IW-12, see Figure 3) within and around the building. These borings were installed for the collection of subsurface soil analytical samples and used to determine pre-treatment baseline conditions. The borings were also converted into oxidant injection wells. The boring logs for the injection wells are presented in Appendix B. The soil analytical results for the pre-treatment baseline soil conditions are presented in Table 2.

A collection trench was also constructed near the property line between 93B and 95 Maple Avenue using a backhoe. The trench was installed as a control point in case NAPL was mobilized and began to migrate during ISCO treatment. NAPL mobilization did not occur during ISCO treatments so the trench was used as a groundwater monitoring point throughout the remainder of the project.

Based on the analytical results of soil samples collected from borings B-1, B-2, B-5, B-8, B-10 and B-11, the average total PAH concentration for the treatment zone was determined to be 3,133 ppm when the duplicate for boring B-5 (12.5-13) is included in the statistic. The range of PAH concentrations was between 439 ppm and 7,543 ppm. Unfortunately, these data were not available until after the first ISCO injection (designed for 1,200 ppm total PAHs) was completed.

4.2 Event 2 Pre-Injection Activities

On May 19 after the first injection event, six borings were drilled and sampled to confirm the results of the first ISCO treatment event. The boring locations are shown in Figure 4 and the analytical results are presented in Table 3. The results showed an average total PAH concentration remaining of 1514 ppm (again using the duplicate for B-16 (13.5 -14)) with a range of between 1.5 and 6122 ppm. These data resulted in a number of discussions between O&R, the NYSDEC, GEI and XDD.

As a follow-up to a June 7, 2004 conference call between O&R, GEI, XDD and the NYSDEC, on June 18, 2004 GEI provided the NYSDEC a letter detailing a scope of work to further characterize soil concentrations within the impacted zone. The purpose of the

[1] The 1200 ppm total PAH was selected based on the results of the September/October 2003 analytical results and from other nearby results from the Phase I OU-I excavation.

additional sampling and analysis was to address the apparent PAH variability of the site so a supplemental ISCO treatment could be properly designed. On June 22, GEI mobilized to collect additional soil samples and install injection wells IW-13 through IW-25.

Samples were analyzed for PAHs, Diesel Range Organics (DRO), and Gasoline Range Organics (GRO). DRO and GRO analysis was conducted as a supplement to the analysis of PAHs and served as another measure of overall hydrocarbon reduction on the site. The borings/injection well installations were completed on July 2, 2004. The supplemental boring locations are illustrated on Figure 5 and the boring logs are provided in Appendix B. Analytical results are provided in Table 4.

The soil analytical results from IW-13 through IW-25 revealed additional variability in total PAH concentrations with a maximum total PAH concentration of 14,778 ppm in a sample obtained from IW-15. Due to the apparent disparity with the rest of the soils data, the sample from IW-15 was re-analyzed and the laboratory reported total PAH concentrations of 1948 ppm. GEI checked with the laboratory and they confirmed that there were no procedural problems with either analysis. The laboratory attributed the variance to heterogeneity of the sample itself. Using the higher result for IW-15 the average total PAH concentration for the June 2004 sample round was 2,530 ppm (again using all data). Results ranged from 0.45 ppm to 14,778 ppm total PAHs.

The results of this investigation in conjunction with previously collected data were used to design subsequent ISCO treatments, designated for this report as treatment events 2 and 3. On November 22, 2004 GEI submitted for review and approval by the NYSDEC a supplemental ISCO treatment Work Plan. The approval letter was signed on November 30, 2004 by the NYSDEC (see Appendix A).

In December 2004, GEI replaced two injection wells (IW-9 and IW-10) that had leaked oxidant around the riser during the first injection event. The replacement was performed using a hollow stem auger drill rig; the wells were constructed with a bentonite seal above the sand pack and grouted to the surface. Flush-mount road boxes were set in oversized concrete pads to insure that no leakage took place. After the wells were installed potable water was pumped into the wells at a rate of 1 gallon per minute to mimic the flow rate of the injected oxidant. No leakage was observed. Logs of the reinstalled injection wells are found in Appendix B.

5. Oxidant Injection Summary

5.1 Event 1 Injection

On March 28, 2004 the contractor (XDD) arrived at 93B Maple Avenue to prepare for the first injection event. Dilute solutions of sodium persulfate and catalytic reagent were prepared on site from bulk stock material and potable water. A total volume of approximately 7,080 gallons of oxidant and catalytic reagent solution was injected following the schedule provided in Table 5. The oxidant and reagent was injected into four wells at a time at a rate of approximately one gallon per minute per well. The injections took place between March 29 and April 1, 2004.

All the wells except for IW-9 and IW-10 accepted approximately 580 gallons of oxidant and reagent. As mentioned above, wells IW-9 and IW-10 exhibited signs of leakage around the top of the well casing so the injected volumes were reduced. They were replaced later in the year.

Groundwater Monitoring

During the first injection event XDD monitored groundwater quality using low flow sampling techniques to track oxidant distribution subsurface reactions. Groundwater was sampled and field measurements of pH, temperature, conductivity, oxidation-reduction potential, dissolved oxygen, ferrous iron, and sodium persulfate were recorded. Results of the field analysis are provided in Appendix C.

An in-situ oxidant concentration of 200 grams per liter (g/L) was measured at well IW-3 one day after the injection into the first set of wells. Sodium persulfate measurements at the same well ranged from 30 and 100 g/L two days after the injections began. Evidence of oxidant distribution was observed in adjacent injection wells (IW-2, IW-4, IW-5 and IW-7) used as monitoring points during oxidant injection into the first set of injection wells.

Two limited groundwater sampling events were conducted approximately two and five weeks after the oxidant was injected to assess the persistence of the oxidant and catalytic reagents. Sampling methods and measured parameters were the same as in previous events. The results of the post-injection groundwater sampling are summarized in Table 6.

Residual sodium persulfate was measured in injection wells throughout the treatment area at concentrations up to 28 g/L two and five weeks after the injection. Residual ferrous iron (catalyst) was present at concentrations up to 5 mg/L. Reduced groundwater pH (less than 4), attributable to the addition of the citric acid and persulfate, was also observed in the weeks following the injection.

Confirmation Soil Sampling

Confirmatory soil sampling was performed by GEI seven weeks after completion of the first oxidant injection event. Six Geoprobe® borings (B-13, B-14, B-15, B-16, B-17 and B-18, see Figure 4) were drilled between injection wells to collect soil samples for PAH analysis to assess the efficacy of the oxidant treatment. Soil samples were collected from the target treatment zone. Total PAH concentrations ranged from 1.5 ppm to 6,122 ppm. The average concentration was 1,514 ppm. The analytical results are presented in Table 3. Boring logs are presented in Appendix B.

Conclusion of ISCO Treatment – Event 1

Groundwater data generated during and after oxidant injection generally demonstrated that the oxidant and catalytic reagent were distributed throughout the treatment area and that the oxidation process was not limited by site conditions. Initially, there was a rapid decline in oxidant concentration followed by a slower tapering off of oxidant concentration in groundwater. Oxidant persistence was more than 30 days. These finding were expected for the applied level of treatment.

The average PAH concentration (Table 3, Confirmation Soil Analytical Results) in subsurface soils of the treatment area was 1,514 ppm after the first oxidant injection event. Combining the pretreatment soil analytical data from the fall of 2003 and March 2004 (including duplicate samples) the results of the first ISCO treatment event show approximately an 844 ppm reduction in average total PAHs. Nonetheless, this first injection event failed to reduce PAH concentrations to the target cleanup level of 25 ppm total PAH.

XDD was confident that the remedial goal was attainable, and GEI and O&R agreed to make another attempt, based on an improved understanding of the actual treatment area conditions (incomplete data set, highly variable and elevated PAH concentrations, the presence of "hot spots"). As mentioned above additional Geoprobe borings were drilled in June after the first event to better characterize the soils beneath and around the building. The data from these borings was then used in the design of a second ISCO treatment event.

A supplemental ISCO treatment Work Plan was submitted to and approved by the NYSDEC in November of 2004.

5.2 Events 2 and 3 Injections

The design for the supplemental treatment of ISCO incorporated three key changes from the first event, as follows:

- the treatment area beneath and around the building was divided into seven sub-areas, each requiring unique dosages of oxidant;
- injected oxidant volumes were designed for the maximum concentration of total PAHs in each sub-area; and,
- the supplemental treatment was to be conducted over two events to allow enough time for the oxidant to react.

For the purposes of this report the two supplemental ISCO treatment events are designated as Events 2 and 3. The treatment sub-areas and injection wells are identified in Figure 6.

Oxidant injection was performed in January (Event 2) and March (Event 3) of 2005. Due to the cold weather conditions encountered in January the sodium persulfate solution was prepared off site by the supplier with distilled water at a concentration of approximately 200 g/L and delivered to the site in a liquid cargo tanker. The tanker was parked next to the 93B building on a secondary spill containment pad. Dilute solutions of iron chelate were prepared on-site from bulk stock material and potable water. The iron chelate solution was prepared with approximately 33 g/L of citric acid and 1.5 to 2.8 g/L ferrous sulfate.

Sodium persulfate and iron chelate solution injection was performed by sub-area using up to four injection wells at a time at approximately 1.5 gallons per minute (gpm) per well. Sodium persulfate and iron chelate solution was uniformly distributed among designated wells in each treatment sub-area at a sodium persulfate to iron chelate solution volume ratio of 2:1.

A total volume of approximately 13,328 gallons of sodium persulfate and iron chelate solution was injected over the two events. Approximately 14,625 pounds of sodium persulfate and 1,269 pounds of iron chelate were injected. Volumes and weights are summarized in Table 7. Oxidant injection field data sheets are provided in Appendix D.

Groundwater Sampling

Groundwater sampling was performed at the collection trench and seven injection well locations before, during, and after both the second and third treatment events to monitor chemical oxidant distribution and persistence. Groundwater samples were collected with a peristaltic pump using low-flow sampling techniques. Field analyses were performed for pH,

temperature, conductivity, oxidation-reduction potential (ORP), dissolved oxygen (DO), ferrous iron, total iron, and sodium persulfate. Results of the field analyses are summarized in Table 8 and groundwater sampling logs are provided in Appendix C.

Sodium persulfate concentrations were measured as high as 140 g/L during the two injection events. As shown in Table 8, residual sodium persulfate was measured in injection wells throughout the treatment area at concentrations up to 42 g/L five weeks after Event 2 and up to 70 g/L four weeks after Event 3.

Eight weeks after Event 2 sodium persulfate concentrations were observed to have declined to a maximum of 7 g/L. The observed trend indicated sodium persulfate decomposition occurred over an extended period of time (several months)

Reduced groundwater pH (generally less than 3), attributable to the addition of the iron chelate solution and a result of the oxidation process, was observed four to five weeks after each injection event. Eight weeks after Event 2 groundwater pH was observed to begin to rebound increasing 1 to 2 pH units in most wells.

Iron required for activation of the persulfate was measured at concentrations in excess of 100 mg/L four to five weeks after each injection event and eight weeks after Event 2. Post-injection groundwater ORP measurements were generally in excess of 600 mV indicating a highly oxidizing environment had been created and sustained for at least 11 weeks after the start of the second injection event.

Groundwater monitoring data indicate that a proper geochemical environment for the oxidation process to occur had been established and sustained for an extended period of time (several months) following each injection event. Combined with the observed decreasing trend in groundwater sodium persulfate concentration it appeared the oxidation process was sustained for a period of at least four to eight weeks after each injection event.

Based on groundwater residual oxidant measurements approximately 1,560 pounds of oxidant were estimated to have been present in the subsurface at the time of the post-injection soil confirmation sampling and the oxidation process appeared to have been on-going. Estimates of residual persulfate mass in each sub-area are presented in Table 9.

Confirmatory Soil Sampling

Approximately six weeks after injection Event 3, seven subsurface soil confirmation samples were collected and analyzed for PAHs, GRO, and DRO. The confirmation boring locations are presented in Figure 7. The results are presented in Table 10.

Total PAH concentrations for the seven post-injection soil samples ranged from 41 ppm to 9,774 ppm. The average total PAH concentration is 1,970 ppm, including the duplicate data. These results are substantially higher than the clean-up goal of 25 ppm total PAHs.

Post-injection GRO and DRO data are also presented in Table 10 and generally indicate DRO make up the majority of the contaminant mass remaining at the site and that DRO concentrations are 4 to 5 times higher than total PAH concentrations.

6. Analysis and Discussion

This discussion reviews the results of all of the ISCO treatments at 93B Maple Avenue using the total PAH data from the soil analysis conducted throughout the project. In order to view the affect of the ISCO treatment from a total treatment area point of view, Table 11 was created. In it we compare the total PAH results for all pretreatment samples (samples from September/October 2003 and March 2004), to the intermediate samples (i.e. those collected between events 1 and 2) and to the final post treatment confirmation samples. (Note when mean concentrations are presented they are slightly different than the average values presented in the report sections above. This is because for the purposes of discussion, only samples taken from the MGP impact zone are used and if a duplicate sample was collected, only the sample with the highest total PAH value was used in the calculation of the mean value).

Two observations can be made when viewing the data in Table 11. First, even though the numbers of samples used to calculate the mean for each group are different, the mean concentrations of PAHs do not vary across the time frame of the project. Also because the standard deviations are so large, the mean concentrations are not considered representative of the range of concentrations of PAHs measured across the treatment zone. High concentrations of total PAHs, in the thousands of ppm's, exist during every sample round. Even though there is some indication of mass reduction in total PAHs, after three rounds of oxidant injection there still remain hot spots of MGP NAPL as supported by the data from the last round of confirmation samples.

The application of sodium persulfate oxidant to the soils under the building at 93B Maple Avenue failed to meet the cleanup objective of 25 ppm total PAH. The groundwater data collected during and after each treatment indicated that the oxidant was uniformly present and appeared to be undergoing reactions during each treatment event. However the range of soil PAHs remaining after each treatment was substantial. After the first treatment the range was over 14,700 ppm and after the second and third event the range was still over 9700 ppm. Only by calculating differences in total PAH mass on a smaller scale than the 30 x 45 foot target treatment area can something be said about destruction of PAHs.

Estimates of the mass of total PAH present in soil, groundwater, and NAPL phases in the impacted area prior to and after the second and third oxidant injection events are evaluated, see Tables 12 and 13. Calculation of pre-injection total PAH mass estimates used in designing the oxidant injection loading for each sub-area are presented in Table 12. The same method was used to calculate the post-injection total PAH mass remaining in the

treatment area and is presented in Table 13. The following analysis is built around viewing the treatment site by sub-area depicted on Figure 6 .

The highest soil total PAH concentration measured in each of the seven sub-areas was used to calculate total PAH mass. An estimated 896 pounds of total PAH was present in the treatment area prior to the two 2005 injection events. Since confirmation samples were collected in only five out of the seven sub-areas after the third treatment event, the comparison in PAH mass has to be limited to the five sub-areas. Thus the pretreatment total PAH mass for the five sub-areas was calculated at 582 pounds. Comparing this to the mass calculated from the post treatment data results in a reduction of total PAH of approximately 60%. If we then assume that 60% reduction was achieved across the entire treatment site then 537 pounds of PAH was removed during the treatment process.

At the time of the post-injection soil sampling approximately 1,560 pounds of oxidant were estimated to have been present in the subsurface. Estimates of persulfate mass remaining in each treatment sub-area are presented in Table 9.

Given that 14,625 pounds of persulfate was injected, an estimated 13,065 pounds of persulfate was used in destroying approximately 537 pounds of total PAH, yielding a destruction efficiency of approximately 24 pounds persulfate to 1 pound total PAH.

The basis of design assumed a persulfate to total PAH destruction efficiency of 15 to 1 indicating the oxidation process may not have been as efficient as designed. Limitations on mass transfer of PAH constituents to the aqueous phase where the oxidation reactions take place may have contributed to the reduced destruction efficiency observed.

7. Conclusions

After eighteen months of design and implementation of an in-situ chemical oxidation treatment of a MGP contaminated soil mass under the office/warehouse building in Haverstraw, New York, it is the conclusion of the project that the technology was not effective in achieving its goal of reducing the total PAH concentrations to less than 25 ppm. Based on bench-scale treatment studies performed at other MGP sites in New York by XDD just prior to the application at Haverstraw, there was good evidence that the chemistry was correct and the ISCO treatment with sodium persulfate was promising. The nature of the contaminant levels in the soils at the site was found to be confounding at best. Due to varying ranges of total PAHs measured in each sample round, it was difficult to identify the starting total PAH concentrations that were targeted for destruction.

Groundwater monitoring performed during and after the oxidant injection indicated that the sodium persulfate and iron chelate were well distributed throughout the treatment area and the geochemistry of the oxidation process did not appear to have been limited by site conditions. The initial rapid decline followed by tapering of the oxidant concentration in groundwater and persistence for more than four weeks was as expected. At the time of the post-injection soil sampling residual oxidant was present throughout the treatment area and the oxidation process appeared to be on-going.

A straightforward analysis of the total PAH concentrations both before and after each treatment event indicated that there were little to no effective reduction in soil concentrations. The wide range of total PAH values, even after three treatment events was determined not to be anomalous but to be representative of the heterogeneity of the contaminated soils with a strong likelihood that NAPL was present in the treatment zone. Only by subdividing the treatment area and comparing maximum PAH values between pre and post treatment can some indication of mass reduction be estimated. As presented, there may have been upwards of a 60% mass reduction however mass reduction was not a technical objective of the IRM.

Analysis of the oxidant to contaminant destruction efficiency indicates approximately 24 pounds persulfate to 1 pound total PAH was required. The basis of design assumed a persulfate to total PAH destruction efficiency of 15 to 1 indicating the oxidation process was not effectively designed. Limitations on mass transfer of PAH constituents to the aqueous phase where the oxidation reactions take place most likely contributed to the reduced destruction efficiency observed and non-attainment of the cleanup goal.

Tables

Table 1
Soil Analytical Results - Preliminary Site Characterization
September/October 2003
93B Maple Avenue
Haverstraw, NY

Sample ID Depth (feet) Date Collected	GP-42[1] 13-14.3 09/30/03	GP-42 19-20 09/30/03	GP-43[1] 12-13VERT 10/01/03	GP-43 16-17VERT 10/01/03	GP-44[1] 9-10.5VERT 10/01/03	GP-44[1] 11-12VERT 10/01/03	GP45[1] 7.5-8 10/02/03	GP45 14-15 10/02/03
BTEX, mg/kg								
Benzene	8.7 U	0.002 J	18 U	0.004 J	0.012 U	0.013 U	18 U	0.12
Ethylbenzene	8.8	0.0009 J	71	0.001 J	0.002 J	0.013 U	18	0.021
Toluene	2 J	0.003 J	5.7 J	0.005 J	0.002 J	0.013 U	3.9 J	0.005 J
Total BTEX	58.8	0.0139	306.7	0.016	0.037	0.004	151.9	0.193
Xylene, Total	48	0.008 J	230	0.006 J	0.033 J	0.004 J	130	0.047
PAHs, mg/kg								
Acenaphthene	26	0.5	220	0.46 U	0.75 U	0.11 J	120	0.44 U
Acenaphthylene	4.3 J	0.076 J	27 J	0.46 U	1.3	0.13 J	18 J	0.44 U
Anthracene	24	0.47	280	0.46 U	0.31 J	0.84	120	0.44 U
Benzo[g,h,i]perylene	5.9 J	0.064 J	44 J	0.46 U	1.2	0.16 J	25 J	0.44 UJ
Fluoranthene	35	0.74	360	0.46 U	0.11 J	1.8	200	0.44 U
Fluorene	26	0.49	230	0.46 U	0.087 J	0.36 J	130	0.44 U
Methylnaphthalene,2-	37	0.84	240	0.46 U	0.75 U	0.42 U	220	0.44 U
Naphthalene	82	1.9	680	0.077 J	0.75 U	0.047 J	550	0.4 J
Phenanthrene	67	1.5	600	0.46 U	0.75 U	1	350	0.44 U
Pyrene	37	0.77	270	0.46 U	0.53 J	1.5	170	0.44 U
Benz[a]anthracene	17 J	0.37 J	170	0.46 U	0.26 J	0.44	95	0.44 U
Benzo[a]pyrene	17 J	0.23 J	110	0.46 U	3.5	0.68	62 J	0.44 UJ
Benzo[b]fluoranthene	11 J	0.17 J	88 J	0.46 U	2.2	0.48	37 J	0.44 U
Benzo[k]fluoranthene	11 J	0.24 J	110	0.46 U	1.2 J	0.61	70 J	0.44 U
Chrysene	14 J	0.3 J	150	0.46 U	0.56 J	0.47	68 J	0.44 U
Dibenz[a,h]anthracene	4.5 J	0.043 J	20 J	0.46 U	0.5 J	0.19 J	12 J	0.44 U
Indeno[1,2,3-cd]pyrene	7.9 J	0.097 J	51 J	0.46 U	1	0.35 J	29 J	0.44 U
Total PAHs	**426.6**	**8.8**	**3650**	**0.077**	**12.757**	**9.167**	**2276**	**0.4**
Hydrocarbons, mg/kg								
Diesel Range Organics	NA	NA	NA	NA	NA	NA	NA	NA
Gasoline Range Organics	NA	NA	NA	NA	NA	NA	NA	NA

Notes:

[1] Sample from MGP impacted area used in calculation of overall average

U - Not detected at or above the reporting limit shown

J - Estimated value

UJ - Not detected at or above the reporting limit shown; the reporting limit is estimated

Table 2
Pre-Treatment Baseline Soil Analytical Results
March 2004
93B Maple Avenue
Haverstraw, NY

Sample ID Date Collected	B-1 11.5-12 3/23/04	B-2 12.5-13 03/24/04	B-5 12.5-13 03/25/04	Duplicate of B-5 12.5-13 03/25/04	B-8 13.5-14 03/23/04	B-10 6.5-7 03/24/04	B-11 7-8 03/24/04
PAHs, mg/kg							
Acenaphthene	35	110	290	390	250	16 J	18 J
Acenaphthylene	8.8 J	16 J	59 J	62 J	40 J	5.6 J	19 J
Anthracene	32	130	410	470	290	50	33 J
Benz[a]anthracene	33	73	290	350	210	35	110
Benzo[a]pyrene	22 J	99 J	190 J	240	210 J	25 J	43 J
Benzo[b]fluoranthene	19	36 J	170 J	180 J	88 J	15 J	43 J
Benzo[g,h,i]perylene	5.5 J	30 J	48 J	67 J	47 J	4.5 J	9.6 J
Benzo[k]fluoranthene	19	39 J	180 J	230	120 J	20	69 J
Chrysene	29	73	250	300	170	29	98
Dibenz[a,h]anthracene	5 J	14 J	47 J	64 J	27 J	4.7 J	13 J
Fluoranthene	58	140	590	680	400	63	230
Fluorene	30	100	370	470	300	28	98
Indeno[1,2,3-cd]pyrene	10 J	36 J	77 J	100 J	85 J	10 J	19 J
Methylnaphthalene,2-	15 U	40 U	550	790	270	17 U	8.4 J
Naphthalene	3.2 J	67 J	1200 J	1400 J	730 J	17 UJ	18 J
Phenanthrene	77	300	880	1100	760	100	370
Pyrene	53 J	300 J	490	650	520 J	61 J	110 J
Total PAHs	**439.5**	**1563**	**6091**	**7543**	**4517**	**466.8**	**1309**

Notes:
U - Not detected at or above the reporting limit shown
J - Estimated value
UJ - Not detected at or above the reporting limit shown; the reporting limit is estimated
Analytical data summary provided to XDD by GEI Consultants, Inc on 6/4/04

Table 3
Confirmation Soil Analytical Results - Treatment Event 1
May 2004
93B Maple Avenue
Haverstraw, NY

Sample ID Date Collected	B-13 14-14.5 05/19/04	B-14 13.5-14 05/19/04	B-15 12-12.5 05/19/04	B-16 13.5-14 05/19/04	Duplicate of B-16 13.5-14 05/19/04	B-17 7-7.5 05/19/04	B-18 7-7.5 05/19/04
Acenaphthene	420	2.2	1.5 J	85	17	100	0.39 U
Acenaphthylene	69 J	1.7	3.3	17 J	4 J	36 J	0.061 J
Anthracene	380	2.9	5.9	86	20	200	0.39 U
Benz[a]anthracene	280	3.5	6	73	15	180	0.39 U
Benzo[a]pyrene	200	9.4	5.3	51	11	110	0.1 J
Benzo[b]fluoranthene	200	6.5	6.8	61	13	140	0.079 J
Benzo[g,h,i]perylene	61 J	6.4	1.5 J	12 J	2.3 J	18 J	0.11 J
Benzo[k]fluoranthene	160 U	1.6 U	3.3 U	34 U	8.5 U	80 U	0.17 J
Chrysene	240	4.4	5.8	60	14	150	0.14 J
Dibenz[a,h]anthracene	27 J	3.5	1.4 J	13 J	8.5 U	14 J	0.39 U
Fluoranthene	570	6.2	13	170	32	390	0.27 J
Fluorene	450	3.2	5.5	99	20	210	0.39 U
Indeno[1,2,3-cd]pyrene	85 J	5.9	2.8 J	21 J	5.5 J	56 J	0.079 J
Methylnaphthalene,2-	310	1.6 U	2.3 J	7.7 J	1.2 J	11 J	0.39 U
Naphthalene	1100	0.4 J	3.2 J	87	15	370	0.39 U
Phenanthrene	1200	12	15	270	56	540	0.46
Pyrene	530	6.7	11	140	29	280	0.068 J
Total PAHs	**6122**	**74.9**	**90.3**	**1252.7**	**255**	**2805**	**1.537**

Notes:
U - Not detected at or above the reporting limit shown
J - Estimated value
Analytical data summary provided to XDD by GEI Consultants, Inc. on 6/4/04

Table 4
Soil Analytical Results - Supplemental Borings
June/July 2004
93B Maple Avenue
Haverstraw, NY

Sample ID Depth (feet) Date Collected	IW-13 9-10.5 06/23/04	IW-14 8-10.5 06/29/04	IW-15 10.5-11 06/29/04	Reanalysis IW-15 10.5-11 06/29/05	IW-16 12-13 06/29/04	IW-17 13-13.5 06/29/04	IW-18 14-16 06/23/04	IW-19 12-12.5 06/29/04	IW-20 12-13.5 06/23/04	IW-21 15-16 06/23/04	IW-22 6-7 06/23/04	IW-23 6.25-6.75 06/29/04	Duplicate of IW-23 6.25-6.75 06/29/04	IW-24 10-11 06/23/04	IW-25 9.5-10 06/23/04
BTEX, mg/kg															
Benzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ethylbenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Toluene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total BTEX	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Xylene, Total	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PAHs, mg/kg															
Acenaphthene	4.5	0.75 U	950 J	120 J	0.4 U	260	1.6 U	380	0.11 J	24	0.041 J	450	200	0.4 U	0.41 U
Acenaphthylene	3.1 J	1.2	230 J	24 J	0.087 J	71 J	1.2 J	91 J	0.41	5.7 J	0.41 U	82 J	53 J	0.4 U	0.071 J
Anthracene	6.7	0.35 J	1000 J	130 J	0.045 J	280	0.53 J	390	0.79	35	0.054 J	410	210	0.4 U	0.042 J
Benzo[g,h,i]perylene	4.2	1.5	140 J	27 J	0.079 J	44 J	4.5	42 J	0.29 J	5.2 J	0.1 J	51 J	33 J	0.24 J	0.14 J
Fluoranthene	17	0.11 J	1300 J	230 J	0.12 J	530	5.8	660	2.6	59	0.17 J	730	450	0.4 U	0.16 J
Fluorene	5.3	0.097 J	1000 J	160 J	0.4 U	330	0.17 J	450	0.58	28	0.077 J	580	290	0.4 U	0.41 U
Methylnaphthalene, 2-	3.2	0.75 U	720 J	72 J	0.4 U	170	1.6 U	33 J	0.17 J	2.6 J	0.41 U	720 J	260 J	0.4 U	0.41 U
Naphthalene	5.5	0.75 U	3000 J	120 J	0.041 J	290	1.6 U	750	0.16 J	50	0.41 U	1200 J	490 J	0.4 U	0.41 U
Phenanthrene	16	0.75 U	2700 J	350 J	0.051 J	730	0.53 J	1100	3	95	0.12 J	1200 J	660 J	0.051 J	0.059 J
Pyrene	18	0.14 J	1200 J	220 J	0.1 J	390	6.1	480	2.3	46	0.13 J	540	300	0.056 J	0.11 J
Benz[a]anthracene	9.6	0.12 J	610 J	120 J	0.053 J	230	5.4	270	1.2	27	0.042 J	340	190	0.4 U	0.054 J
Benzo[a]pyrene	9.4	0.6 J	430 J	86 J	0.047 J	160	8.2	190 J	0.74	18	0.41 U	200	120 J	0.045 J	0.085 J
Benzo[b]fluoranthene	7.5	0.39 J	220 J	64 J	0.093 J	93 J	3.2	120 J	0.73	11 J	0.41 U	110 J	73 J	0.06 J	0.067 J
Benzo[k]fluoranthene	6.5	0.33 J	400 J	83 J	0.098 J	180	4.1	210	0.76	17	0.41 U	240	140 J	0.4 UJ	0.081 J
Chrysene	8.5	0.31 J	620 J	90 J	0.19 J	190	5.9	240	1.1	24	0.051 J	290	170	0.4 U	0.17 J
Dibenz[a,h]anthracene	2 J	0.48 J	98 J	20 J	0.4 U	36 J	2.6	54 J	0.22 J	5.4 J	0.41 U	50 J	18 J	0.4 U	0.41 U
Indeno[1,2,3-cd]pyrene	5.8	1	160 J	32 J	0.091 J	66 J	3.6	82 J	0.57	7.9 J	0.41 U	81 J	48 J	0.4 U	0.075 J
Total PAHs	**132.8**	**6.627**	**14778**	**1948**	**1.095**	**4050**	**51.83**	**5542**	**15.73**	**460.8**	**0.785**	**7274**	**3705**	**0.452**	**1.114**
Hydrocarbons, mg/kg															
Diesel Range Organics	890	5.2 UJ	9800 J	8200 J	2.7 UJ	24000 J	1100	9900 J	66	3400	0.71 U	14000 J	22000 J	0.7 U	0.78 U
Gasoline Range Organics	0.68 J	0.024 UJ	100	90 J	0.019 UJ	6900 J	0.082 J	730	0.071 UJ	0.5 J	0.059 U	1300 J	1200 J	0.12 J	0.04 UJ

Notes:
U - Not detected at or above the reporting limit shown
J - Estimated value
UJ - Not detected at or above the reporting limit shown; the reporting limit is estimated

Table 5
Oxidant Injection Summary - Treatment Event 1
March 2004
93B Maple Avenue
Haverstraw, NY

Sodium Persulfate and Reagent Solution Injection Volume (gallons)													
Date	IW-1	IW-2	IW-3	IW-4	IW-5	IW-6	IW-7	IW-8	IW-9	IW-10	IW-11	IW-12	Total
3/29/2004	241		217			254		252					964
3/30/2004	343		368			350		374					1435
3/31/2004		581		585	604		549		36	96	130	80	2661
4/1/2004					530	510					478	502	2020
Total	**584**	**581**	**585**	**585**	**1134**	**1114**	**549**	**626**	**36**	**96**	**608**	**582**	**7080**

Notes:

1) Approximately equal volumes of oxidant (sodium persulfate) and reagent solution (citric acid/ferrous sulfate) were injected at each well (refer to oxidant injection ("POD Data Log") field data sheets)
2) Sodium persulfate solution was prepared at approximately 200 g/L
3) Reagent solution was prepared with citric acid at 10 g/L and ferrous sulfate at 1.5 g/L
4) Total mass of sodium persulfate injected was 5445 pounds (refer to Chemical Oxidant Batching Log)
5) Total mass of citric acid and ferrous sulfate injected was 314 pounds (refer to Chemical Oxidant Batching Log)

Table 6
Post Injection Groundwater Monitoring Summary - Treatment Event 1
April/May 2004
93B Maple Avenue
Haverstraw, NY

Date	Location	Na2S2O8 (g/L)	pH	Fe+2 (mg/L)	Fe, Total (mg/L)	Color	Sampling Observations
4/15/2004	IW-01	5.6 to 8.4	< 4	2 to 3	5	lt. yellow	NAPL/staining on poly sampling tube
4/15/2004	IW-03	14 to 28	< 4	5	5	lt. yellow	NAPL/staining on poly sampling tube; Fe+2 test kit produced heavy iron floc and significant gas production
4/15/2004	IW-06	8.4 to 11.2	< 4	0 to 1	4	med. Yellow	NAPL/staining on poly sampling tube; Citric acid concentration appears higher than IW-01 and IW-03 based on darker yellow color of sample
4/15/2004	IW-08	14 to 28	< 4	2 to 3	4	med. Yellow	Fe+2 test kit produced heavy iron floc and significant gas production
4/15/2004	IW-10	4.2 to 5.6	< 4	2 to 3	5	lt. orange	Fe+2 test kit produced heavy iron floc and significant gas production
4/15/2004	Sump	0.021 to 0.028	7	2 to 3	6	lt. yellow/org.	slight sheen on waters' surface in sump
5/7/2004	IW-03	14 to 28	< 4	2	3.5	med. Yellow	gas evolution during ferrous test
5/7/2004	IW-06	1.4 to 2.1	< 4	0	10	lt. yellow	no gas evolution during ferrous test

Notes:
Sodium persulfate (Na2S2O8) measurement by Chemets test kit
Total iron (Fe) and ferrous iron (Fe+2) measurement by Hach test kit
pH measurement by Hach test strip

Table 7
Oxidant Injection Summary - Treatment Events 2 and 3
January/March 2005
93B Maple Avenue
Haverstraw, NY

Treatment Event	Date	Injection Volumes (gal) by Area						Total
		I	II	III	IV	V	VI	
2	1/19/2005			119				119
	1/20/2005			1378	454			1832
	1/25/2005			1437				1437
	1/26/2005		750	100		460	270	1580
	1/27/2005	700						700
	1/28/2005	325				422		747
							Subtotal	*6414*
3	3/14/2005	661						661
	3/15/2005	330	754	540	376			2000
	3/16/2005			1080	750			1830
	3/17/2005			1092	720			1812
	3/18/2005	315		187	109			611
							Subtotal	*6914*
	Total	**2331**	**1504**	**5932**	**2409**	**882**	**270**	**13328**

Notes:
1) Oxidant (sodium persulfate) and reagent (citric acid/ferrous sulfate) solutions were equally distributed among wells in a particular area at an approximate 2:1 oxidant to reagent volume ratio.
2) Sodium persulfate solution was prepared at approximately 200 g/L
3) Reagent solution was prepared with citric acid at 33 g/L and ferrous sulfate at 1.5 to 2.8 g/L
4) Total mass of sodium persulfate injected for Event 1 and Event 2 was 7,125 and 7,500 pounds respectively
5) Total mass of citric acid and ferrous sulfate injected for Event 1 and Event 2 was 607 and 662 pounds respectively

Injection Wells in each area:

Area I	Area II	Area III	Area IV	Area V	Area VI
IW-1, IW-2	IW-14	IW-5, IW-6	IW-7, IW-8	IW-9, IW-10	IW-11, IW-12
IW-13	IW-17	IW-15, IW19	IW-20, IW-21	IW-23	

Table 8
Groundwater Monitoring Summary Data - Treatment Events 2 and 3
January/March 2005
93B Maple Avenue
Haverstraw, NY

Date	Well	DTW feet	pH -	COND. mS/cm	ORP mV	DO mg/L	TEMP. °C	Fe2+ mg/L	Total Iron mg/L	Persulfate mg/L	NOTES
Treatment Event 2 - Baseline Conditions (prior to injection into Area 1)											
1/25/2005	IW-01	7.23	7.85	1.80	-120	0.01	7.43	1.06	1.54	0	sample grey tinge, odor
Treatment Event 2 - During Injection											
1/26/2005	IW-24	2.11	2.65	41.4	260	0.34	10.1	0.21	1.39	10,000	sample cloudy
1/26/2005	Sump	2.19	6.20	0.68	12.7	4.29	6.21	0.16	0.12	0	
1/27/2005	IW-21	NA	1.04	85.0	665	72.0	11.0	> 33	> 33	140,000	sample silty yellow, DO very unstable
Treatment Event 2 - Post-Injection Sampling											
3/3/2005	IW-2	7.38	5.95	1.63	370	2.37	10.9	0.00	0.40	280	sample clear
3/3/2005	IW-14	9.50	2.63	48.0	688	0.55	11.1	0.52	0.87	28,000	sample dark yellow, gas evolution
3/3/2005	IW-17	9.42	2.74	9.82	690	0.76	11.4	7.90	10.2	2,100	sample light yellow, gas evolution
3/3/2005	IW-15	9.14	2.13	52.5	727	1.49	10.2	29.8	37.8	21,000	sample dark yellow, gas evolution
3/3/2005	IW-20	9.20	2.78	24.7	669	5.31	12.4	14.2	20.1	5,600	sample light yellow, gas evolution
3/3/2005	IW-23	3.36	2.64	16.6	556	1.62	9.80	24.5	65.8	7,000	sample dark yellow, gas evolution
3/3/2005	IW-25	3.17	2.11	62.1	655	4.58	9.89	122	101	42,000	sample dark yellow/brown, gas evolution
3/3/2005	Sump	3.15	6.82	0.73	NA	5.14	6.53	0.01	0.07	2.1	sample clear
Treatment Event 3 - Baseline Conditions (prior to injection into Area 1)											
3/14/2005	IW-2	7.37	6.56	0.90	270.0	0.30	12.0	0.02	0.40	175	Sample clear
3/14/2005	IW-14	9.5	4.25	23.1	623.0	66.0	11.9	6.00	327	7000	Sample light yellow, Fe2+ sample off-color
3/14/2005	IW-15		3.20	9.50	634.0	0.55	11.6	4.75	66.3	2800	Sample light yellow to clear, Fe2+ sample off-color
3/14/2005	IW-17		4.48	23.8	657.0	1.74	12.2	16.5	48.8	5600	Sample light yellow, Fe2+ sample off-color
3/14/2005	IW-20		2.74	8.92	619.0	0.60	12.7	5.50	61.0	1400	Sample light yellow, Fe2+ sample off-color
3/14/2005	IW-23		2.76	12.0	556.0	2.03	9.81	27.3	43.0	4200	Gas evolution, Fe2+ sample off-color

Notes:
Sodium Persulfate ($Na_2S_2O_8$) measurement by Chemetric field test kits.
Total iron (Fe) and Ferrous iron (Fe^{2+}) measurement by Hach field test kits.
All other field parameters measured by YSI 600 series multi-parameter meters

Table 8
Groundwater Monitoring Summary Data - Treatment Events 2 and 3
January/March 2005
93B Maple Avenue
Haverstraw, NY

Date	Well	DTW feet	pH -	COND. mS/cm	ORP mV	DO mg/L	TEMP. °C	Fe2+ mg/L	Total Iron mg/L	Persulfate mg/L	NOTES
Treatment Event 3 - During Injection											
3/16/2005	IW-2		2.00	28.9	583	2.43	14.7	4.75	45.0	14000	Sample dark yellow, Fe2+ sample off-color
3/16/2005	IW-17		1.63	62.3	651	6.39	15.7	6.25	19.0	49000	Sample dark yellow, Fe2+ sample off-color
3/17/2005	IW-2		2.01	21.0	583	5.22	13.9	1.90	47.3	14000	Sample light yellow, Fe2+ sample off-color
3/17/2005	IW-14		1.68	72.5	688	2.71	14.5	3.75	23.8	70000	Sample light yellow, Fe2+ sample off-color
3/17/2005	IW-17		1.67	71.3	681	3.27	15.6	20.5	46.3	70000	Sample dark yellow, Fe2+ sample off-color
3/17/2005	IW-23		2.90	14.2	529	7.65	10.7	23.5	71.3	5600	Sample dark yellow, Fe2+ sample off-color
3/17/2005	IW-25		2.39	60.5	670	4.18	10.3	limit	71.3	70000	Sample dark yellow almost orange , Fe2+ sample off-color
3/18/2005	IW-15		1.53	84.5	678	4.48	15.7	1.75	15.0	140000	Sample light yellow, Fe2+ sample off-color
3/18/2005	IW-17		1.61	76.7	692	6.35	15.2	16.0	26.3	70000	Sample dark yellow, Fe2+ sample off-color, gas evolution
3/18/2005	IW-18		2.86	14.2	523	7.46	10.6	40.8	52.5	2800	Sample dark yellow, Fe2+ sample off-color
3/18/2005	Sump		6.68	0.50	475	46.1	5.68	0.04	0.06	0.7	Very light yellow tint to water
Treatment Event 3 - Post Injection Sampling											
4/15/2005	IW-2	7.52	2.70	11.0	610	0.40	13.0	7.00	59.0	4200	sample light yellow, Fe2+ off-color
4/15/2005	IW-14	9.53	2.00	48.0	740	0.24	14.0	57.5	54.8	28000	sample yellow, Fe2+ sample off-color, gas evolution
4/15/2005	IW-15	9.18	1.70	43.0	741	0.24	14.1	limit	65.0	21000-28000	sample dark yellow, Fe2+ sample off-color, gas evolution
4/15/2005	IW-17	9.58	2.00	48.6	739	0.25	13.8	limit	58.5	35000	sample very dark yellow, Fe2+ sample off-color, gas evolution
4/15/2005	IW-20	9.42	2.04	55.0	770	0.20	15.7	limit	53.5	35000	sample yellow grey, Fe2+ sample off-color, gas evolution
4/15/2005	IW-23	4.26	2.20	28.0	634	0.58	12.5	50.3	51.8	21000	sample dark orange, Fe2+ sample off-color, gas evolution
4/15/2005	IW-25	3.48	1.68	62.0	726	0.22	12.1	limit	78.0	70000	sample dark orange, Fe2+ sample off-color, gas evolution
4/15/2005	Sump	3.45	6.35	1.10	405	0.18	9.73	0.05	0.20	5.6	sample clear light yellow

Notes:
Sodium Persulfate ($Na_2S_2O_8$) measurement by Chemetric field test kits.
Total iron (Fe) and Ferrous iron (Fe^{2+}) measurement by Hach field test kits.
All other field parameters measured by YSI 600 series multi-parameter meters

Table 9
Groundwater Residual Persulfate Mass Estimates
Post-Treatment Event 3
93B Maple Avenue
Haverstraw, NY

Area	Injection Wells	Persulfate Conc. (mg/L)	Pore Volume (L)	Total Persulfate Mass (lbs)
1	IW-2	4200	3194	30
2	IW-14 IW-17	28000 35000	1699 1699	105 131
3	IW-15	24500	3059	165
4	IW-20	35000	2039	157
5	IW-23	21000	1699	79
6	IW-25	70000	1699	262
7	(see Note 2)	*37625*	7646	634
			Total	**1562**

Notes:

1. Area pore volume estimates assume residual persulfate is distributed over 2-foot vertical interval and formation porosity of 0.30
2. Area 7 persulfate groundwater concentration is estimated as average of Area 3, 4, 5 & 6 since there are no wells in this area.

Table 10
Confirmation Soil Analytical Data - Post Treatment Events 2 and 3
93B Maple Avenue ISCO
Haverstraw, NY

Location ID: / Depth Interval in feet:	C-1 11.5-12	C-2 11.25-11.75	C-3 12.5-13	C-4 14-14.5	C-5 6-7	Duplicate of C-5 6-7 C-10 10-10.5	C-6 9-10.5	C-7 14-16
PAHs, mg/kg								
Naphthalene	2.2 J	72 J	30 J	2300	46	29 J	0.76 J	12 J
2-Methylnaphthalene	1.6 U	62 J	7.8 U	960	4.1 U	4 U	0.21 U	3.9 U
Acenaphthylene	1.2 J	39 J	18 J	120 J	6.6 J	8.7 J	2 J	7.1 J
Acenaphthene	0.47 J	66 J	74 J	480	20 J	13 J	1.6 J	12 J
Fluorene	0.47 J	90	140	560	6	49	4	27 J
Phenanthrene	2.6	220	550	1700	160	160	16	130
Anthracene	1.2	110	58 J	520	40 J	38 J	4	47
Fluoranthene	6.8	270	320	820	100	130	14	140
Pyrene	3.7	180	220	690	67	71	11	110
Benzo(a)anthracene	3.8	110	120	350	42	49	9	59
Chrysene	3.6	120	120	380	38 J	47	10	54
Benzo(b)fluoranthene	2.6	54 J	71 J	140 J	17 J	22 J	6	32 J
Benzo(k)fluoranthene	3.4	87	79	230 J	28 J	34 J	8	35 J
Benzo(a)pyrene	4.7	98	94	250 J	29 J	34 J	8	45
Indeno(123-cd)pyrene	2.2	44 J	47 J	110 J	12 J	17 J	7	22 J
Dibenzo(ah)anthracene	0.99 J	20 J	29 J	54 J	5 J	4 U	3	8.3 J
Benzo(ghi)perylene	1.4 J	37 J	36	110 J	9.1 J	12 J	6	19 J
Total PAHs	**41**	**1679**	**2006**	**9774**	**676**	**718**	**110**	**759**
Correlating Boring ID	IW-13	B-5	IW-19	B-8	B-17	B-17	B-11	B-13
Correlating Boring TPAH Value (2004)	133	7543	5542	4617	2805	2805	1309	6122
Percent Reduction	**69%**	**78%**	**64%**	**-112%**	**76%**	**74%**	**92%**	**88%**
GRO (mg/kg)	0.25 U	27	190	3400	29	8.3	0.25 U	8
DRO (mg/kg)	530	6800	11000	47000	3000	2100	95	4600
PAH/DRO (percentage)	8%	25%	18%	21%	23%	34%	115%	17%

Notes:
U - Not detected at or above the reporting limit shown
J - Estimated value
Average total PAHs based on all sample results, including duplicate samples

Table 11
Summary of Total PAH Means in Treatment Area Soil
93B Maple Avenue
Haverstraw, NY

Pre-Event 1 Soil Data		Intermediate Soil Data		Post Treatment- Events 2 and 3 Soil Data	
Sample ID	TPAH (ppm)	Sample ID	TPAH (ppm)	Sample ID	TPAH (ppm)
GP-42 13-14.3	426.6	B-13 14.0-14.5	6122	C-1 11.5-12.0	41
GP-43 12-13	3650	B-14 13.5-14.0	74.9	C-2 11.25-11.75	1679
GP-44 9-10.5	12.8	B-15 12.0-12.5	90.3	C-3 12.5-13.0	2006
GP-44 11-12	9.2	B-16 13.5-14.0	1252.7	C-4 14.0-14.5	9774
GP-45 7.5-8.0	2276	B-17 7.0-7.5	2805	C-5 6.0-7.0	718
B-1 11.5-12	439.5	B-18 7.0-7.5	1.5	C-6 9.0-10.5	110
B-2 12.5-13.0	1563	IW-13 9.0-10.5	132.8	C-7 14.0-16.0	759
B-5 12.5-13.0	7543	IW-14 8.0-10.5	6.6		
B-8 13.5-14.0	4517	IW-15 10.5-11.0	14778		
B-10 6.5-7.0	466.8	IW-16 12.0-13.0	1.1		
B-11 7.0-8.0	1309	IW-17 13.0-13.5	4050		
		IW-18 14.0-16.0	51.8		
		IW-19 12.0-12.5	5542		
		IW-20 12.0-13.5	15.7		
		IW-21 15.0-16.0	460.8		
		IW-22 6.0-7.0	0.8		
		IW-23 6.25-6.75	7274		
		IW-24 10.0-11.0	0.5		
		IW-25 9.5-10.0	1.1		
TPAH Mean Value	**2019.3**		**2245.3**		**2155.3**
Standard Deviation	**2360.0**		**3871.5**		**3439.1**
Range	**9.1 to 7543**		**0.5 to 14,778**		**41 to 9774**

Table 12
Pre-Injection PAH Mass Estimate Calculations
93B Maple Avenue
Haverstraw, NY

2004 PAH mass estimate based on maximum detected total PAH concentration in each area after the first treatment event.

Area	Well	Soil Boring ID (Sample Depth)	TPAH Values (mg/kg)	Design PAH Conc (mg/kg)	Treatment Vol (ft3)	PAH Soil Mass (lbs)	PAH GW Mass (lbs)	PAH NAPL Mass (lbs)	Total PAH Mass (lbs)
1	IW-13	IW-13 (9-10.5)	133	6122	188	126	17	3	146
	IW-1	B-1 (11.5-12)	439						
	IW-2	B-14 (13.5-14)	75						
		B-2 (12.5-13)	1563						
		B-13 (14-14.5)	6122						
2	IW-14	IW-14 (8-10.5)	6.6	4050	200	89	12	3	104
		B-15 (12-12.5)	90						
		B-16 (13.5-14)/dup	255 / 1252						
	IW-17	IW-16 (12-13)	1						
		IW-18 (14-16)	52						
		IW-17 (13-13.5)	4050						
3	IW-15	B-5 (12.5-13)/dup	6091 / 7543	14778	180	292	38	3	333
		IW-15 (10.5-11)	14778						
	IW-19	IW-19 (12-12.5)	5542						
4	IW-20	IW-20 (12-15.5)	16	461	120	6	1	2	9
	IW-21	B-21 (15-16)	461						
	IW-21	IW-18 (14-16)	52						
		B8 (13.5-14)	4517						
5	IW-22	IW-22 (6-7)	1	7274	100	80	10	2	92
	IW-23	B-23 (6.25-6.75)	3705 / 7274						
	IW-23	B-18 (7-7.5)	2						
		B-10 (6.5-7)	467						
		B-17 (7-7.5)	2,805						
6	IW-11	IW-24 (10-11)	1	1	100	0	0	2	2
		B-18 (7-7.5)	2						
		B-11 (7-8)	1309						
	IW-25	B-25 (10-11)	1						
		B-10 (6.5-7)	467						
7		GP-43	3650	3650	450	180	24	7	211
		GP-44	13						
	(Area 7 is under office - no injection wells are installed in this area)								
					Total PAH Mass	774	101	21	896

Notes:
1) The maximum concentration is duplicate samples was used in analysis.
2) Mass estimates based on maximum detected total PAH concentration in each area.

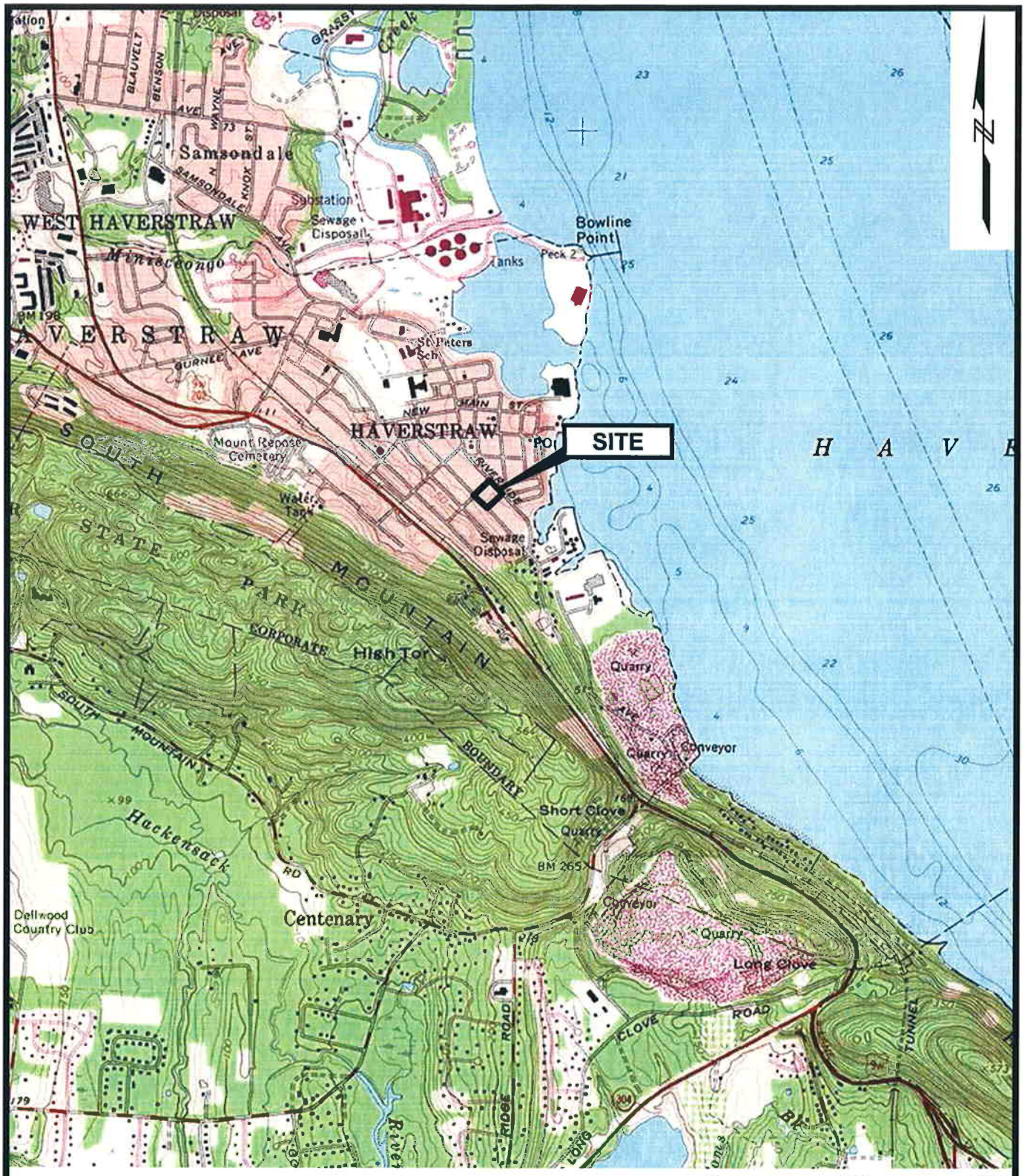
Table 13
Post-Injection PAH Mass Estimate Calculations
93B Maple Avenue
Haverstraw, NY

Post-injection event 3 PAH mass estimate based on maximum detected total PAH concentration in each area.

Area	Injection Wells	Soil Boring ID (Sample Depth)	Soil TPAH Conc (mg/kg)	Max TPAH Conc (mg/kg)	Treatment Vol (ft3)	PAH Soil Mass (lbs)	PAH GW Mass (lbs)	PAH NAPL Mass (lbs)	Total PAH Mass (lbs)
1	IW-13 IW-1 IW-2	C-1 (11.5-12) C-7 (14-16)	41 759	759	188	16	2	3	21
2	IW-14 IW-17	(No confirmation borings in this area)			200				
3	IW-15 IW-5 IW-19 IW-6	C-2 (11.25-11.75) C-3 (12.5-13)	1679 2006	2006	180	40	5	3	48
4	IW-20 IW-7 IW-21 IW-8	C-4 (14-14.5)	9774	9774	120	129	17	2	148
5	IW-9 IW-10 IW-23	C-5 (6-7) C-5 (6-7) dup	676 718	718	100	8	1	2	10
6	IW-11 IW-12	C-6 (9-10.5)	110	110	100	1	0	2	3
7		(No confirmation borings in this area)			450				
					Total PAH Mass	193	25	11	229

Notes:
1) The highest concentration from a duplicate samples was used in analysis.
2) Mass estimates based on maximum detected total PAH concentration in each area.

Figures



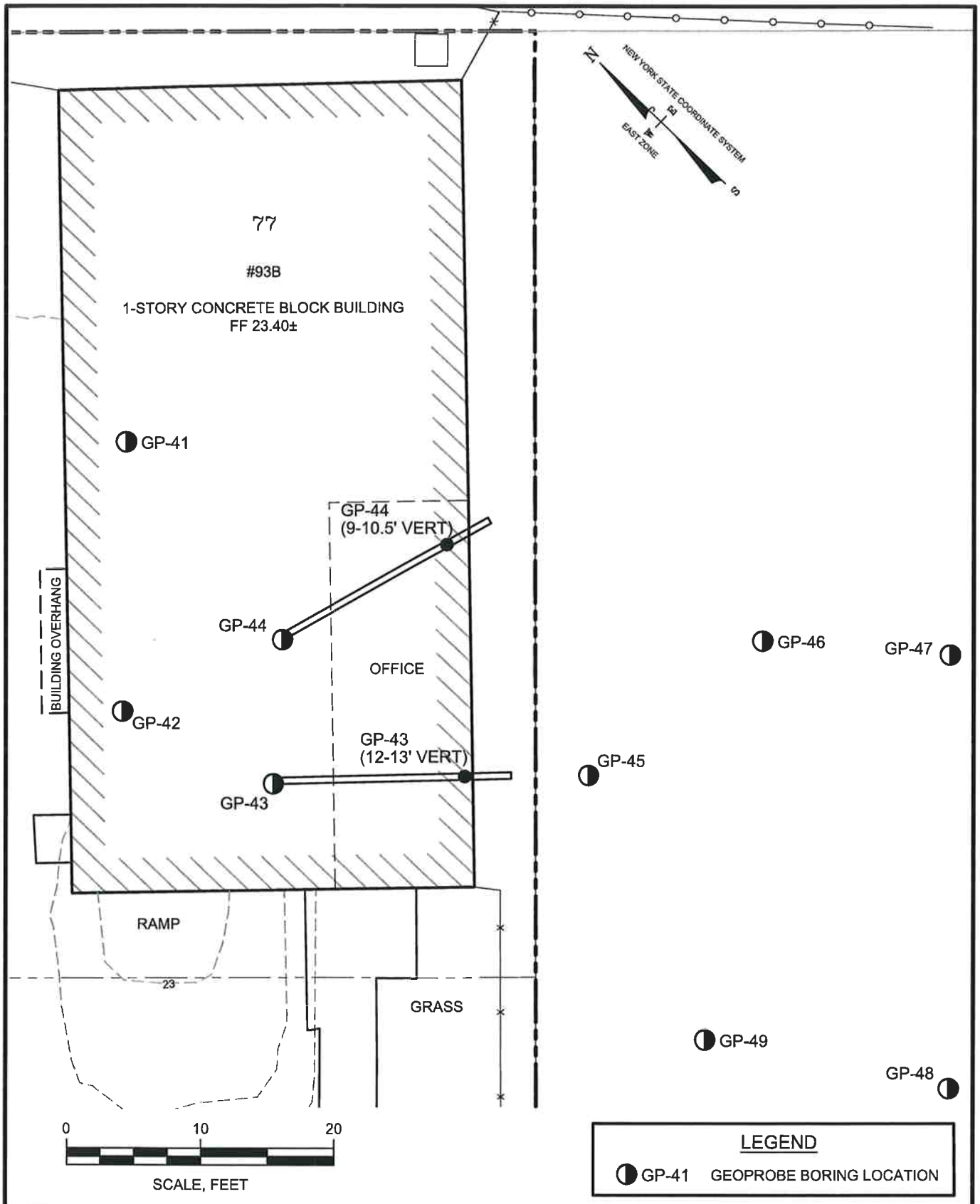
SOURCE: Map created with TOPO! ® ©2001 National Geographic (www.nationalgeographic.com/topo)

0 2000 4000

SCALE, FEET

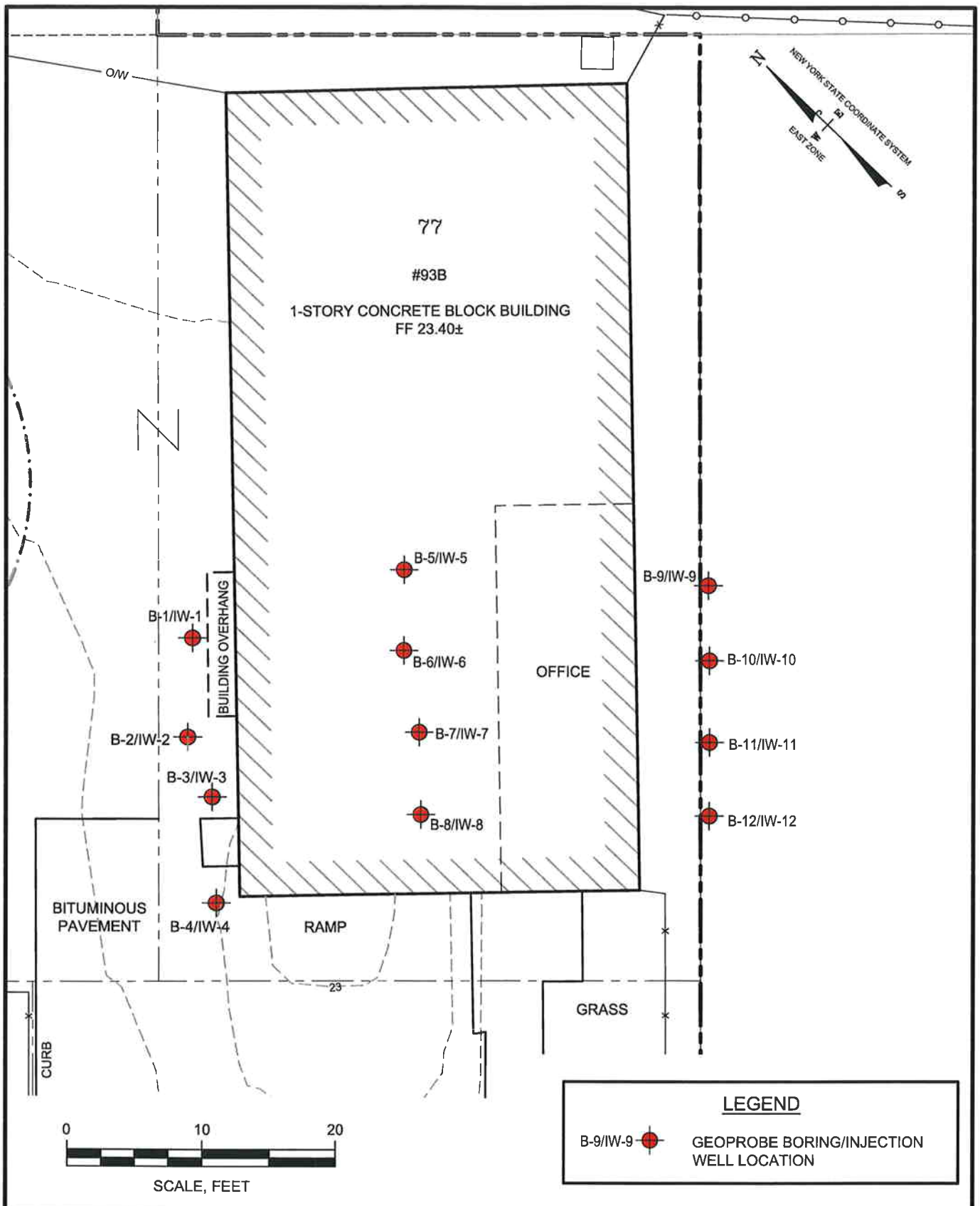
93B MAPLE AVENUE FORMER MGP SITE HAVERSTRAW, NEW YORK	GEI Consultants	**SITE LOCATION MAP**
ORANGE AND ROCKLAND	PROJECT 040600	March 2006 Figure 1

OR&ROCK\HAVERSTRAW\040600-ISCO REPORT\93B MAPLE-LOC.PPT



93B MAPLE AVENUE FORMER MGP SITE HAVERSTRAW, NEW YORK	GEI Consultants	**GEOPROBE BORINGS SEPTEMBER/OCTOBER 2003**
ORANGE AND ROCKLAND	Project 040600	March 2006 Figure 2

OR&ROCK\HAVERSTRAW\040600-ISCO RPT\93B-BORINGS.dwg



93B MAPLE AVENUE FORMER MGP SITE
HAVERSTRAW, NEW YORK

ORANGE AND ROCKLAND

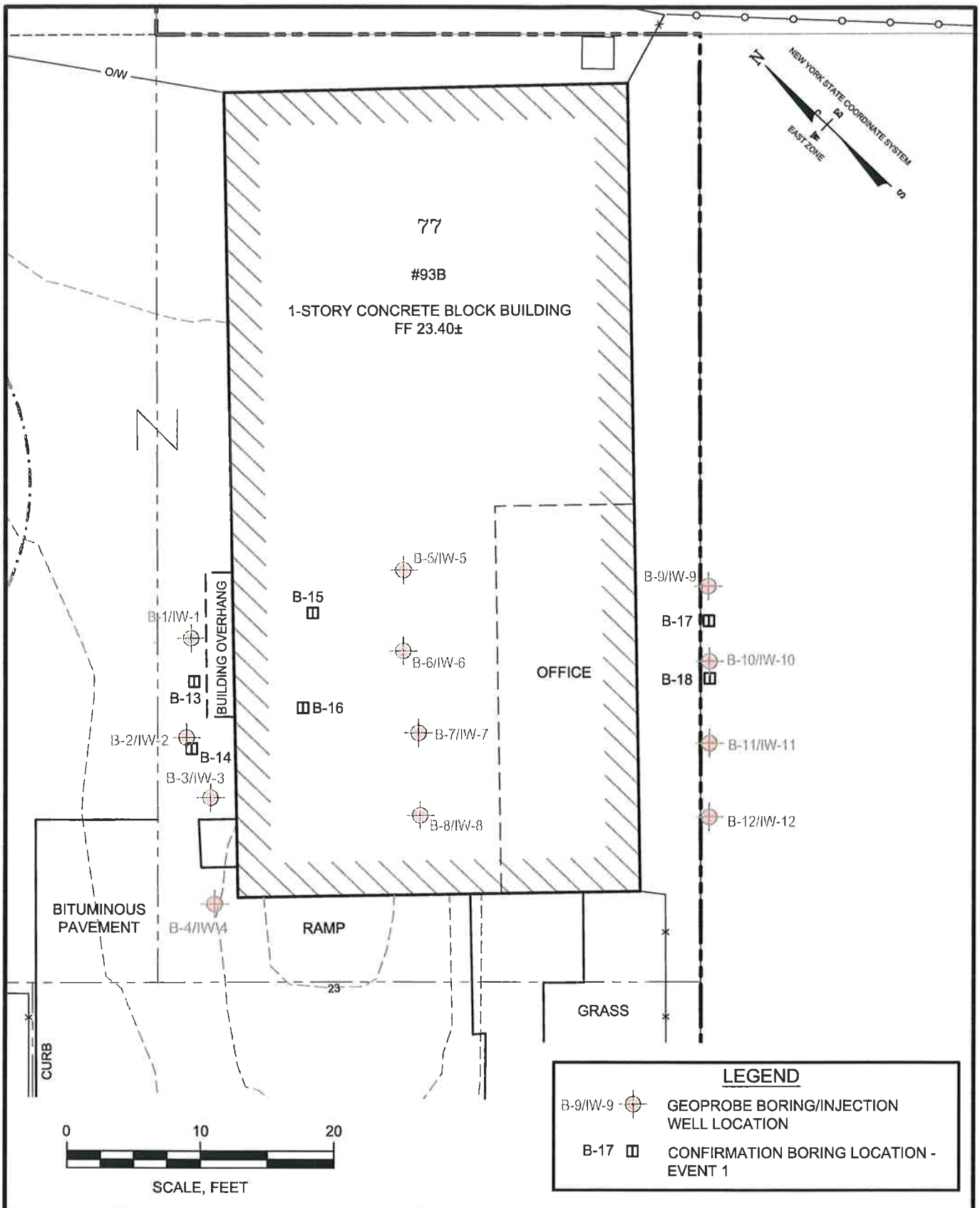
GEI Consultants

Project 040600

INJECTION WELL AND BORING LOCATIONS - MARCH 2004

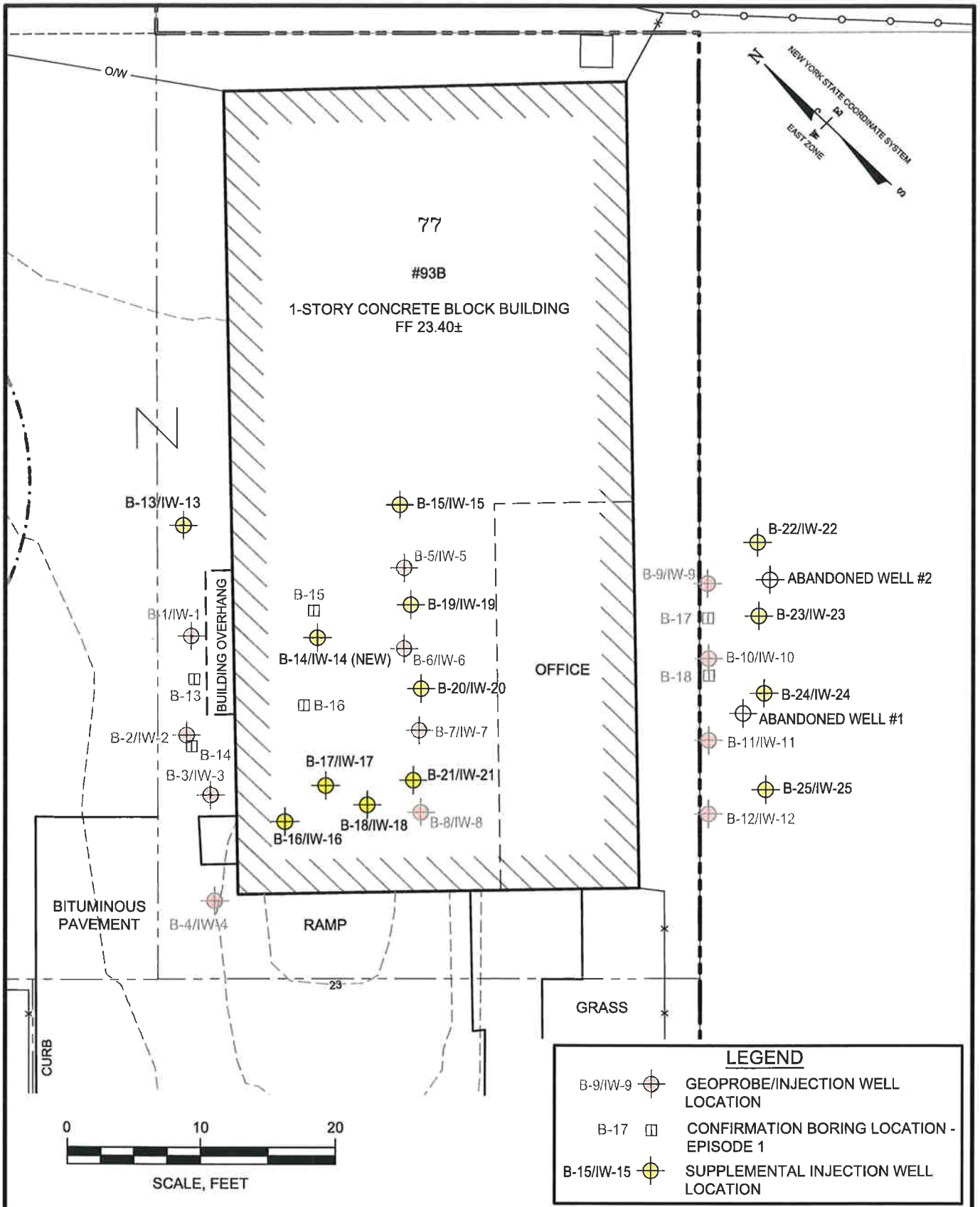
March 2006 Figure 3

OR&ROCK\HAVERSTRAW\040600-ISCO RPT\93B-BORINGS.dwg



93B MAPLE AVENUE FORMER MGP SITE HAVERSTRAW, NEW YORK	GEI Consultants	**CONFIRMATION BORING LOCATIONS - EVENT 1**
ORANGE AND ROCKLAND	Project 040600	March 2006 Figure 4

OR&ROCK\HAVERSTRAW\040600-ISCO RPT\93B-BORINGS.dwg



93B MAPLE AVENUE FORMER MGP SITE
HAVERSTRAW, NEW YORK

ORANGE AND ROCKLAND

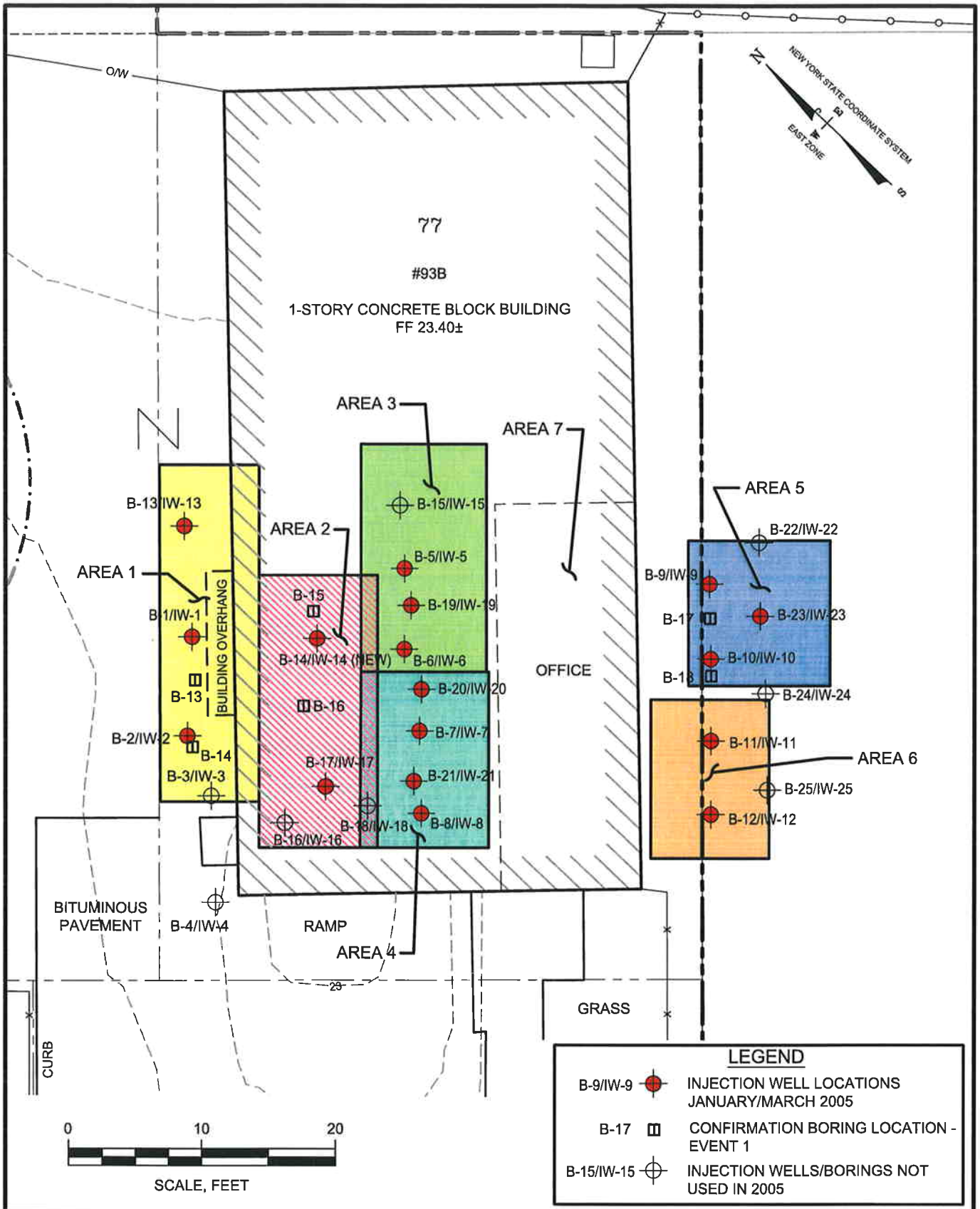
GEI Consultants

Project 040600

SUPPLEMENTAL INJECTION WELL AND BORING LOCATIONS - JUNE/JULY 2004

March 2006 Figure 5

OR&ROCK\HAVERSTRAW\040600-ISCO RPT\93B-BORINGS.dwg



93B MAPLE AVENUE FORMER MGP SITE
HAVERSTRAW, NEW YORK

ORANGE AND ROCKLAND

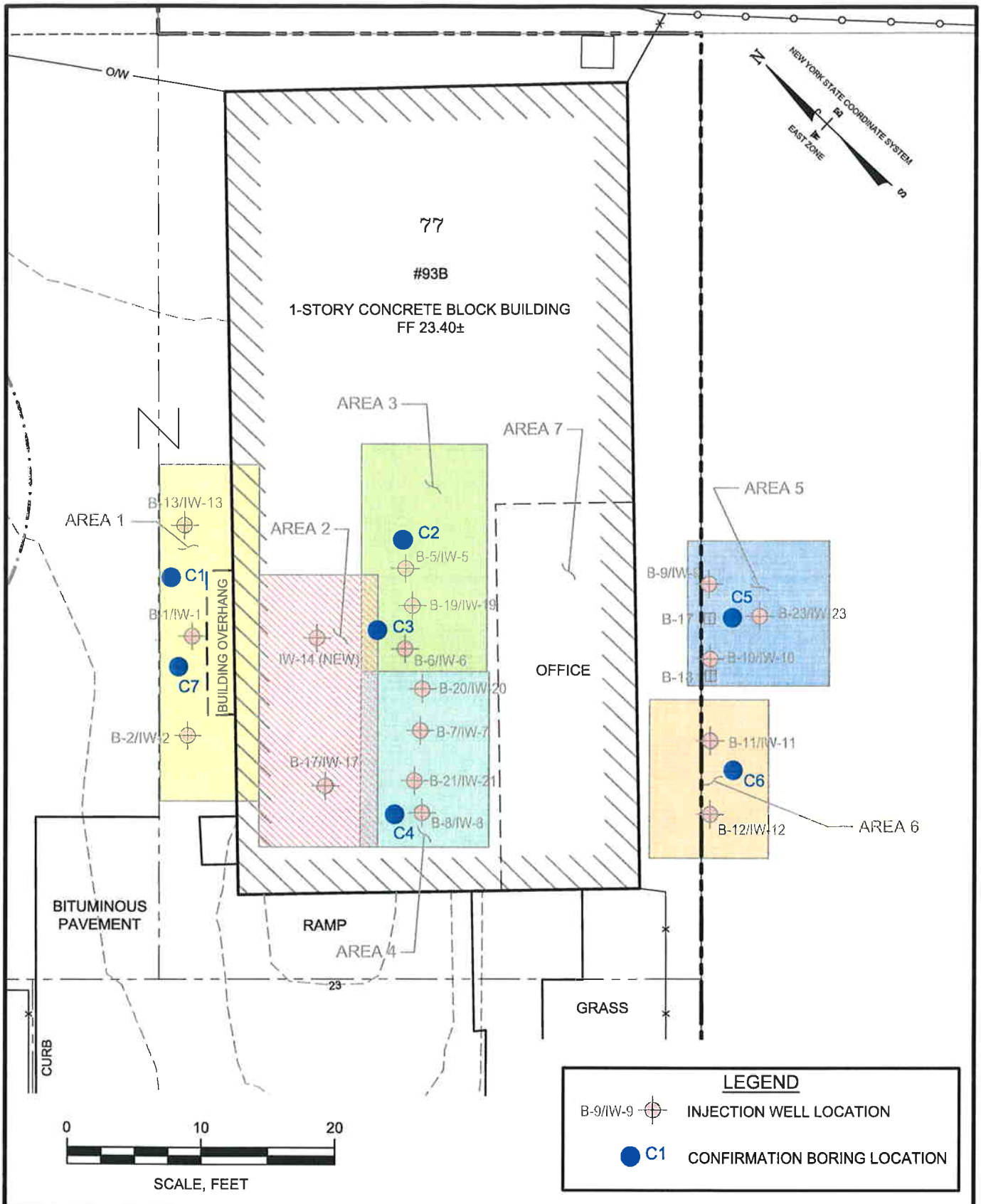
GEI Consultants

Project 040600

SUB-AREA LOCATIONS JANUARY/MARCH 2005

March 2006 Figure 6

OR&ROCK\HAVERSTRAW\040600-ISCO RPT\93B-BORINGS.dwg



93B MAPLE AVENUE FORMER MGP SITE
HAVERSTRAW, NEW YORK

ORANGE AND ROCKLAND

GEI Consultants

Project 040600

CONFIRMATION BORING LOCATIONS - EVENTS 2 AND 3

March 2006 Figure 7

OR&ROCK\HAVERSTRAW\040600-ISCO RPT\93B-BORINGS.dwg