USACE CONTRACT NO. DACW33-94-D-0002
TASK ORDER NO. 020
TOTAL ENVIRONMENTAL RESTORATION CONTRACT

PILOT-SCALE TREATABILITY STUDY WORK PLAN FOR THE CHROMIUM AND VOC GROUNDWATER OPERABLE UNIT (OU) 2
EE/CA
STRATFORD ARMY ENGINE PLANT
Stratford, Connecticut

November 3, 1999

Prepared for

U.S. Army Corps of Engineers
New England District
Concord, Massachusetts

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Prepared for:

U.S. Army Corps of Engineers
New England District
Concord, Massachusetts

Prepared by:

Foster Wheeler Environmental Corporation
Boston, Massachusetts

and

Harding Lawson Associates
Portland, Maine

November 1999

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PILOT-SCALE TREATABILITY STUDY WORK PLAN FOR
THE CHROMIUM AND VOC GROUNDWATER OPERABLE UNIT (OU) 2 EE/CA
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1.0 PROJECT DESCRIPTION

Foster Wheeler Environmental Corporation (Foster Wheeler) and Harding Lawson Associates (HLA) have been contracted through the U.S. Army Corps of Engineers (USACE) – New England District (NEA) to complete a Non-time Critical Removal Action (NCRA) for chromium and volatile organic compound (VOC) groundwater contamination (Operable Unit [OU] 2) at the Stratford Army Engine Plant (SAEP) under Task Order No. 020 of Contract No. DACW33-94-D-0002. The objectives of this Task Order are to: 1) complete additional field activities necessary to provide further characterization of subsurface conditions at SAEP, 2) summarize the results of previous field activities in a report, 3) conduct bench-scale and pilot-scale testing to determine the effectiveness of particular in-situ technologies at reducing the levels of contamination in groundwater at the site, and 4) document the decision process for selection of a removal action for OU 2 in an Engineering Evaluation/Cost Analysis (EE/CA).

Two pilot-scale treatability studies are planned during this time period to investigate the effectiveness of in-situ treatment technologies at reducing concentrations of hexavalent chromium and VOCs, primarily trichloroethylene (TCE), in groundwater hot-spot areas at SAEP. Information obtained during operation of the pilot-scale systems will aid in cost estimation and design of full-scale systems for treatment of the hot-spot areas. Treatability study activities are proposed to address hot-spot contamination only and are not intended to fully remediate site groundwater.

This Work Plan was developed in accordance with the U.S. Environmental Protection Agency (USEPA) Guide for Conducting Treatability Studies Under CERCLA (i.e., the Comprehensive Environmental Response, Compensation, and Liability Act of 1980) (USEPA, 1992). It summarizes the activities proposed for completion of the pilot-scale tests and incorporates the results of pre-design investigations activities, including soil and groundwater sampling, bench-scale testing, and aquifer testing. This Work Plan is supplemental to the Final OU 2 NCRA Work Plan submitted by Foster Wheeler/HLA on August 27, 1999 (Foster Wheeler/HLA, 1999). Comments received from the USEPA on the Draft Work Plan have been incorporated into this document. A copy of the response to USEPA comments is included as Appendix D.

1.1 SITE DESCRIPTION AND HISTORY

SAEP is located on approximately 126 acres in Stratford, Connecticut, on the Stratford Point peninsula in the southeast corner of Fairfield County (Figure 1) (see Appendix A). About 76 acres of the land are improved and 48 acres are riparian (water) rights (see Figure 1).

SAEP was formerly a government-owned, contractor-operated facility. The land and buildings are owned by the U.S. Army, and former plant equipment (removed in early 1998) was owned by both the U.S. Army and it's contractor AlliedSignal Engines. The

U.S. Army-owned land, buildings, and equipment were formerly provided to AlliedSignal under a facilities contract for executing government contracts, including the manufacture and testing of turbine engines for the U.S Army. The SAEP property consists of 49 buildings, paved roadways and grounds, and five paved parking lots (Figure 2).

Responsibility for the jurisdiction, control, and accountability of SAEP was transferred from the U.S. Army Aviation and Troop command to the U.S. Army Tank-Automotive and Armament Command (TACOM) in September 1995. In October 1995, SAEP was placed on the Base Closure and Realignment (BRAC) list, known as BRAC 95. Pursuant to the Defense Base Closure and Realignment Act of 1990, the BRAC Environmental Restoration Program mandates that environmental contamination on BRAC properties be investigated and remediated, as necessary, prior to disposal and reuse. In August 1998, SAEP was transitioned from an active production facility to caretaker status.

Section Two of the URS Greiner-Woodward Clyde Federal Services (URSGWCFS) Remedial Investigation (RI) Work Plan (URSGWCFS, 1998) provides a description of SAEP, including a land use assessment, a physical setting description, an ecological setting description, and a site history. Attachment 2 of the Final OU 2 NCRA Work Plan (Foster Wheeler/HLA, 1999) contains a copy of Section Two of the URSGWCFS RI Work Plan.

1.2 PREVIOUS INVESTIGATIONS

For BRAC 95 facilities, the Environmental Restoration Program begins with an Environmental Baseline Survey (EBS) to describe the environmental condition of the property. ABB Environmental Services (subsequently HLA) published the Final EBS in December 1996. An RI is currently being conducted by URSGWCFS under a contract to the USACE to characterize the type and extent of contamination at SAEP and evaluate potential risks to human health and the environment.

Several other previous investigations have been completed at SAEP, including:

- Preliminary Assessment Screening
- Resource Conservation and Recovery Act (RCRA) Facility Assessment
- Phase I Investigation
- Phase II Investigation
- Remedial Investigation

These investigations, and the EBS, are summarized in Section 3.0 of the URSGWCGS RI Work Plan (URSGWFS, 1998) and in the Final OU 2 NCRA Work Plan (Foster Wheeler/HLA, 1999).

In June 1998, SAEP hired AJS Environmental Services, Inc., through a subcontract to AlliedSignal, to perform soil sampling beneath the floor of the Chromium Plating Facility. AJS collected over 60 subsurface soil samples from 30 borings, and analyzed the samples for total chromium. Analytical results indicated total chromium concentrations in soil would exceed the Connecticut Department of Environmental Protection (CTDEP) Remediation Standard Regulation (RSR) criteria for hexavalent chromium (if all the total chromium was the hexavalent species); however, no chromium speciation was performed as part of this initial sampling event.

As a result, SAEP contracted HLA, through a subcontract to AlliedSignal, to perform additional site characterization and develop a removal action recommendation for the site. The following activities have been completed to support the recommendation of a removal action for the area near the former Chromium Plating Facility and SAEP groundwater:

- Preliminary Investigations
- Chromium Plating Facility Decontamination
- Chromium Plating Facility Investigations
- VOC Groundwater Investigations

SAEP subsequently hired the Foster Wheeler/HLA team (Team) to conduct additional evaluations of the OU2 groundwater contamination at the site. To date, the Team has completed the following tasks:

- Bench-scale Testing
- Aquifer Testing

Results of these activities are summarized in the following subsections.

1.2.1 Preliminary Investigations

HLA's preliminary investigations were conducted on August 20, 1998, and consisted of the collection of 12 subsurface soil samples and two groundwater samples from six locations beneath the former Chromium Plating Facility. Sampling results indicated concentrations of total chromium (analyzed by the Synthetic Precipitate Leaching Procedure [SPLP]) exceeded the CTDEP RSR Pollutant Mobility Criteria in soil. In addition, hexavalent chromium concentrations in groundwater exceeded the CTDEP RSR Surface Water Protection Criteria (SWPC) by two orders of magnitude. Figure 3 identifies HLA's previous soil boring locations in the area of the former Chromium Plating Facility at SAEP.

HLA's sampling also identified high concentrations of chromium in dust samples within the former chromium plating building. Based on the concentrations of total chromium in the dust samples, a Time-Critical Removal Action Memorandum was written, proposing decontamination of the former Chromium Plating Facility and further investigation of site soil and groundwater followed by in-situ hexavalent chromium reduction of soil.

1.2.2 Chromium Plating Facility Decontamination

The facility decontamination was completed in December 1998. Decontamination procedures included sweeping, the removal of debris and dust from the concrete floor, and pressurized steam washing of the ceiling, overhead beams, walls, and floor. Wipe sampling conducted following the decontamination procedures indicated that relatively high concentrations of hexavalent chromium were still present on the floor and in limited areas on overhead beams and walls. The disposition of areas containing residual concentrations of hexavalent chromium will be addressed in the EE/CA.

1.2.3 Chromium Plating Facility Investigations

GeoProbe investigations were initiated in January 1999 to further define the extent of chromium contamination in subsurface soil and groundwater in the area around the former Chromium Plating Facility. Figure 3 identifies HLA's previous soil boring locations and Figure 4 identifies HLA's hexavalent chromium groundwater sampling locations. The following bullets summarize activities conducted during the GeoProbe investigation:

- Collection of 41 subsurface soil samples from 21 boring locations (0-7 feet below ground surface [bgs]).

- Off-site analysis of these samples for hexavalent chromium, total chromium, cyanide, and pH.

- One sample from each boring was also analyzed off-site for manganese and total chromium using the SPLP method.

- Collection of 7 groundwater samples from 7 sampling locations (sample depth 7 to 9 feet bgs) that received on-site analysis for ferrous iron and off-site analysis for hexavalent chromium, inorganic compounds, cyanide, sulfate, and alkalinity.

- Collection of 182 groundwater samples from 32 sampling locations (WP-99-01 through WP-99-32) (discreet 4-foot intervals ranging from 7 to 71 feet bgs) that received on-site Hach™ kit testing for hexavalent chromium and ferrous iron.

- Collection of field readings of pH, temperature, dissolved oxygen, specific conductivity, turbidity, and oxidation-reduction potential (ORP) for each of the above-mentioned 182 groundwater samples.

- Four of these samples were sent off-site for analysis for VOCs and semi-volatile organic compounds (SVOCs).

- Collection of 30 groundwater samples for confirmation analysis at an off-site laboratory for hexavalent chromium, inorganic compounds, cyanide, sulfate, and alkalinity.

Sampling results from the Chromium Plating Facility investigation indicated hexavalent chromium concentrations in groundwater as high as 950 milligrams per liter (mg/L), and detectable hexavalent chromium (greater than 0.1 mg/L) at depths ranging from the groundwater surface to approximately 50 feet bgs. Figure 5 identifies the horizontal location of hexavalent chromium contamination exceeding the CTDEP RSR criteria in groundwater and Figures 6 and 7 provide cross sections of hexavalent chromium concentrations in groundwater.

In addition, concentrations of VOCs in the four samples sent for off-site analysis were in exceedance of the CTDEP RSR criteria, with one sample containing TCE at a concentration above 100 mg/L. Results from the Chromium Plating Facility Investigation are contained in the Draft Data Package for the Chromium Plating Facility Investigation submitted to TACOM and AlliedSignal Engines in April 1999 (HLA, 1999).

1.2.4 VOC Groundwater Investigations

Based on the VOC concentrations from the four samples collected and analyzed for VOCs during the Chromium Plating Facility Investigations, SAEP directed HLA to begin a VOC groundwater investigation in March 1999. GeoProbe equipment was used to collect groundwater samples from around the SAEP site. Exploration locations and the estimated horizontal extent of selected VOCs in groundwater are identified on Figure 8. Figure 9 presents a cross section of VOC concentrations in groundwater in the area of the former Chromium Plating Facility. The GeoProbe VOC groundwater investigation consisted of:

- Collection of 126 groundwater samples from 40 sampling locations (WP-99-33 through WP-99-72) (discreet 4-foot sample intervals ranging from 6 to 82 feet bgs) that received on-site analysis for select VOCs using a gas chromatograph (GC).

- Collection of field readings of pH, temperature, dissolved oxygen, specific conductivity, turbidity, and ORP for each sample.

- Split sample collection of 10 groundwater samples for VOC confirmation analysis at an off-site laboratory.

Results of the GeoProbe VOC investigation indicated concentrations of several VOCs exceeding CTDEP Surface Water Protection RSR criteria, including TCE, tetrachloroethylene (PCE), 1,1,1-trichloroethane (1,1,1-TCA), and 1,1-dichlroethylene (1,1-DCE). The Draft Data Package for the Chromium Plating Facility Investigation contains data results from the GeoProbe VOC investigation (HLA, 1999).

HLA conducted additional VOC groundwater investigations in April and May 1999 using a cone penetrometer to access depths not attainable by the GeoProbe equipment. Sample locations are identified on Figure 8 (CP-99-01 through CP-99-18). The cone penetrometer VOC groundwater investigation consisted of:

- Eighteen total cone penetrometer explorations were completed for stratigraphic data acquisition and collection of groundwater samples.
- A total of 87 groundwater samples from the water table to a maximum depth of 158 feet bgs, were sent to an off-site laboratory for VOC analyses.
- Stratigraphic logs of the explorations were recorded to better define in-situ subsurface geologic conditions beneath SAEP.
- Thirty-eight dissipation tests were conducted to obtain estimates of in-situ horizontal hydraulic conductivity.

Results of the cone penetrometer investigation provided deeper groundwater information and additional horizontal groundwater characterization to supplement the results obtained during the GeoProbe investigation. Analytical results provided better delineation to the extent of VOC groundwater contamination. The results of cone penetrometer investigations will be presented in the OU 2 NCRA Pre-design Investigation Report, scheduled for submittal in December 1999.

1.2.5 Bench-scale Testing

Bench-scale testing (i.e., remedy-screening testing) was completed in August 1999 to evaluate the effectiveness of potential in-situ treatment technologies on site contamination. Three potential treatments, hexavalent chromium reduction using ferrous sulfate, VOC chemical oxidation using potassium permanganate, and VOC chemical oxidation using hydrogen peroxide, were tested on three areas of the site. Area 1, named the TCE Area, tested the effectiveness of potassium permanganate and hydrogen peroxide at oxidizing VOCs, primarily TCE. Area 2, the Hexavalent Chromium Area, tested the effectiveness of ferrous sulfate at reducing hexavalent chromium. Area 3, the 1,1,1-TCA Area tested the effectiveness of potassium permanganate and hydrogen peroxide on VOCs; however, the primary contaminant of concern was 1,1,1-TCA. These three areas are identified on Figure 10.

Samples used for bench-scale testing consisted of aquifer soil and groundwater collected from the depth of maximum contaminant (groundwater) concentrations in the respective hot-spots. A soil sample was collected from the zone of maximum contamination and sent off-site for analysis for VOCs, SVOCs, and inorganics during completion of a soil boring in each hot-spot. A pre-test sample of the groundwater/soil mixture (a water sample) also was collected and analyzed on-site for hexavalent and total chromium, ferrous iron, total iron, pH, temperature, and ORP and off-site for VOCs and the water quality parameters alkalinity; hardness; dissolved calcium, magnesium, and manganese; sulfide; and chloride. Pre-test sample results were used to estimate the contaminant mass in an individual test jar (contaminant mass in soil and groundwater) and subsequently calculate the stoichiometric amount of reagent necessary to complete each test.

Generally, testing was completed using 200 grams of soil and approximately 900 milliliters of water in each of six 1-liter jars. Testing consisted of the addition of a specified reagent (e.g., ferrous sulfate solution, hydrogen peroxide solution, or potassium permanganate) and the necessary catalysts (e.g., sulfuric acid or ferrous sulfate solution) to the prepared 1-liter jars. Two tests were run for Areas 1 and 3, the TCE and the 1,1,1-TCA Areas, respectively. The first test involved the addition of ferrous sulfate catalyst and hydrogen peroxide solution to six jars. A specific volume of a 10 percent ferrous sulfate solution was first added to each jar, then a 5 percent hydrogen peroxide solution was added at various multiples of the stoichiometrically-determined dosage (ranging from 0 to 10 times). The second test for Areas 1 and 3 involved the addition of a 5 percent solution of potassium permanganate to jars at various multiples of the stoichiometric dosage (ranging from 0 to 4 times) (see Tables 1 and 2).

In Area 2, testing consisted of the addition of various volumes of sulfuric acid or sodium hydroxide to adjust each jar's pH, followed by the addition of a 10 percent ferrous sulfate solution. Various dosages of ferrous sulfate were added to the jars, ranging from 0 times the stoichiometric dosage (the control sample) to 2 times the stoichiometric dosage.

The samples were mixed and allowed to settle, then the water was analyzed both on- and off-site to assess the effectiveness of each test condition. The tests determined the chemical dose needed for maximum conversion of contaminants with minimum residual reagent.

Both quantitative and qualitative assessments of the bench-scale tests were recorded. Table 1 presents the analytical data obtained from bench-scale testing including on-site Hach test kit results and off-site laboratory analysis. Table 2 presents field parameter data collected during completion of the testing and qualitative assessments.

In general, bench-scale testing indicated that potassium permanganate was slightly more effective than hydrogen peroxide at reducing concentrations of chlorinated ethenes (e.g., TCE and 1,1-DCE) in the jar samples. Neither potassium permanganate nor hydrogen peroxide appeared effective at reducing concentrations of chlorinated ethanes (e.g., 1,1,1-

TCA) in jar samples; therefore, alternative technologies such as air sparging or six-phase heating will be considered for the 1,1,1-TCA area. Testing in samples collected from Area 2 indicated ferrous sulfate appeared capable of reducing hexavalent chromium present in jar samples to trivalent chromium. Although the reaction was most successful at a pH of approximately 6.0, a much lower pH (approximately 2.5) was necessary to prevent excessive precipitation of trivalent chromium and ferric iron.

As a result of bench-scale testing, potassium permanganate will be the reagent tested during pilot-scale treatability studies (i.e., remedy-selection testing) on TCE contamination near Area 1 and ferrous sulfate will be tested on the hexavalent chromium near Area 2 during treatability testing. The OU 2 NCRA Pre-design Investigation Report will describe in detail the results of bench-scale testing.

1.2.6 Aquifer Testing

Aquifer testing was completed between August 30 and September 2, 1999. The testing consisted of an initial step-drawdown test to assess immediate aquifer response to pumping, identify the approximate specific capacity of the pumping well, and determine an appropriate pumping rate for a longer-term constant rate test. A 48-hour constant-rate pumping test was then conducted to evaluate aquifer hydraulic parameters in the vicinity of the pumping well and the former Chromium Plating Facility, including transmissivity, hydraulic conductivity, and specific yield.

The testing revealed that the pumping zone (20 to 40 feet bgs) has high specific capacity that indicates a relatively high aquifer transmissivity. The pumping well responded largely in an unconfined manner with a quick flattening of drawdown that can be associated with either delayed drainage from an unconfined aquifer, or leakage through semi-confining overlying soils. Shallow piezometers close to the pumping well exhibited relatively small drawdown responses, indicating that geologic stratification is likely restricting the vertical propagation of pumping stresses. Similar small drawdowns at more distant piezometers screened in the same zone as the extraction well (e.g. PZ-99-01B) suggests that delayed drainage or leakage buffered pumping stresses so that they had not yet appeared within this three-day test.

Cyclical tidal influence limited the usefulness of data from any of the observation wells, particularly because the drawdown from pumping in all observation wells was so small. Tidal variation, while only about 0.03 feet in magnitude, was generally equal to 30 percent or more of the apparent drawdown.

The best estimate of aquifer transmissivity is derived from the pumping well specific capacity. Specific capacity was approximately one gallon per minute (gpm) per foot of drawdown at each of the four test pumping rates (step test and constant-rate test discharge rates). The transmissivity derived empirically from this specific capacity is 1500 gallons per day per foot.

Using this approximation of transmissivity and the observational evidence that anisotropy (stratification) limits the flow of water from the upper portion of the saturated zone, the aquifer thickness is best approximated at 20 feet, equivalent to the length of the extraction well screen. Using this aquifer thickness produces an estimate of the horizontal hydraulic conductivity for the pumping zone of 10 feet per day (ft/d).

Based on this hydraulic information, preliminary groundwater flow evaluations of the pilot-scale test scenario have been completed to aid in development of the pumping system. Groundwater flow evaluation results are presented in Subsection 3.1 and Appendix C. The aquifer testing indicates the injection/extraction scenario proposed for the pilot-test should not be restricted by the aquifer properties.

1.3 EXISTING SITE CONDITIONS

Analytical results from pre-design investigations provide information on the distribution of hexavalent chromium and VOC contamination in the subsurface in the area of the former Chromium Plating Facility.

Figures 5 through 7 present the horizontal and vertical extent of hexavalent chromium contamination in the area proposed for the hexavalent chromium pilot test. Groundwater samples in this area (sampling location WP-99-15) were collected from discreet 4-foot intervals ranging in depth from the groundwater surface (approximately 6 feet bgs) to 60 feet bgs. Based on the results of sample analysis and bench-scale testing, the 4-foot zone containing the highest concentrations of hexavalent chromium in groundwater was located approximately 30 to 34 feet bgs. This is the zone that will be targeted during pilot testing.

Figures 8 and 9 present the horizontal and vertical extent of VOC contamination in the area proposed for the VOC pilot test. Groundwater samples in this area (sampling locations WP-99-33 and WP-99-67) were also collected from discreet 4-foot intervals ranging in depth from the groundwater surface (approximately 6 feet bgs) to 80 feet bgs. Based on the results of sample analysis and results of bench-scale testing, the 4-foot zone containing the highest concentrations of TCE in groundwater is located approximately 20 to 36 feet bgs (see Figure 9). This is the zone that will be targeted during pilot testing.

1.4 PURPOSE AND SCOPE OF WORK PLAN

Data from HLA's groundwater and soil investigations from August 1998 through March 1999 were evaluated and summarized in the Draft Data Package for the Chromium Plating Facility Investigation (HLA, 1999). In order to provide a removal action recommendation for OU 2, additional data is required regarding the effectiveness of in-situ treatment technologies at reducing concentrations of hexavalent chromium and VOCs in source area hot spots. As a result, remedy-selection testing (i.e., pilot-scale testing) will be conducted in two areas near the former Chromium Plating Facility. Pilot-scale test results will be used to evaluate the remedy effectiveness for each type of contamination and will aid in the development of a full-scale design. A Treatability Study Letter Report will document the results of the pilot tests and an EE/CA will present the recommended OU 2 removal action alternatives.

The purpose of this Work Plan is to describe the activities proposed for completion for the OU 2 pilot-scale testing. Because a detailed Work Plan has been completed for OU 2 NCRA activities, this Work Plan will reference applicable sections of that Work Plan (Foster Wheeler/HLA, 1999) rather than duplicate that information, when appropriate. This Work Plan may also reference applicable sections of the URSGWCFS RI Work Plan (URSGWCFS, 1998).

This Work Plan is intended to provide information on tasks that are anticipated to be completed during pilot testing. If field conditions during testing indicate changes to the scope may provide improved results, these changes may be made on-site. A Field Change Request Form will document changes made to this Work Plan scope during pilot test activities.

2.0 TREATABILITY STUDY OBJECTIVES

This section summarizes the objectives for OU 2 pilot-scale treatability studies at SAEP. It includes the regulatory framework for testing, a description of the proposed treatment technologies, identified data gaps, data quality objectives (DQOs), and Applicable or Relevant and Appropriate Requirements (ARARs).

2.1 REGULATORY FRAMEWORK

The NCRA for OU 2 at SAEP is being performed under CERCLA. In October 1995, SAEP was placed on the BRAC 95 list. The BRAC Environmental Restoration Program mandates that environmental contamination on U.S. Army BRAC properties be investigated and remediated, as necessary, prior to disposal and reuse. Pilot test activities are being conducted as part of OU 2 NCRA investigations.

Regulatory oversight is being provided by the CTDEP and the USEPA. This Work Plan was prepared in accordance with CTDEP, CERCLA, and BRAC requirements, including the USEPA Guide for Conducting Treatability Studies under CERCLA (USEPA, 1992).

2.2 TREATMENT TECHNOLOGY DESCRIPTIONS

Two treatment technologies will be investigated in separate test areas during pilot-scale testing at SAEP. In-situ hexavalent chromium reduction will investigate the ability of ferrous sulfate to reduce concentrations of hexavalent chromium in site groundwater. In-situ chemical oxidation will investigate how well potassium permanganate reduces concentrations of VOCs in site groundwater. A brief description of these two technologies is presented in the following subsections.

2.2.1 In-situ Hexavalent Chromium Reduction

In the presence of ferrous iron, hexavalent chromium can be reduced to the less toxic trivalent form through the reaction:

$$HCrO_4^- + 3Fe^{2+} + 7H^+ \rightarrow Cr^{3+} + 3Fe^{3+} + 4H_2O$$

In general, three ferrous iron ions each donate a single electron to the chromium ion to reduce it to trivalent chromium. A ferrous sulfate solution is capable of providing ferrous iron (Fe^{2+}) to facilitate the reaction, which generally runs to completion in less than 5 minutes. When the pH of the aquifer is greater than 4, the trivalent chromium will precipitate with the ferric iron (Fe^{3+}) in a solid solution (Palmer, 1994).

The in-situ hexavalent chromium reduction pilot-scale test will be completed in a 30-foot by 30-foot area near the hexavalent chromium hot-spot area (Figure 11). The test will be completed by injecting various concentrations of a ferrous sulfate solution into a 10-foot thick subsurface zone (depth of 27 to 37 feet bgs) at a pH of approximately 2.5 to reduce hexavalent chromium in groundwater to trivalent chromium. Subsurface injection will be authorized by a CTDEP Discharge to Groundwater Permit. Sulfuric acid will be used to temporarily reduce pH in order to prevent the precipitation of iron and chromium near the injection wells and prevent injection well fouling. The solution will be mixed using on-site potable water and injected using four polyvinyl chloride (PVC) injection wells positioned on the edges of the test area. Groundwater will be pumped from a PVC extraction well placed in the center of the test area to create an artificial gradient and induce groundwater and ferrous sulfate solution flow through the test area. It is anticipated that the pH of the aquifer will stabilize away from the injection wells, thereby promoting the precipitation of trivalent chromium and ferric iron.

Extracted groundwater will be pre-treated for VOCs using granular activated carbon and discharged to the Chemical Waste Treatment Plant (CWTP) for hexavalent chromium treatment and eventual discharge to the Housatonic River. Discharge will be regulated under the Emergency Discharge Authorization issued by the CTDEP on March 18, 1999. Sampling and on-site GC analysis of the discharge water for VOCs will be conducted to ensure the limits of the permit are not exceeded.

Piezometers will be installed between the injection wells and the extraction well to monitor groundwater elevations and collect groundwater samples for chemical analysis before, during, and after system operation. The screens for injection wells, the extraction well, and piezometers will be installed from 27 to 37 feet bgs to intercept the zone of maximum hexavalent chromium concentrations (see Figures 6 and 7). The existing nested piezometer PZ-99-02 (see Figure 11) will also be used to monitor system effectiveness and evaluate vertical movement in the system. The shallow screen for this piezometer is located from 4 to 9 feet bgs, the intermediate screen from 30 to 35 feet bgs, and the deep screen from 45 to 50 feet bgs.

Effectiveness monitoring and hydraulic containment determinations will be made by collecting water level information and by sampling and analysis of subsurface soil and groundwater samples. Subsurface soil samples will be collected during well and piezometer installation and analyzed for target contaminants. The average contaminant concentration (in conjunction with the average groundwater concentration) will be used to determine the dosages of ferrous sulfate solution to inject during system operation.

Groundwater samples will be collected from the injection wells and the piezometers prior to system start up. Contaminant concentrations will be used to determine the average concentration of hexavalent chromium in the test area (in conjunction with the average soil concentration) and the estimated mass of contaminant. This value will be used to calculate the ferrous sulfate dosing requirements. Groundwater samples will also be collected during system operation and immediately following system shutdown to monitor system effectiveness. Six additional monthly rounds of groundwater sampling will be conducted following system shutdown to evaluate potential rebound concentrations of contaminants.

Figure 12 presents the proposed layout for the in-situ pilot tests and Figures 13 and 14 show a schematic of the proposed pumping system.

2.2.2 In-situ Chemical Oxidation using Potassium Permanganate

Potassium permanganate can oxidize chlorinated VOCs (i.e., TCE) through the following reaction:

$$2MnO_4^- + C_2HCl_3 \rightarrow 2CO_2 + 2MnO_2 + 3Cl^- + H^+$$

The in-situ chemical oxidation pilot-scale test will be completed near the TCE hot-spot area within the former Chromium Plating Facility (see Figure 11). The test will be completed in a 30-foot by 30-foot area using potassium permanganate to oxidize VOC contamination (consisting primarily of TCE). The hydraulic system for this test will be similar in design to the system installed for the hexavalent chromium test and will be installed at the same interval, 27 to 37 feet bgs, to intercept the zone of maximum TCE contamination. Various concentrations of a potassium permanganate solution will be mixed with potable water and injected into the aquifer through four injection wells installed on the edges of the test area. An artificial groundwater gradient will be achieved by pumping groundwater from a single extraction well located in the center of the test area (see Figure 12). Extracted groundwater will be treated for residual VOCs using a granular activated carbon system and will then be discharged to the CWTP (see Figure 14).

Piezometers will be installed inside the test area, as for the hexavalent chromium pilot test, to monitor water levels and determine chemical conditions in the aquifer before, during, and after system operation (see Figure 12). The existing nested piezometer PZ-99-01 (see Figure 11) will also be used to monitor system effectiveness and evaluate vertical movement in the system. The shallow screen for this piezometer is located from 4 to 9 feet bgs, the intermediate screen from 30 to 35 feet bgs, and the deep screen from 45 to 50 feet bgs. Subsurface soil and groundwater sampling will be conducted in a manner similar to that described for the hexavalent chromium pilot-scale test.

2.3 DATA GAPS

The USEPA guidance on conducting treatability studies suggests that the two primary objectives of a remedy-selection tier treatability study should be to 1) achieve quantitative performance goals based on anticipated clean-up criteria and 2) provide specific cost and engineering information necessary for completion of a detailed analysis of the alternative, including a cost estimate. This Work Plan presents the activities proposed to meet these two objectives.

As part of Work Plan development, a review of existing chemical and physical groundwater data, including analytical, bench-scale, and aquifer testing data, was completed. The review encompassed previous data collected by HLA and URSGWCFS at the site, in addition to review of data from other sites and the literature, and identified the following site-specific data gaps:

- Information regarding reasonable reduction levels for contaminants in-situ with SAEP's specific site conditions is not available;
- Information on the effectiveness of ferrous sulfate at reducing hexavalent chromium in-situ at SAEP is lacking;
- Information on the effectiveness of potassium permanganate at oxidizing TCE in-situ at SAEP is lacking;
- Details regarding the ability of an injection/extraction system to maintain hydraulic control in a proposed test area is not available;
- Cost and design information necessary for a full-scale design and cost estimate of these in-situ systems is not available.

2.4 DATA QUALITY OBJECTIVES

DQOs have been developed to focus the OU 2 pilot-testing activities and ensure the necessary data are collected to support recommendation of a removal action alternative. The DQOs can be qualitative or quantitative, and identify the type and/or quality of data required to characterize a site, support an action, and, satisfy ARARs.

The following list presents the DQOs for OU 2 pilot-scale treatability studies, and is the basis for the field activities identified in Section 3.0.

- Determine what treatment levels can reasonably be achieved using the in-situ treatment technologies.

- Determine if ferrous sulfate can reduce hexavalent chromium concentrations to meet the CTDEP RSR SWPC of 0.11 mg/L.

- Determine if potassium permanganate can reduce TCE concentrations to meet the CTDEP RSR SWPC of 2.34 mg/L.

- Demonstrate the effectiveness of the pumping system at maintaining hydraulic control in the pilot test system.

- Develop the necessary information for full-scale system costing and design.

Quantitative DQOs such as detection limits are discussed in Section 3.0 of the SAEP Quality Assurance Project Plan (QAPP) presented in Appendix B of the OU 2 NCRA Work Plan (Foster Wheeler/HLA, 1999).

2.5 REGULATORY COMPLIANCE PLAN (ARARS)

Federal, state, and local laws and statutes have been reviewed for two purposes: 1) to determine if permits are required for the proposed treatability study activities, and 2) to evaluate the environmental criteria against which analytical results will be compared. CTDEP RSR criteria will be followed as one of the driving considerations in the selection and implementation of any removal action(s). It is important to note that treatability study activities are proposed to investigate the effectiveness of potential treatment technologies on hot-spot contamination only, and are not intended to fully remediate site groundwater.

2.5.1 Permit Requirements

Disposal of investigation-derived waste (IDW) water is covered under an Emergency Discharge Authorization, which was issued by the CTDEP on March 18, 1999. This authorization covers discharge of wastewater from the SAEP CWTP generated during additional investigation and remediation activities conducted on-site. The expiration date for this authorization is March 18, 2000.

A temporary authorization for discharge to groundwater will be obtained from the CTDEP prior to initiation of treatability studies. The authorization is intended to address the injection of treatment solutions to the subsurface aquifer.

2.5.2 Criteria for Comparison to Analytical Results

CTDEP has established RSR criteria for various media including target concentrations for indoor air and criteria for soil, groundwater, and surface water. The OU 2 pilot test analytical results will compare residual contaminant concentrations against RSR criteria to determine the effectiveness of in-situ treatment technologies. The criterion to be considered includes:

- Groundwater analytical data will be compared to CTDEP's SWPC for substances in groundwater, as indicated in Subsection 2.4.

3.0 TREATABILITY STUDY WORK APPROACH

This section provides a brief summary of the pilot testing approach. It includes a description of the process and results of the groundwater flow evaluation used to determine the hydraulic capture of the proposed pilot-test pumping systems.

3.1 GROUNDWATER FLOW EVALUATION AND HYDRAULIC CONTROL

Hydraulic control of fluids injected and recovered during the pilot test was evaluated through the use of a groundwater flow evaluation. The objective of the pilot test is to ascertain the effectiveness of an extraction/injection system in the treatment of hexavalent chromium and TCE, at two distinct locations, in groundwater and associated soil. Concern has been expressed over the potential of the loss of hydraulic containment for the plume and injected fluids. The purpose of the groundwater flow evaluation is to evaluate the potential for loss of containment in addition to providing information on likely flow pathways and travel times for the fluids injected and captured by the extraction well. The proposed pattern of wells is four injection points equally spaced along a 30-foot diameter circle with the extraction well at the center. Screen lengths of all wells will be 10 feet, and screens will be placed at the same depth, from 27 to 37 feet bgs. The site groundwater is characterized by a very low hydraulic gradient (less than 0.002 feet/foot), and probable low velocity, on the order of only 12 to 36 feet per year for hydraulic conductivities of 5 and 15 ft/d, respectively. If the hydraulic conductivity is on the order of 100 ft/d, the estimated groundwater velocity would be about 240 feet per year. The hydraulic conductivity estimated from aquifer testing results is 10 ft/d. This value is used as the basis for the flow evaluation.

The flow evaluation effort is summarized in this section. Details of the flow evaluation and graphical output are contained in Appendix C for the interested reader. The discussion that follows pertains to the planned pilot test for addressing the hexavalent chromium in groundwater and associated soil. The area containing TCE is expected to behave in a hydraulically similar manner.

The flow evaluation suggests that a pilot test extraction flow rate of 5 gpm should provide a reasonable travel time for injected fluids for the planned 10 days. Travel times along the major routes of flow are from about 1.5 to 5 days, allowing several pore flushes over the test period for these pathways. An injection rate (total of 4 gpm) slightly lower than the extraction rate provides for a greater assurance of containment and less disruption of the contaminant plume (only 1 gpm at each injection point), but does allow for some influx of contaminated groundwater in zones between the injection points. A greater number of injection points along the perimeter of the circle would cut down on some of these gaps, but such an expense is considered unnecessary for the pilot test. Observation piezometers are planned at several points within the circle, both on and off the main radii defined by lines from the injection wells to the extraction well (see Figure 12).

Sensitivity analyses showed little variation in travel times or hydraulic containment with varying hydraulic conductivity, even over a range of 5 to 100 ft/d. This is because the proposed pumping rate greatly exceeds the natural rate of groundwater flow through the area. Since the net effect of the system is a net loss of groundwater, there is little anticipated disturbance of the contaminant plume outside of the treatment zone. Some residual injected fluid (i.e., ferrous sulfate or potassium permanganate solution) may remain after the pilot test, but this should rapidly dissipate as it contacts contaminants. Hydraulic containment during the pilot test within the 30-foot by 30-foot test zone is expected to be excellent based on initial particle tracking results.

3.2 IN-SITU HEXAVALENT CHROMIUM REDUCTION

This subsection describes the experimental procedures, equipment, and sampling requirements specific to the in-situ reduction of hexavalent chromium. Some modifications to these procedures may be made in the field, if necessary, during implementation based on preliminary results.

3.2.1 Experimental Design and Procedures

The general scheme of treatment is to inject a ferrous sulfate solution in four wells in a perimeter around a single extraction well. The rationale for well placement and flow rates for hydraulic control is discussed in Subsection 3.1. Adequate amounts of ferrous sulfate to treat the estimated mass of hexavalent chromium in soil and groundwater will be injected during a ten-day period of operation. Based on the bench-scale test results, six moles (two times the stoichiometric relationship) of ferrous sulfate are required for each mole of hexavalent chromium estimated to be present within the treatment area. In addition, the injection solution will be adjusted a pH of approximately 2.5 using sulfuric acid to prevent injection well plugging.

The analysis completed for Subsection 3.1 demonstrated that the proposed injection and extraction system would establish four individual lobes of ferrous sulfate migrating from the injection wells to the extraction well. The pilot-scale test will take advantage of this injection pattern by injecting a different concentration of ferrous sulfate in each well to evaluate the effect of ferrous sulfate dose at the pilot scale. One injection well will not receive any ferrous sulfate to evaluate the effect of flushing only. The other three injection wells will receive three, six, and nine moles of ferrous sulfate per mole of hexavalent chromium respectively.

Soil and groundwater will be sampled and analyzed before the test to estimate the mass of hexavalent chromium and required mass of ferrous sulfate. Groundwater and extracted groundwater will be monitored during and after the test to evaluate changes in the concentration of hexavalent chromium within the pilot test treatment area.

Sampling and analysis during the test will monitor for the movement of the ferrous sulfate front as it progresses to the extraction well. Piezometers will be monitored for several chemical parameters discussed in Subsection 3.2.3 to detect the front. Evidence of the front will be used to verify the predicted travel times from Subsection 3.1. Piezometers will be installed at locations with predicted travel times from the injection well, to the piezometers of 1.0, 1.5, and 2.0 days.

Sampling and analysis after the test will monitor for rebounding groundwater concentrations. As discussed in Section 2, the objective of the NCRA will be to reduce groundwater concentrations below CTDEP SWPC. A key measure of success of the treatment will be the ability to meet these concentrations and maintain them. If insufficient chemical is injected or if inadequate delivery of chemical to low-permeability zones occurs, groundwater concentrations are expected to slowly increase from the initial remediation concentrations achieved. Therefore, ongoing groundwater monitoring will be conducted to look for such rebounding groundwater concentrations.

3.2.2 Equipment and Materials

The in-situ chromium reduction pilot system generally consists of two systems: the injection system and the extraction and organic pre-treatment system. The major equipment and materials for each of these components would be as follows:

The ferrous sulfate injection system will generally consist of the following:

- ferrous sulfate make-up tank with mixer and metering pump;
- clean water supply
- flow distribution panel with a flow meter, chemical injector, and control valve for each well; and
- tubing between the various process units.

A general process flow diagram is included in Figure 13. Equipment will be rented if available and economically favorable, otherwise equipment will be purchased.

The extraction system for hydraulic control will consist of a single submersible pump in the central extraction well, which will discharge via flexible pipe through two activated carbon units in series for removal of VOC contamination. Treated water will then be discharged to a holding tank to await sampling and analysis. After demonstration of VOC removal, water will be discharged by gravity to the CWTP sump at Building 63 for chromium removal. A process flow diagram for the extraction and pre-treatment system is included in Figure 14. A bill of materials estimated to be required for the pilot-test system is included in Table 3.

3.2.3 Sampling and Analysis

Sampling and analysis will be conducted to monitor the treatment area for hydraulic control, movement of the ferrous sulfate front, reduction in hexavalent chromium in groundwater within the treatment area, and rebound in groundwater contaminant concentrations after the test. Table 4 presents the proposed sampling locations, type, frequency, and rationale for collection of samples. Table 5 presents the proposed sample analysis methods for each proposed sample type.

3.3 IN-SITU CHEMICAL OXIDATION

This subsection describes the experimental procedures, equipment, and sampling requirements specific to the in-situ oxidation of TCE. Most of the procedures, equipment, and sampling for in-situ oxidation of TCE are identical to in-situ hexavalent chromium reduction. This subsection describes only the differences between in-situ oxidation of TCE and in-situ hexavalent chromium reduction. Some modifications to these procedures may be made in the field, if necessary, during implementation based on preliminary results.

3.3.1 Experimental Design and Procedures

The general scheme of treatment for in-situ oxidation is identical to the in-situ chromium reduction with the exception that potassium permanganate replaces ferrous sulfate as the injected chemical. Enough potassium permanganate to treat the estimated mass of TCE will be injected during the 10-day period of operation.

The TCE pilot-scale test will also take advantage of the four-lobe injection pattern by injecting a different concentration of potassium permanganate in each well to evaluate the effect of potassium permanganate dose at the pilot scale. One injection well will not receive any potassium permanganate to evaluate the effect of flushing only. The other three injection wells will receive 1, 1.5, and 2.5 moles of potassium permanganate per mole of TCE respectively. In addition, all potassium permanganate injection solutions will be adjusted to a pH of approximately 5.0 to prevent well plugging.

Soil and groundwater will be sampled and analyzed before the test to estimate the mass of TCE and required mass of potassium permanganate. Groundwater and extracted groundwater will be monitored during and after the test to evaluate changes in the concentration of TCE within the pilot test treatment area. Monitoring for movement of the chemical front through the treatment area and monitoring rebounding groundwater concentrations will be conducted.

3.3.2 Equipment and Materials

Equipment and materials for in-situ oxidation are identical to the equipment and materials for in-situ reduction with the replacement of ferrous sulfate by potassium permanganate. The size of tanks and metering pumps and the amount of chemical required may be slightly different due to the mass of contaminants, the stoichiometry, and the chemical properties.

3.3.3 Sampling and Analysis

Sampling and analysis will be conducted to monitor the treatment area for hydraulic control, movement of the potassium permanganate front, reduction in TCE concentrations in groundwater within the treatment area, and rebound in groundwater contaminant concentrations after the test. Table 6 presents the proposed sampling locations, type, frequency, and rationale for collection of samples. Table 7 presents the proposed sample analysis methods for each proposed sample type.

3.4 RESIDUALS MANAGEMENT

The types of residuals that are anticipated to be generated during the pilot-scale treatability test include the following:

- lab samples
- used containers
- used PPE
- soil cuttings
- purge water
- hexavalent chromium-contaminated water
- spent activated carbon

All of these items except hexavalent chromium-contaminated water and spent activated carbon are addressed in Section 7.0 of the Non-Time Critical Removal Action Work Plan (Foster Wheeler/HLA, 1999). As described in Subsections 3.2 and 3.3, chromium-contaminated water will be sent to the CWTP for treatment and discharge. Spent activated carbon will either be picked up for regeneration or sent to an off-site disposal facility in accordance with Federal and State regulations.

4.0 DATA MANAGEMENT

Both qualitative and quantitative data will be collected during the completion of treatability studies. The following subsections detail the documentation, analysis, and interpretation of this data.

4.1 DATA MANAGEMENT

The collection and results of field data will be documented in two ways in the field, in a hardcover logbook and on field data sheets. Data will be collected during well and piezometer installation, during system operation, and following system shutdown.

Table 8 lists the types of data anticipated to be collected during the treatability studies. Section 3 of this workplan further discusses the data needs for the pilot tests.

4.2 DATA ANALYSIS AND INTERPRETATION

Data collected during the treatability studies will be presented in the Treatability Study Letter Report in data tables. In addition, analytical data will be entered into the SAEP Microsoft Access database.

Analytical results from soil borings and piezometers located inside the test area will be used to determine the overall effectiveness of the in-situ treatment technologies based on percent removal of target contaminants. In addition, a comparison of analytical results collected from the four different solution concentration pathways will evaluate the optimum dosage of reagent. Water level data from piezometers located inside of the test areas will be used to evaluate the hydraulic control achieved by the pumping system. Qualitative results regarding injection and extraction rates and mixing times will be used to modify the pilot-scale design for implementation as a full-scale system.

Qualitative and quantitative results collected during the pilot test will provide information to be used during the design and costing of a full-scale system. Section 3 of this workplan further describes the anticipated analysis and interpretation of data collected during pilot-scale treatability studies.

5.0 HEALTH AND SAFETY

Health and safety procedures governing work completed for the pilot-scale treatability studies are outlined in the Health and Safety Plan, included as Appendix C in the OU 2 NCRA Work Plan (Foster Wheeler/HLA, 1999). Revisions to this Health and Safety Plan will be made, as necessary, to incorporate treatability study activities.

6.0 DOCUMENTATION

This section presents the reports that will be prepared in order to provide a removal action recommendation for OU 2 at SAEP. It also provides a brief summary of community relations activities conducted in support of treatability study activities.

6.1 REPORTS

Three reports will be written to document field activities at SAEP. The Pre-design Investigation Report will document results of previous investigations conducted in support of an OU 2 removal action recommendation. The Treatability Study Letter Report will present the results of pilot-scale testing. The EE/CA will present the recommended removal action alternative for OU 2 and will document the decision process used to complete the recommendation.

6.1.1 Pre-design Investigation Report

Task 4 of the OU 2 NCRA involves the development of the Pre-design Investigation Report. This report will summarize the results of previous groundwater investigations, including data collected between August 1998 and May 1999, and new data produced from investigations proposed in this NCRA Work Plan. Activities summarized in the report will include: 1) Preliminary Investigations, 2) Chromium Plating Facility Decontamination, 3) Chromium Plating Facility Investigations, 4) VOC Groundwater Investigations, 5) bench-scale testing, and 6) aquifer testing. Optional tasks proposed for the OU 2 NCRA, if performed, will be summarized in an Addendum to the Pre-design Investigation Report.

6.1.2 Treatability Study Letter Report

A Treatability Study Letter Report will be developed to document the operation and results of pilot-scale testing completed for the hexavalent chromium area and the VOC area. The report will: 1) present analytical results in tables, 2) present an analysis of the pumping rates and their effectiveness, 3) present a comparison of the four chemical dosages tested using the contaminant removal percentages, and 4) provide the rationale for the optimum dosage calculation.

The information in the Treatability Study Letter Report will describe data that can be used to design and cost full-scale treatment systems.

6.1.3 EE/CA Report

Four documents will be prepared for the administrative record, an EE/CA, a fact sheet, a response to significant comments, and a Removal Action Memorandum (RAM).

An EE/CA Report will be written to provide the rationale behind the development of removal actions alternatives and document the decision process for selection of a recommended alternative. The EE/CA will be developed in accordance with the USEPA "Guidance on Conducting Non-time Critical Removal Actions Under CERCLA" (USEPA, 1993). Prior to initiation of the required 30-day public comment period, a fact-sheet providing a brief summary of the EE/CA will be prepared for the public. Following the public comment period, a response to significant comments will be prepared for inclusion in the RAM.

A RAM will be written to provide documentation of the selection of a removal action for a site. The RAM will contain a summary of the EE/CA, the recommended removal action, a copy of the transcript from the public hearing, and a response to significant comments received during the 30-day public comment period.

6.2 COMMUNITY RELATIONS

Community relations activities for the SAEP site are conducted by SAEP representatives and HLA under a separate contract. Field activities proposed for completion during treatability testing and test progress reports will be presented to the public and interested parties during scheduled Restoration Advisory Board meetings and technical presentations. These activities will also be presented in a quarterly newsletter issued by SAEP.

7.0 MANAGEMENT AND STAFFING

Information regarding the management and staffing to be used during treatability testing has been included in Section 8 of the OU 2 NCRA Work Plan (Foster Wheeler/HLA, 1999).

Subcontractors anticipated to be used to complete treatability studies include:

- Drilling subcontractor – installation of extraction wells and completion of soil borings;
- GeoProbe subcontractor – installation of injection wells, piezometers, and soil borings;
- Laboratory subcontractor – off-site analysis of soil and groundwater confirmation samples;
- Data Validation subcontractor – validate off-site laboratory data;
- Waste Transport subcontractor – transport and dispose of drummed wastes off site; and
- Survey subcontractor – provide horizontal and vertical coordinates of installed wells and piezometers.

Subcontractors will be managed by Foster Wheeler/HLA personnel.

8.0 TREATABILITY STUDY SCHEDULE

Figure 15 details the anticipated schedule for treatability testing at the site.

1,1-DCE	1,1-dichloroethylene
1,1,1-TCA	1,1,1-trichloroethane
ARAR	Applicable or Relevant and Appropriate Requirements
bgs	below ground surface
BRAC	Base Closure and Realignment
CERCLA	Comprehensive Response, Compensation, and Liability Act
CTDEP	Connecticut Department of Environmental Protection
CWTP	Chemical Waste Treatment Plant
DQO	data quality objective
EBS	Environmental Baseline Survey
EE/CA	Engineering Evaluation/Cost Analysis
Foster Wheeler	Foster Wheeler Environmental Corporation
ft/d	feet per day
GC	gas chromatograph
gpm	gallons per minute
HLA	Harding Lawson Associates
IDW	investigation-derived waste
mg/L	milligrams per liter
NCRA	Non-time Critical Removal Action
NEA	New England District
ORP	oxidation-reduction potential
OU	Operable Unit
PCE	tetrachloroethylene
PID	photoionizaton detector
PVC	polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
QAPjP	Quality Assurance Project Plan
RAM	Removal Action Memorandum
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation

RSR	Remediation Standard Regulation
SAEP	Stratford Army Engine Plant
SPLP	Synthetic Precipitate Leaching Procedure
SVOC	semi-volatile organic compound
SWPC	Surface-water Protection Criteria
TACOM	U.S. Army Tank-Automotive and Armament Command
TCE	trichloroethylene
TOC	total organic carbon
URSGWCFG	URS Greiner-Woodward Clyde Federal Services
USACE	U.S. Army Corps of Engineers – New England District
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

Foster Wheeler Environmental Corporation/Harding Lawson Associates (Foster Wheeler/HLA), 1999. Final Work Plan for the Non-time Critical Removal Action for Chromium and VOC Groundwater Operable Unit (OU) 2 EE/CA, Stratford Army Engine Plant. Prepared for the U.S. Army Corps of Engineers, August 27, 1999.

Harding Lawson Associates (HLA), 1999. Draft Data Package for the Chromium Plating Facility Investigation. Prepared for TACOM and AlliedSignal, April 9, 1999.

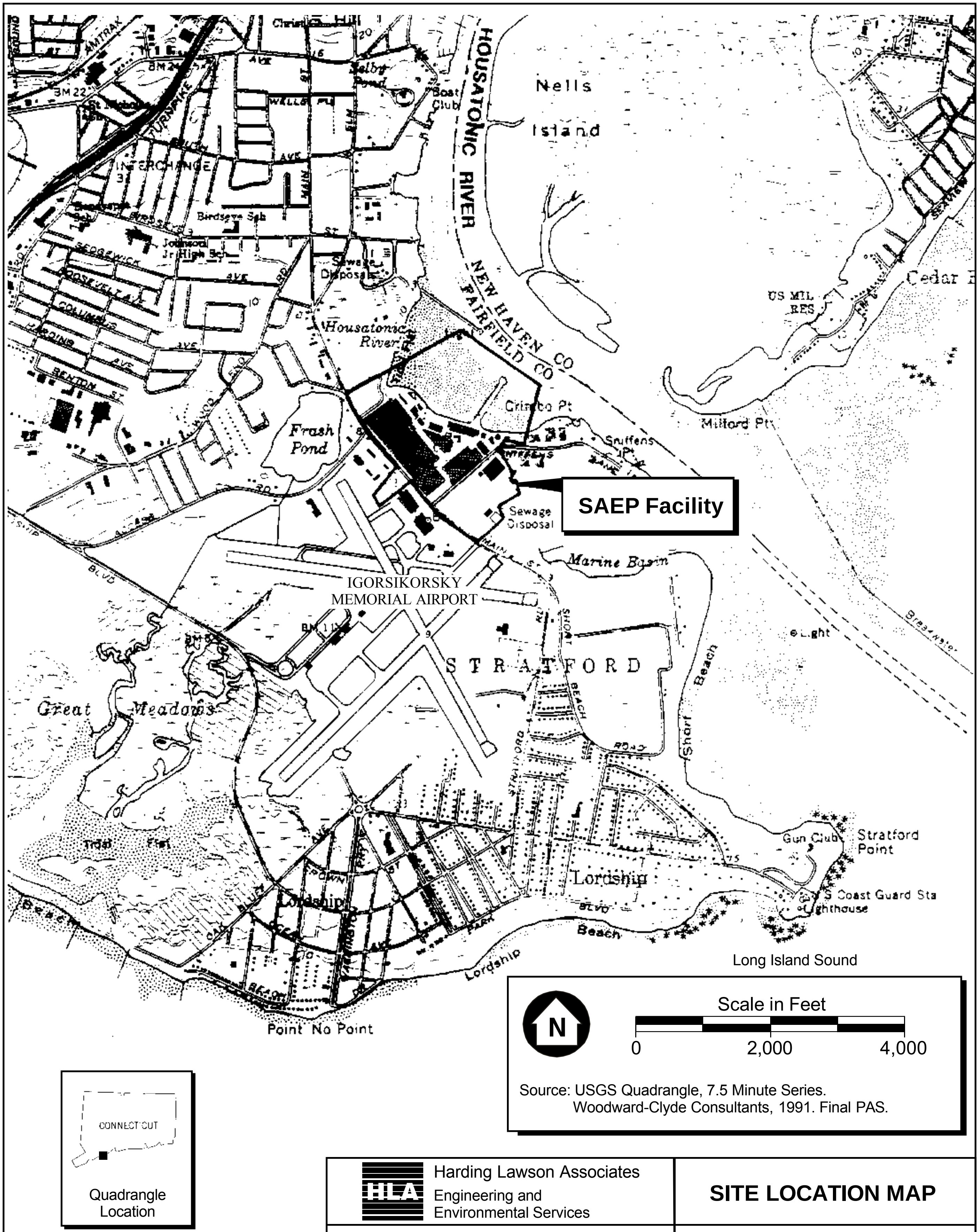
Palmer, Carl D. and Robert W. Puls (Palmer), 1994. Natural Attenuation of Hexavalent Chromium in Groundwater and Soils. EPA Ground Water Issue, Office of Solid Waste and Emergency Response. EPA/540/5-94/505. October 1994.

URS Greiner-Woodward Clyde Federal Services (URSGWCFS), 1998. Remedial Investigation Work Plan for the Stratford Army Engine Plant. Prepared for the U.S. Department of the Army, October 26, 1998.

U.S. Environmental Protection Agency (USEPA), 1992. Guide for Conducting Treatability Studies under CERCLA. Final. Office of Solid Waste and Emergency Response. EPA/540/R-92/071a, Washington DC, October 1992.

U.S. Environmental Protection Agency (USEPA), 1993. Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA. Office of Emergency and Remedial Response. USEPA/540-R-93-057, Washington DC, August 1993.

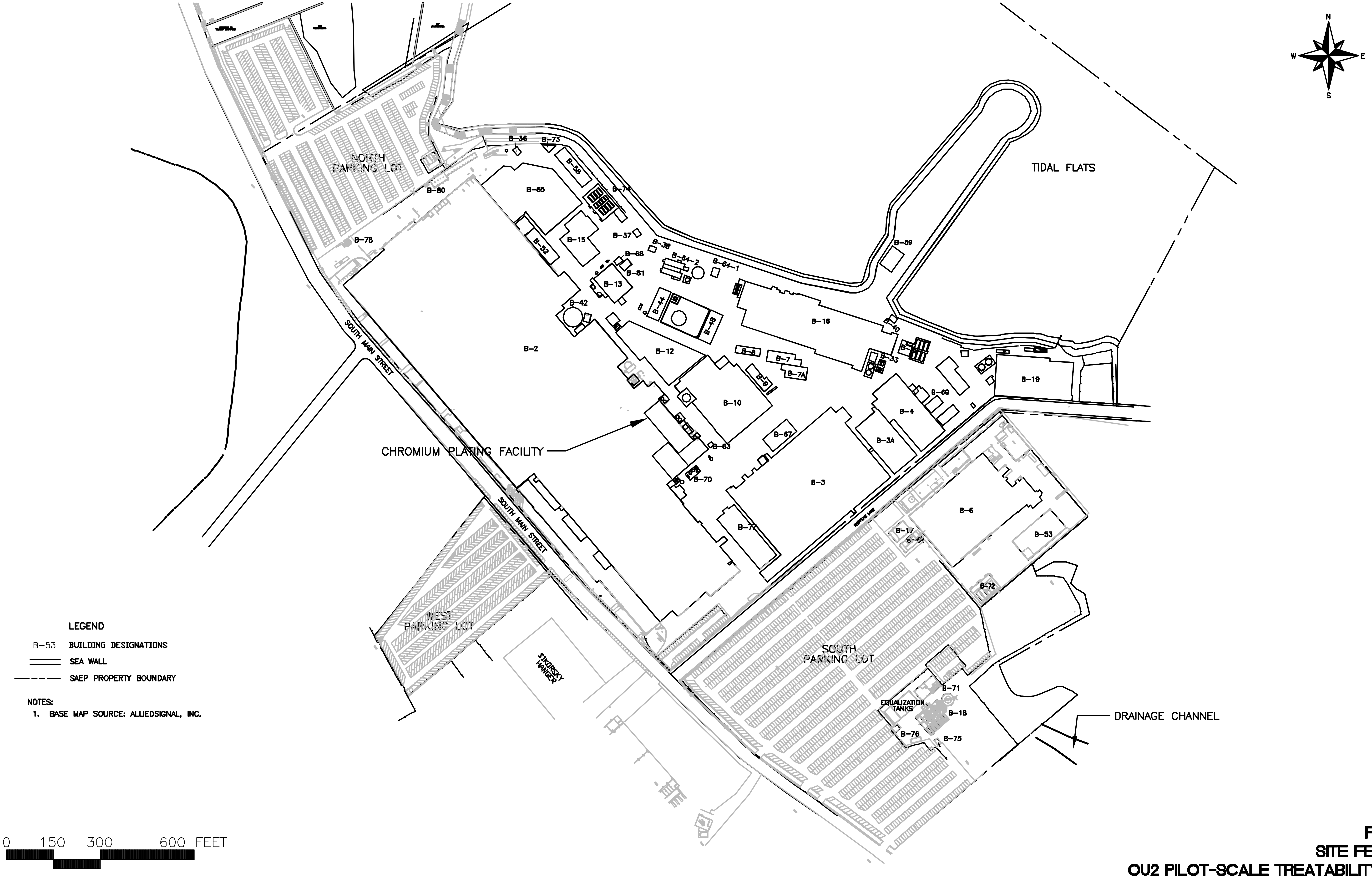
FIGURES



Source: USGS Quadrangle, 7.5 Minute Series.
Woodward-Clyde Consultants, 1991. Final PAS.

Harding Lawson Associates Engineering and Environmental Services	**SITE LOCATION MAP**
TOTAL ENVIRONMENTALRESTORATIONCONTRACT STRATFORD ARMYENGINEPLANT	OU2 TREATABILITY STUDY 47254 — **FIGURE 1**

W9909003



0 150 300 600 FEET

SCALE: 1"=300'

G:\PROJECTS\TERCS\PROJECTS\D020\OU2\FIGURES\47254201 10/27/99

FIGURE 2
SITE FEATURES
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

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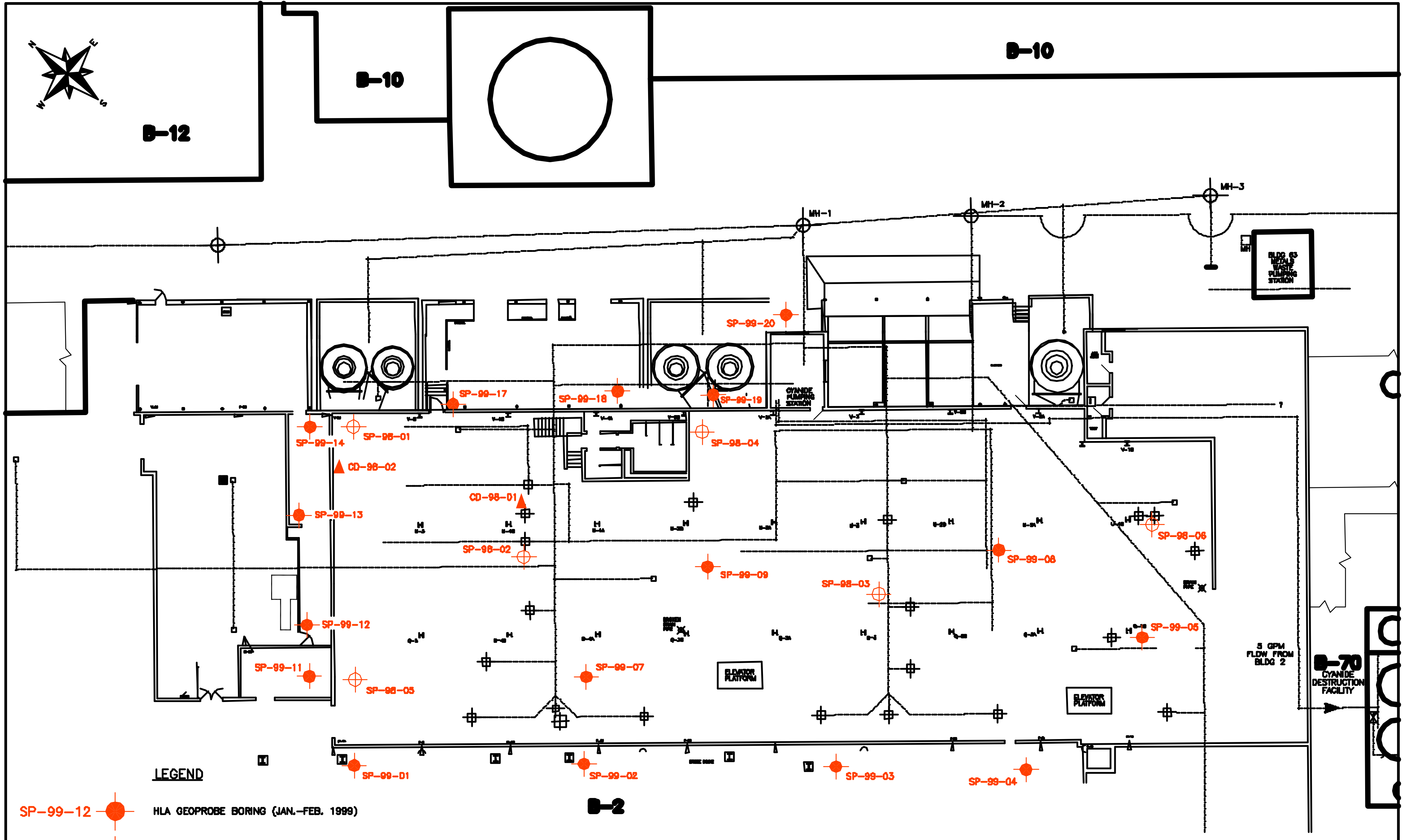

LEGEND

SP-99-12	●	HLA GEOPROBE BORING (JAN.-FEB. 1999)
SP-98-05	⊕	HLA GEOPROBE BORING (8/20/98)
CD-98-02	▲	CONCRETE DUST SAMPLE (8/20/98, 12/16/98, AND 12/17/98)
	H	SUPPORT BEAM
	⊞	SUMP (VISUALLY IDENTIFIED)
	◻	SUMP (FROM ALLIEDSIGNAL CAD DRAWING)
	-------	CHEMICAL WASTE LINE (FROM ALLIEDSIGNAL CAD DRAWING)

0 15 30 60 FEET

SCALE: 1"=30'

FIGURE 3
CHROMIUM PLATING FACILITY
SOIL BORING LOCATIONS
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT

Harding Lawson Associates

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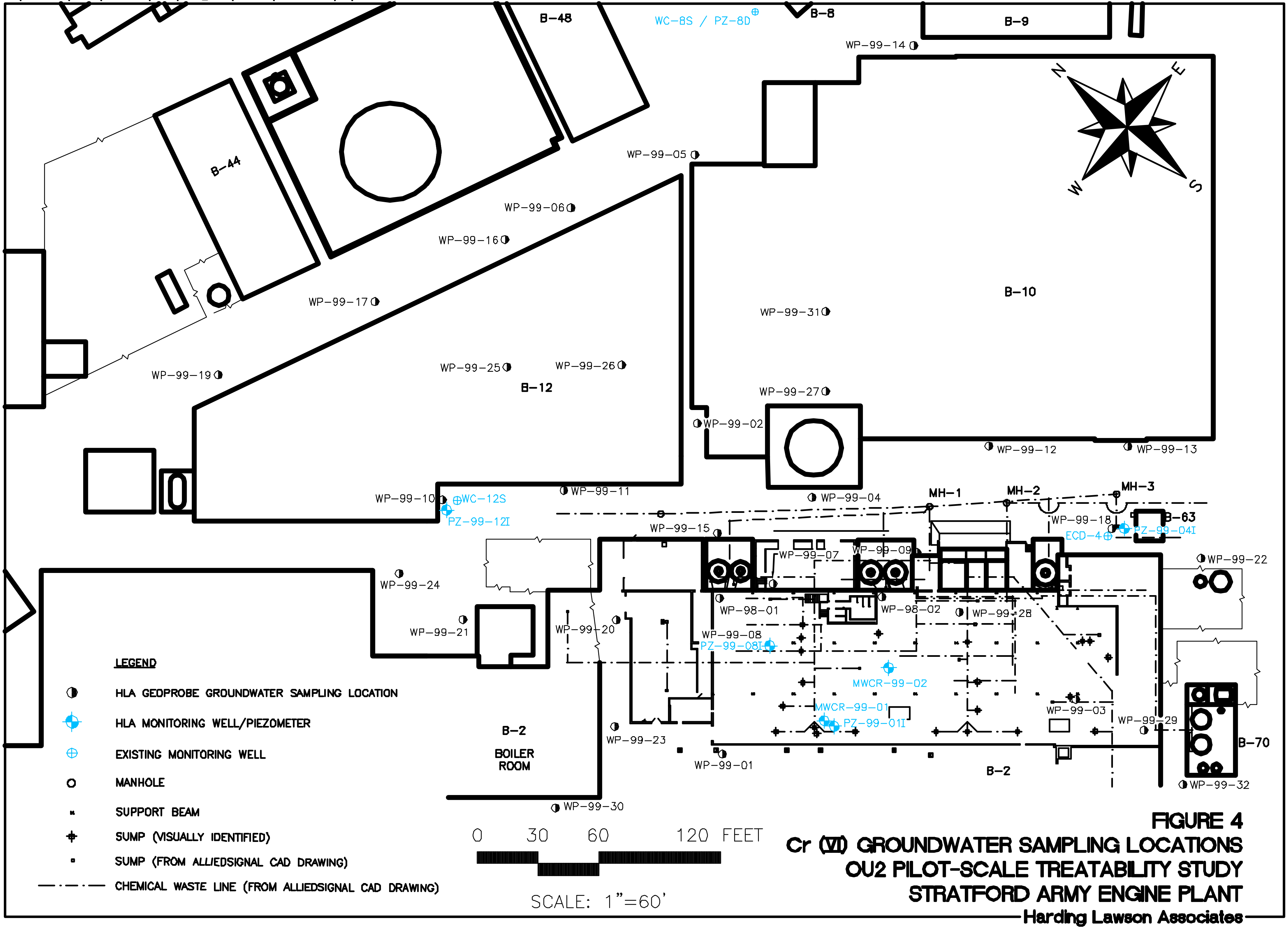
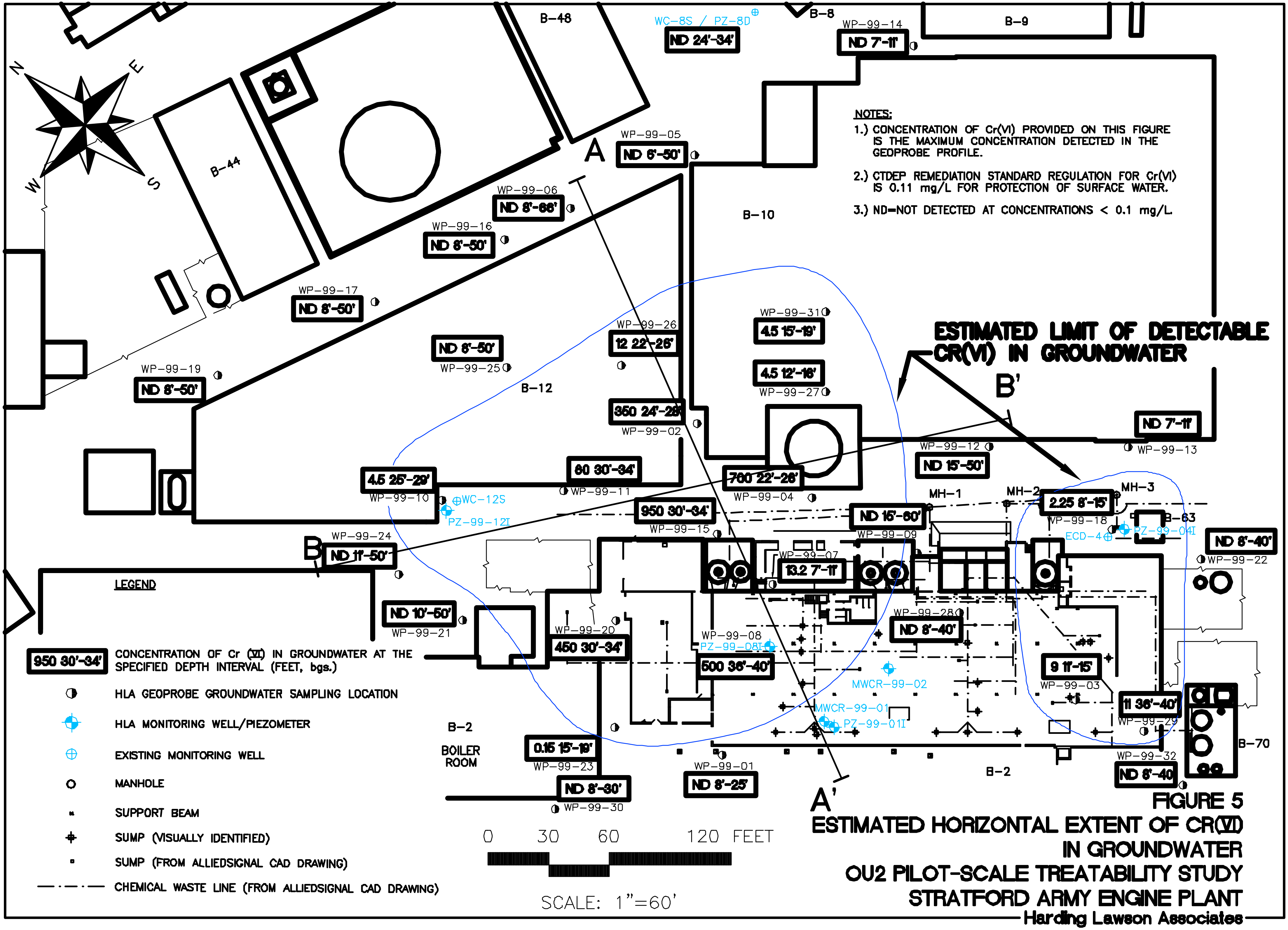


FIGURE 4
Cr (VI) GROUNDWATER SAMPLING LOCATIONS
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT

Harding Lawson Associates

G:\PROJECTS\TERCS\PROJECTS\D020\PILOT_TEST\FIGURES\47254204.DWG DEL 10-27-99



NOTES:

1.) CONCENTRATION OF Cr(VI) PROVIDED ON THIS FIGURE IS THE MAXIMUM CONCENTRATION DETECTED IN THE GEOPROBE PROFILE.

2.) CTDEP REMEDIATION STANDARD REGULATION FOR Cr(VI) IS 0.11 mg/L FOR PROTECTION OF SURFACE WATER.

3.) ND=NOT DETECTED AT CONCENTRATIONS < 0.1 mg/L.

LEGEND

950 30'-34' CONCENTRATION OF Cr (VI) IN GROUNDWATER AT THE SPECIFIED DEPTH INTERVAL (FEET, bgs.)

◑ HLA GEOPROBE GROUNDWATER SAMPLING LOCATION

⌖ HLA MONITORING WELL/PIEZOMETER

⊕ EXISTING MONITORING WELL

○ MANHOLE

▪ SUPPORT BEAM

✚ SUMP (VISUALLY IDENTIFIED)

▫ SUMP (FROM ALLIEDSIGNAL CAD DRAWING)

—·—·— CHEMICAL WASTE LINE (FROM ALLIEDSIGNAL CAD DRAWING)

0 30 60 120 FEET

SCALE: 1"=60'

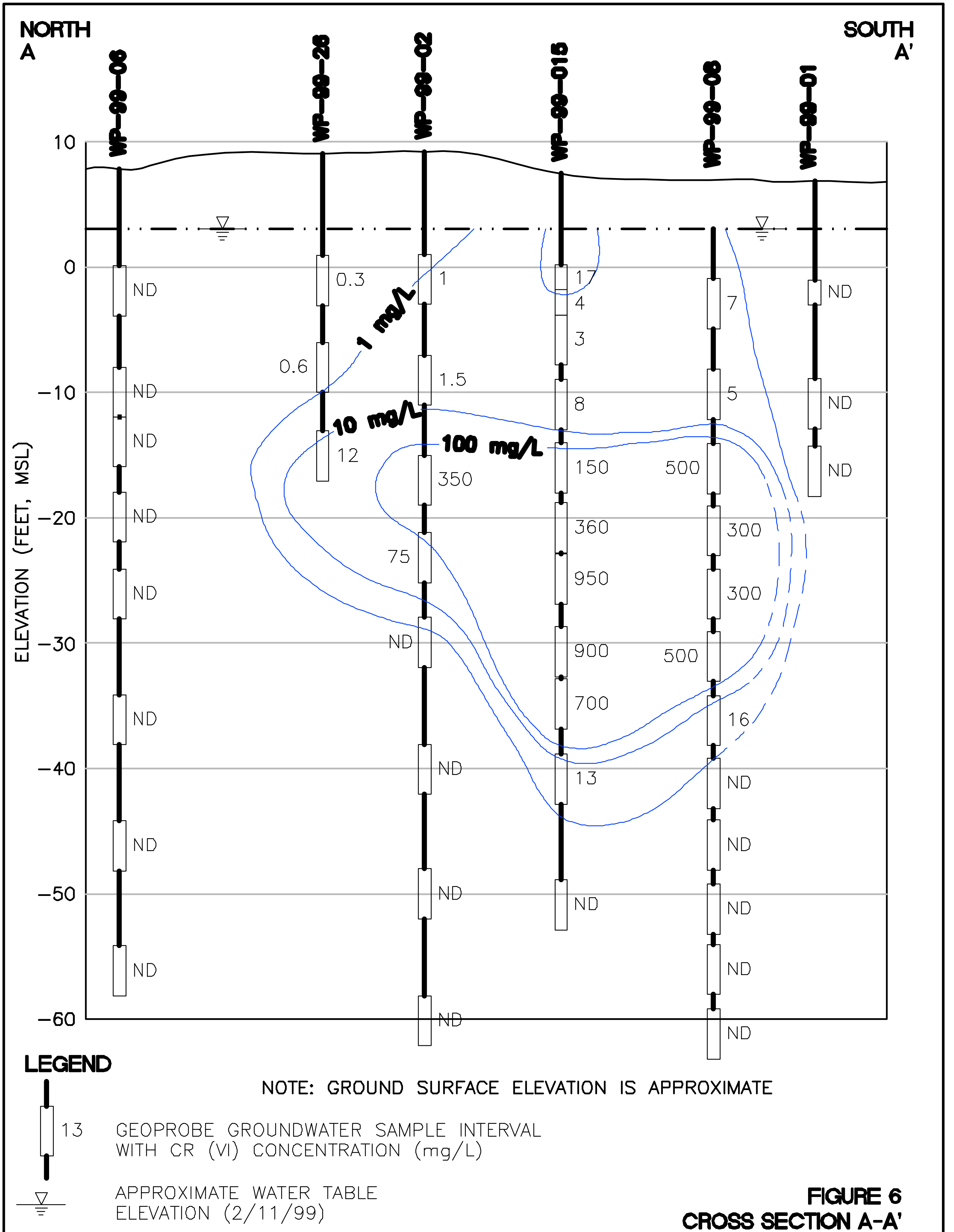
FIGURE 5

ESTIMATED HORIZONTAL EXTENT OF CR(VI) IN GROUNDWATER

OU2 PILOT-SCALE TREATABILITY STUDY

STRATFORD ARMY ENGINE PLANT

Harding Lawson Associates



NOTE: GROUND SURFACE ELEVATION IS APPROXIMATE

GEOPROBE GROUNDWATER SAMPLE INTERVAL
WITH CR (VI) CONCENTRATION (mg/L)

APPROXIMATE WATER TABLE
ELEVATION (2/11/99)

HORIZONTAL SCALE: 1"=50'
VERTICAL SCALE: 1"=10'

FIGURE 6
CROSS SECTION A-A'
CR VI GROUNDWATER PROFILE
CHROMIUM PLATING FACILITY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

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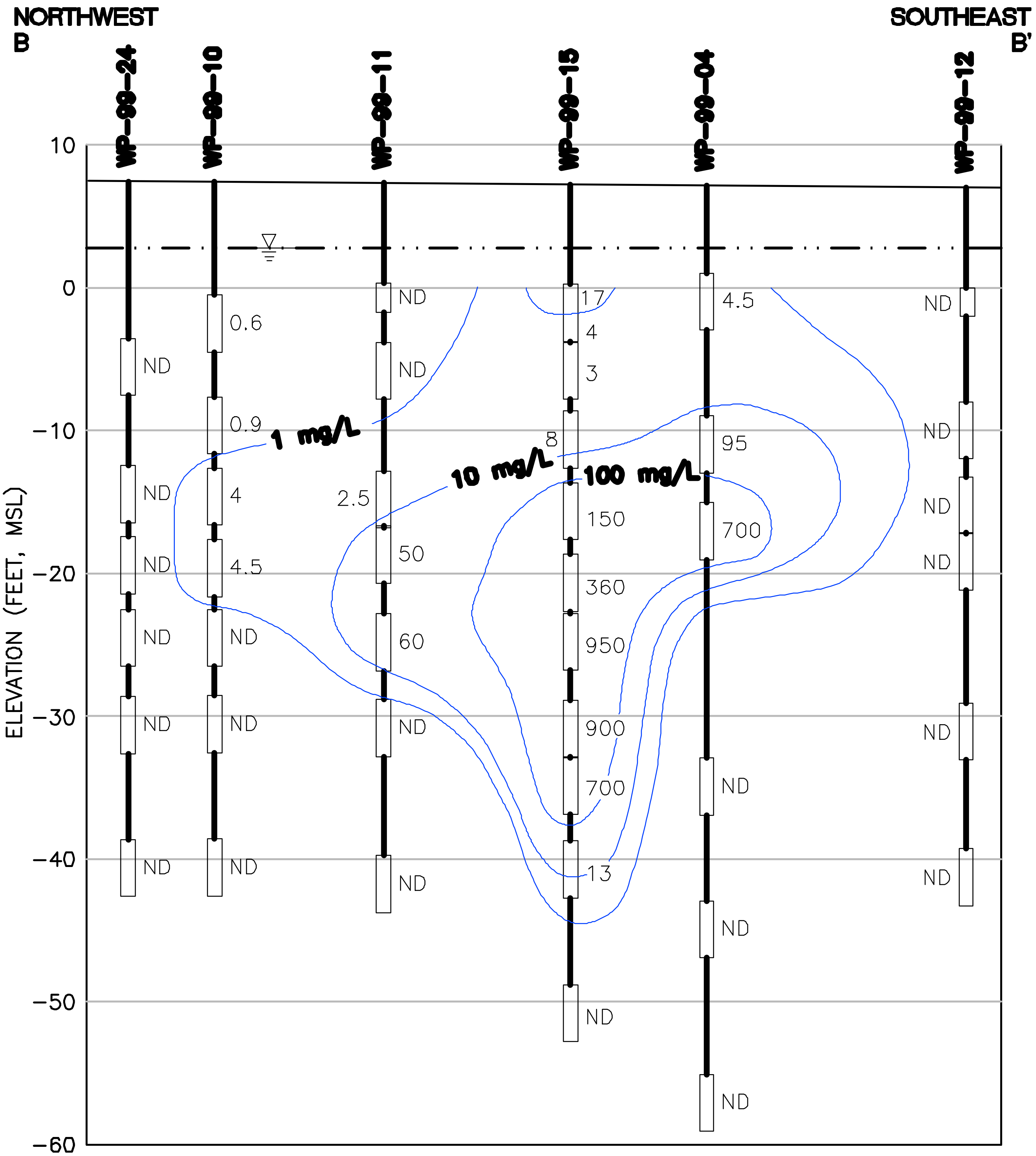

LEGEND

NOTE: GROUND SURFACE ELEVATION IS APPROXIMATE

13 GEOPROBE GROUNDWATER SAMPLE INTERVAL WITH CR (VI) CONCENTRATION (mg/L)

APPROXIMATE WATER TABLE ELEVATION (2/11/99)

HORIZONTAL SCALE: 1"=50'
VERTICAL SCALE: 1"=10'

FIGURE 7
CROSS SECTION B-B'
CR VI GROUNDWATER PROFILE
CHROMIUM PLATING FACILITY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

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LEGEND

CP-99-03 ●	EXISTING HLA CONE PENETROMETER LOCATIONS
⊕	PROPOSED U.R.S.-GRENIER / WOODWARD-CLYDE MONITORING WELLS (LOCATIONS ARE APPROXIMATE)
◑	EXISTING HLA GEOPROBE GROUNDWATER SAMPLING LOCATION
⊕	EXISTING PIEZOMETER LOCATION
⊕	EXISTING WOODWARD-CLYDE MONITORING WELL
◕	C.A. RICH CONSULTANTS MONITORING WELL
B-53	BUILDING DESIGNATIONS
	FENCE
═	SEA WALL
— — —	SAEP PROPERTY BOUNDARY
—	11-DCE RSR EXCEEDANCES IN GROUNDWATER
—	PCE RSR EXCEEDANCES IN GROUNDWATER
—	TCE RSR EXCEEDANCES IN GROUNDWATER
—	1,1,1-TCA RSR EXCEEDANCES IN GROUNDWATER

NOTES:

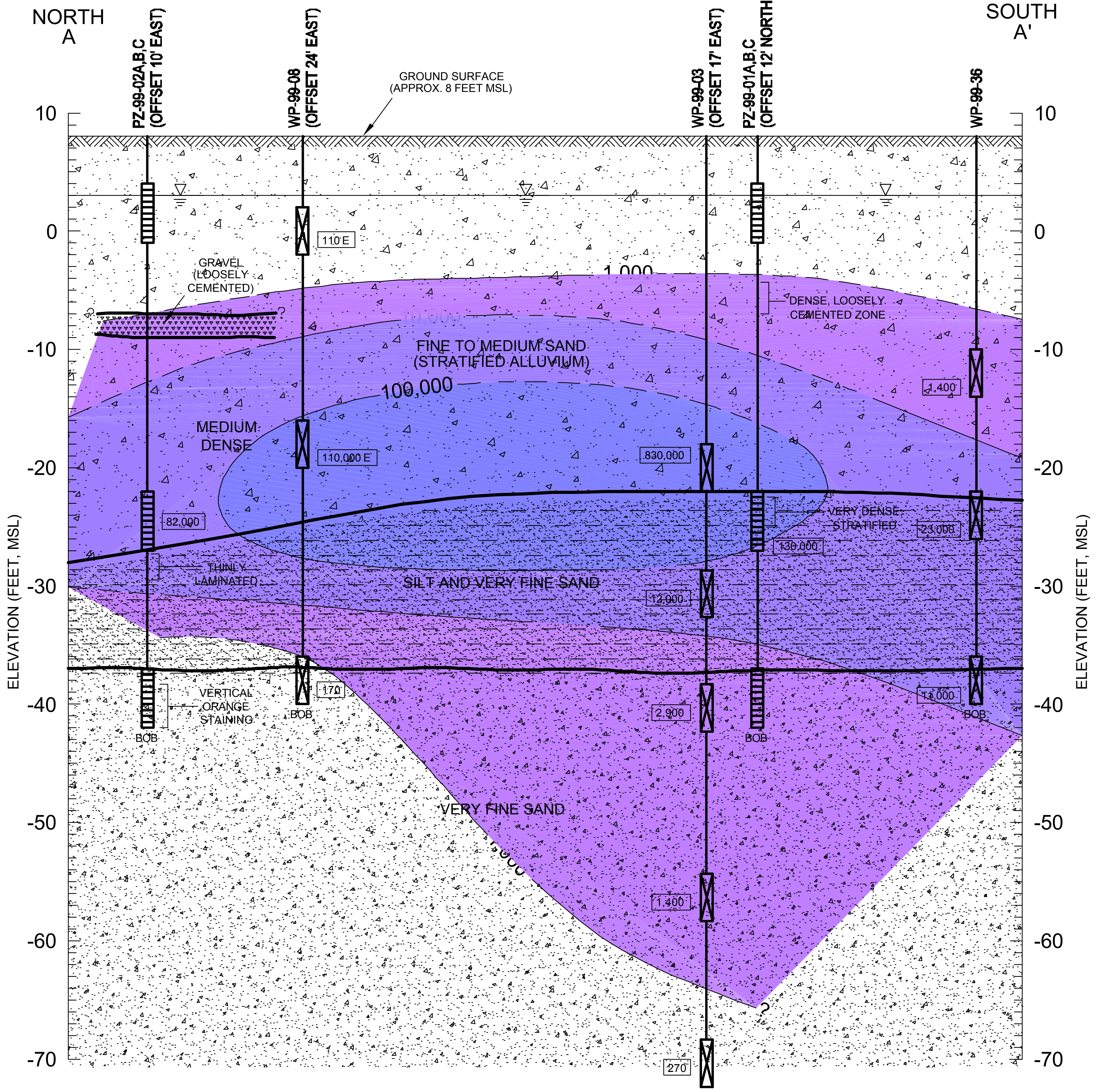
1. BASE MAP SOURCE: ALLIEDSIGNAL, INC.
2. EXCEEDANCES DELINEATED USING MAXIMUM CONCENTRATION OF THE VOC DETECTED IN EACH GEOPROBE AND CONE PENETROMETER SAMPLING LOCATION (IRRESPECTIVE OF DEPTH).

0 60 120 240 FEET

SCALE: 1"=120'

G:\PROJECTS\TERCS\PROJECTS\D020\PILOT_TEST\FIGURES\47254205 11/02/99

FIGURE 8
ESTIMATED HORIZONTAL EXTENT OF SELECT VOCs IN GROUNDWATER
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates



CROSS-SECTION A-A'

LEGEND

GROUNDWATER ELEVATION

GROUNDWATER SAMPLE INTERVAL

WELL SCREEN INTERVAL

? STRATIGRAPHIC CONTACT (DASHED WHERE INFERRED)

BOB BOTTOM OF BORING

E CONTRATION EXCEEDS UPPER END OF ANALYTICAL INSTRUMENT CALIBRATION RANGE

1,400 CONCENTRATION OF TCE IN GROUNDWATER (ug/L)

—1,000— INTERPRETIVE ISO CONCENTRATION CONTOUR (ug/L)

0 15 30 600 FEET

SCALE: 1"=30' HORIZ.
1"=10' VERT.

FIGURE 9
INTERPRETIVE VERTICAL DISTRIBUTION OF TCE IN GROUNDWATER
CROSS-SECTION A-A'
CHROMIUM PLATING FACILITY
OU2 NON-TIME CRITICAL REMOVAL ACTION
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

G:\PROJECTS\TERCS\PROJECTS\DO20\OU2\PREDESIGN\FIGURES\47254006.DWG 11-04-99 DEL

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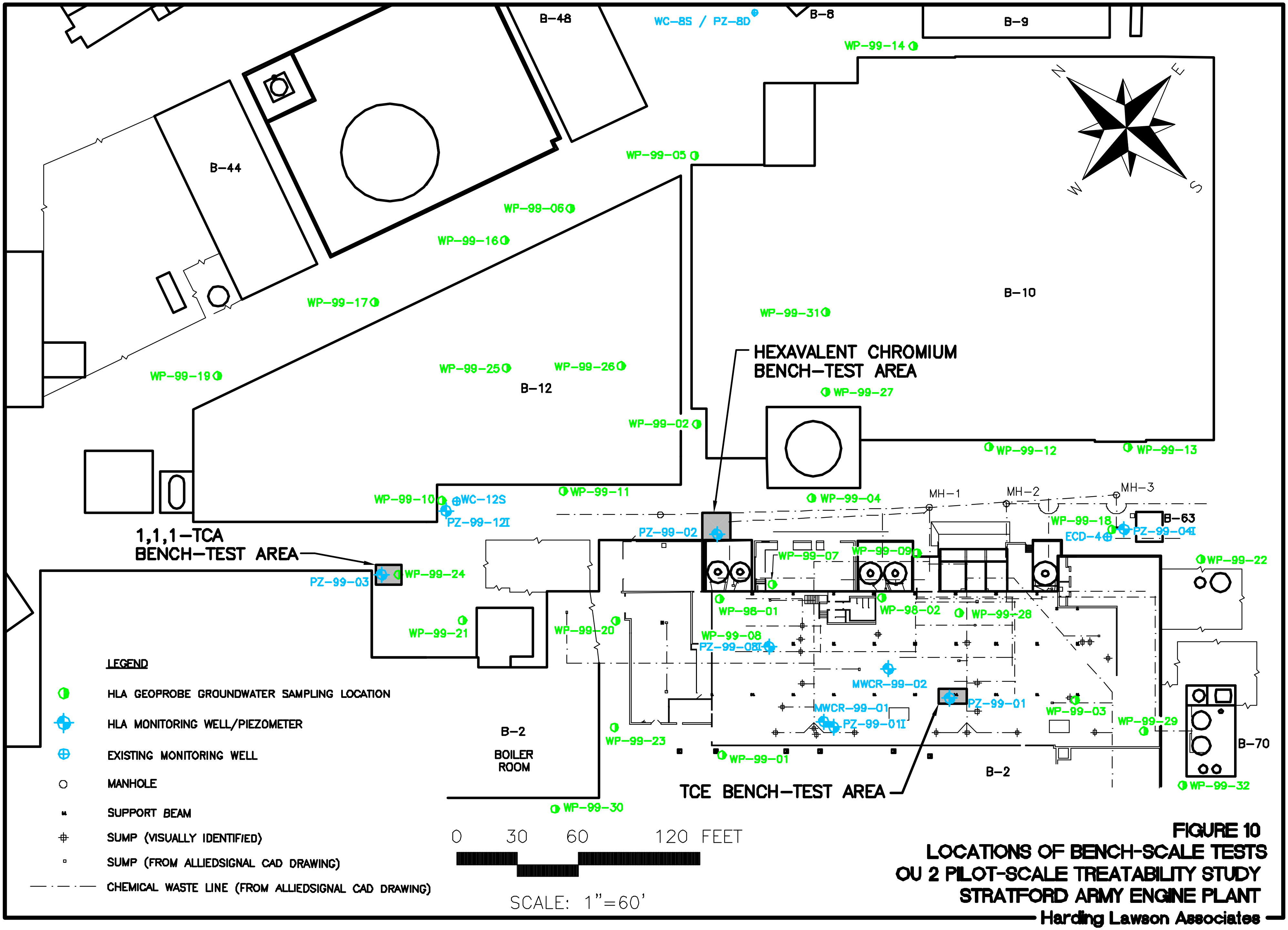

FIGURE 10
LOCATIONS OF BENCH-SCALE TESTS
OU 2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

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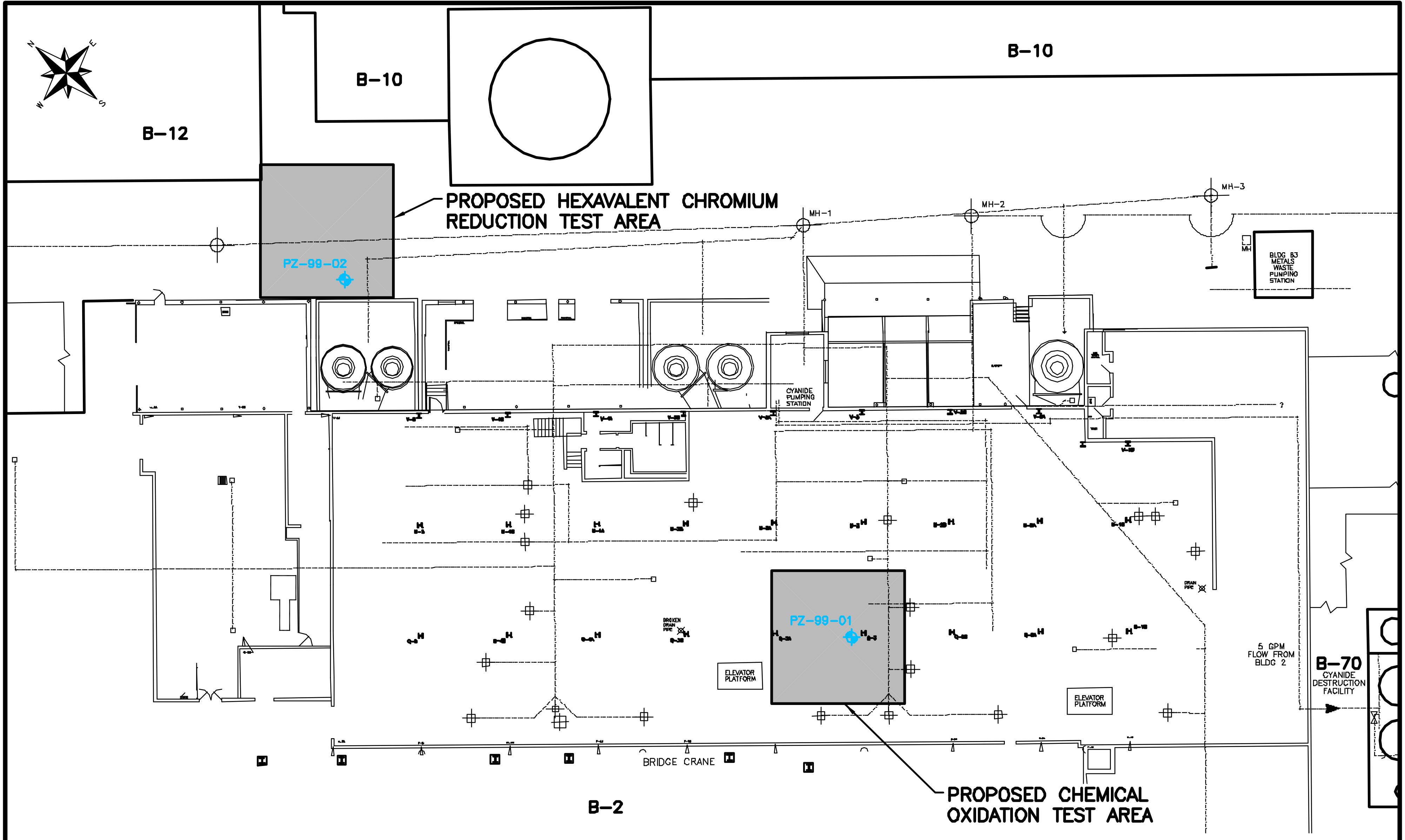


LEGEND

⌖	HLA MONITORING WELL/PIEZOMETER
H	SUPPORT BEAM
⊕	SUMP (VISUALLY IDENTIFIED)
☐	SUMP (FROM ALLIEDSIGNAL CAD DRAWING)
------------	CHEMICAL WASTE LINE (FROM ALLIEDSIGNAL CAD DRAWING)

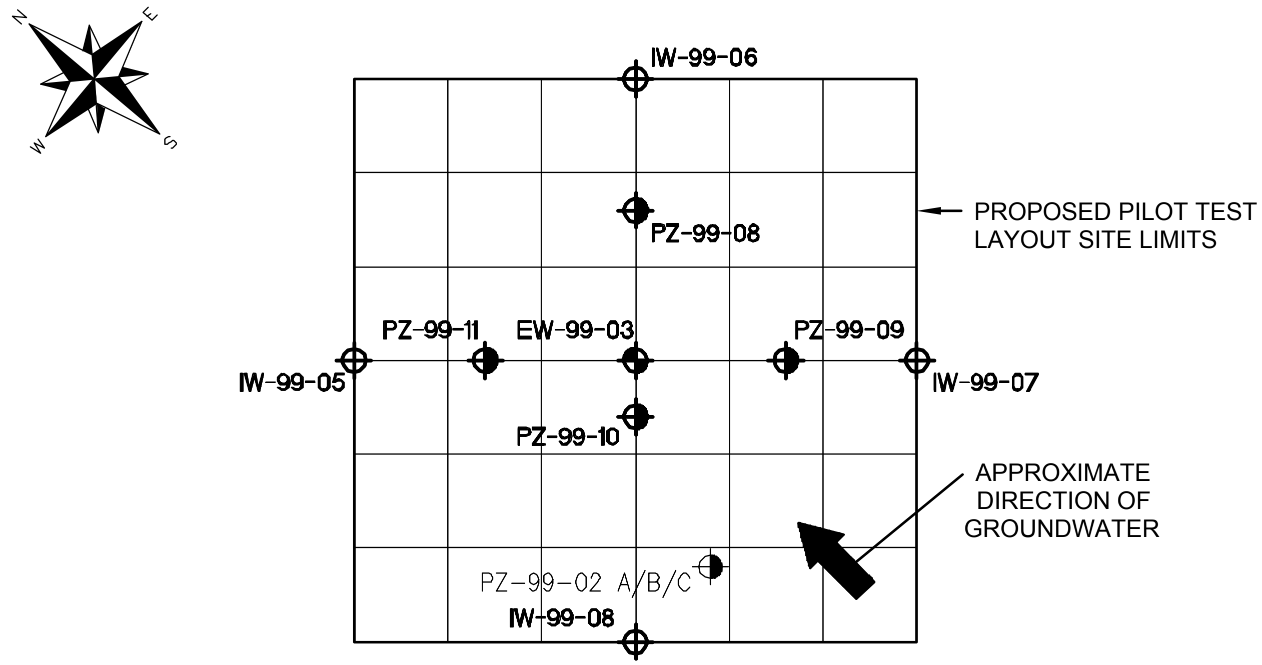
0 15 30 60 FEET

SCALE: 1"=30'

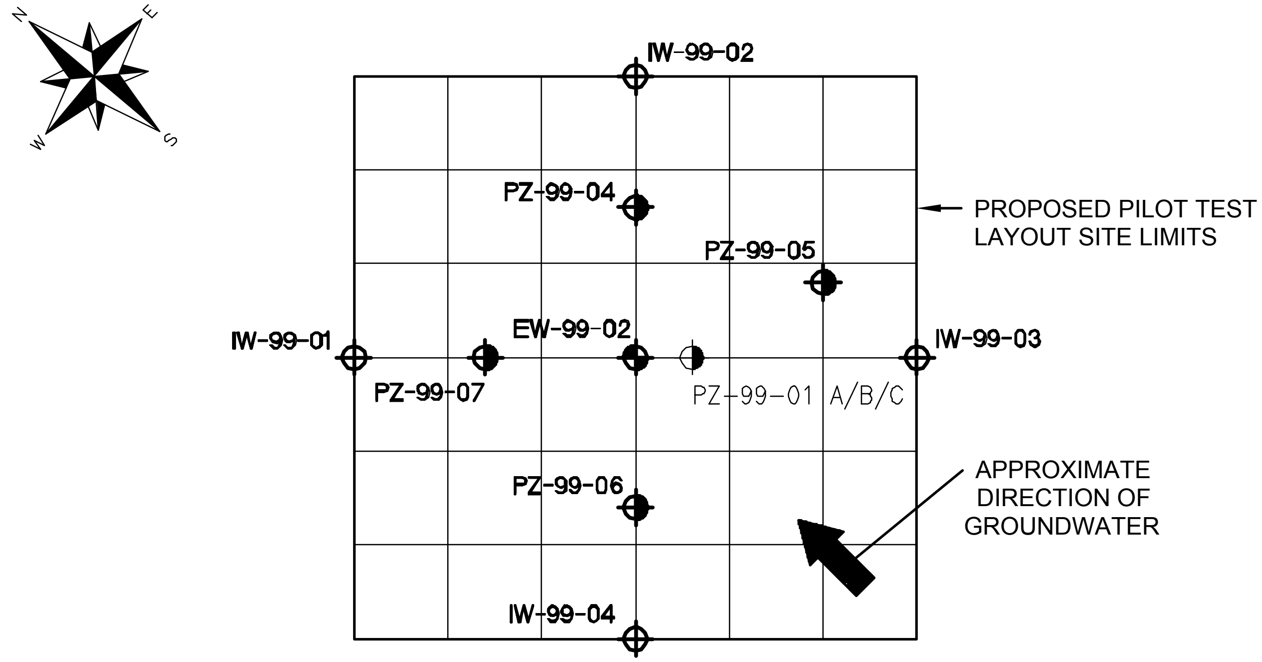
FIGURE 11

LOCATIONS OF PROPOSED PILOT-SCALE TESTING
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT

Harding Lawson Associates



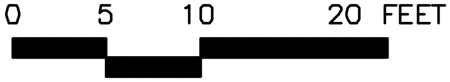
HEXAVALENT CHROMIUM TEST AREA



TCE TEST AREA

LEGEND

PZ-99-06 ● PROPOSED PIEZOMETER
IW-99-03 ⊕ PROPOSED INJECTION WELL
EW-99-03 ● PROPOSED EXTRACTION WELL
PZ-99-01 ◐ EXISTING PIEZOMETER



SCALE: 1"=10'

FIGURE 12
CHROMIUM PLATING FACILITY
PROPOSED PILOT TEST LAYOUTS
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

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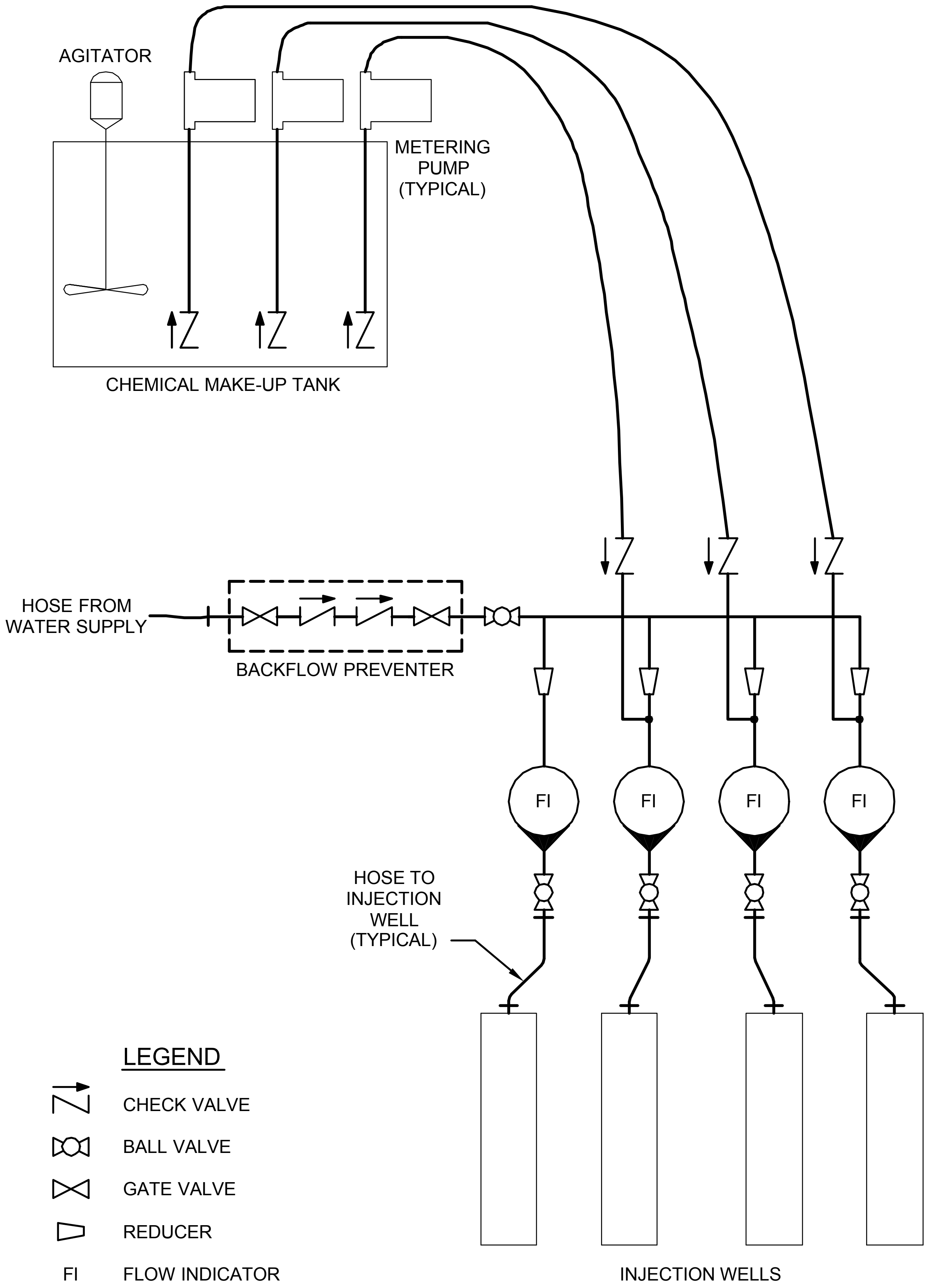

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FIGURE 13
PROPOSED PILOT-SCALE INJECTION SYSTEM
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

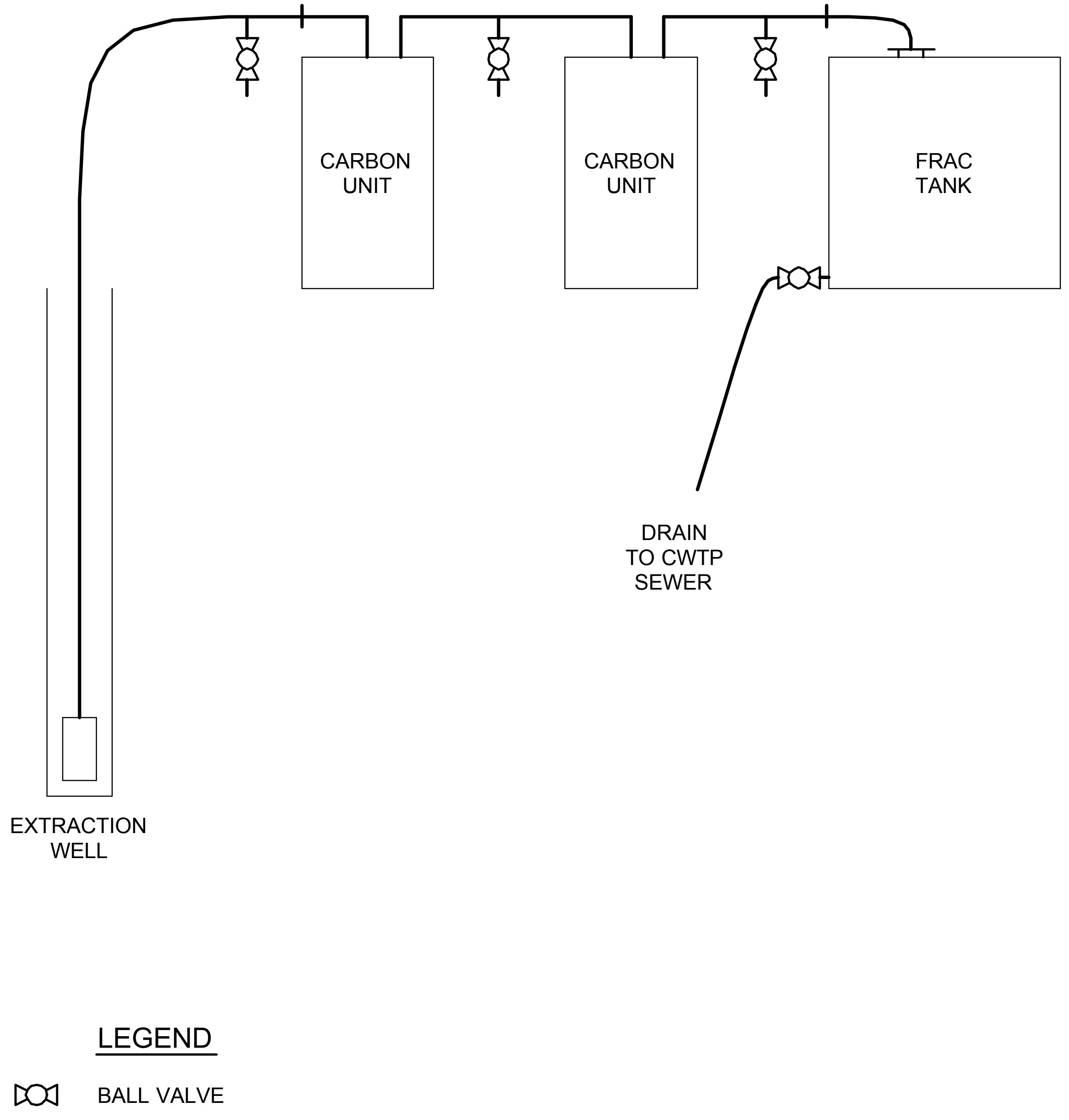

FIGURE 14
PROPOSED PILOT-SCALE
EXTRACTION AND TREATMENT SYSTEM
OU2 PILOT-SCALE TREATABILITY STUDY
STRATFORD ARMY ENGINE PLANT
Harding Lawson Associates

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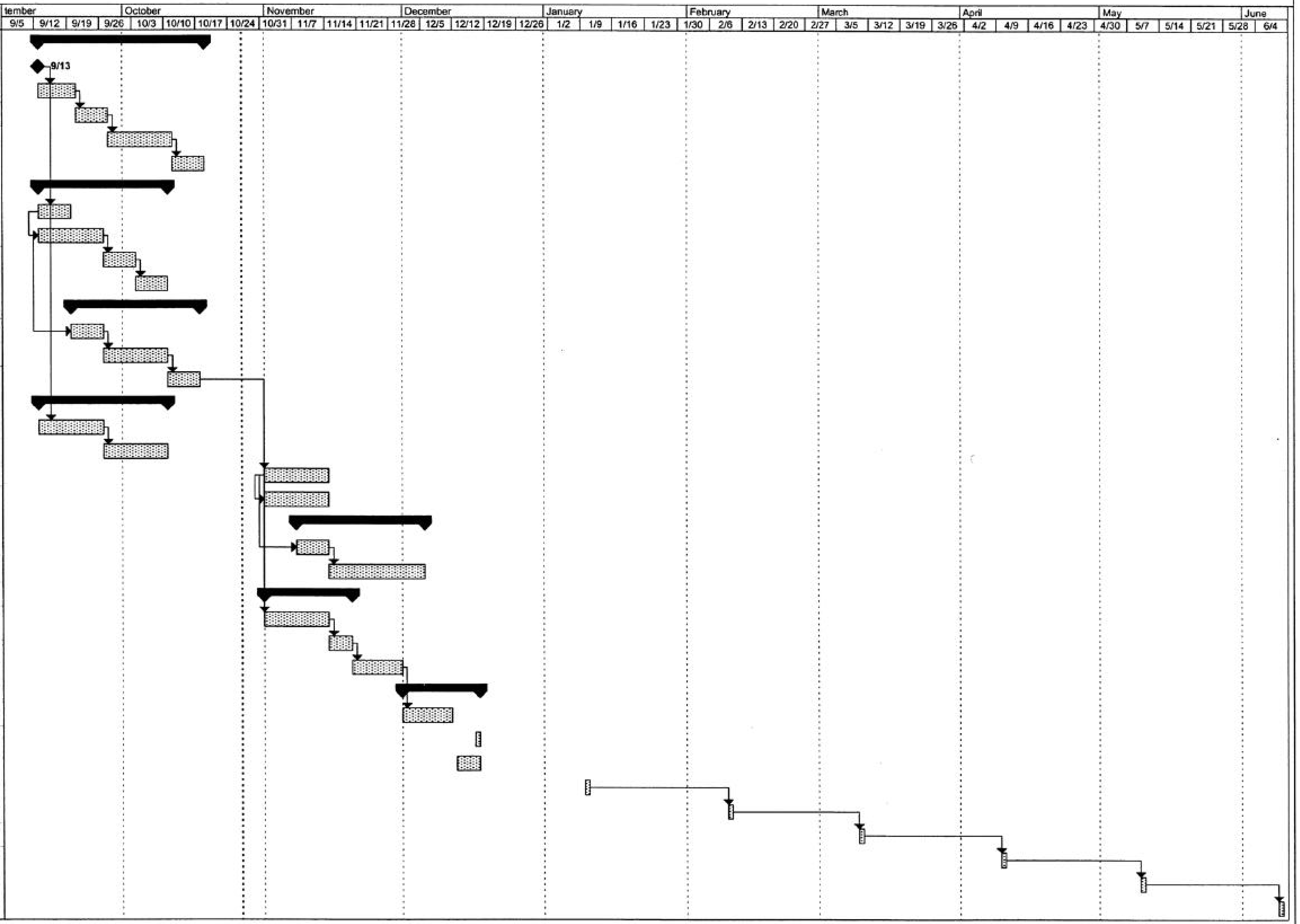
FIGURE 15
OU2 PILOT-SCALE TREATABILITY STUDY SCHEDULE
STRATFORD ARMY ENGINE PLANT

ID	Task Name	Duration	Start	Finish
1	**Work Plan**	**36 days**	**Mon 9/13/99**	**Mon 10/18/99**
2	Draft to Army	0 days	Mon 9/13/99	Mon 9/13/99
3	Army Review	8 days	Mon 9/13/99	Mon 9/20/99
4	Revise	7 days	Tue 9/21/99	Mon 9/27/99
5	Regulatory Agency Review	14 days	Tue 9/28/99	Mon 10/11/99
6	Revise	7 days	Tue 10/12/99	Mon 10/18/99
7	**Proposal**	**28 days**	**Mon 9/13/99**	**Sun 10/10/99**
8	USACE Prepare RFP	7 days	Mon 9/13/99	Sun 9/19/99
9	FW Submits Proposal	14 days	Mon 9/13/99	Sun 9/26/99
10	Negotiations	7 days	Mon 9/27/99	Sun 10/3/99
11	Award	7 days	Mon 10/4/99	Sun 10/10/99
12	**Subcontracting**	**28 days**	**Mon 9/20/99**	**Sun 10/17/99**
13	Write RFPs	7 days	Mon 9/20/99	Sun 9/26/99
14	Bid/Procurement Proc.	14 days	Mon 9/27/99	Sun 10/10/99
15	Award	7 days	Mon 10/11/99	Sun 10/17/99
16	**Permitting**	**28 days**	**Mon 9/13/99**	**Sun 10/10/99**
17	Application	14 days	Mon 9/13/99	Sun 9/26/99
18	Review/Approval	14 days	Mon 9/27/99	Sun 10/10/99
19	**Well Installation**	**14 days**	**Mon 11/1/99**	**Sun 11/14/99**
20	**Piezometer Installation**	**14 days**	**Mon 11/1/99**	**Sun 11/14/99**
21	**GC w/operator**	**28 days**	**Mon 11/8/99**	**Sun 12/5/99**
22	Mob	7 days	Mon 11/8/99	Sun 11/14/99
23	Operation	21 days	Mon 11/15/99	Sun 12/5/99
24	**Construct System**	**19 days**	**Mon 11/1/99**	**Fri 11/19/99**
25	Equipment Delivery	14 days	Mon 11/1/99	Sun 11/14/99
26	Piping/Electrical Fabrication	5 days	Mon 11/15/99	Fri 11/19/99
27	**Start-Up**	**11 days**	**Sat 11/20/99**	**Tue 11/30/99**
28	**Pilot Test**	**17 days**	**Wed 12/1/99**	**Fri 12/17/99**
29	Inject/Monitor	11 days	Wed 12/1/99	Sat 12/11/99
30	Post Test GW Monitoring (Round 1)	1 day	Fri 12/17/99	Fri 12/17/99
31	Demobilization	5 days	Mon 12/13/99	Fri 12/17/99
32	Post-Test GW Monitoring (Round 2)	1 day	Mon 1/10/00	Mon 1/10/00
33	Post-Test GW Monitoring (Round 3)	1 day	Thu 2/10/00	Thu 2/10/00
34	Post-Test GW Monitoring (Round 4)	1 day	Fri 3/10/00	Fri 3/10/00
35	Post-Test GW Monitoring (Round 5)	1 day	Mon 4/10/00	Mon 4/10/00
36	Post-Test GW Monitoring (Round 6)	1 day	Wed 5/10/00	Wed 5/10/00
37	Post-Test GW Monitoring (Round 7)	1 day	Fri 6/9/00	Fri 6/9/00



Project: sch090899
Date: Wed 10/27/99

Task	▨	Progress	■	Summary	▼	Rolled Up Split	....	Rolled Up Progress	■
Split	....	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	External Tasks	▨
Project Summary	▼								

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TABLES

TABLE 1
BENCH-SCALE TEST ANALYTICAL RESULTS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Test Area	Sample ID	Treatment Solution	Catalyst Volume (mL)[1]	Multiple of Stoichiometric Dosage	Total Cr (mg/L or mg/kg)	Hex Cr (mg/L or mg/kg)	Total Iron (mg/L)	Ferrous Iron (mg/L)	TCA (ug/L)	TCE (ug/L)	1,1-DCA (ug/L)	1,1-DCE (ug/L)	1,2-DCA (ug/L)	1,2-DCE (ug/L)	OTHERS (ug/L)
1	PZ1B082499	Pre-test water[2]	NA	NA	<0.1	<0.1	16	<0.1	<1000	130000	<1000	<1000	<1000	<1000	
	PZ9901033XX	Pre-test soil	NA	NA	NA	NA	NA	NA	700	100000	<50	<50	2000	<50	Tolune = 1700
	BS990101XX	Potassium Perm.	NA	0	<0.1	<0.1	12	<0.1	<5000	120000	<5000	<5000	<5000	<5000	
	BS990102XX	Potassium Perm.	NA	0.5	<0.1	<0.1	8	<0.1	<12	420	<12	<12	<12	<12	1,1,2-TCA = 34; PCE = 16
	BS990131XX	Potassium Perm.	NA	1.0	<0.1	<0.1	15	<0.1	<5	<5	<5	<5	6.8	<5	1,1,2-TCA = 36; PCE = 1J
	BS990104XX	Potassium Perm.	NA	1.5	<0.1	<0.1	10.5	<0.1	<5	<5	<5	<5	5.4	<5	1,1,2-TCA = 30
	BS990105XX	Potassium Perm.	NA	2.0	<0.1	<0.1	8.75	<0.1	<3.1	<3.1	1.2J	<3.1	8.9	<3.1	1,1,2-TCA = 30
	BS990106XX	Potassium Perm.	NA	4.0	<0.1	<0.1	15	<0.1	0.54J	0.39J	1.1J	0.43J	8.7	<3.1	1,1,2-TCA = 25; PCE = 0.35J
	BS990107XX	Hydrogen Perox.	0/0	0	<0.1	<0.1	7.5	<0.1	<5000	110000	<5000	<5000	<5000	<5000	
	BS990108XX	Hydrogen Perox.	0.75/5	1.0	<0.1	<0.1	56	1.2	<1000	22000	<1000	<1000	<1000	<1000	
	BS990109XX	Hydrogen Perox.	0.75/5	2.0	<0.1	<0.1	120	2.8	<100	2800	<100	<100	<100	<100	
	BS990110XX	Hydrogen Perox.	0.75/5	4.0	<0.1	<0.1	150	4.9	<100	2300	<100	<100	<100	<100	
	BS990111XX	Hydrogen Perox.	0.75/5	7.0	<0.1	<0.1	100	5.8	<10	300	<10	<10	<10	<10	1,1,2-TCA = 26; PCE = 1.1J
	BS990112XX	Hydrogen Perox.	0.75/5	10.0	<0.1	<0.1	67	5.8	<2.5	70	<2.5	<2.5	<2.5	<2.5	1,1,2-TCA = 23; PCE = 0.46J
	BS990113XX	Potassium Perm.	NA	1.0	NA	NA	NR	NR	12	<2.5	1.4J	1.4J	2.5	<2.5	1,1,2-TCA = 12
	BS990114XX	Potassium Perm.	NA	1.5	NA	NA	NR	NR	11	<2.5	1.5J	2.5	<2.5	<2.5	1,1,2-TCA = 11
2	PZ2B081999	Pre-test water[2]	NA	NA	450	450	1.75	<0.1	<5000	82000	<5000	<5000	<5000	<5000	
	PZ9902032XX	Pre-test soil	NA	NA	TAT	151	TAT	TAT	TAT	TAT	TAT	TAT	TAT	TAT	
	Test1-Jar6	Ferrous Sulfate	0.6 (NaOH)	0.3	NR	290	NR	NR	NA	NA	NA	NA	NA	NA	
	Test3-Jar5	Ferrous Sulfate	2.6 (NaOH)	0.7	200	100	48	<0.1	NA	NA	NA	NA	NA	NA	
	Test3-Jar6	Ferrous Sulfate	5.7 (NaOH)	1.3	150	100	30	<0.1	NA	NA	NA	NA	NA	NA	
	Test4-Jar5	Ferrous Sulfate	7.5 (NaOH)	2.0	<0.1	<0.1	520	150	NA	NA	NA	NA	NA	NA	
	Test1-Jar4	Ferrous Sulfate	0.7 (H2SO4)	0.3	NR	320	NR	NR	NA	NA	NA	NA	NA	NA	
	Test1-Jar2	Ferrous Sulfate	1.3 (H2SO4)	0.3	NR	350	NR	NR	NA	NA	NA	NA	NA	NA	
	Test2-Jar2	Ferrous Sulfate	5.5 (H2SO4)	0.3	NR	500	1600	<0.1	NA	NA	NA	NA	NA	NA	
	Test5-Jar4	Ferrous Sulfate	8.0 (H2SO4)	1.3	NR	80	NR	<0.1	NA	NA	NA	NA	NA	NA	
	Test5-Jar5	Ferrous Sulfate	10.0 (H2SO4)	2.0	NR	<0.1	NR	50	NA	NA	NA	NA	NA	NA	
	Test5-Jar6	Ferrous Sulfate	10.0 (H2SO4)	2.7	350	<0.1	1740	300	NA	NA	NA	NA	NA	NA	
	BS990215XX	Post-test water	7.0 (H2SO4)	2.0	220	<0.1	1600	110	TAT	TAT	TAT	TAT	TAT	TAT	

TABLE 1
BENCH-SCALE TEST ANALYTICAL RESULTS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Test Area	Sample ID	Treatment Solution	Catalyst Volume (mL)[1]	Multiple of Stoichiometric Dosage	Total Cr (mg/L or mg/kg)	Hex Cr (mg/L or mg/kg)	Total Iron (mg/L)	Ferrous Iron (mg/L)	TCA (ug/L)	TCE (ug/L)	1,1-DCA (ug/L)	1,1-DCE (ug/L)	1,2-DCA (ug/L)	1,2-DCE (ug/L)	OTHERS (ug/L)
3	PZ03081899XX	Pre-test water[2]	NA	NA	<0.1	<0.1	NR	<0.1	34000	1700	2800	9400	ND	290J	
	PZ9903012XX	Pre-test soil	NA	NA	NA	NA	NA	NA	<140	<140	<140	<140	<140	<140	
	BS990301XX	Potassium Perm.	NA	0	NA	NA	NA	NA	13000	530	2100	1900	<500	180J	
	BS990302XX	Potassium Perm.	NA	1.0	NA	NA	NA	NA	12000	<500	1900	<500	<500	<500	
	BS990303XX	Potassium Perm.	NA	1.5	NA	NA	NA	NA	12000	<500	2000	<500	<500	<500	
	BS990304XX	Potassium Perm.	NA	2.0	NA	NA	NA	NA	13000	<500	2000	<500	<500	<500	
	BS990305XX	Potassium Perm.	NA	4.0	NA	NA	NA	NA	14000	<500	2300	<500	<500	<500	
	BS990306XX	Potassium Perm.	NA	8.0	NA	NA	NA	NA	12000	<500	1800	<500	<500	<500	
	BS990307XX	Hydrogen Perox.	0.6/6.6	0	NA	NA	NA	NA	11000	420	1900	2200	<250	190J	
	BS990308XX	Hydrogen Perox.	0.6/6.6	1.0	NA	NA	NA	NA	11000	<250	1400	<250	<250	<250	
	BS990309XX	Hydrogen Perox.	0.6/6.6	2.0	NA	NA	NA	NA	13000	<250	1300	<250	<250	<250	
	BS990310XX	Hydrogen Perox.	0.6/6.6	4.0	NA	NA	NA	NA	12000	<250	900	<250	<250	<250	
	BS990311XX	Hydrogen Perox.	0.6/6.6	7.0	NA	NA	NA	NA	11000	<250	690	<250	<250	<250	
	BS990312XX	Hydrogen Perox.	0.6/6.6	10.0	NA	NA	NA	NA	9800	<250	520	<250	<250	<250	

Notes:

[1] Catalysts for hydrogen peroxide test were sulfuric acid\ferrous sulfate. Catalysts for Area 2 tests were sulfuric acid (H2SO4) or sodium hydroxide (NaOH).

[2] Pre-test water filed parameter results are values taken from one set of test jars. The results may have been different for subsequent tests.

Test Area 1 is the TCE hot-spot
Test Area 2 is the Hexavalent Chromium hot-spot
Test Area 3 is the 1,1,1-TCA hot-spot
DCA = dichloroethane
DCE = dichloroethylene
H2SO4 = sulfuric acid
Hex Cr = hexavalent chromium
mg/kg = milligrams per kilogram
mg/L = milligrams per liter

NA = not applicable/analyzed
NaOH = sodium hydroxide
ND = non detect
NR = not recorded
PCE = tetrachloroethylene
TAT = results not received from off-site lab
TCA = trichloroethane
TCE = trichloroethylene
ug/L = micrograms per liter

TABLE 2
BENCH-SCALE TEST FIELD PARAMETER RESULTS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Test Area	Sample ID	Treatment Solution	Catalyst Volume (mL)[1]	Multiple of Stoichiometric Dosage	Temp (deg C)	pH	REDOX (mV)	Turbidity (NTUs)	Conductivity (ms/cm)	Qualitative Assessments
1	PZ1B082499	Pre-test water[2]	NA	NA	23.1	6.4	333	1	3.79	
	PZ9901033XX	Pre-test soil	NA	NA	NA	NA	NA	NA	NA	
	BS990101XX	Potassium Perm.	NA	0	24.3	6.38	16.8	645	3.82	
	BS990102XX	Potassium Perm.	NA	0.5	24.5	4.46	750	65	4.11	
	BS990131XX	Potassium Perm.	NA	1.0	24.4	4.77	784	963	4.52	
	BS990104XX	Potassium Perm.	NA	1.5	24.4	4.86	799	712	4.57	
	BS990105XX	Potassium Perm.	NA	2.0	24.4	4.89	808	688	4.78	
	BS990106XX	Potassium Perm.	NA	4.0	24.4	4.89	827	426	5.45	
	BS990107XX	Hydrogen Perox.	0\5	0	23.1	6.82	187	28	NA	
	BS990108XX	Hydrogen Perox.	0.75\5	1.0	NA	3.1	570	20	NA	
	BS990109XX	Hydrogen Perox.	0.75\5	2.0	NA	2.9	588	33	NA	
	BS990110XX	Hydrogen Perox.	0.75\5	4.0	NA	2.89	588	NA	NA	
	BS990111XX	Hydrogen Perox.	0.75\5	7.0	NA	2.87	556	45	NA	
	BS990112XX	Hydrogen Perox.	0.75\5	10.0	NA	2.85	555	48	NA	
	BS990113XX	Potassium Perm.	NA	1.0	NR	NR	NR	NR	NR	
	BS990114XX	Potassium Perm.	NA	1.5	NR	NR	NR	NR	NR	
2	PZ2B081999	Pre-test water[2]	NA	NA	21.4	6.45	236	35	4.01	
	PZ9902032XX	Pre-test soil	NA	NA	NA	NA	NA	NA	NA	
	Test1-Jar6	Field Tests	0.6 (NaOH)	0.3	NR	5.33	504	104	NR	
	Test3-Jar5	Field Tests	2.6 (NaOH)	0.7	NR	5.74	271	61.2	NR	
	Test3-Jar6	Field Tests	5.7 (NaOH)	1.3	NR	5.89	270	28.5	NR	
	Test4-Jar5	Field Tests	7.5 (NaOH)	2	23.5	5.92	281	79	7.1	
	Test1-Jar4	Field Tests	0.7 (H2SO4)	0.3	22.9	3.38	565	90.2	NR	
	Test1-Jar2	Field Tests	1.3 (H2SO4)	0.3	22.9	3.25	564	120	NR	
	Test2-Jar2	Field Tests	5.5 (H2SO4)	0.3	NR	2.62	643	29	NR	
	Test5-Jar4	Field Tests	8.0 (H2SO4)	1.3	22.2	2.47	648	638	NR	
	Test5-Jar5	Field Tests	10.0 (H2SO4	2	22.2	2.35	538	6.4	NR	
	Test5-Jar6	Field Tests	10.0 (H2SO4	2.7	22.2	2.36	486	5.9	NR	
	BS990215XX	Post-test	7.0 (H2SO4)	2.0	21.4	2.54	516	NR	NR	

TABLE 2
BENCH-SCALE TEST FIELD PARAMETER RESULTS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Test Area	Sample ID	Treatment Solution	Catalyst Volume (mL)[1]	Multiple of Stoichiometric Dosage	Temp (deg C)	pH	REDOX (mV)	Turbidity (NTUs)	Conductivity (ms/cm)	Qualitative Assessments
3	PZ03081899XX	Pre-test water[2]	NA	NA	25.4	5.95	-200	2	1.05	
	PZ9903012XX	Pre-test soil	NA	NA	NA	NA	NA	NA	NA	
	BS990301XX	Potassium Perm.	0.1/6.6	0	23.2	3.79	121	37.4	NR	
	BS990302XX	Potassium Perm.	0.1/6.6	1.0	23.1	1.76	864	249	NR	
	BS990303XX	Potassium Perm.	0.1/6.6	1.5	23.1	1.66	925	167	NR	
	BS990304XX	Potassium Perm.	0.1/6.6	2.0	23.0	1.71	939	135	NR	
	BS990305XX	Potassium Perm.	0.1/6.6	4.0	22.0	1.68	966	181	NR	
	BS990306XX	Potassium Perm.	0.1/6.6	8.0	22.9	1.72	979	109	NR	
	BS990307XX	Hydrogen Perox.	0/0	0	25.5	3.68	128	16	1.27	Gray-brown color
	BS990308XX	Hydrogen Perox.	0.6/6.6	1.0	25.8	3.1	516	37	1.73	Rust color
	BS990309XX	Hydrogen Perox.	0.6/6.6	2.0	25.9	3.13	583	35	1.73	Rust color
	BS990310XX	Hydrogen Perox.	0.6/6.6	4.0	25.9	3.12	585	82	1.76	Rust color
	BS990311XX	Hydrogen Perox.	0.6/6.6	7.0	26.0	3.13	588	56	1.71	Rust color
	BS990312XX	Hydrogen Perox.	0.6/6.6	10.0	25.9	3.16	573	77	1.66	Rust color

Notes:

[1] Catalysts for hydrogen peroxide test were sulfuric acid\ferrous sulfate. Catalysts for Area 2 tests were sulfuric acid (H2SO4) or sodium hydroxide (NaOH).

[2] Pre-test water filed parameter results are values taken from one set of test jars. The results may have been different for subsequent tests.

Test Area 1 is the TCE hot-spot
Test Area 2 is the Hexavalent Chromium hot-spot
Test Area 3 is the 1,1,1-TCA hot-spot

deg C = degrees Celcius
H2SO4 = sulfuric acid
mL = milliliters
mv = millivolts
NA = not applicable/analyzed
NaOH = sodium hydroxide
ND = non-detect
NR = not recorded
NTU = nephalometric units
TCA = trichloroethane
TCE = trichloroethylene

TABLE 3
BILL OF MATERIALS FOR TREATABILITY EQUIPMENT

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Item No.	Description	Quantity
1	Chemical Make-up Tank	2
2	Chemical Metering Pump	6
3	Metering Pump Foot Valve	6
5	Metering Pump Hose	70 feet
6	Tank Mixer	2
7	Backflow Preventer	1
8	Flow Meter 0.2-2 GPM	8
9	Flow Control Valve ½ inch	8
10	Flow Control Valve 1 inch	2
11	1 inch PVC Tubing	1,000 feet
12	½ inch PVC Tubing	500 feet
13	Miscellaneous PVC Pipe and Fittings	1
14	Ferrous Sulfate-heptahydrate	3000 pounds
15	Manual Drum Pump for Sulfuric Acid	1
16	Extraction Well Pump	2
17	Carbon Treatment Unit	4
18	Frac Tank	4
19	Potassium Permanganate	200 pounds
20	Sulfuric Acid 66 degrees	230 pounds
21	Flow Meter 1-10 gpm	2

TABLE 4
HEXAVALENT CHROMIUM TEST AREA SAMPLE COLLECTION

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Location	Sample Type	Sampling Frequency	Purpose of Monitoring
EW-99-03, IW-99-05, IW-99-06, IW-99-07, IW-99-08, PZ-99-02 PZ-99-08, PZ-99-09, PZ-99-10, PZ-99-11	Soil and Groundwater PZ-99-02 $_{\text{A/B/C}}$ Groundwater only	One sample collected during installation phase.	Characterize hexavalent chromium at the beginning of the test for each lobe of the test area.
All Piezometers	Water Elevation	daily	Monitor for hydraulic control of the treatment area.
PZ-99-08, PZ-99-09, PZ-99-11	Groundwater	0, 20, 21, 22, 23, 24, 25, 26, 27, 28 hours, daily thereafter	Monitor for movement of the ferrous sulfate front through the treatment zone. These piezometers are positioned at approximately 1 day travel time from the injection wells.
PZ-99-10	Groundwater	0, 24, 32, 33, 34, 35, 36, 37, 38, 39, 40 hours, daily thereafter	Monitor for movement of the ferrous sulfate front through the treatment zone. This piezometer is positioned at approximately 1.5 days travel time from the injection well.
EW-99-03, PZ-99-02$^{\text{A/B/C}}$	Groundwater	0, 24, 44, 45, 46, 47, 48, 49, 50, 51, 52 hours, daily thereafter	Monitor for movement of the ferrous sulfate front through the treatment zone. The extraction well and this piezometer are positioned at approximately 2 days travel time from the injection well.
All piezometers and wells	Groundwater	Round 1, one week after completion of 10 day test; Rounds 2-7, monthly after completion of test	Check for contaminant concentration rebound due to leaching from soil to groundwater.
Treated Water Frac Tank	Water	One sample from each tank prior to discharge to CWTP	Verify removal of VOCs prior to discharge to CWTP.

Note: Well, piezometer, and boring designations are as referenced on Figure 9.

TABLE 5
HEXAVALENT CHROMIUM TEST AREA SAMPLE ANALYSIS

OU 2 TREATABILITY STUDY REPORT
STRATFORD ARMY ENGINE PLANT

Sample Type	Cr(VI)	Cr(total)	VOCs	Fe2+	pH	Conductivity	Elevation	ORP
Soil - Collected during installation	x	x	x					
Groundwater - Collected during installation	x	x	x		x	x		x
Groundwater - During test	x	x	x(1)	x	x	x	x	x
Groundwater - 1 week after test and 2 weeks after test	x	x		x	x	x	x	x
Water - From treated water frac tanks.	x		x		x			x

Notes: (1) VOCs to be analyzed for samples from EW-99-03 only.
Cr(VI) by Field Test Kit or EPA Method 360A/7196
Cr(total) by Field Test Kit or SW846 Method 6010/7000
VOCs by SW846 Method 8260B
Fe^{2+} by field test kit or SW846 Method 6010
pH, Conductivity, and ORP by portable field instrumentation.

TABLE 6
TCE TEST AREA SAMPLE COLLECTION

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Location	Sample Type	Sampling Frequency	Purpose of Monitoring
EW-99-02, IW-99-01, IW-99-02, IW-99-03, IW-99-04, PZ-99-04, PZ-99-05, PZ-99-06, PZ-99-07	Soil and Groundwater	One sample collected during installation.	Characterize TCE at the beginning of the test for each lobe of the test area.
All Piezometers	Water Elevation	daily	Monitor for hydraulic control of the treatment area.
PZ-99-04, PZ-99-06, PZ-99-07	Groundwater	0, 20, 21, 22, 23, 24, 25, 26, 27, 28 hours, daily thereafter	Monitor for movement of the potassium permanganate front through the treatment zone. These piezometers are positioned at approximately 1 day travel time from the injection wells.
PZ-99-01$^{A/B/C}$	Groundwater	0, 24, 32, 33, 34, 35, 36, 37, 38, 39, 40 hours, daily thereafter	Monitor for movement of the potassium permanganate front through the treatment zone. This piezometer is positioned at approximately 1.5 days travel time from the injection well.
EW-99-02, PZ-99-05	Groundwater	0, 24, 44, 45, 46, 47, 48, 49, 50, 51, 52 hours, daily thereafter	Monitor for movement of the potassium permanganate front through the treatment zone. The extraction well and this piezometer are positioned at approximately 2 days travel time from the injection well.
All piezometers and wells	Groundwater	Round 1 one week after completion of 10 day test; Rounds 2-7,monthly after completion of test	Check for contaminant concentration rebound due to leaching from soil to groundwater.
Treated Water Frac Tank	Water	One sample from each tank prior to discharge to CWTP	Verify removal of VOCs prior to discharge to CWTP.

Note: Well, piezometer, and boring designations are as referenced on Figure 9.

TABLE 7
TCE TEST AREA SAMPLE ANALYSIS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

Sample Type	Cr(VI)	Cr(total)	Mn(total)	TOC	VOCs	Fe(II)	pH	Conductivity	Elevation	ORP
Soil - Collected during installation	x	x	x	x	x					
Groundwater - Collected during installation	x	x	x	x	x		x	x	x	x
Groundwater - During test	x(1)		x		x		x	x	x	x
Groundwater - 1 week after test; and 2 weeks after test	x	x	x	x	x		x	x	x	x
Water - From treated water frac tanks.	x				x		x			x

Note: (1) Cr(VI) to be analyzed for samples from EW-99-02 only.
Cr(VI) by Field Test Kit or EPA Method 360A/7196
Cr(total) by Field Test Kit or SW846 Method 6010/7000
Mn(total) by Field Test Kit or EPA Method 6010/7000
TOC by SW846 Method 415.1 or 9060
VOCs by SW846 Method 8260B
Fe(II) by field test kit or SW846 Method 6010
pH, Conductivity, and ORP by portable field instrumentation.
Cr(VI) = hexavalent chromium
Cr(total) = total chromium
Fe(II) = ferrous iron
ORP = oxidation-reduction potential
VOCs = volatile organic compounds
EW = extraction well
EPA = Environmental Protection Agency

TABLE 8
DATA NEEDS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

ACTIVITY	DATA TYPE	COMMENTS
Monitoring well/piezometer installation	Boring logs	Including soil classification and visual observations
	PID readings	
	Subsurface soil sample analysis	On-site analysis: VOCs Off-site analysis: hexavalent chromium, total chromium, TOC
	Well installation diagrams	
Monitoring well/piezometer development	Well development records	
	Field parameters	Collected using a water quality meter: pH, temperature, specific conductivity, dissolved oxygen content, ORP
Pre-test sampling	Water level measurements	
	Groundwater sample analysis	On-site analysis: VOCs, hexavalent chromium, total chromium, total iron, ferrous iron Off-site analysis: dissolved calcium, magnesium, manganese
	Field parameters	Collected using a water quality meter: pH, temperature, specific conductivity, dissolved oxygen content, ORP
	Qualitative assessments	Suspended solids, color, odor
Pilot-test operation	Optimum injection/extraction rates	
	Mixing rates (time)	
	Dosage information	Optimum concentrations

TABLE 8
DATA NEEDS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

ACTIVITY	DATA TYPE	COMMENTS
Pilot test Operation (continued)	Solution information	pH, alkalinity, temperature, ORP Qualitative assessments: suspended solids, color, odor
	Water level measurements	
	Groundwater sample analysis	To monitor solution front On-site Analysis: VOCs, hexavalent chromium, total chromium, total iron, ferrous iron Off-site Analysis: Water quality parameters
	Field parameters	Collected using a water quality meter: pH, temperature, specific conductivity, dissolved oxygen content, ORP
	Discharge sampling	Collected to ensure discharge to CWTP does not exceed permit limits
Post-test Sampling	Boring logs	Including soil classification and visual observations
	PID readings	
	Subsurface soil sample analysis	On-site analysis: VOCs Off-site analysis: hexavalent chromium, total chromium, TOC
	Water level measurements	

TABLE 8
DATA NEEDS

OU 2 TREATABILITY STUDY WORK PLAN
STRATFORD ARMY ENGINE PLANT

ACTIVITY	DATA TYPE	COMMENTS
Post-test Sampling (continued)	Groundwater sample analysis	To check for contaminant rebound On-site Analysis: VOCs, hexavalent chromium, total chromium, total iron, ferrous iron, field parameters Off-site Analysis: Water quality parameters
	Field parameters	Collected using a water quality meter: pH, temperature, specific conductivity, dissolved oxygen content, ORP

Notes:

CWTP = Chemical Waste Treatment Plant
ORP = oxidation-reduction potential
PID = photoionization detector
TOC = total organic carbon
VOCs = volatile organic contaminants

FLOW EVALUATION TO DEMONSTRATE HYDRAULIC CONTAINMENT FOR PILOT TEST TREATMENT

Introduction:

A pilot test demonstration is being planned for the Stratford Army Engine Plant (SAEP) for evaluating in-situ treatment for hexavalent chromium in groundwater and soil. Groundwater will be extracted and treated, while ferrous sulfate solution at lowered pH (about 2.5) will be used to reduce the hexavalent chromium to trivalent chromium in soil and in situ groundwater through injection in an array of wells surrounding the extraction well. A similar scheme is being considered for treatment of trichloroethylene (TCE) in groundwater and soils at the site. Potassium permanganate will be used to chemically oxidize the TCE in a separate location. The proposed pilot test is intended to show patterns of injection, dispersal, and containment that would be common to the remediation of either contaminant. The injection wells will be located along a 30-foot diameter circle about the extraction well. The wells will be screened from 27 to 37 feet below ground surface (bgs) to intercept the zone of maximum contaminant concentrations (30 to 34 feet [bgs]). The principal objective is to evaluate treatment of the contaminated zones while maintaining hydraulic containment of the contaminated groundwater. Concern has been expressed about the possible adverse effect the pilot test may have on the contaminant plumes, causing some disruption of the existing plume distribution and extent.

While the net change of water in the system will be nearly zero, or negative, a groundwater flow model with particle tracking has been developed to show expected flow patterns within the aquifer over the anticipated 10-day pilot test.

Model Selection and Discretization:

The U.S. Geological Survey (USGS) groundwater modeling code MODFLOW has been selected for the flow evaluation demonstration. Particle tracking is being performed with MODPATH. Both of these programs are run within the ModelCad (copyright Geraghty and Miller) for Windows pre- and post-processing modeling platform (HydroTrak, Inc., 1999).

The model has been set up within a 200 by 200-foot square domain with a variable grid. The smallest block widths (one foot) are located at the proposed extraction (one) and injection (four) wells. The block widths vary between this and 5 feet, which are used as we step away from the influence of the wells. There are 57 rows and 57 columns, forming a symmetric grid pattern with the extraction well at the center. The grid, along with the proposed well array and boundary conditions (discussed later), is shown on the first figure.

The water table is encountered at the site at about 6 feet bgs. The effective base of the aquifer is encountered at a depth of about 100 feet bgs, leaving a 94-foot saturated aquifer thickness to model. Each of the contaminant plumes extends over a considerable portion of this thickness, but the highest concentrations have been encountered in a zone about 30 to 34 feet bgs, or 24 to 28 feet into the aquifer. The vertical extent of the model has been discretized into six layers, with thicknesses of 11, 10, 10, 15, 22, and 26 feet, with depth, respectively. The third layer corresponds to the depth and length of the intended placement of a 10-foot screen interval (for both extraction and injection wells) which symmetrically includes the 4-foot zone of maximum contaminant concentrations.

Model Input Parameters and Boundary Conditions:

The model has been set up as a simple box-model. The groundwater hydraulic gradient is specified via constant heads assigned to columns 1 (93.8 feet) and 57 (94.2 feet) of each layer. The heads assigned are arbitrary, with zero corresponding to the elevation of the assumed base of the aquifer. Flow in the model is from right to left. Since the total model width is 200 feet, the 0.4 head differential converts to a hydraulic gradient of 0.002 feet per foot, which has been estimated for the site. The remainder of the row 1 and row 57 model boundaries are no-flow boundaries, which implies that unstressed flow conditions in the model result in streamlines parallel to these rows.

No diffuse recharge has been assumed, but this added water would be insignificant compared to the rate of water being exchanged in the simulated extraction/injection system over the relatively short duration of the pilot test. A uniform hydraulic conductivity of 10 feet per day (ft/d) has been assumed throughout the model based on the results of aquifer testing. A range of hydraulic conductivity values was considered in the sensitivity analysis (low of 5 ft/d and high of 100 ft/d). Horizontal isotropy is assumed, and vertical anisotropy (ratio of horizontal to vertical hydraulic conductivity) is taken as 10. The flow model is run as steady-state, and a porosity of 0.3 has been assumed in all layers in order to compute travel times in the particle tracking program.

Simulation Conditions:

Five wells have been specified for the model. The extraction well is in the center node of the model and in layer 3. This layer is 10 feet thick, and so encompasses the entire proposed well screen interval for this well. Four injection wells are assumed to be equally spaced along a 30-foot diameter circle about the extraction well. These are also placed in layer 3 of the model and presumed to have 10-foot screen lengths. Each injection well is assumed to redistribute one-fourth of the total water injected. This pattern was established in order to more equally distribute the injection loading rate, thus reducing the potential for adversely affecting the flow patterns within the aquifer and minimizing any potential loss of injected treatment chemicals. (Note, however, that these chemicals would only result in lessened contaminant concentrations, even if some injected flow were to escape.) In the first runs, the total injection rate was set equal to the extraction rate.

An extraction rate of 10 gallons per minute (gpm) was first tried, but drawdown in the pumped well was excessive. Excessive drawdown also suggests potentials for flow to the well to originate from upper and lower layers in the model, thus decreasing the effectiveness of the treatment within the more contaminated zone. It is also under these conditions that we might expect a greater than desirable potential for loss of hydraulic containment. In the remaining runs, 5 gpm was found to be a good rate at which to run the test. Actual rates may vary slightly in the field due to well construction and any difference between the actual K and assumed value of 10 ft/d (see also sensitivity run discussion).

The flow model was run to steady-state to determine resultant pumping condition head distributions and resulting long-term flow paths. However, hydraulic heads in this very small area should be established very quickly (direct flow paths take only about a day to a day and a half to complete), and this interval should not affect conclusions drawn from the particle tracking based on the steady-state model.

Particle tracking was conducted by releasing 27 particles (a 3x3x3 array) at each of the injection well locations and tracking these forward in the direction of flow. Particle tracks were carried to the endpoint for each particle, but the post-processor allows the user to prescribe maximum times allowed for particles to travel in plotting their pathlines.

A second series of runs was made with an assumption of a lower injection rate relative to the extraction rate, i.e., four injection wells at one gpm each, with the extraction well pumping at 5 gpm. Sensitivity of the capture and travel times was also examined by considering a range of hydraulic conductivity values (5, 10, 15, and 100 ft/d).

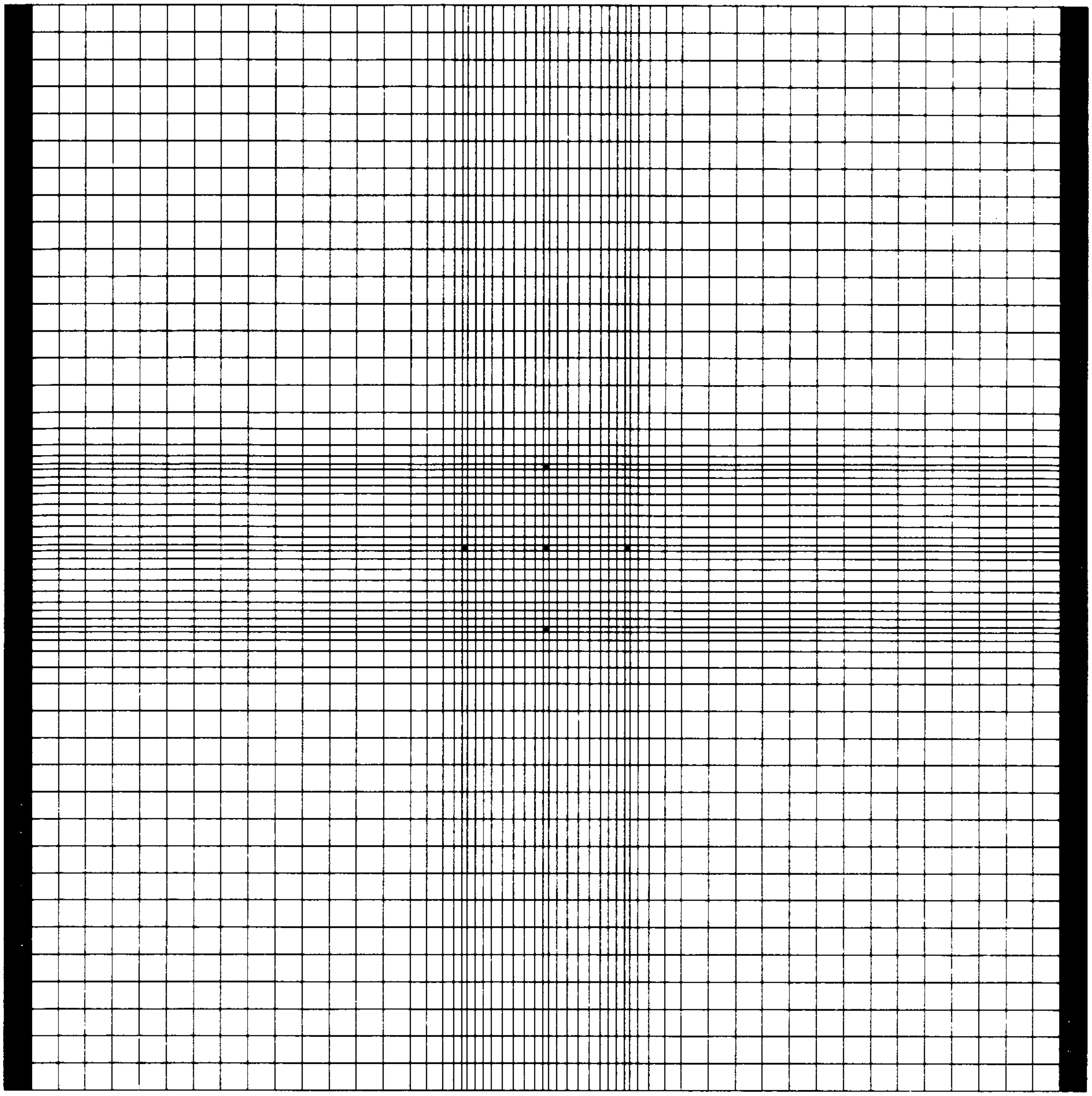
Model Results:

In the first set of attached model particle tracking output figures, the heads contoured are for layer 3. Pumping rates were 5 gpm for the extraction, and 1.0 gpm for each of the four injection wells. The particles were allowed to migrate for specified times of 1, 3, 5, 7, and 10 days to see maximum expected travel distances for any potential losses of treatment fluids during the pilot test. Then the particles were allowed to track for longer periods of time to see their progress under conditions of longer remedy duration. All particles were eventually captured by the extraction well, although the longest travel time was about 1,000 days.

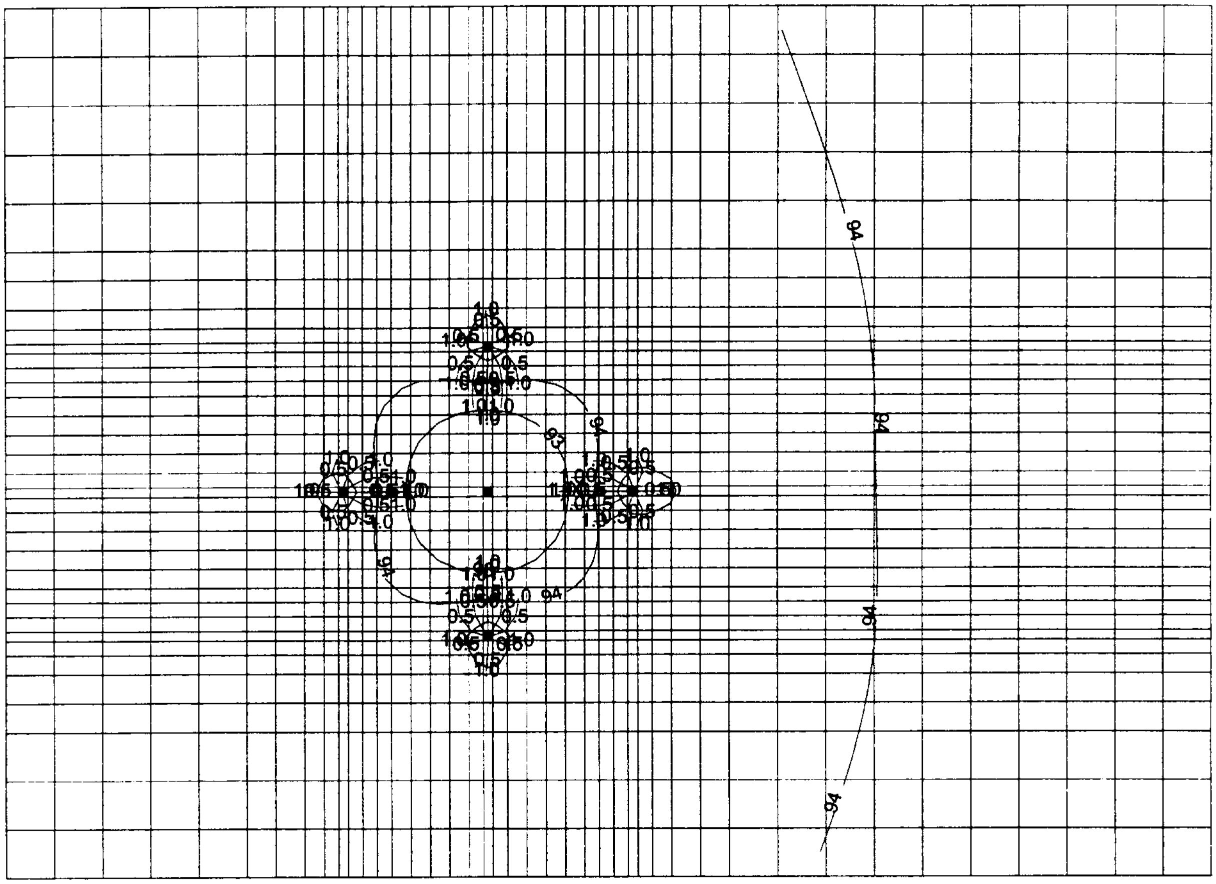
Travel times for water (particles) traversing the path from the injection to the extraction well took from less than a day and a half to about 6 days. The main observation piezometers for monitoring treatment in situ should be placed as closely as possible on a direct line between the extraction and injection well. Other piezometers may be placed in the space between to observe how the ferrous iron is distributed, and how long it takes for these patterns to develop. Hydraulic containment for this simulation of the pilot test would be rated excellent.

Due to the uncertainty in the value for K, sensitivity was conducted on this parameter. In the next three sets of figures, the particle tracks are shown for the 5/4 gpm extraction/injection scheme, with hydraulic conductivities of 5, 15, and 100 ft/d. These all show no significant difference as regards travel times along the axes and along the near 45 degree pathways that develop when the injected water first pushes away from the extraction well, but is finally captured. Some very minor migration occurs away from the injection wells, but does not travel far in the 10-days of the pilot test. Travel times along the principal axes (direct from injection to extraction wells) are about 1.5 days, while along the longer pathways, the travel time is about 4.5 to 5 days at the lower hydraulic conductivities. At the highest K value modeled, 100 ft/d, the natural groundwater flow becomes large enough to prevent much lateral migration away from the two laterally placed injection wells, and this particle track is also captured, but may take up to about 13 days for the path to be completed. The set of three figures for each scenario includes a 10-day particle tracking, a 100-day tracking, and 1,000 or 2,000-day tracking run (to show the long-term capture pattern).

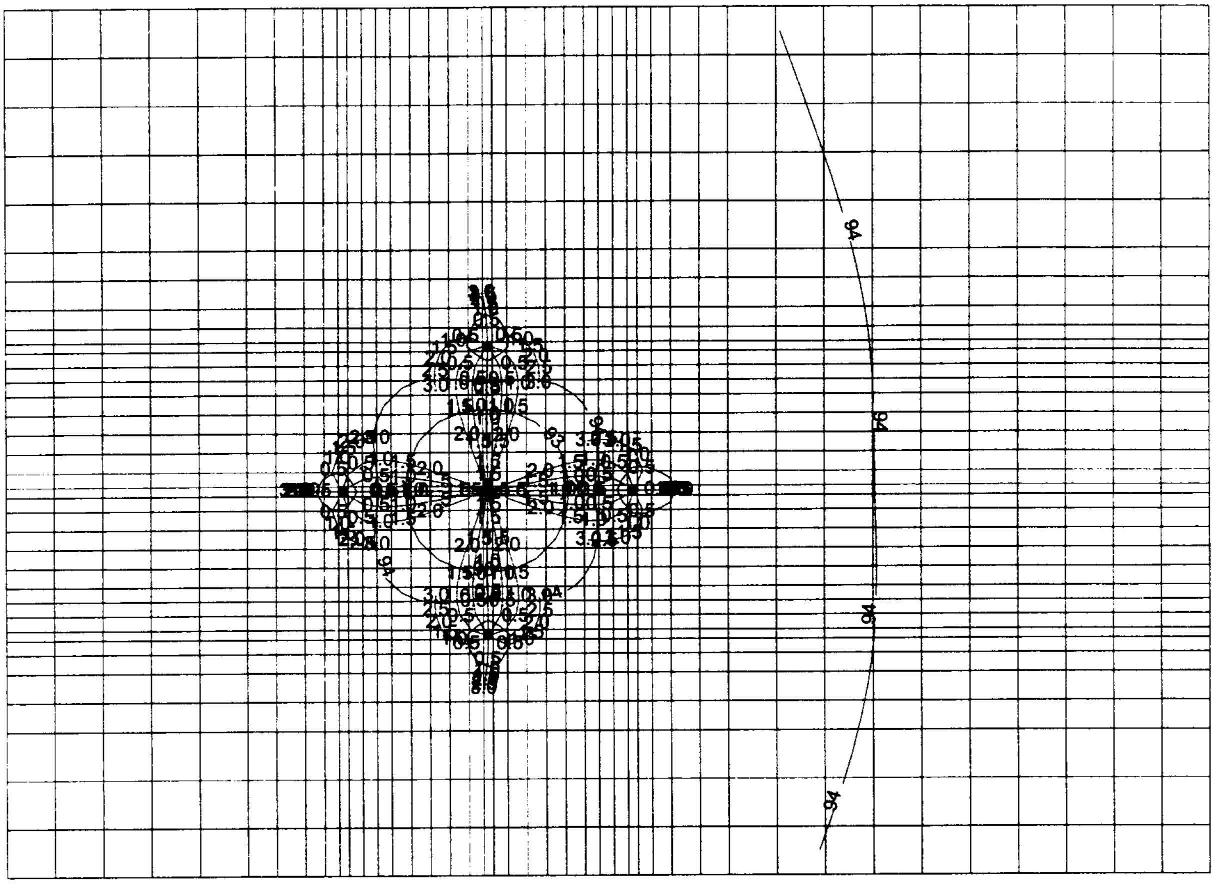
As the injected fluid contains only treatment chemical, any further migration would result in only the treatment of nearby downgradient contaminant sources before the ferrous sulfate would be oxidized by the presence of hexavalent chromium, and the iron would effectively precipitate out of solution.



Model Grid



K = 10 ft/d
Travel time = 1 d
Extraction = 5 gpm
Inj. = 4 @ 1 gpm each



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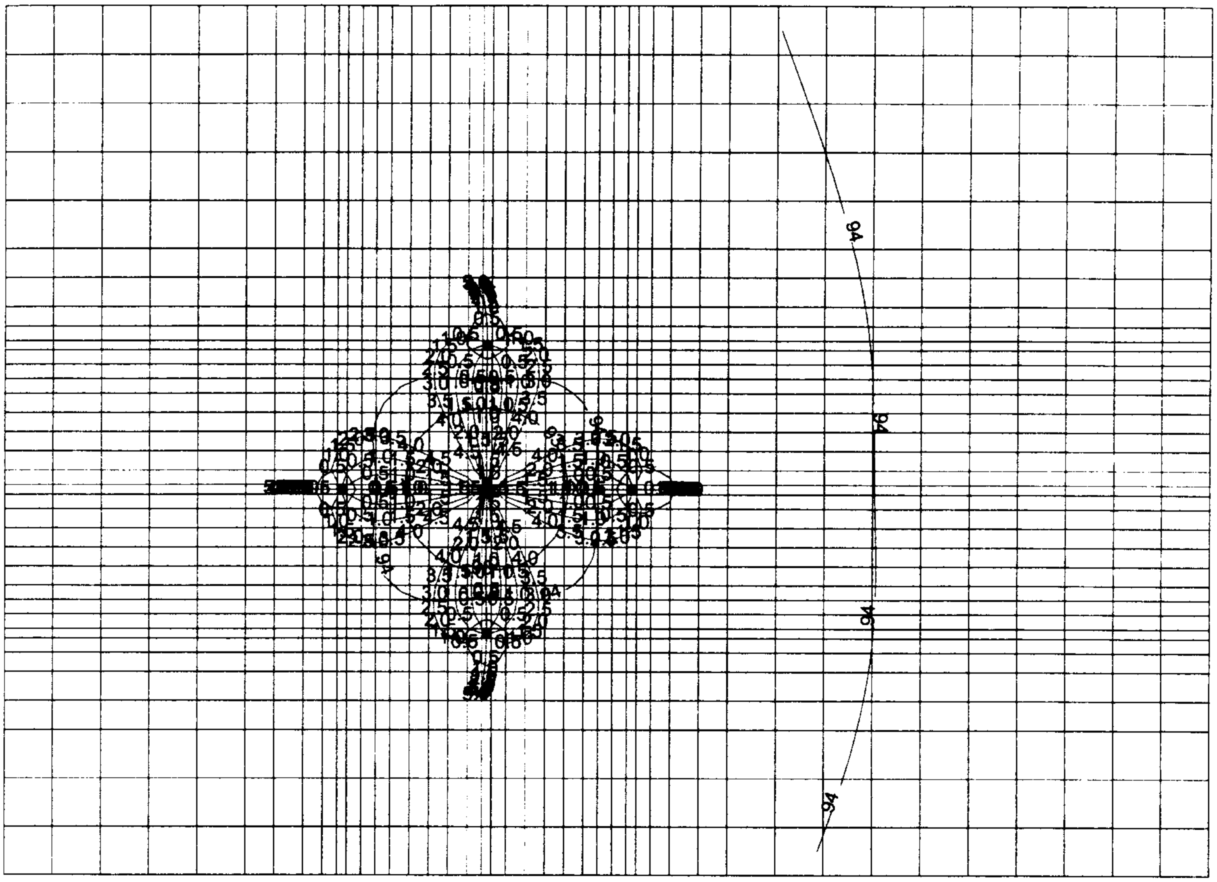
Extraction = 5 gpm
Inj. = 4@1gpm each



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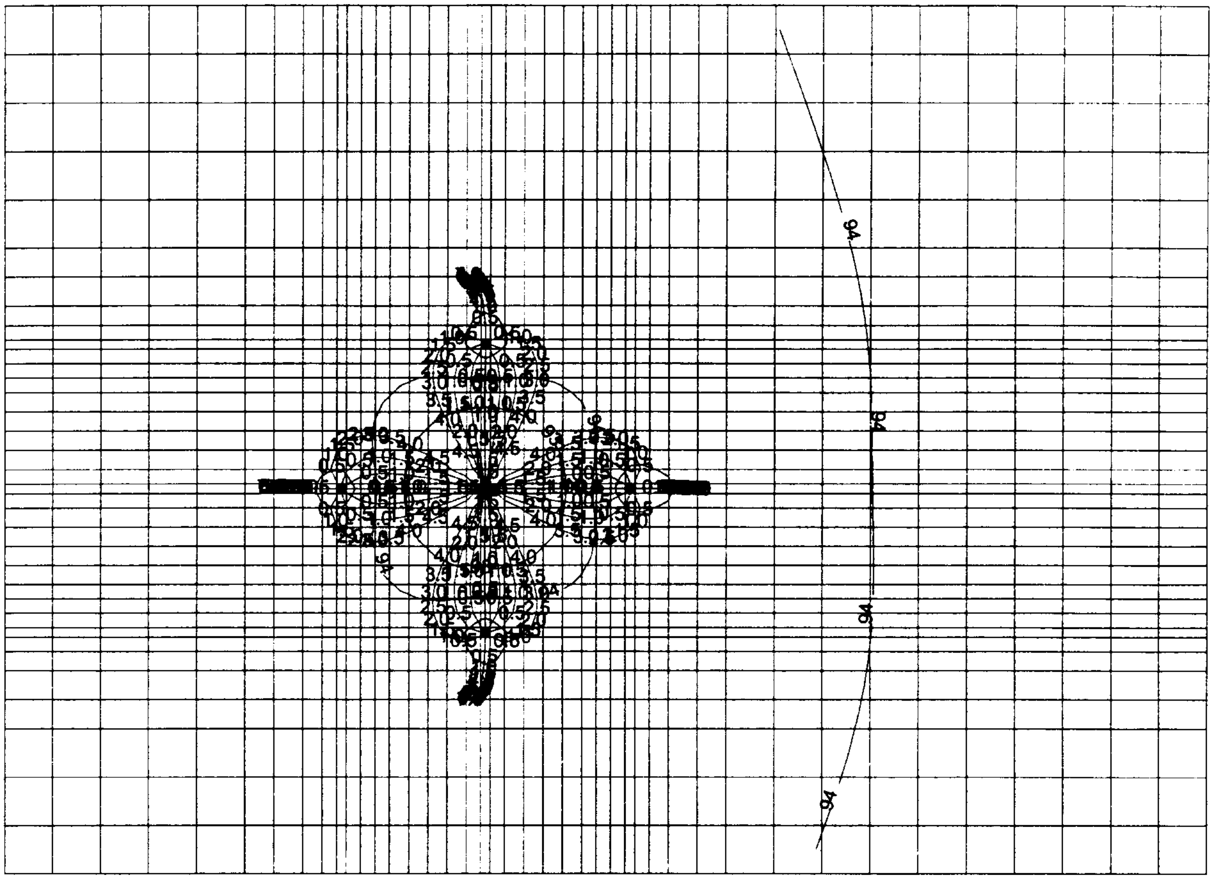
Extraction = 5 gpm
Inj. = 4 @ 1 gpm each



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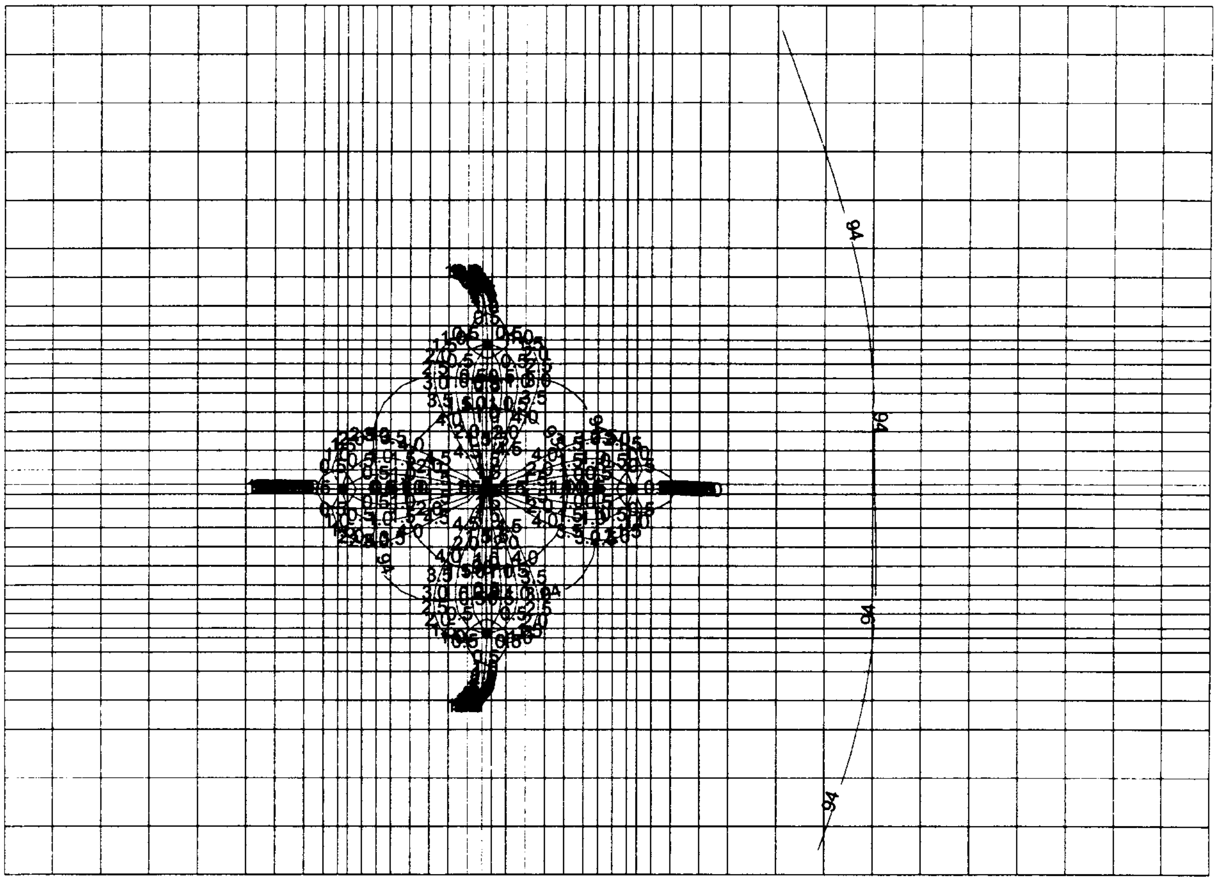
Travel time = 7d
Extraction = 5 gpm
Injection = 4@1gpm ea



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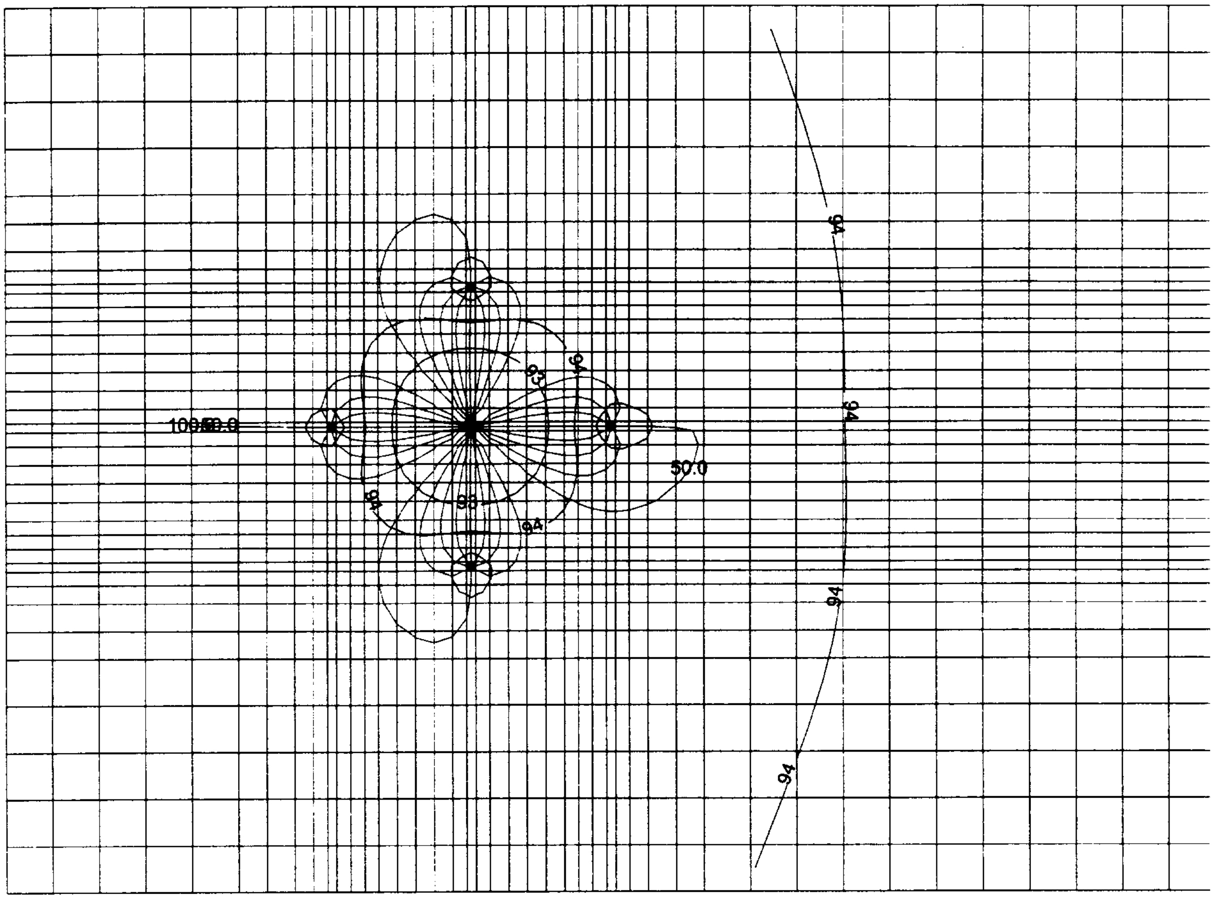
Travel time = 10 d
Extraction = 5 gpm
Inj. = 4@1 gpm each



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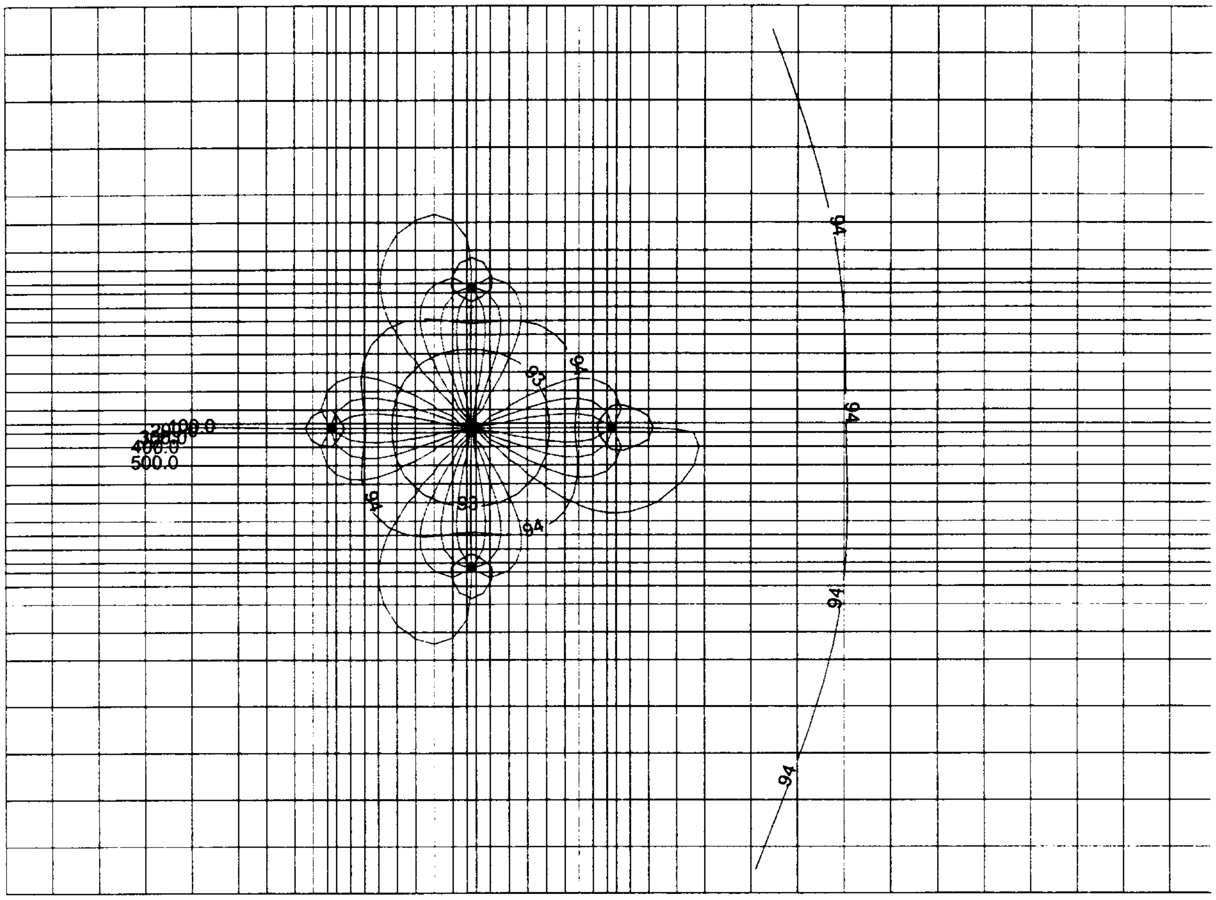
Inj. = 4 @ 1 gpm each



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Travel time = 500 d
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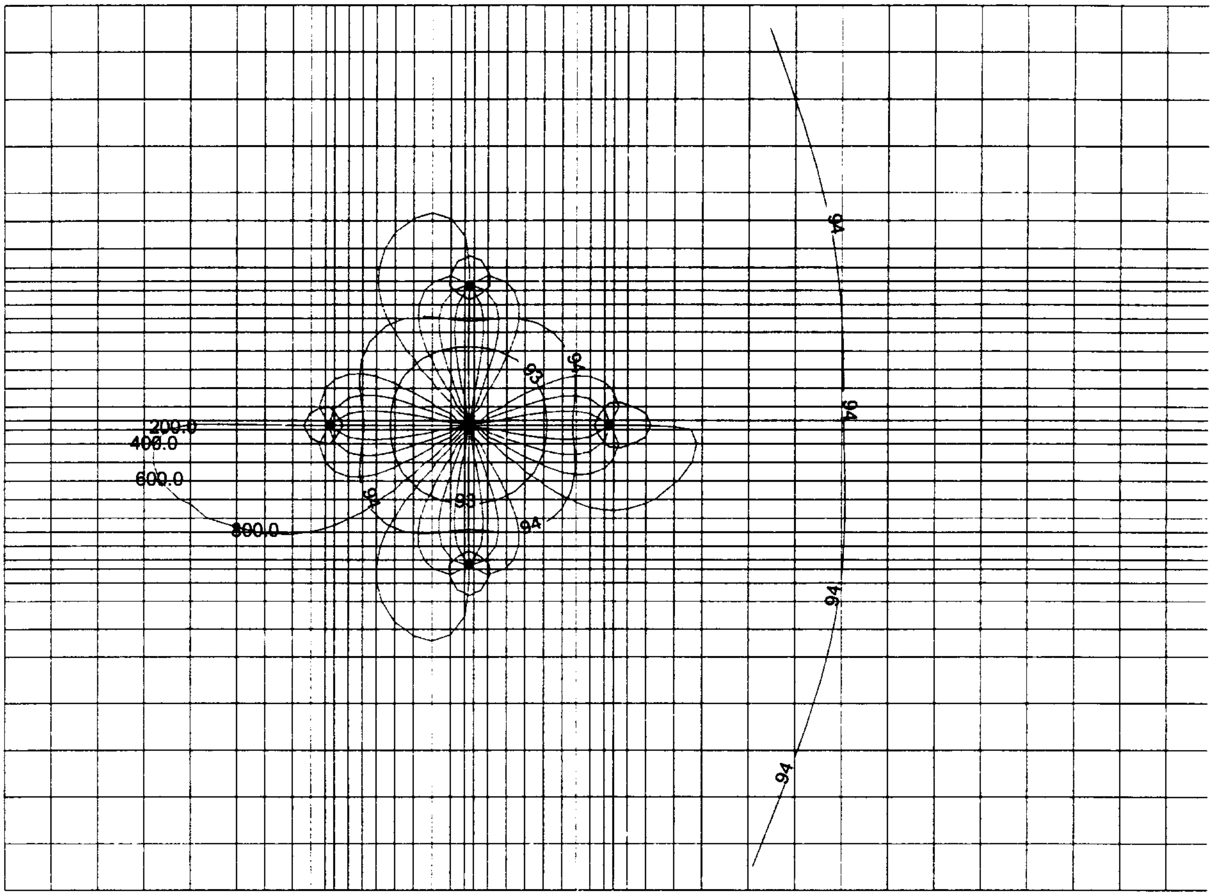

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Travel time = 1000d
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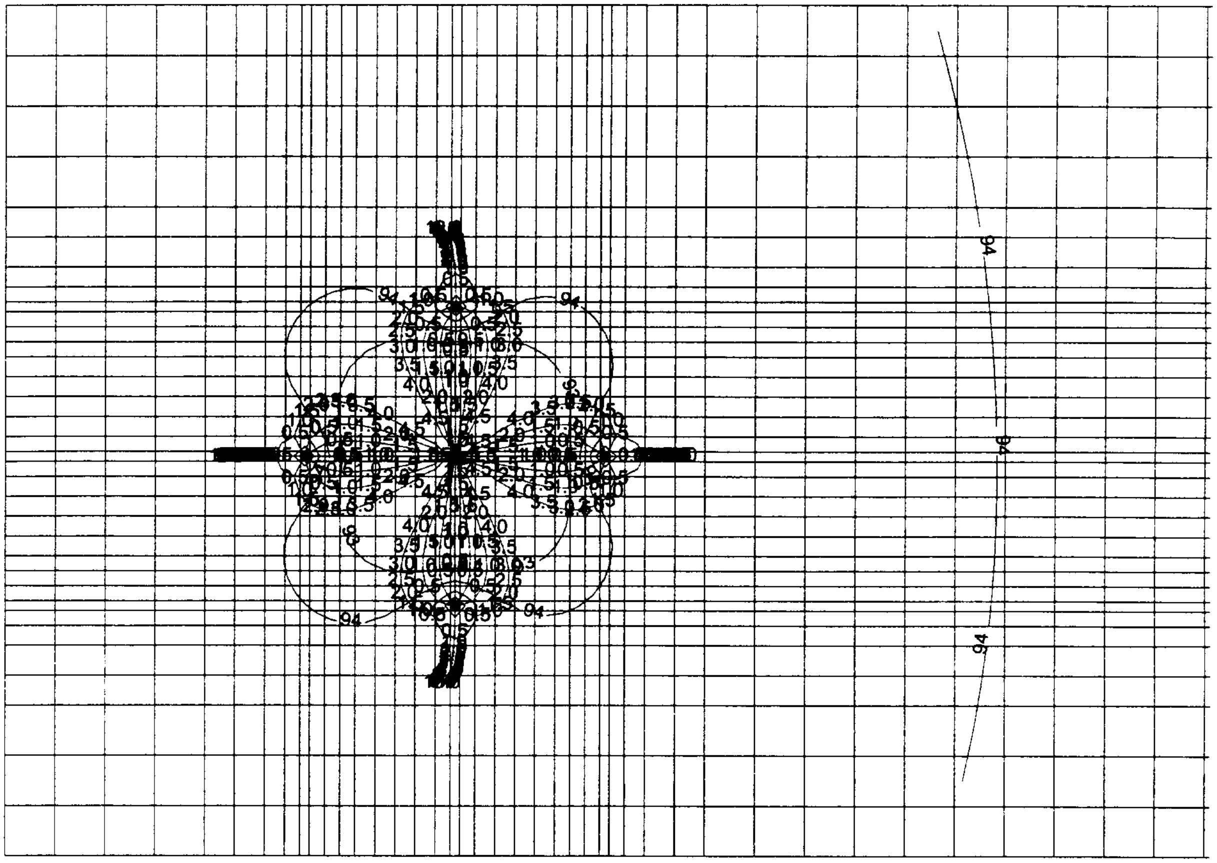
Inj. = 4 @ 1 gpm each



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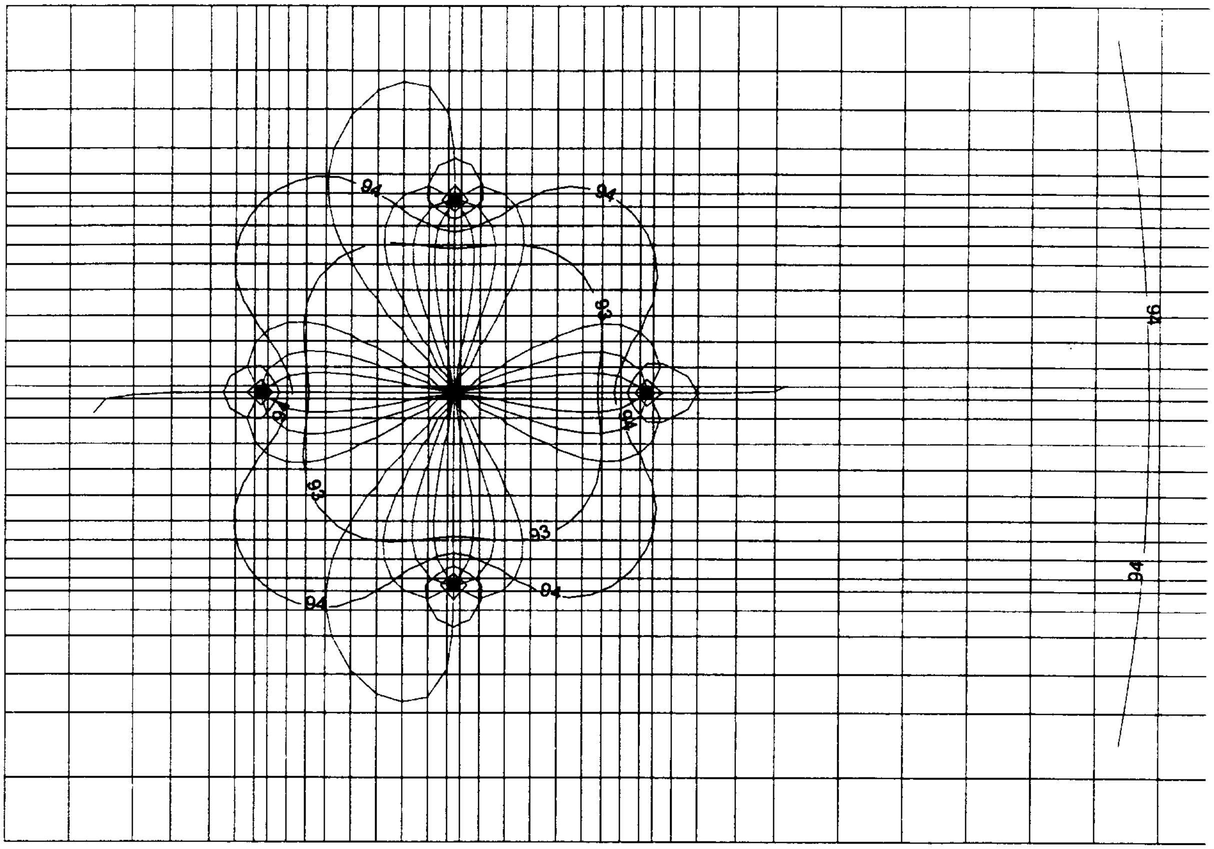

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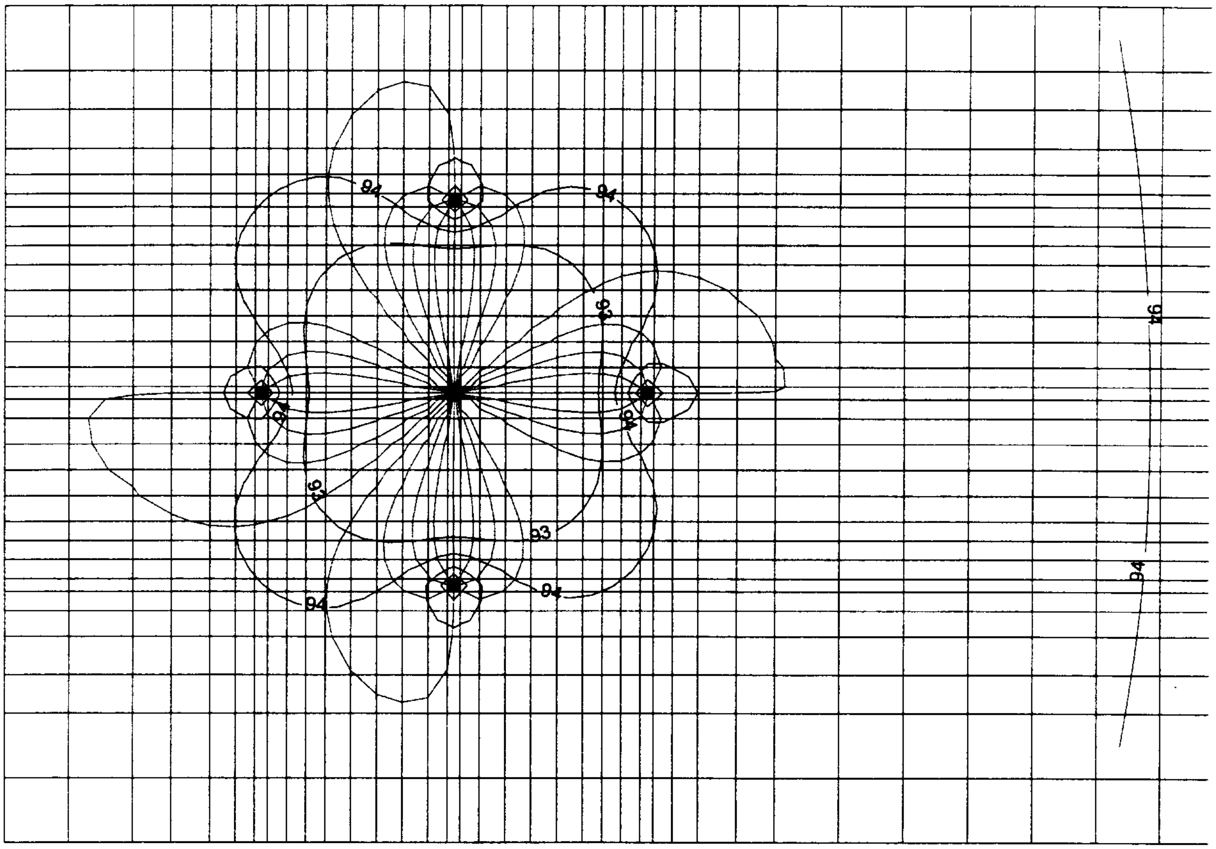

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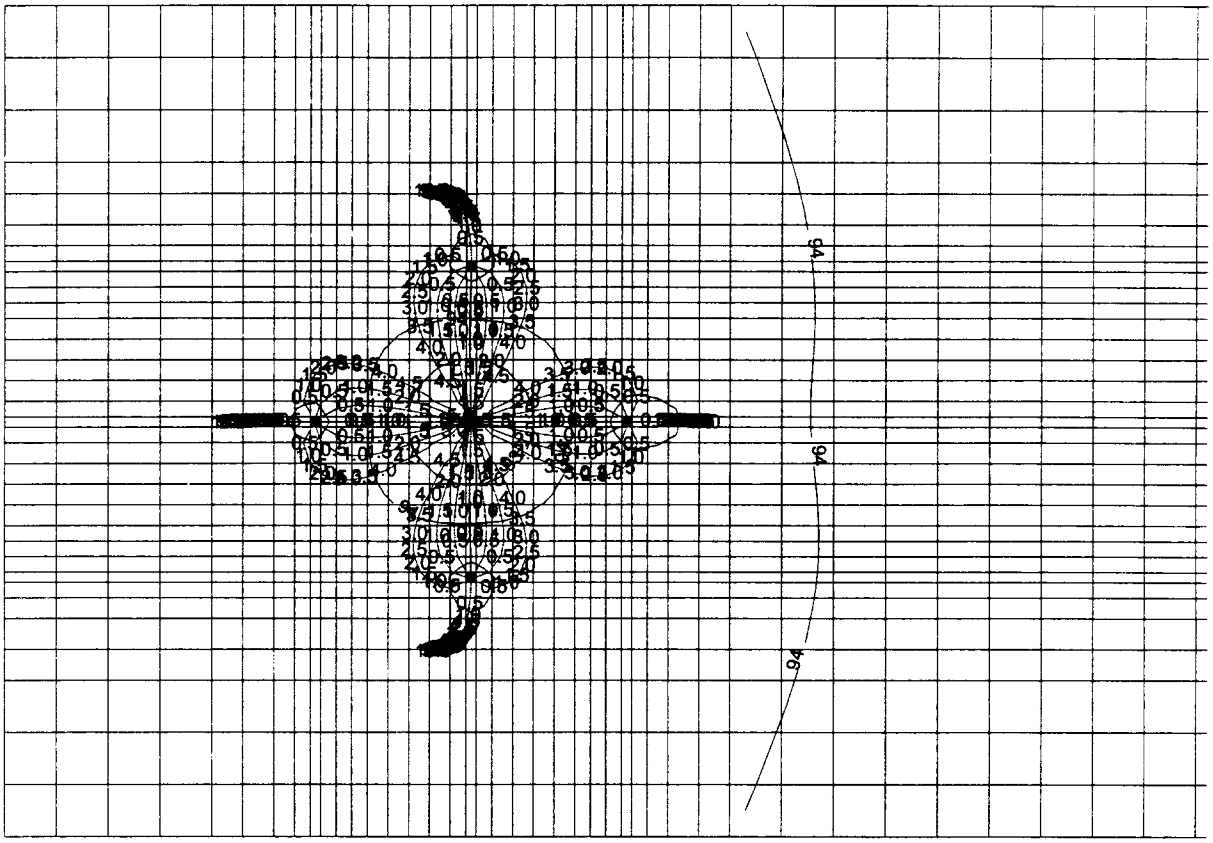
t = long (1000d)
Ext = 5gpm
Inj = 4@1gpm



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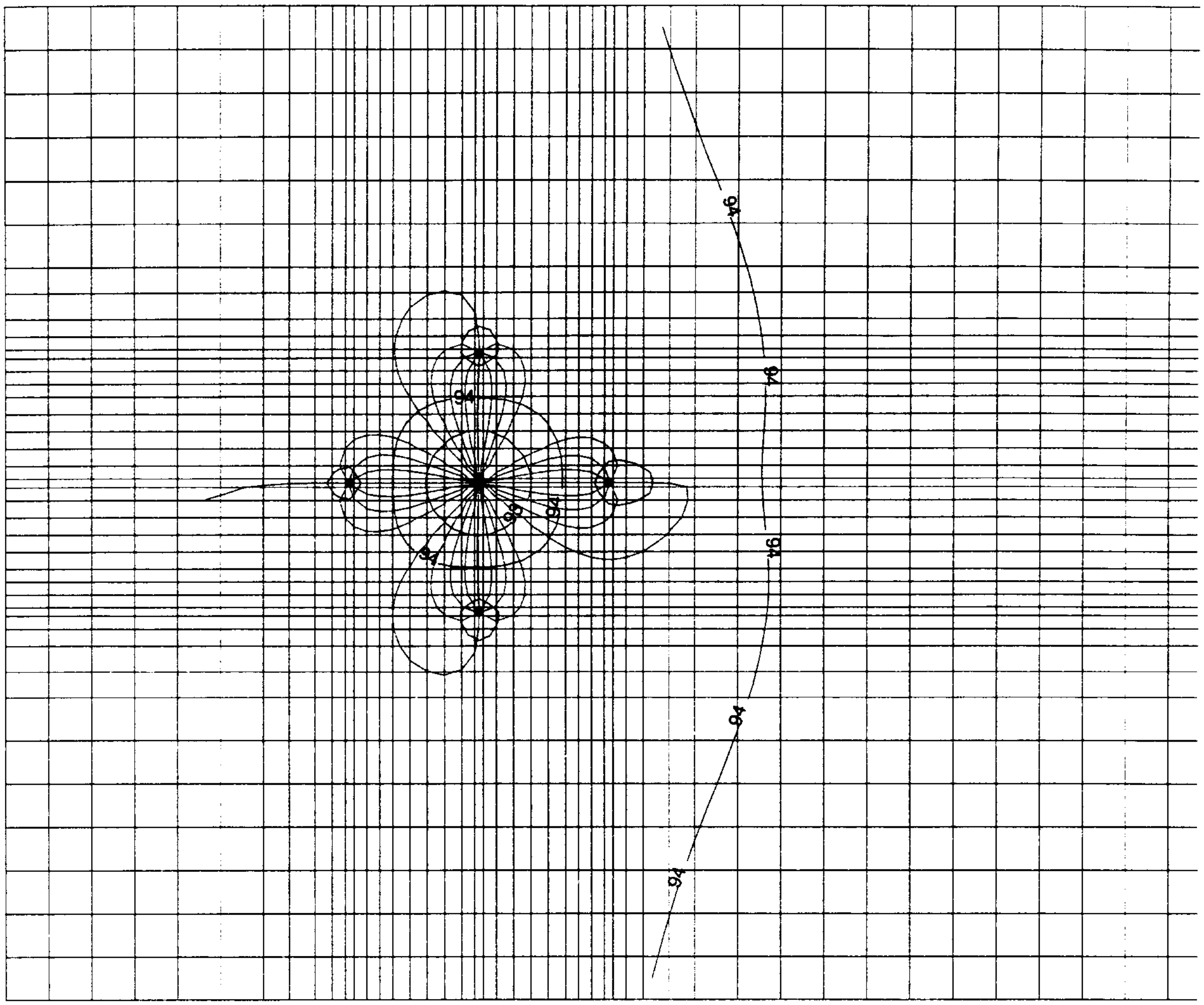
Inj = 4@ 1gpm ea



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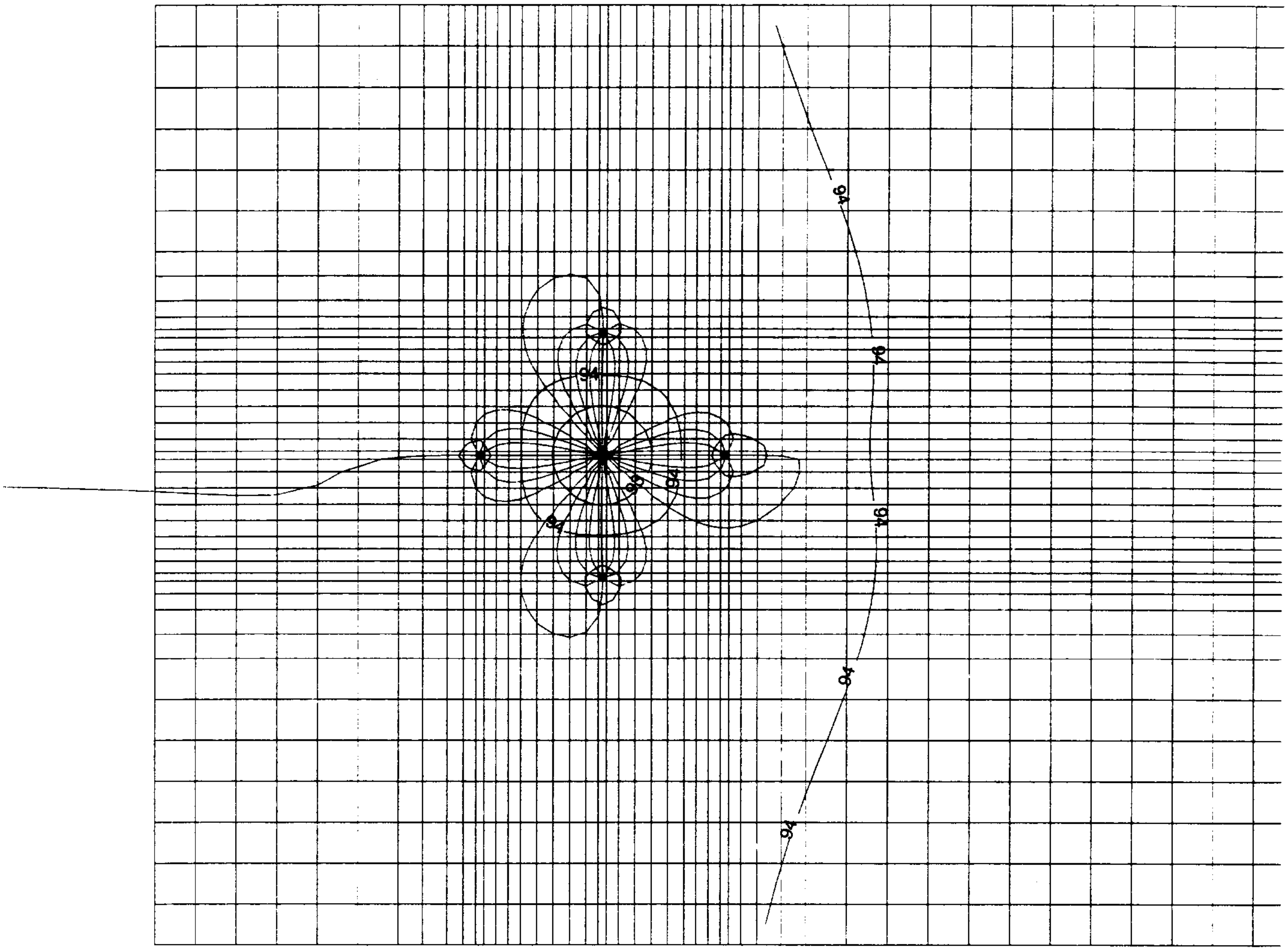
Ext. = 5 gpm
Inj = 4 @ 1 gpm

Pan 5/18



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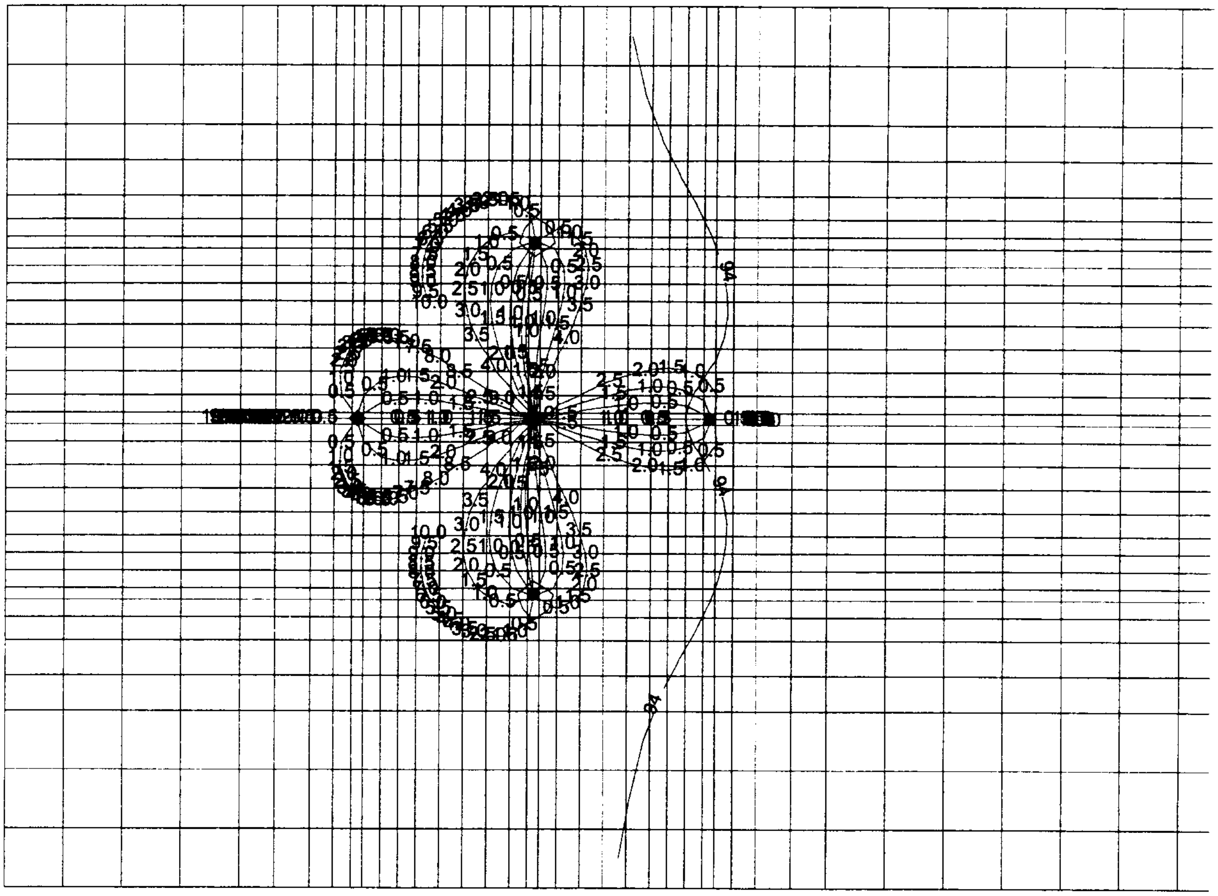
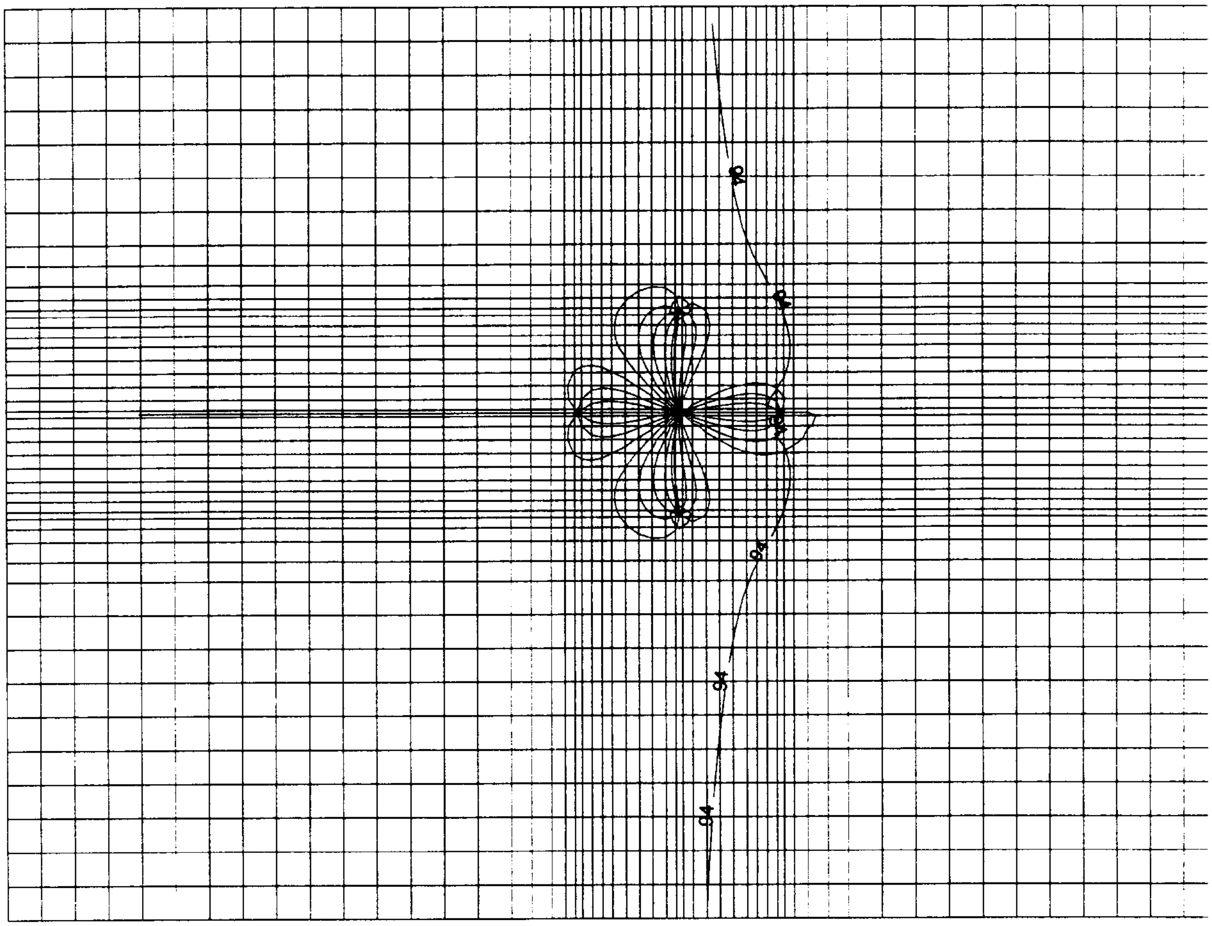
Inj = 4 @ 1 gpm

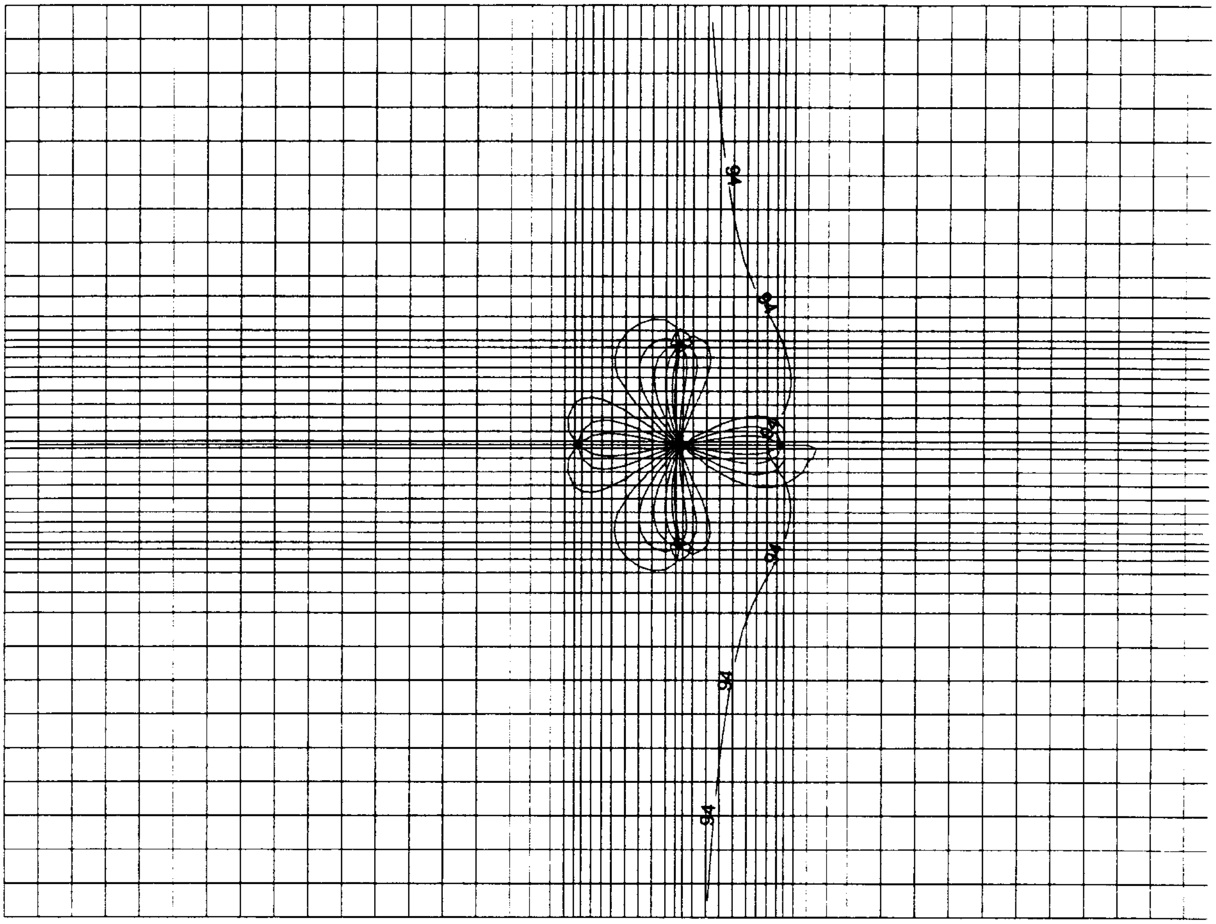


K = 100 ft/d
t = 10 days
Ext = 5 gpm
Inj = 4 @ 1 gpm ea

Figure . 8



K = 100 ft/d
t = 100 days
Ext. = 5 gpm
Inj. = 4 @ 1 gpm each



K = 100 ft/d
t = long time (1000 d)
Ext. = 5 gpm
Inj = 4 @ 1 gpm each

RESPONSE TO USEPA COMMENTS ON DRAFT PILOT TEST WORK PLAN

APPENDIX D

DRAFT PILOT-SCALE TREATABILITY STUDY WORK PLAN,
CHROMIUM AND VOC GROUNDWATER OPERABLE UNIT (OU) 2, EE/CA
STRATFORD ARMY ENGINE PLANT
SEPTEMBER 27, 1999

USEPA RESPONSE TO COMMENTS

The following are responses the United States Environmental Protection Agency's (USEPA's) October 1999 comments on the draft document entitled "Pilot-Scale Treatability Study Work Plan, Chromium and VOC Groundwater Operable Unit (OU) 2, EE/CA, Stratford Army Engine Plant". The draft document was dated September 27, 1999.

General Comments

1. **Comment:** The general concept of in situ reduction of the CR(VI) and oxidation of the TCE seems to be well conceived, and the results of the bench experiments are encouraging. The bench-top experiments clearly demonstrate the efficacy of the ferrous iron and the potassium permanganate treatments. The proposed pilot test is critical, because it will help to address questions concerning the role of transport of the reductant or oxidant to the target contaminants that were not confronted in the "batch" experiments on the bench-top. The bench-scale experiments achieve complete mixing of the reactants, while the *in situ* application requires that mixing be achieved by dispersion due to the flow along tortuous pathways within the porous soil. Without mixing, the injected fluid will simply displace the contaminated groundwater toward the extraction well, and the system will effectively be operating as a pump-and-treat approach. Only the field-scale test can answer this critical questions.

   Response: The pilot test, as designed will in part remediate through flushing. Because extracted water is not used for reinjection, contaminated water will be removed as it is replaced with injected chemicals. HLA does not anticipate extensive dispersion along the front of injected chemical as it moves toward the extraction well; however, dispersion of chemicals into less porous silt lenses, if present, will be important. Contact of chemical with NAPL, if present, is also possible. To compare remediation achieved by extraction/flushing only with remediation by oxidation/reduction, one of the lobes for injection does not include any chemical.

2. **Comment:** The bench-scale and pilot-scale tests separate the issues of remediation of CR(VI) contamination and TCE contamination. However, it appears that there are areas where both are present at high levels, particularly in the area of the historic B-2 chromium plating facility at depths of –10 to –40 feet MSL. (For example, WP-99-04 with 700 µg/L CR(VI) and WP-99-09 with 130,000 µg/L TCE are in close proximity.) Has the in situ remediation for *both* contaminants in the same domain been considered? How will the proposed treatments interact? For example, has the re-oxidation of CR(III) to CR(VI) be reaction with MnO_2 been considered? Oxidation of the TCE by potassium

permanganate leaves MnO_2 as a product (see e.g., reaction shown on p. 2-3), while manganese oxides have been shown to oxidize CR(III) (see e.g., [1], [2]).

Response: The TCE area does contain some overlap with the Cr(VI) area. The pilot test will be conducted where there is minimal overlap. The pilot test includes analyses to look for the oxidation of Cr(III) to Cr(VI) by $KMnO_4$ or MnO_2. For a full-scale remediation it may be necessary to conduct the in-situ oxidation remediation of TCE first, followed by the in-situ reduction remediation of Cr(VI) such that the entire chrome plating area is left in reducing conditions. The manganese oxides will increase the chemical demand required to achieve reducing conditions and will be considered for full-scale remediation cost estimates.

3. **Comment:** The Work Plan does not speculate on possible configurations for full-scale remedial systems, should the pilot tests support such an effort. Is it envisioned that a distribution of "five-spot" injection/extraction cells might be employed in a full-scale effort? Have issues of scaling up from the pilot tests been considered? For example, if the same configuration were to be used, but at larger dimensions, would the mixing of injectate and contaminated groundwater be the same? (For example, it is widely observed that dispersion – and hence mixing of the reactants – is scale-dependent.) Or, if a different configuration were to be employed in order to remediate larger areas, would inferences from the pilot test carry over directly to the new geometry? (The degree of mixing of injectate and contaminated groundwater might be expected to be rather sensitive to the configuration.)

   Response: Dispersion of injected chemical with groundwater will not be a primary objective of full-scale remediation except to achieve delivery of some chemicals to the lower permeability silt layers. The primary objective of the chemical injection will be to deliver chemical to the pore space where it can contact contaminants sorbed to the soil, or NAPLs, if present. Evaluation of full-scale injection/extraction well configurations will be completed prior to installation by groundwater modeling of the areas.

   To maximize the in-situ aspect of these remediation technologies the use of extracted water for chemical makeup and reinjection will be considered as it reduces the removal by pump-and-treat. However, approval for reinjection of water that exceeds CTDEP RSR regulatory criteria may be difficult or impossible to obtain. Injection well fouling is also a concern for reusing extracted water.

4. **Comment:** The experimental design appears to be flawed to the extent that evaluation of the effects of different solution concentrations cannot be determined based on our understanding of the description of the experiment in Section 3.2.1. With four test lobes in each treatment area, each receiving a different solution concentration, the experiment must be capable of determining the change in the mass of hexavalent chromium in each lobe. It is not clear from the experimental design how this would be done. The description of the experiment in Section 3.2.1 appears to refer to the entire test area rather than each test lobe. The work plan should better explain the proposed work or correct the apparent deficiencies in the experimental design.

Response: HLA reviewed the experimental design including the issue of the limitation on completing a mass balance given the mixed effluent from the extraction well. Possible remedies to that issue were identified which included soil and groundwater sampling within the treatment lobes. However, to effectively complete a mass balance, the number of soil sampling locations in each lobe would have to be statistically based in order to overcome heterogeneity in the soil contamination within each lobe. Such a statistically based sampling program would be much more extensive and costly.

Alternatively, HLA considered a different approach to evaluating the effectiveness of the pilot tests in which the absence of rebounding groundwater concentrations will be the critical measure of success. This approach is consistent with the ultimate remediation objective of meeting CTDEP RSRs in groundwater. Ongoing groundwater monitoring for six months following the test was added to the pilot test program to provide a longer term evaluation of the potential of rebounding groundwater concentrations.

5. **Comment:** The experimental design encompasses, in a sense, four experiments conducted simultaneously at each area (i.e., the hexavalent chromium test area and the TCE test area). Because of an interest in looking at the response to different concentrations of reactants in the injectate, the design proposes to introduce a different concentration at each injection well (see p. 3-2, sec. 3.2.1 and p. 3-4, sec. 3.3.1), so that a different experiment is done within each of the four "lobes" of the flow field. While this is a clever design that addresses an important independent variable within a single experimental run, the price paid is that the analytical results obtained from the extraction well may become somewhat ambiguous. That is, the chemistry observed at the midpoint piezometers along each of the four direct pathways from injection to extraction clearly reflects processes along those paths, while the chemistry at the central well results from a combination of the processes within the four lobes, each of which is different. Detailed numerical transport modeling of the experimental configuration may prove to be valuable in interpreting the results, particularly those from the central well, and should be considered as an integral part of the pilot test.

   Response: The experimental design focuses on reducing groundwater contamination levels to below CTDEP RSRs criteria and preventing of rebounding groundwater concentrations. Groundwater modeling using particle tracking was used during the experimental design. Monitoring of piezometers and wells during the test will enable evaluation of movement of the chemical front through the treatment zones and comparison of actual results to groundwater modeling predictions.

6. **Comment:** As design concepts for remediation of the dissolved TCE plume move forward, the likelihood of the presence of DNAPL at the site should not be neglected. With concentrations in the plume approaching the aqueous solubility limit, there is a strong indication that free-phase DNAPL may be present. In the long term, this could replenish a dissolved-phase plume after an elaborate and costly effort to remove the dissolved phase has been completed. An aggressive DNAPL investigation should be considered in parallel with the effort to remediate the known plume.

Response: Groundwater investigations completed previously have failed to identify the presence of DNAPLs. Despite this finding, HLA agrees that there is a potential of residual pure product in the soil given the concentrations detected in groundwater. It is the intent of the pilot test to deliver enough chemical to remediate both dissolved TCE and sorbed or residual TCE in the soil; however, delivery of chemicals to silt lenses and mass transfer may be limiting factors for treatment of non-dissolved TCE. A primary focus of the experiment will be to look for rebounding groundwater concentrations following the test which will indicate dissolution of TCE from these potential NAPLs.

7. **Comment:** A better summary description of the groundwater plumes (hexavalent chromium and VOCs) is required to properly evaluate this work plan. While this information is probably available in other documents for the site, this work plan needs to provide enough information to allow it to be evaluated on its own. Only Appendix C contains information about the vertical extent of the plumes and that the greatest contaminant concentrations are found at approximately 30 to 35 feet below ground surface. Also, the depth to groundwater is not presented in the work plan text, but is only found in Appendix C. The work plan should include this information in an appropriate location in the work plan, not just in Appendix C.

   Response: Section 1 of the Work Plan has been revised to include a more complete summary description of the site conditions. A new subsection, entitled "Existing Site Conditions" has been added to the Work Plan and includes a summary of contaminant distributions and the site conceptual model. Figures will also be added to clarify the locations and depths of site contaminants in the area of the Former Chromium Plating Facility.

8. **Comment:** Several times in the work plan (page 3-1 and Appendix C, for example) it is stated that a recirculating well system will be created to execute this pilot test of the in situ technologies. However, Figure 11 appears to show that all extracted groundwater will be pretreated then discharged to the CWTP sewer. Please clarify the meaning of the references to a recirculating system, which would suggest that a portion of the extracted groundwater would be returned through the injection wells, or delete the references.

   Response: The system does not recirculate water. References to recirculation have been changed.

<u>**Specific Comments**</u>

1. **Comment: Page iii.** The title of Figure 9 does not match the title on Figure 9 in Appendix A. Please correct the title in the List of Figures.

   Response: The title in the List of Figures will be changed to, "Proposed Pilot Test Layouts."

2. **Comment: Page 1-4, § 1.2.3.** Please include the depth range from which the groundwater samples were collected for the fourth and fifth bullets.

   In the sixth bullet, were there parameters monitored for all 189 of the samples mentioned in the fourth and fifth bullets? Please clarify.

   Response: The groundwater samples identified in the fourth bullet were collected from depths of 7 to 9 feet bgs (the approximate depth of the groundwater table). These depths have been added to this bullet.

   The 182 samples referenced in the fifth bullet were collected from discreet 4-foot intervals at depths ranging from the groundwater table (approximately 7 feet bgs) to 71 feet bgs. These depths have been added to this bullet.

   The text in the sixth bullet has been revised to read, "...for each of the above mentioned 182 groundwater samples."

3. **Comment: Page 1-5, § 1.2.3.** The second half of the first sentence in the last paragraph for this section mentions "… detectable chromium at depths …" Does this refer to hexavalent chromium or total chromium? Please clarify the text.

   Response: The text has been revised to read, "…detectable hexavalent chromium at depths…".

4. **Comment: Page 1-5, § 1.2.4.** In the first bullet in this section, please add the depth range from which the samples were collected.

   Response: The 126 samples referenced in this bullet were collected from discreet 4-foot intervals at depths ranging from the groundwater table (approximately 6 feet bgs) to 82 feet bgs. The text in this bullet has been revised accordingly.

5. **Comment: Page 1-7, § 1.2.5, ¶ 6.** The bench-scale experiments demonstrated that the TCA was not readily oxidized by the reagents tested. Has further consideration been given to the possibility of in situ treatment of the TCA? If so, what are the alternative additives? If not, what alternative remedial schemes (e.g., pump and treat, etc.) might be considered?

   Response: Additional additives would not likely improve the oxidation of TCA. The following sentence has been added after the second sentence of the paragraph, "Alternative technologies such as air sparging and six-phase heating will be considered for the TCA area."

6. **Comment: Page 1-7, § 1.2.5, ¶ 6.** The text notes that the bench-scale experiments showed that the pH had to be kept low in order to prevent "excessive" precipitation of trivalent chromium and ferric iron. Is this simply a qualitative judgement? Were criteria

established for the mass of precipitates that would likely lead to problematic plugging of the porous medium (assuming that this is the concern)? If so, what are they?

Response: The acceptable mass of precipitants is a qualitative judgement. The largest concern is that there be no particles in the injection water, as this will lead to plugging of the well. As the chemical moves out, and the oxidation-reduction reaction between Cr(VI) and Fe(II) occurs, Cr(III) and Fe(III) are expected to precipitate out. As long as the pH is maintained low enough such that excessive precipitation immediately around the well does not occur, plugging of the porous medium is not expected to be a problem.

7. **Comment: Page 2-2, § 2.2.1.** The last sentence in the second to last paragraph refers to a final round of groundwater sampling conducted one week after system shutdown. However, Figure 12 and Table 4 state that two rounds of sampling will occur one and two weeks after shutdown. Clarify this discrepancy.

   Response: Groundwater samples will be collected and analyzed one week after the pilot test, one month after the pilot test, and every month thereafter for five additional months. The text, figures, and tables have been revised accordingly.

8. **Comment: Page 2-5, § 2.5.2.** Are there relevant CTDEP RSR criteria for soil that could be evaluated for this pilot test? Please add if appropriate.

   Response: CTDEP RSR criteria do not apply to soil below the water table.

9. **Comment: Page 3-1, § 3.1.** In the first paragraph, include the depth at which the screens will be set.

   Response: The text has been revised to indicate that the screens will be set from 27 feet below ground surface to 37 feet below ground surface (10-foot screen lengths). The ground surface is essentially level in the pilot test area.

10. **Comment: Page 3-2, § 3.2.1.** Based on the ferrous sulfate dosing rate described in this section, the accuracy of the third sentence in the first paragraph is questionable. It appears that only two lobes will have enough ferrous sulfate to treat the estimated mass in their respective lobe. Provide additional information to support the information presented.

    Response: The ferrous sulfate dose will be based on the total estimated mass of contamination in the lobe including soil and groundwater. Because a portion of the mass will be removed by flushing to the extraction well prior to reaction with ferrous sulfate, the lower ferrous sulfate dose may be capable of treating the residual contamination. It is also possible that the observed optimum dose of ferrous sulfate from the bench-scale test is greater than necessary in situ.

11. **Comment: Page 3-2, § 3.2.1.** Please clarify the meaning of the last sentence in the first paragraph. It appears that the sentence is saying that the injected solution will have a pH

of 2.5, but could be read that a pH of 2.5 is the goal for the groundwater in the test lobe. If, as discussed in Section 2.2.1, the goal is to achieve a pH of less than 4 in the groundwater in the test lobe, how was it determined that a pH of 2.5 in the injection solution would achieve this? If a pH of 2.5 is in fact the goal for the groundwater in the test lobe, how was the necessary amount of chemical to achieve this determined? Was this calculated using the dilution rate for the injected solution and the buffering capacity of the groundwater? Please explain and clarify.

Response: The goal of pH reduction is to avoid fouling of the injection wells and the porous medium immediately surrounding the injection wells. A pH of 2.5 in the test lobe is not the object. The actual pH of the injection solution may vary from 2.5 as necessary to avoid fouling and acid requirements will change from the bench-scale tests due to the use of potable water for the injection water source. The sentence has been revised as follows, "...adjusted to a pH of approximately 2.5 using sulfuric acid to prevent injection well plugging."

12. **Comment: Page 3-2, § 3.2.1.** Where would the soil samples, referred to in the first sentence of the third paragraph, be collected? Are such samples proposed for each lobe of each test area? Note that Tables 4 and 6 do not account for the referenced soil samples. Please provide information to address these issues.

    Response: Soil samples will be collected only during installation of wells and piezometers. Monitoring for groundwater concentration rebound will be the primary method for evaluating the potential for residual soil contamination that redissolves into the groundwater. The text has been revised to reference only groundwater samples.

13. **Comment: Page 3-3, § 3.2.1.** The first sentence on page 3-3 states that the concentration of hexavalent chromium will be monitored at the perimeter (of the treatment area). However, Table 4 shows that all wells and piezometers will be sampled on installation. Will the concentrations at the perimeter only be used to characterize the hexavalent chromium concentration of all water that flows into the test area over the course of the experiment? Will there be any differentiation made for each test lobe? Provide clarifying information.

    The second sentence states that $CR(VI)_{OUT}$ will be estimated using the concentration of hexavalent chromium sent to the industrial wastewater treatment plant and the net flow rate of one gpm to the plant. Since this does not appear to be a recirculating system (see previous comments), the average flow rate to the treatment plant will be approximately five gpm not one gpm. Also, it is not clear where samples would be collected to determine the concentration of hexavalent chromium in extracted groundwater. Because the concentration of hexavalent chromium in the extraction well discharge is expected to vary over time it would not be appropriate to collect grab samples from the discharge line. Also, it would not be appropriate to collect samples after the carbon adsorption units because some removal of metals through the carbon would be expected. It appears that a frac tank and pump is required upstream of the carbon adsorption units so that a sample from each filled frac tank can be collected and analyzed for hexavalent chromium to characterize that entire volume. Using the concentration and volume of the frac tank contents, the mass of hexavalent chromium can be calculated. Provide information to better describe how $Cr(VI)_{OUT}$ will be determined.

Please indicate which wells, piezometers, or other sample locations will be used to perform the mass balance analysis for each of the treatment lobes so the effectiveness of the various solution concentrations can be evaluated.

The work plan would benefit from the inclusion of sample calculations to clarify how the various mass terms in the mass balance would be calculated.

Response: The mass balance approach to the experimental design has been removed from the work plan and replace with an approach based on monitoring for rebounding groundwater concentrations. See response to General Comment 4.

14. **Comment: Page 3-2, § 3.2.1, ¶ 1.** It was noted in the bench-scale experiments that twice the stoichiometric ratio of ferrous sulfate to chromate was required to reduce the Cr(VI). How is this result interpreted, and how might that interpretation relate to the pilot- or full-scale attempt to reduce Cr(VI) in situ? Is the excess ferrous sulfate being oxidized by something else? This may be significant because of the concern for plugging of the porous medium by iron oxide, and the desire to introduce the minimum mass of iron. Could dissolved oxygen (DO) in the groundwater have contributed significantly to the oxidation of the ferrous sulfate (see, e.g., [3])? Was DO in the agitated samples in the bench experiment comparable to that in *in situ* groundwater? One reason to be concerned is that this excess iron oxide may contribute to potential clogging of the porous medium, and it is desirable to minimize this impact. It is noted that DO measurements will be acquired in the course of sampling (e.g., Table 7-8); particular care should be taken with these data, as they are important, yet it is difficult to obtain reliable analyses of DO from field instruments.

    Response: The higher than required dosages required in the bench-scale tests could be a result of oxidation of ferrous sulfate by oxygen. Bench-scale tests were agitated aggressively to mix the ferrous sulfate with the water and soil mixture. It is likely that some ferrous sulfate was oxidized by oxygen from the air that was introduced during the tests.

15. **Comment: Page 3-2, § 3.2.1, ¶ 1.** The proposed experiment for reduction of CR(VI) will use sulfuric acid "… to achieve a pH of approximately 2.5 …" Is the intent to keep the solution pH at 2.5 over the entire path from injection to extraction? Has dilution by ambient water been considered in determining the target pH of the injectate? Is it possible that the mass of added sulfate (as both ferrous sulfate and sulfuric acid) in the injection solution will result in the precipitation of solid phases containing CR(VI), in the presence of other groundwater ions (e.g., $Ca(Cr,S)O_4 2H_2O$)?

    Response: The intent of pH reduction is to prevent injection well plugging. Cr(VI) is a highly soluble species. It is not expected that any chrome sulfate species would precipitate in the presence of high sulfate concentrations. Sulfur compounds are frequently used in industrial waste treatment systems for reduction of Cr(VI), but are precipitated as hydroxides.

16. **Comment: Page 3-3, § 3.2.1, ¶ 2.** The text states that piezometers will be placed at locations corresponding to "… travel times from the injection well to the extraction well of 1.0, 1.5, and 2.0 days." Should this read "… from the injection well to the piezometer?" How are these predicted travel times reconciled with the prediction (e.g., Appendix C) that the travel time from injection well to extraction well is now 1.5 days? The travel times to the piezometers must be less than that to the extraction well.

    Response: The sentence has been changed to read, "...from the injection well to the piezometer." The travel time from the injection well to the extraction well on a direct line path is predicted to be 1.875 days (about 2 days) from the particle tracking described in Appendix C. Chemicals travelling along the outer limit of each lobe will take approximately 5 days to reach the extraction well. PZ-99-02 and PZ-99-05 are positioned along a longer flow path, approximately 2 days travel time from the injection well.

17 **Comment: Page 3-3, §3.2.2.** The text does not specify whether the groundwater samples are to be filtered or unfiltered. Please clarify and provide the rationale.

Response: The samples will be unfiltered. Hexavalent chromium and ferrous iron, the two inorganics of concern are predominantly present as dissolved species. Differentiation between dissolved and particulate Cr(III) is not necessary.

18. **Comment: Page 3-4, §3.3.1, ¶ 2.** The proposed experiment for oxidation of TCE will employ a solution "… adjusted to achieve a pH of less than 5.0." What will be used to make this pH adjustment? Is the intent to keep the solution pH below 5.0 over the entire path from injection to extraction? Has dilution by ambient water been considered in determining the target pH of the injectate?

    Response: Sulfuric acid will be used for pH adjustment. The intent is to prevent plugging of the injection wells. The sentence has been clarified.

19. **Comment: Page 3-4, § 3.3.1.** Based on the potassium permanganate dosing rate described in this section, the accuracy of the last sentence in this first paragraph is questionable. Although the dosing rate from the bench-scale testing was not referenced here, it is presumed to be 1.5 moles of potassium permanganate per mole of TCE. Therefore, only two lobes will have enough potassium permanganate to treat the estimated mass in their respective lobe. Please delete or rewrite this sentence.

    Response: See response to comment 10 for ferrous sulfate, similar rationale applies for the TCE areas.

20. **Page 3-4, § 3.3.1.** Please clarify the meaning of the last sentence in the second paragraph. It appears that the sentence is saying that the injected solution will have a pH of 5.0, but could be read that a pH of 5.0 is the goal for the groundwater in the test lobe.

    How was it determined that a pH of 5.0 in the injection solution is appropriate? If a pH of 5.0 is in fact the goal for the groundwater in the test lobe, how was the necessary amount of chemical to achieve this determined? Was this calculated using the dilution rate for the injected solution and the buffering capacity of the groundwater? Provide clarifying information.

    Response: The pH of 5.0 is to avoid plugging of the well. This has been clarified in the text.

21. **Comment: Page 3-4, § 3.3.1.** All the comments on page 3-3 of Section 3.2.1 also pertain to this section. However, if a frac tank is used upstream of the carbon adsorption units, the mass balance will need to account for (or ignore with justification) TCE that volatilizes into the air space above the liquid collected in the tank.

    Response: Samples will be collected before the carbon units and frac tank. A mass balance calculation will not be performed.

22. **Comment: Page 3-4, § 3.3.3 and Table 7.** Manganese should be added to the analyte list for the TCE experiment. This will allow an internal check on the fate of the oxidant as it reacts with the TCE. Also, the addition of large quantities of manganese to the groundwater may pose a risk to downgradient receptors. This may need to be assess if full-scale remediation by this method is implemented, so that a full understanding of the fate and transport of manganese will be essential.

    Response: Manganese measurements will be added to the test. Manganese tests will be for total manganese using HACH™ type field test kits with off-site lab QA samples. The manganese oxidation state will not be determined.

23. **Comment: Page 4-1, § 4.2.** The third sentence in the second paragraph refers to the monitoring of piezometers located outside the test areas; however, Table 4 and 6 do not appear to include such piezometers and the titles of the tables suggest that only piezometers in the test areas are included in these tables. Please clarify what is intended by this sentence and provide an appropriate table.

    Response: The sentence has been changed to read, "Water level data from piezometers located inside the test areas will be used to evaluate the hydraulic control achieved by the pumping system.

24. **Comment: Figure 1.** This figure references the Installation Restoration Program at the Massachusetts Military Reservation in the title block. Please correct the reference.

    Response: The Reference has been corrected.

25. **Comment: Figure 2.** Notes 1 and 3 are not pertinent to this figure. Please delete them.

Response: The notes have been deleted.

26. **Comment: Figure 8.** Will it be necessary to avoid the drain lines that cross each of the test areas when installing wells and piezometers?

The wall along the southwestern edge of the hexavalent chromium test area may make it difficult to install the injection well at the proposed location. Please review and revise the work plan as necessary.

Response: It will be necessary to avoid the drain lines during installation. The injection well will be located as close as possible to the location shown on the figure. The indicated locations of the test areas may be adjusted slightly in the field to accommodate utilities and structures.

27. **Comment: Figure 9.** Are the existing piezometers screened at the required elevation for the pilot test? The required elevation is 27 to 37 feet below ground surface according to Appendix C.

Response: These piezometers are nested with three screened intervals which allow the assessment of vertical affects during the test (not anticipated) as well as the desired test interval. The shallow screen in each existing piezometer is located from 4 to 9 feet bgs; the intermediate screen from 30 to 35 feet bgs; and the deep screen from 45 to 50 feet bgs. The zone of the proposed pilot tests and the screen intervals of the new and existing wells have been added to the text in Section 2 for clarification.

28. **Comment: Figure 10.** Does the backflow preventer meet the stated design criteria for the proposed use?

This figure shows, and the bill of material confirms, that the discharge line from each metering pump will split to dose two injection wells from each metering pump. Control of the chemical flow in this configuration may prove difficult. Each discharge line will need to be calibrated properly. Chemical injection valves installed at the end of each discharge line are recommended.

Response: The backflow preventer meets AWWA Standard c-510x for the proposed use. The injection system has been modified to include three metering pumps from a single make-up tank. Flow control will be at each metering pump. Injection lines will have check valves and anti-siphon back-pressure valves.

29. **Comment: Figure 11.** It is understood that this figure is not a design drawing, but the carbon units should be plumbed and valved to allow change out of spent units unless the units are sized to last for the entire pilot test.

Please refer to comments on the experimental design in Sections 3.2.1 and 3.3.1. It does not appear that this layout will satisfy the requirements to achieve the pilot test objectives. For example, where would samples of extracted groundwater be collected for hexavalent chromium and TCE? Please edit this layout and the work plan as necessary or clarify the work plan in support of this layout.

Response: Two 1000-pound carbon units will be provided for each test area. This may be adequate for the complete test; however, sampling will be conducted to evaluate for potential breakthrough. Change out of the carbon will be easily implemented, if necessary. Sampling from the extraction well will be conducted before the carbon units. A sample valve has been added to the figure.

30. **Comment: Tables 1 & 2.** Why doesn't Test Area 2 list ferrous sulfate in the Treatment Solution column?

    Response: "Field Test" has been changed to "Ferrous Sulfate."

31. **Comment: Table 3.** Consider adding chemical injection valves at the discharge end of each chemical metering line to better control the chemical addition rate to each injection well.

    Presumably, a drum of (dilute) sulfuric acid will also be provided. A drum of sodium hydroxide solution would also be recommended for pH adjustment. Will separate drums of acid and base be provided for each test area and will drum pumps by shared by each area? Please edit as necessary.

    Response: Injection check values are included. Concentrated sulfuric acid will be supplied. A single drum and drum pump will be used to dispense acid for dilution and addition to the chemical make-up tanks for both areas. Sodium hydroxide will not be provided for the pilot test.

32. **Comment: Table 4.** Comparing this table with the description of the experimental design in Section 3.2.1, there appear to be anomalies in the table that require correction.

    The first sentence in the third paragraph of Section 3.2.1 refers to "before" and "after" samples for soil and groundwater; however, samples collected immediately after the test are not included in this table. Please edit the work plan to correct this discrepancy.

    Sampling included in this table needs to address the fact that the experimental design requires evaluation of each test lobe independently.

    Will PZ-99-02 also be sampled (for groundwater) at the beginning (and end) of the pilot test? Please correct as necessary.

    Clarify where extracted groundwater will be sampled for the mass balance calculations.

Response: Soil samples will not be collected after the test. The text has been modified to address this. The experimental design has been modified such that sampling and analysis are consistent with the objectives of the design. Each lobe will be observed independently. Sampling of PZ-99-02 has been added to the beginning of the test. It was already included at the end of test. Mass balance calculations will not be performed (see response to General Comment 4).

33. **Comment: Table 4 and 6.** The tables show the sampling frequency for groundwater samples at the piezometers and the extraction wells. The sampling schedule is strongly predicated on the prediction that the travel time for the injectate from the injection well to the extraction well is 2 days (i.e., the sampling is concentrated around 48 hours to resolve the "breakthrough"). What is the basis of this prediction for the travel time? (It is not discussed explicitly in the test.) Is the proposed sampling schedule based on the distribution of arrival times of particles in the particle tracking calculations shown in Appendix C? What is the relationship between the prediction of a travel time of 1.5 days along the most direct path (see, e.g., Appendix C) and the two days around which the sampling is centered? If significant injectate and/or reaction products arrive at the extraction well as early as 36 hours after start-up, the sampling program will not resolve the breakthrough in detail. It may be prudent to perform more detailed transport modeling in order to reduce uncertainty in the travel time to guide the sampling schedule, or to consider adding sampling events to resolve possible earlier breakthrough. It should be noted that the particle tracking calculations employed to date, while effective in mapping out the advective flow field, do not address dispersion, which is critical to the mixing process required to achieve in situ reduction or oxidation of the contaminants, and will spread out the breakthrough curve for reactants to some extent.

Response: The travel time is based on the particle tracking. The actual travel time predicted is 1.875 days (45 hours). Additional transport monitoring would not be able to significantly improve this prediction without additional field investigations to better define the hydrogeology of the test area. If the chemical front moves more rapidly than the predicted time, this should be initially observed in the piezometers between the injection and extraction wells and the subsequent sampling times will be adjusted. The sampling schedule has been modified to bracket 45 hours.

34. **Comment: Table 5.** The table indicates no TOC analyses for the soil samples. Has the site soil been characterized previously for TOC? If not, this should be added to the analyses proposed for the pilot test program. Organic carbon could play a role in the processes affecting CR(VI) distribution. For example, oxidation of organic carbon in the soil may reduce some CR(VI), even in the absence of the ferrous iron.

Response: Oxidation of organic carbon could contribute to the reduction of Cr(VI); however, the time scale of this process would not be sufficient to meet the requirements of the NCRA. Therefore, TOC has not been added to the analyses.

35. **Comment: Table 5.** Addition of dissolved organic carbon (DOC) to the analyte list for the groundwater samples should be considered. DOC has been shown to influence the formation of soluble organic complexes with CR(III) [4].

Response: Soluble organic complexes with Cr(III) would be detected in total chromium analyses. While DOC analysis would provide additional insight into the concentrations of total Cr detected following treatment, it is not necessary for evaluation of the technology.

36. **Comment: Table 5.** Analysis for ferrous iron should be added for the pre-test groundwater ("Groundwater – Collected during installation") in order to characterize the background ferrous iron. Although under the strongly oxidizing conditions observed in the test area, the concentration of ferrous iron in solution should be negligible, this should be verified by pre-test analyses.

Response: Ferrous iron has been analyzed from the proposed test areas already (see Table 1 pre-test water). The expected low concentrations for ferrous iron were confirmed. Additional verification is not necessary.

37. **Comment: Tables 5 and 7.** Modify these tables as required in response to comments made and associated resolution of comments that impact these two tables. For example, soil and groundwater collected immediately after the test, and sampling of extracted groundwater for mass balance calculations.

Response: The tables have been modified as required.

38. **Comment: Table 6.** Discrepancies similar to those identified in Table 4 exist between Table 6 and the text in Section 3.3.1. Please make the necessary corrections.

Will PZ-99-01 also be sampled (for groundwater) at the beginning (and end) of the pilot test? Please correct as necessary.

Clarify where extracted groundwater will be sampled for the mass balance calculations.

Response: Discrepancies have been corrected. PZ-99-01 has been added as appropriate. The mass balance approach to experimental design has been replaced (see response to General Comment 4).

39. **Comment: Table 7.** The table indicates an analysis only of CR(VI) during the test, and only at the extraction well. Why is characterization of CR(VI) during the test limited to the extraction well? Total CR and CR(VI) should be characterized throughout the domain during the test, as well as afterward, due to the potential complexity of the interaction between CR(VI) and the permanganate solution.

Response: Analysis of Cr(VI) at the extraction well will provide data necessary to demonstrate if Cr(III) is oxidized to Cr(VI) in the treatment area during the test. Analysis of total Cr will be added to the test to improve the ability to observe this circumstance.

Analysis of total Cr and Cr(VI) will also be added for all locations prior to and following the test. Analysis for total Cr and Cr(VI) for each piezometer during the test has not been added because the information collected will not significantly improve the evaluation, and will add a significant analytical burden during an already intensive sampling and analysis scheme that may distract from the more critical analyses related to the VOC treatment. Only the extraction well will be analyzed for total Cr and Cr(VI) during the test.

40. **Comment: Table 8.** This table refers to on-site analyses for VOCs, chromium, and iron species; however, it is not clear from the work plan that an on-site laboratory is planned. Please review and correct as necessary.

Please identify sampling that will be conducted in support of the mass balance calculations and add that to this table. Note that the experimental design requires evaluation of the various test lobes independently to determine the effect of various chemical dosages.

This table appears to be more complete than Table 4, 5, 6, and 7.

Response: An on-site laboratory is planned. The mass-balance approach to the experimental design has been removed (see response to General Comment 4). The table has been updated to be consistent with the new experimental design approach.

41. **Comment: Appendix C.** The second paragraph refers to a recirculating system; however, it appears that a recirculating system will not be used. Please correct as appropriate.

What is the 4-foot hot zone referred to at the top of the second page of text? Please clarify this in the text of the work plan.

On the second page of test, is the porosity consistent with the apparently tight formation found at the sight? Is the assumption of a porosity of 0.3 supported by field investigations at the site? Please explain or document if possible.

Response: Please see the response to General Comment 8.

The 4-foot hot zone refers to the discreet 4-foot interval from which the sample with the maximum contaminant concentrations was obtained during pre-design investigations (30 to 34 feet bgs for both hexavalent chromium and TCE). Appendix C has been revised to read "... includes the 4-foot zone of maximum contaminant concentrations." In addition, Section 2 of the Work Plan text has been revised to include the zone for the proposed pilot tests and the depth of the most contaminated zones.

The porosity estimate used during modeling (0.3) is based on the type of soil generally identified at the SAEP site during pre-design investigations (sand to silty sand). Data obtained from the aquifer pumping test and other investigations does not provide information on the actual effective porosity at the site. The actual effective porosity is likely to range from 0.25 to 0.35 (based on professional experience); however, a change in porosity over this range will only impact the travel time of particles in the model, not the overall result (zone of capture) of the model.