Shaw Environmental & Infrastructure Engineering of New York, P.C.

13 British American Boulevard
Latham, NY 12110-1405
518.783.1996
Fax 518.783.8397

Shaw® Shaw Environmental, Inc.

DOWNGRADIENT TREATMENT SYSTEM PROJECT
FINAL ENGINEERING DESIGN REPORT

National Heatset Printing Site
Babylon, New York

Site No. 1-52-140

January 20, 2005

Prepared for:

New York State Department of Environmental Conservation
625 Broadway
Albany, New York 12233-7015

Prepared by:

Shaw Environmental & Infrastructure Engineering of New York P.C
13 British American Boulevard
Latham, New York 12110-1405

STATE OF NEW YORK
EDWARD A. WEINBERG
075440
LICENSED PROFESSIONAL ENGINEER

1/20/05

N;/802901NHS/response to comment letter/final document/final design report

TABLE OF CONTENTS:

TABLES:

FIGURES:

APPENDICES:

Tab 1- Plume Migration Calculations
Tab 2- Air Stripper Calculations
Tab 3 – Carbon Adsorption Calculations
Tab 4 – Tank Volume and Tank Residence Calculations
Tab 5 – Miscellaneous Equipment
Tab 6 – Optimum Pipe Size Calculations
Tab 7 – Head Loss Calculations - Extraction Well Pumps
Tab 8 – Metals Removal Calculations ($KMnO_4$, Sludge Generation, pH Adjustment, Polymer)
Tab 9 – Process Pump Calculations
Tab 10 – Friction Loss due to Gravity Flow Calculations
Tab 11 – Air Modeling Calculations and Addendum
Tab 12 - Building Heat Load Calculations
Tab 13 –Lighting Calculations
Tab 14 – Recharge Basin Calculations

F. Suffolk County Sanitary Code, Article 12

1.0 INTRODUCTION

1.1 Introduction, Purpose, and Organization

Shaw Environmental & Infrastructure of New York, P.C. (Shaw) has prepared the following *Downgradient Treatment System Project Final Design Report* to address the Volatile Organic Compound (VOC) impacted on-site and off-site aquifer plume at the New York Department of Environmental Conservation (NYSDEC) National Heatset Printing (NHP) Site No. 1-52-140 under the State Superfund Standby Contract Work Assignment. This report was prepared in accordance to the NYSDEC approved Remedial Design Work Plan, September 29, 2000 (Shaw, formerly IT Corporation). In accordance with this work plan a two-tiered approach to the on-site and off-site aquifer remediation is presented. Two designs for each portion of the aquifer are presented. The first tier presents performance specifications for in-well stripping (recirculation) remediation systems, while the second tier presents a design for groundwater extraction and treatment systems.

The purpose of this report is to evaluate and address issues necessary to proceed with the designs of the aquifer restoration systems. Included are such elements as the results of the aquifer pump test, selection of preferred locations and geometries of the extraction wells for the extraction and treatment systems, definition of the performance requirements for the recirculation well system, and process flow for the on-site and off-site groundwater extraction and treatment systems. This report discusses and suggests solutions for design concerns and uncertainties that could adversely affect adjacent properties, the environment, or the operation of the remedy. This report finalizes the design of the on-site and off-site groundwater extraction and treatment systems described in the Pre-Final Design Report by incorporating comments from the NYSDEC and adding sufficient design detail for bidding the construction via the Contract Documents. The Final Design Report document will be used as a reference to support the Contract Documents.

Based on these changes, the Final design report is divided into the following Sections:

Section 1 presents the introduction, site background, and site geology.

Section 2 presents the pre-design activities.

Section 3 presents the aquifer analysis, including pre-test activities, step drawdown test, aquifer test methodologies, aquifer test data analysis, and aquifer test results.

Section 4 presents the remediation system design considerations including remedial objectives, proposed treatment scenarios, design basis and criteria for the groundwater extraction and treatment systems, and performance requirements for the in-well stripping recirculation system.

Section 5 presents the evaluation of the groundwater extraction and treatment alternatives for on-site and off-site considerations.

Section 6 presents an evaluation of the groundwater extraction and treatment systems, including process options and permitting requirements for on-site and off-site consideration.

Section 7 presents a summary of the final design for the on-site and off-site extraction and treatment systems.

Section 8 presents a list of the technical specifications to be included in the Contract Documents and a project implementation schedule.

Appendices include the final design drawings, supporting design calculations, and off-gas discharge modeling results.

1.2 Site Background

The National Heatset Printing site is located at One Adams Boulevard in the Hamlet of East Farmingdale, Town of Babylon, Suffolk County (**Figure 1-1**). The site contains one multi-tenant industrial building approximately 4.5 acres in size. The National Heatset Printing Company occupied a portion of this building from July 1983 to April 1989. Their operations consisted of lithographic tri-color printing of newspaper and periodical advertisements and the manufacture of lithographic printing plates. National Heatset had been using organic solvents at the site since 1983. Inspections by the Suffolk County Department of Health Services (SCDHS) in 1983 and 1986 reported improper storage and discharge of waste materials.

The National Heatset Printing Company filed for bankruptcy in 1987. The SCDHS discovered that after filing for bankruptcy, National Heatset disposed of its chemical inventory by dumping the materials onto the soils and into a leaching pool located off the rear of the building on the northeast side of the property.

Investigations conducted by the SCDHS and the property owner's consultant reported the presence of on-site subsurface soil contamination and on-site and downgradient groundwater contamination. The contaminants identified consisted of VOCs, principally Tetrachloroethylene (PCE). The site was listed in the Registry as a Class 2 in 1993.

A Remedial Investigation (RI) was performed by Holzmacher, McLendon & Murrell, P.C. for the NYSDEC from August 1997 to January 1999. The RI reported the presence of a groundwater plume containing VOCs, which at that time extended approximately 7,100 feet downgradient of the site. The highest concentrations of PCE in groundwater were detected at approximately 80 feet below ground surface (bgs) on top of a clay layer. Concentrations of VOCs greater than 1,000 parts per billion (ppb) (maximum 12,021 ppb) in the groundwater were present in the 75 to 85-foot sampling interval to approximately 4,100 feet downgradient (south-southeast) of the site. Contaminated soils were detected in the saturated zone, below the water table, and were located directly below the leaching pool in the rear of the property.

The Suffolk County Water Authority (SCWA) Albany Avenue well field is located 6,500 feet downgradient from the site. The wells are screened at depths of 419 to 509 feet bgs below the contaminant plume. Monthly monitoring of these wells has not detected the presence of any contamination. Data collected during the RI indicates that the groundwater contaminant plume migrating from the National Heatset site is sinking, and therefore may eventually contaminate the public drinking water well field. However, exposure to contaminants that may reach the Albany Avenue well field is not expected since these wells are monitored on a monthly basis and must meet NYSDOH standards.

Potential remedial alternatives for the National Heatset Printing site were identified, screened and evaluated in a Feasibility Study (FS). Based on the RI and FS, the Department issued a Record of Decision (ROD) document dated June 17, 1999 that identified the selected remedy for the site. The major elements of the National Heatset printing site remedy, as presented in the ROD, are as follows:

- A remedial design program that includes a pilot test to verify the components of the conceptual design and provide the details necessary for the construction, operation, maintenance, and monitoring of the remedial program. Additional investigation needed for the pilot test or the remedial design will be conducted.
- Based on the pilot test data, the effectiveness of the in-well stripping system at the source area will be evaluated. Since the high VOC concentrations at the source area indicate the presence of undissolved product mixed with groundwater, an alternative remedy such as extraction and treatment or sparging with air or ozone may be chosen to recover and/or treat the undissolved product. The two downgradient in-well stripping systems would be retained to prevent migration of the contaminant plume.
- Construction and implementation of the in-well stripping systems or an alternative remedy supported by pilot test data, which includes:
  - One system at the source area, consisting of two groundwater circulation wells. This system will remediate the area with the highest VOC concentrations;
  - One system at the south end of the site consisting of three groundwater circulation wells. This system will prevent additional VOC contamination from

leaving the site; and

- One system downgradient of the southern edge of the one (1) ppm groundwater contamination contour. This system will consist of seven wells and will halt further migration of VOCs downgradient of the site.

- Providing public water to any properties that utilize private wells within the affected area. Any private wells identified downgradient of the site will be tested for VOCs by the Suffolk County Department of Health Services. If site-related contaminants are detected in the well samples, the home or business serviced by the contaminated well will be connected to public water.

Since the remedy results in untreated hazardous waste remaining at the site, a long-term monitoring program will be instituted. Monitoring wells will be installed, where needed, and sampled upgradient and downgradient of each of the in-well stripping systems. Wells already exist on-site and upgradient and downgradient of the site. Additional wells will be installed downgradient of the site. This program will allow the effectiveness of the in-well stripping to be monitored and will be a component of the operation and maintenance for the site; and institutional controls will be implemented and deed restrictions will be recorded in the chain of title of the property to restrict future use of groundwater at the site.

Since the ROD for this site was signed, the NYSDEC has attempted to obtain competitive bids using in-well stripping remedial technology at another inactive hazardous waste site. Since the NYSDEC was unable to obtain bids at a reasonable cost at the other site using re-circulation well technology, an alternate remedy was needed to avoid the same problems from occurring at this site. In June 2000, the NYSDEC issued an Explanation of Significant Differences (ESD) for this site. The ESD added groundwater extraction and treatment as an alternate remedy for the downgradient groundwater contamination.

1.3 Site Geology/Hydrogeology

The following sections have been adapted from the 1999 *Remedial Investigation Report* (H2M Group, 1999).

1.3.1 Surface Features

The local topography surrounding the Heatset Site consists of relatively flat terrain with a slight south-southwest slope. The gradient of the natural land surface within the site boundaries is less than four feet. Gradients of man-made surfaces (i.e., paved surfaces) at the Heatset Site can vary as much as four feet due to truck loading bays sloping back toward the building. The recharge basin located at the adjoining property to the west, has moderately sloping sides with a base elevation approximately 15 to 20 feet below that of the surrounding property. A site topography map is provided as **Figure 1-3**.

1.3.2 Surface Water Hydrology

No surface water bodies exist within the Heatset Site property boundaries. There is no evidence of ephemeral streams or steam-cut channels at the site. Review of the Amityville 7.5 min quadrangle United States Geographic Survey (USGS) topographic maps support these field observations. The nearest downgradient stream shown on the topographic map is a creek tributary connected to Avon Lake, approximately 1.7 miles south of the site. The headwaters of this creek are located just to the south of Sunrise Highway in the Town of Amityville. The headwaters of the Carmans Creek and Massapequa Creek occur approximately 2.0 miles south-southeast and southwest of the site, respectively.

1.3.3 Hydrogeologic Setting

The geologic formations that underlie Suffolk County are composed of a series of thick deposits of unconsolidated water bearing sediments of the late Cretaceous and Pleistocene age. These unconsolidated deposits are underlain by crystalline bedrock of Precambrian age.

There are three primary water bearing aquifers underlying Suffolk County. These aquifers, from shallow to deep, are the Upper Glacial, Magothy, and Lloyd. The aquifers are considered to be hydraulically connected, with the Glacial and Magothy contributing recharge for the underlying Lloyd aquifer. Together, they are a federally designated sole source of drinking water for Long Island.

During the great glacial retreat, the area was covered with outwash deposits that constitute most of the Upper Glacial aquifer of Long Island. The Upper Glacial aquifer is the most permeable aquifer on Long Island because these sand and gravel deposits contain virtually no interstitial clay and silt. The estimated average horizontal hydraulic conductivity of the outwash is from 1,000 to 1,500 gpd/ft^2. The direction of groundwater movement through Long Island's aquifers is horizontal and is generally more rapid than the movement in the vertical direction. This arises because of an anistrophic effect: the largest dimensions of particles in the interbedded fine- and coarse-grained layers tend to be oriented horizontally.
Groundwater in the Upper Glacial aquifer flows away from two major highs on the main water table divide on Long Island. The general directions of groundwater flow of the Island are north toward the Long Island Sound and south toward the Great South Bay. Based on site-specific data, local groundwater flow at the site moves south to southeast toward the Great South Bay with a gradient of 0.0014 foot per foot (ft/ft) and a velocity of approximately 1.34 ft/day.

2.0 DESIGN ACTIVITIES

Several work tasks have been completed as part of the source delineation/pre-design work. The complete tasks include:

- Health and Safety Plan Preparation
- Source Area Investigations
  - Soil Borings and Sampling
  - Monitoring Well Installation
  - Groundwater Sampling
- Aquifer Pump Test
- Pump and Treat and In-Well Stripping System 35% Engineering Design Report
- 65% Engineering Design Report
- 95% Engineering Design Report
- 100% Design Report
- Site Survey and Site Plan Preparation
- Meeting with the Suffolk County Water Authority (SCWA)
- Final Engineering Design Report

The Site Specific Health and Safety Plan (HASP) was updated on January 15, 2001.

Source area investigation work was completed from January through April 2001 and included completion of several soil borings and monitoring wells. The investigation also included the collection and analysis of several soil and groundwater samples from the site source area. The investigation work concentrated on an area of the site with the potential for Dense Non-Aqueous Phase Liquid (DNAPL) to exist at the lower confining clay layer. (Refer to the on-site General Site Plan included as **Figure 2-1**).

An aquifer pump test was performed at the site from April 23, 2001 to April 27, 2001.

The 35% Engineering Design Report was submitted July 5, 2001. The 65% Engineering Design Report was submitted November 8, 2001. The 95% Engineering Design Report was submitted December 18, 2002 and a 100% Design Report was issued July 17, 2003. Other than meetings at the SCWA, no additional site work has been implemented as of the writing of this Final Design Report. Refer to the off-site General Site Plan included as **Figure 2-2**.

3.0 AQUIFER TEST ANALYSIS

Between April 24 and 27, 2001, an aquifer test was conducted at the site to determine the transmissivity and specific yield of the upper glacial aquifer. Transmissivity (T) is the measure of the amount of water that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under a hydraulic gradient of one. Specific yield (Sy) is the ratio of the volume of water that drains from a saturated rock owing to the attraction of gravity to the total volume of the rock. These hydraulic characteristics were later utilized in the design of the groundwater recovery and treatment systems at the site. The following sections detail the activities that were conducted for the aquifer test.

3.1 Pre-Test Activities and Data Collection

Based on site hydrogeologic conditions, it was determined that a pumping rate of up to 50 gallons per minute (gpm) was a sustainable pumping rate that would sufficiently stress the aquifer to obtain useful hydrogeologic data from the existing set of monitoring wells. Monitoring well MW-10 was selected as the pumping well for the aquifer test due to its down-gradient location on the property and the surrounding network of monitoring wells. Pressure transducers were placed in monitoring wells MW-2A, MW-3A, MW-4A, MW-9 and MW-10 and were controlled by a Hermit™ 3000 Datalogger. In addition, a downhole Troll™ was installed in monitoring well MW-H to record water levels at that location. Prior to initiating pumping, water levels were manually gauged at all on-site monitoring wells to aid in assessment of the influence of pumping across the property.

3.1.1 Groundwater Treatment Activities

Based on previous groundwater sampling results in the aquifer test area, groundwater generated during well development and aquifer test activities required treatment prior to discharging via sanitary sewer to the local Publicly Owned Treatment Works (POTW). The treatment consisted of filtering the water through a series of two 500-pound granular activated carbon (GAC) vessels temporarily set up at the site. Prior to the aquifer test, Shaw obtained approval to discharge to the POTW from Suffolk County Department of Health Services (SCDHS).

On April 27, 2001 a representative from SCDHS collected one sample of the discharge effluent.

3.1.2 Background Water Levels and Meteorological Data

To determine if changes in water levels observed during the aquifer test could be attributed to pumping or non-pumping conditions, meteorological data from the National Weather Service (NWS) station located at Farmington, NY, approximately four miles west of the site, was monitored. During the aquifer test, approximately 0.02 inches of rain fell the evening of April 24,

2001. Prior to the aquifer test, rainfall had not fallen for 3 days. Thus, recharge due to rainfall is not believed to have affected the results of the aquifer test. Because the aquifer is unconfined, barometric pressure changes do not affect the aquifer response to pumping.

A summary of meteorological data is provided along with the gauging results in **Appendix A**.

3.2 Aquifer Test Pumping

The aquifer test was initiated on April 24, 2001 at approximately 6:35 PM. The initial 2.5 hours of the test was conducted as a step-drawdown test to assess the well efficiency and to determine the optimal pumping rate for the three-day aquifer test. The initial pumping rate was 30 gpm, which was maintained for a period of 60 minutes, followed by a pumping rate of approximately 40 gpm, which was maintained for a period of 95 minutes, followed by a pumping rate of 50 gpm which was maintained for the duration of the test. The pump was shut down at approximately 1:30 PM on April 27, 2001.

Pumping rates were assessed by monitoring a flow totalizer installed in-line after the GAC vessels. Pumping rates were controlled by adjusting a ball valve located in-line between the pumping well and the GAC vessels.

Because flow rates were measured downstream of the GAC vessels, flow rates were slow to stabilize due to pressure effects in the GAC vessels. As a result, pumping rates fluctuated for approximately 10 minutes until an accurate flow reading could be obtained at the desired pumping rate. This is evident in the early time-drawdown (displacement) graphs shown in **Appendix B**. Flow stabilization based on the meter reading was difficult during this time period. The effect is also more noticeable due to the logarithmic scale on which the data is analyzed. Therefore, the early time-drawdown data were not weighted as heavily in the curve matching analysis.

The pump was periodically shut down (for approximately 5 minutes at a time) to refuel the generators. This occurred approximately once every 5 hours. There was some difficulty restarting the generator at approximately 1:15 AM on April 26, 2001. This resulted in the pump being non-operational for approximately 35 minutes at 1,800 to 1,900 minutes into the test, during which time the water levels rebounded (See time-drawdown graphs in **Appendix B**). Upon restarting this pump, water levels quickly returned to their previous lower levels. The total downtime of the pump over the three-day aquifer test amounted to less than one percent of the operational duration of the test. Based on the observation well data, these shutdowns did not have a significant effect on the results of the aquifer test.

3.3 Aquifer Test Monitoring

Throughout the aquifer test, water levels in five adjacent monitoring wells (MW-2A, MW-3A, MW-4A, MW-9 and MW-H) were measured with a pressure transducer and datalogger. Data was recorded on a schedule of decreasing frequency. Measurements were initially collected approximately once every 2 seconds. After forty seconds of measurements, the interval between measurements was increased by a factor of 1.06 until a final interval of one measurement every 10 minutes was reached. This frequency of measurement was maintained until after pumping had been discontinued. Prior to turning off the pump at the end of the aquifer test, all on-property wells were manually gauged to assess the influence of pumping across the site.

At approximately 8:00 AM on April 27, 2001 a truck drove across the cable to MW-9, moving the pressure transducer and thus making subsequent data acquired at that location unreliable. Data from monitoring well MW-H were considered not useable. All other data were considered accurate and reliable.

The time-drawdown and recovery data for each observation well are included in **Appendix B**. The variables shown in the solution section of the data sheet represent the following aquifer characteristics: transmissivity (T), storativity (S), specific yield (Sy), and the compressibility of the water (β). Transmissivity (T) is the measure of the amount of water that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer under a hydraulic gradient of one. Specific yield (Sy) is the ratio of the volume of water that drains from a saturated rock owing to the attraction of gravity to the total volume of the rock. Storativity (S) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in head.

3.4 Aquifer Test Data Analysis

The following sections describe the procedures used to analyze the data collected during the aquifer test activities and their results. The data was analyzed by graphical curve matching methods. Due to the initial instability in the pumping rate (see Section 3.2) when the pumping rates were adjusted, curve matching focused on data from after the first 10 minutes of the pumping test.

3.4.1 Data Analysis Methodology

The time-drawdown data from all wells with measurable drawdowns attributable to the aquifer test was plotted on graphs with logarithmic axes and graphically analyzed by the Neuman method for unconfined aquifers (1974), utilizing an aquifer test analysis software package (AQTESOLV for Windows by HydroSOLVE, Inc.). The Neuman method was utilized since the circumstances associated with the pump test correlate to the assumptions assumed in the Neuman method (unconfined aquifer, vadose zone has no influence on the drawdown, the drawdown is negligible compared to the saturated aquifer thickness, can model wells that partially penetrate the aquifer, etc.). Documentation for the software and description of the basis for the analytical solutions supported by it are provided in **Appendix C** pages 66 through 73. The equations associated with the Neuman method can be referenced in **Appendix C**, pages 66-68. The variables are defined on page 109.

The assumptions used to graphically analyze the aquifer test data in order to determine the transmissivity (T), storativity (S), specific yield (Sy), and compressibility of the water (β) included:

1. An infinite, homogeneous (isotropic), unconfined aquifer with a uniform thickness of 70 feet, underlain by an impermeable bed (clay) with an initially horizontal water table within the zone of influence of the test;
2. Partial penetration of the aquifer by the monitoring wells and pumping well;
3. Partially penetrating extraction and observation wells with negligible water storage capabilities in the well; and
4. Unsteady flow to the pumping well.

These assumptions are believed to be appropriate for the site. The sand aquifer is as homogenous as any naturally occurring aquifer. The clay layer was encountered at approximately 85 feet below ground surface at all borings advanced that deep at the site. The water table is generally horizontal (a gradient of approximately 0.0015 based on the ROD), relative to the drawdown generated during the pumping test (greater than 20 feet in MW-10 and over 0.3 feet at the nearest monitoring wells).

3.5 Aquifer Test Results

After 67 hours of pumping, drawdown in the pumping well was approximately 22.29 feet. Drawdown in the observation wells ranged between 0.09 feet and 0.35 feet.

Analysis of the pumping test data yielded values for transmissivity (T) and specific yield (Sy) for each well that exhibited greater than 0.3 feet of drawdown. These data are presented in **Table 3-1**. Hydraulic conductivity (Kh (feet/day) = T (square feet)/b (ft)) values were obtained from the transmissivity (T) values by assuming a constant saturated thickness (b) of 70 feet across the aquifer. A horizontal hydraulic conductivity (Kh=T/b=9,594/70=137 feet/day) was calculated for the area surrounding MW-10. This value is typical for the geologic material. This horizontal hydraulic conductivity was calculated as the arithmetic mean conductivity, since it is assumed that all flow between these wells was parallel to the geological bedding.

There was no apparent correlation between aquifer response and direction from the pumping well. This isotropic behavior is typical for an aquifer comprised primarily of alluvial outwash deposits (sand). The Neuman method allows the calculation of the vertical to horizontal hydraulic conductivity ratio, based on the β-value used to obtain the best curve fit.

$$\beta = r^2 * Kv \,/\, b^2 * Kh$$

where

β	=	compressibility of the water (1/(lb/feet squared));
r	=	radial distance (feet);
Kv	=	vertical hydraulic conductivity (feet/day);
b	=	aquifer thickness (feet); and
Kh	=	hydraulic conductivity (feet/day).

Based on the results of this analysis, the vertical to horizontal hydraulic conductivity ratio is approximately 1:1. This isotropic behavior is not uncommon for clean alluvial outwash sands.

3.6 Pumping Rate Determination

To begin the design of the groundwater extraction and treatment system, the pumping rate necessary to achieve containment of the VOC plume was calculated based on hydrologic and contaminant concentration data obtained from the pump test and monitoring activities. The analytical solution used in this calculation and the results are discussed below.

3.7 Pumping Rate Determination Methodology

3.7.1 Analytical Solution Method

An analytical solution described by Keely and Tsang (1983) and developed further by Erdmann (2000) was used to calculate the pumping rate necessary to generate a capture zone of a specified width (i.e., extent in the cross-gradient direction). This calculation was performed for two pumping systems, one to contain groundwater crossing the National Heatset property and another to contain the down-gradient groundwater plume. The results and an example of the calculations are presented in **Table 3-2. Appendix D** contains a copy of the journal article describing the analytical solution.

The calculation performed is based on complex potential theory (e.g., flow net mathematics) for steady flow in an isotropic, homogeneous aquifer. The maximum width of the capture zone was calculated, assuming steady-state flow conditions, according to the following equation (Keely & Tsang, 1983):

$$W_{\max} = \frac{Q}{KiB};$$

where

W_{max} = width of capture zone infinitely up-gradient of the pumping well (feet);
Q = flow to well (feet^3/day);
K = average hydraulic conductivity (feet/day);
i = hydraulic gradient (feet/foot); and
B = thickness of the aquifer.

The width of the capture zone at the pumping well (Erdmann, 2000) is calculated as

$$W_0 = \frac{Q}{2KiB};$$

where

W_0 = width of capture zone at the pumping well (feet).

The calculations for the down-gradient groundwater extraction system assume that three wells will be placed along Benjoe Drive and Albany Avenue to intercept the plume. The width of the plume (**Table 3-2**) at that location was assumed based on the groundwater data collected in 1998 by H2M. To account for continuing plume dispersion, the width was assumed to be 133% of the maximum width of the 1.0 mg/L isopleth for total VOCs in groundwater at 75-85 bgs (H2M, 1998, Figure 4.3). Additional groundwater data was collected in July 2002 by Shaw and was utilized to adjust the downgradient treatment system data presented in **Table 3-2**. The older and current versions have been included in **Table 3-2** for comparison. The location of any wells along Benjoe Drive and Albany Avenue are not expected to interfere with the production capacity of the Albany Avenue public water supply wells due to the fact the wells are in different aquifers. The public supply wells are located in the Magothy Aquifer and the pumping wells will be in the Glacial Aquifer. **Appendix D** contains a copy of the journal article describing the analytical solution.

3.7.2 Pumping Rate Determination Data

The hydraulic conductivity of the aquifer was obtained from the average value calculated in the pump test analysis. Given the relatively consistent geology at the site, the use of the aquifer test data to describe down-gradient hydraulic conductivity is believed to be appropriate. The aquifer thickness was assumed to be a constant 70 feet and the gradient to be 0.0018, based on the most recent round of groundwater gauging conducted on August 8, 2001. This gradient was estimated using gauging data from the National Heatset property wells, as well as down-gradient wells M-11 and M-12. Because these data points are situated longitudinally to one another, there is some uncertainty regarding the calculated gradient. However, this uncertainty is somewhat lessened because they are situated along the inferred axis of migration of the plume (i.e., roughly along the hydraulic gradient).

Because the chemical concentration data previously available for the down-gradient portion of the site was several years old (1998), a simple calculation was performed to estimate plume migration. The plume configuration from the most heavily impacted depth interval sampled (75 to 85 feet below ground surface) was used as a basis for this calculation (see H2M, February, 1999 Figure 4.3). The calculation was conservatively performed without consideration of contaminant retardation to help ensure that the well locations selected for the groundwater extraction system were sufficiently down-gradient to effectively capture the contaminant plume. The calculation performed was:

$$x = \frac{Ki}{\eta} \times t;$$

where

x = distance plume has migrated (feet);

n = effective porosity of the aquifer (assumed to be 0.25); and

t = elapsed time (days).

Based on this calculation it was estimated that the plume had migrated approximately 1,350 feet down-gradient between August 1998 and September 2001. **Appendix E, Tab 1** presents the calculation of this distance. This distance of migration would put the leading edge of the 1 mg/L isopleth of the plume approximately 100 feet up-gradient of the proposed Benjoe Drive and Albany Avenue extraction well locations. In July of 2002, a groundwater sampling event was performed to further characterize the location of the off-site plume. Analytical results from the 2002 groundwater sampling event confirmed the calculated plume migration. The plume, as determined by 1998 groundwater date, and the proposed groundwater extraction well and treatment plant locations are included in **Figure 3-1**.

Figure 4.3 from the 1999 H2M report, which presents interpreted groundwater contaminant data as concentration isopleths, suggests that the width of the total VOC plume above 1,000 µg/L is approximately 1,150 feet across at its widest point. However, the July 2002 groundwater data suggests that the width of the total VOC plume above 1,000 µg/L is approximately 600 ft across at its widest point. For the purposes of assessing the pumping rate, in this final design report, the older groundwater data was used as a conservative measure and it was assumed that the total plume to be captured is twice this width at the most-down-gradient extraction well.

3.8 Pumping Rate Determination Results

Based on the site data and the calculations outline above, a total minimum groundwater extraction rate of approximately 79 gpm will be necessary to contain contaminated groundwater on the National Heatset Printing property. These calculations further indicate that a total minimum groundwater extraction rate of approximately 330 gpm will be necessary to obtain containment of the down-gradient plume. For the purposes of these calculations, it is assumed that, following treatment, this groundwater will be either discharged to surface water or re-injected into the aquifer in such a way as to not interfere with the capture of the plume. Final design pumping rates will incorporate an uncertainty factor to compensate for limited site data and to provide greater confidence that remedial goals will be met.

As a check on the selected pumping rates, a calculation was performed to determine the total recharge to the calculated capture zones for each well. This calculation was based on the recharge entering the aquifer (Jensen and Soren, 1974), the width of the capture zone, and the distance up-gradient to the groundwater divide (Jensen and Soren, 1974). This calculation is as follows:

$$Q_{\max} = R \times W_{\max} \times L;$$

where

Q_{max} = the maximum sustainable flow rate in the absence of other pumping systems (feet^3/day); and

L = the distance up-gradient to the groundwater divide (feet).

The results of this calculation indicate that the pumping system will not approach the capacity of the aquifer **(Table 3-3)**.

4.0 REMEDIATION SYSTEM DESIGN CONSIDERATIONS

The following section presents the remedial objectives for the Heatset site, the proposed treatment scenarios for the on-site and off-site portions of the aquifer, the design basis and criteria for the groundwater extraction and treatment systems, and the preliminary performance requirements for the in-well stripping system.

4.1 Remedial Objectives

The proposed remedial designs and performance requirements presented in this report, will meet or exceed the remediation goals as set forth in the 1999 ROD. These goals are:

- Meet all Standards, Criteria, and Guidance (SCGs)
- Be protective of human health and the environment
- Eliminate, to the extent practicable, ingestion of groundwater affected by the site that does not attain NYSDOH drinking water standards; and
- Eliminate, to the extent practicable, further off-site migration of groundwater that does not attain NYSDEC Class GA Ambient Water Quality Criteria.

4.2 Proposed Treatment Scenarios

The proposed treatment scenarios presented in this section follow a two-tiered approach to the on-site and off-site aquifer remediation. Two scenarios for each portion of the aquifer are presented. The first scenario requires the use of an in-well stripping remediation system for the on-site and off-site plumes, while the second scenario requires the use of a groundwater extraction and treatment system for the on-site and off-site systems. This approach was chosen to allow the NYSDEC flexibility should they be unable to obtain competitive reasonable cost bids for the in-well stripping technology. Should the lowest responsible bidder utilize the in-well stripping well technology, then that vendor would be given the opportunity to demonstrate the effectiveness of this chosen technology. If the technology does not meet the performance requirements, then the lowest responsible bidder utilizing the groundwater extraction system would be awarded the contract.

4.2.1 On-Site Groundwater Aquifer Remediation

The proposed on-site groundwater remediation scenarios are as follows:

Scenario 1: Two to four in-well stripping wells, adjusted based on the radius of influence determined from the pilot test results, would be installed in the upper aquifer at the downgradient edge of the on-site plume to remediate any remaining groundwater contamination after the source area remedial action. The wells would have the appropriate off-gas treatment. The in-well stripping wells create an elliptical groundwater circulation zone surrounding the well. The groundwater circulation well uses a screened well and a drop tube to create the circulation zone. Air is injected at the bottom of the well via the drop tube, which is installed inside the well casing. The air forms bubbles, which flow upwards within the casing, displacing water and reducing the density of the water column within the well. These air bubbles also effectively strip the volatile contaminants from the water column and transfer them to the air stream within the well. Air emitted from the wells is monitored and exhausted to an appropriate air treatment system prior to being discharged to the atmosphere.

Scenario 2: Two groundwater extraction wells will be screened in the upper aquifer at the downgradient edge of the on-site plume to contain and remediate any remaining groundwater contamination after the source area remedial action. The groundwater treatment system is designed to treat 100 gpm of contaminated water (150% of the 66 gpm pumping rate). The unit operations identified for the treatment plant are oxidation and sedimentation of metals, air stripping of volatile organic compounds and activated carbon polishing of effluent water. Treated groundwater would be discharged to a local retention basin.

4.2.2 Off-site Groundwater Aquifer Remediation

The proposed off-site groundwater remediation scenarios are as follows:

Scenario 1: In accordance with the ROD and to be verified during the pilot test based on the proven radius of influence, approximately six to nine in-well stripping wells would be installed in the upper aquifer at the 10 part per billion (ppb) edge of the off-site plume to protect the Suffolk County Water Authority Albany Avenue well field. The well system would have appropriate off-gas treatment. The in-well stripping wells create an elliptical groundwater circulation zone surrounding the well. The groundwater circulation well uses a screened well and a drop tube to create the circulation zone. Air is injected at the bottom of the well via the drop tube, which is installed inside the well casing. The air forms bubbles that flow upwards within the casing, displacing water and reducing the density of the water column within the well. These air bubbles also effectively strip the volatile contaminants from the water column and transfer them to the air stream within the well. Air emitted from the wells is monitored and exhausted to an appropriate air treatment system.

Scenario 2: Three groundwater extraction wells will be screened in the upper aquifer perpendicular to the down-gradient center axis of the off-site plume to protect Suffolk County Water Authority Albany Avenue well field. The groundwater treatment system is designed to treat 500 gpm of contaminated water (150% of the 340 gpm pumping rate). The unit operations identified for the treatment plant are oxidation and sedimentation of metals, air stripping of volatile organic compounds, activated carbon polishing of effluent water, and catalytic oxidation and/or carbon treatment of off-gases. Treated groundwater would be discharged to a local retention basin.

During the Final design effort, the off-site scenarios were advanced to the final level of engineering completeness based on discussions with the SCWA and NYSDEC regarding the off-site remediation plans for the extraction/treatment system. The off-site system has been finalized in this report as a result of the review and approval by the SCWA.

4.3 Design Basis For In-Well Stripping Systems

Numerous investigations have been completed to evaluate the site geology, hydrogeology and groundwater quality at the site. This information, in conjunction with a pilot scale field test of the proprietary methodology, will be used by the equipment vendor to design an in-well stripping system to meet the project Remedial Objectives. The in-well stripping system would include:

- Collection of groundwater within a stripping well
- Treatment of the groundwater to meet established remedial action criteria
- Discharge of the treated groundwater within the influenced area of the stripping well
- Collection and treatment of any gas generated that may contain site VOC contaminants without discharging to the atmosphere contaminants at or above regulated limits
- Treatment compounds for the air pollution control systems and other above ground appurtenances associated with the in-well stripping systems

4.4 Design Basis for the Groundwater Treatment Plant

Numerous investigations have been and are being performed to evaluate the site geology, hydrogeology, and groundwater quality at the site as well as appropriate treatment technologies. A database created as a result of these investigations, in conjunction with the ROD, has been used to develop a Basis of Design for remediation of the on-site and off-site contaminant plume. Based on the groundwater extraction and treatment scenario, each remediation system includes:

- Extraction of groundwater from the upper aquifer
- Treatment of the extracted groundwater based on the most recent characterization data obtained during remedial and pre-design investigations to meet the established discharge criteria which involves metals removal and VOC removal from the extracted groundwater
- Discharge of the treated groundwater to a town sump (on-site) and recharge basin (off-site)
- Treatment of off-gas to remove VOCs transferred from the groundwater to the air (off-site only)
- Treatment compounds sized to house the process equipment components and associated appurtenances.

4.4.1 Extraction Well Network and Pumping Rates

The extraction well network and pumping rate descriptions are specific to the pump and treat scenario. The configuration of the extraction well networks and pumping rates for the on-site and off-site extraction system have been based on the groundwater monitoring results, pump test data, and groundwater modeling results. The basis of design for this portion of the remedial systems consists of five criteria:

- Capture of the remaining on-site plume to prevent further migration and remediate, to the extent practical, the aquifer to groundwater quality standards.
- Capture the off-site plume to protect the Suffolk County Water Authority Albany Well Field.
- Balance of the well locations (number of wells) and flow rates for efficient plume recovery.
- Minimize the impacts to the surrounding area.
- Allowance for up to 50% increase in the overall groundwater extraction flowrate.

Based on the groundwater extraction system analysis, the on-site extraction system will consist of two extraction wells placed at the downgradient edge of the on-site plume (**Figures 4-1** and **4-3**). These wells will each have a nominal pumping capacity of 50 gallon per minute (gpm).

The off-site extraction system will consist of three extraction wells placed along Benjoe Drive and Albany Avenue well field (**Figures 4-2** and **4-4**). Two wells will have a pumping capacity of 125 gpm, while the third will have a pumping capacity of 250 gpm.

4.4.2 Influent Characteristics

To develop the design criteria for the groundwater extraction and treatment plants, influent characteristics of the extracted groundwater were estimated. As a conservative measure, the maximum known concentrations in the groundwater were used in the design process. **Table 4-1** provides the influent characteristics from the on-site plume (July 26, 2001 sample event) and off-site plume (1999 ROD maximum concentrations and July 2002 sampling event).

4.4.3 Groundwater Treatment System Performance Requirements

The primary objective of the on-site groundwater extraction and treatment system is to prevent further off-site migration of the VOC plume and to remediate any remaining VOC contamination after the source area remedial action. This objective will be met by the installation of two groundwater extraction wells at the downgradient boundary of the Heatset property that are designed to extract the necessary groundwater and transport it to the on-site treatment system. The proposed system shall capture the migrating plume and remediate the aquifer to groundwater quality standards (**Table 4-2**). All off-gases generated by the groundwater extraction and treatment system shall meet NYSDEC DAR-1 (formerly Air Guide-1) discharge requirements (**Table 4-3**).

The primary objective of the off-site groundwater extraction and treatment system is to prevent further off-site migration of the VOC plume and protect the Suffolk County Water Authority Albany Avenue Well Field. This objective will be met by the installation of three extraction wells along Benjoe Drive and Albany Avenue just north of the Albany Avenue well field that are designed to extract the necessary groundwater and transport it to the off-site treatment system. The system shall capture the migrating plume and protect the Albany Avenue Well Field and treat the extracted groundwater to New York State groundwater standards (**Table 4-2**). All off-gases generated by the groundwater treatment system shall meet NYSDEC DAR-1 (formerly Air Guide-1) discharge requirements (**Table 4-3**).

Each of the groundwater treatment systems will follow the following performance requirements.

Removal of VOCs will take place in an air stripper. A downstream liquid-phase granular activated carbon system will be used to polish the air stripper effluent to ensure compliance with the NYSDEC SPDES discharge permit (or permit equivalence). These units have been proven effective in removing contaminants of concern at and exceeding the estimated influent concentrations. An air stripper off-gas treatment system will be provided as necessary to meet the NYSDEC DAR-1 (formerly Air Guide –1) air discharge requirements.

Metals removal (iron pre-treatment) will be accomplished by oxidation/sedimentation. Precipitation of metal hydroxides will be achieved by chemical oxidant addition and pH adjustment. The precipitated metals and suspended solids will settle out in an inclined plate clarifier. This system will minimize fouling of the downstream air stripper, thereby ensuring reliable treatment of the VOCs.

The performance of the final treatment systems will be monitored as required by the substantive requirements of a NYSDEC SPDES permit. The groundwater extraction systems shall be designed to operate on a continuous basis (24 hours/day, 7 days/week) and will be automated, requiring minimal operator attendance under normal operating conditions. Sludge generated from the metals removal process will be disposed of off-site, requiring periodic operator intervention.

Equipment shall be provided in duplicate, where appropriate, so that the on-line spares will provide for uninterrupted service. The treatment systems shall be provided with an alarm and telemetry system such that system upsets are identified to the operator for immediate response.

The goal for the final groundwater treatment systems is to maintain uninterrupted groundwater extraction and treatment operation. However, it may be necessary to reduce the throughput to perform pretreatment or sludge handling tasks, routine, preventative maintenance or equipment change out. In some cases, it may be necessary to shut down the system for maintenance.

4.4.4 Permitting Requirements

Although permitting requirements are waived as part of the inactive hazardous waste disposal site program, the substantive requirements of the following permits will be met:

- SPDES water discharge permit (on-site and off-site treatment systems)
- Exhaust and Ventilation system permit
- Building Permit

4.4.5 Residual Waste Streams

The major waste stream to address is the VOC laden off gas from the air strippers. The air strippers are designed to effectively meet the remedial objectives and produce the minimum volume of off gas for treatment. Based on the on-site air stripper off-gas dispersion modeling the emissions are within DAR-1 guidelines and do not require off-gas controls. However, the off-site treatment system (in-well stripping or extraction/treatment) will have a design included for pollution abatement equipment at the request of the SCWA. The prime choices are vapor phase carbon or an oxidizer (thermal or catalytic). Either of these choices are provided as equipment packages, available from vendors experienced in their design, fabrication, installation, startup and O&M. For the final design, vapor phase carbon has been selected for the off-site treatment system, (refer to **Section 7.4**).

Secondary waste streams include metal hydroxide sludge, sand filter media, and spent bag filters. Both waste streams will be disposed off-site as solid wastes.

4.4.6 Retention Basin Design Basis

On-site treated water will be discharged to the ground surface of a town sump west of the site. **See Figure 4-3.** The Town of Babylon Public Works Department has approved of this discharge location.

Off-site treated water will be discharged to the local recharge basin to be constructed in close proximity to the proposed location of the off-site treatment system. The retention basin will be approximately 2,000 square feet in size and will include sufficient capacity for the 500-gpm maximum discharge rate. Refer to **Figure 4-4.**

4.4.7 Treatment System Enclosure

Year round operation of the treatment system requires protection from the elements and climate control within a suitable, permanent structure. The anticipated footprint of such a structure to house the equipment components, control area, and floor sumps for the treatment of on-site influent water system is estimated at 30-feet by 65-feet. Thus, the design basis of a 1,950 square foot permanent structure dictates a pre-engineered metal building on a slab-on-grade over other types of structures such as fabric buildings, greenhouses, or modularized trailers. Its location has been finalized during this phase of design as this is the smallest structure offered including iron pretreatment equipment. The building height of 18 feet has been designed to accommodate the cone bottom sludge thickener tank, which establishes the highest clearance. An elevation detail of the on-site treatment compound is illustrated in **Figure 4-5**. As a result, utility requirements, well locations and discharge locations have all been finalized and are shown on the final design drawings.

The anticipated footprint of such a structure to house the equipment components, control area, and floor sumps for the treatment of off-site influent water system is estimated at 85 feet by 67 feet. Thus, the design basis of a 5,695 square foot permanent structure dictates a pre-engineered metal building on a slab-on-grade over other types of structures such as fabric buildings, greenhouses, or modularized trailers. Its location has been finalized during this phase of design as this is the smallest structure offered including iron pretreatment equipment. The building height of 17 feet has been designed to accommodate the inclined plate clarifier, which establishes the highest clearance. This is the lowest profile possible to comply with the aesthetic demands of the SCWA and surrounding residences. An elevation detail of the off-site treatment compound is illustrated in **Figure 4-6**. As a result, utility requirements, well locations and discharge locations have all been finalized and are shown on the final design drawings.

Several vendors offer a "Butler" type of metal building, where the pre-engineering is the responsibility of the building vendor. The specifications and resultant shop drawings for these building will then become part of the Contract Documents. The materials of construction availability and building erection implementation easily fall within the timeframe of an extraction and treatment system installation. From a cost perspective, this type of structure is cost effective on a cost per square foot basis. The installation of the pre-engineered buildings will follow National Building Officials & Code Administrators (BOCA and local building code ordinances, including Suffolk County Sanitary Code – Article 12, **Appendix F**).

The treatment compounds for in-well stripping equipment will be designed to fit into modularized containers for the pilot testing. Based upon the pilot test results, the containers can be reused or added to in modular fashion for the full-scale in-well stripping scenarios, once the pilot test has been completed and the contractor has provided the full-scale design plans.

4.5 Other Design Criteria/Considerations

A listing of important design considerations not covered previously in this section that will impact the design of the groundwater treatment plant (GWTP) includes the following:

- The operating life expectancy of the GWTP and in-well stripping systems will be 30 years.
- All piping will be buried below the frost line for freeze protection.
- Secondary containment for the treatment equipment tanks, vessels, etc., will be designed into the building foundation.
- Materials of construction will be compatible with the fluids to be handled.
- The electrical classification is non-hazardous (unclassified) both outdoors and within the treatment building. Hence, explosion proof equipment is not required.
- Unattended operation to the greatest extent possible, for 24 hours per day. Reduction in the hours of daily operation by half has also been considered. (12 hours). Low maintenance equipment preferred.
- Limited form of remote telemetry via an Autodialer.
- The delivery approach shall be design-bid-build.
- As off-gas treatment requirements change more rapidly with time compared to water treatment requirements; consider rent/lease options for off-gas equipment components. Modular containers would be included in the rent/lease option for in-well stripping.
- Innovative alternative technologies have been explored but will not be utilized.
- Electric utilities, and service (clean) water will be required to operate the treatment systems. No other utilities are required.
- Article 12 shall be the design basis for indoor storage tanks and secondary containment features.

5.0 PERFORMANCE REQUIREMENTS FOR RECIRCULATION WELLS

5.1 On-Site In-Well Stripping System

The primary objective of the on-site in-well stripping system is to prevent further off-site migration of the VOC plume and remediate any remaining VOC contamination after the source area remedial action. This objective will be met by the installation of stripping wells at the downgradient boundary of the Heatset property. It is the vendor's responsibility, with Department approval, to determine the number of wells, their design, their location, and their depth. The vendor proposed system shall capture the migrating plume and remediate the aquifer to groundwater quality standards (**Table 4-2**). All off-gases generated by the system shall meet NYSDEC DAR-1 (formerly Air Guide-1) discharge requirements (**Table 4-3**).

5.1.1 Pilot Test Requirements

Prior to the installation of the vendor specified system, the vendor shall be required to install and operate one of the vendor designed in-well stripping wells at the Heatset property to demonstrate that the well system will meet the site performance standards. Primarily, this will be determined by the collection and analysis of water samples. The design of the pilot test will be presented in a workplan prepared by the vendor. Upon approval of the workplan, incorporating the Department's comments, the pilot test will be performed and a report will be written, which documents the pilot test activities and presents the preliminary design for the full scale systems. The pilot test must meet the following minimum requirements:

- Demonstrate horizontal influence in the aquifer at a designated minimum radius away from the stripping well through use of acceptable groundwater tracer compounds (chemical dyes or equivalent).
- Demonstrate vertical influence in the entire depth of the groundwater aquifer through the installation of nested monitoring wells at various depths in the aquifer. Two zones (shallow; from the water table interface to depth 45-feet below ground surface and deep; from 45 feet to a depth of 80 feet below ground surface) of measurement will be used at a minimum. Tracer compound, or other acceptable monitoring devices, must be used to demonstrate the influence.
- Demonstrate effective treatment of the water to the criteria shown in **Table 4-2** in the stripping well through collected and analyzed groundwater samples.
- Demonstrate effective collection and treatment to the criteria shown in **Table 4-3** of any gas from the stripping wells through the collection and analysis of air samples.
- Demonstrate treatment of the groundwater influenced by the in-well stripping system by the collection and analysis of groundwater samples collected from both the shallow and deep zones in the aquifer.

- Demonstrate effective operation of the in-well stripping equipment in terms of fouling by evidence of reductions in removal efficiencies or desired throughput should buildup occur.

The test results will provide information to calculate the actual contaminant removal rates and ensure that the system will be able to achieve groundwater quality standards throughout the impacted aquifer. The pilot test data will also be used to delineate the wells' area of influence. If these parameters differ from the original vendor specified parameters, the vendor shall modify the design as necessary to meet the required remediation goals. This test will be performed over a 60-120 day period, to be agreed upon by the NYSDEC and the vendor (60-90 days for installation and operation and 30 days for preparation of final report). All costs for this test shall be born by the vendor, it shall not be included as a line item in the bid. If the vendor is approved to install the full-scale remediation system, the NYSDEC will reimburse the vendor for the cost of the pilot test.

5.2 Off-Site Recirculation Well System

The primary objective of the off-site in-well stripping well system is to prevent further off-site migration of the VOC plume and to protect the Suffolk County Water Authority Albany Avenue Well Field. This objective will be met by the installation of stripping wells at the 10 ppb iso-concentration contour. The in-well stripping system design will incorporate data gathered during the field pilot test. It is the vendor's responsibility, with Department's approval, to determine the number of wells, their location, and their depth. The vendor proposed system shall capture the migrating plume and protect the Albany Avenue Well Field. All off-gases generated by the system shall meet substantive NYSDEC DAR-1 (formerly Air Guide-1) discharge requirements **(Table 4-3)**.

6.0 EVALUATION OF GROUNDWATER TREATMENT PLANT TREATMENT ALTERNATIVES

This section identifies and describes potentially applicable process options for the groundwater extraction and treatment scenario and provides a screening of each option. The groundwater at the Heatset site not only contains elevated levels of VOCs, but it also contains elevated levels of calcium, iron, and magnesium, which could foul the treatment system. Therefore, process options for the treatment of metals and VOCs have been reviewed to select equipment components for final detailed design.

6.1 Evaluation of Groundwater Treatment Process Options

The purpose of metals removal is to protect downstream VOC removal equipment from fouling or scaling. Not only is this a maintenance issue, but coating and scaling of VOC removal equipment could lead to a reduction in removal efficiencies below that required to meet the remedial objectives and discharge requirements.

Metals Removal

Chemical Precipitation and Sedimentation

Chemical precipitation and sedimentation are the most common method of metals removal. Precipitation is the physicochemical process whereby some or all of a substance in solution is transformed into a solid phase. Precipitation is based on altering the chemical equilibrium relationship of the soluble inorganic species by shifting the equilibrium towards the solid phase. Lime soda softening and oxidation are the most common types of precipitation in water treatment.

Lime soda softening refers to the addition of lime or sodium sulfide to the water in a rapid mixing tank along with flocculating agents. Within the rapid mixing tank and flocculation tank, adequate retention time is provided for the agglomeration of precipitate particles. The agglomerated particles are separated from the liquid phase by either sedimentation or filtration. Because iron is not effectively removed by softening, this type of chemical precipitation will not be retained.

Metals may also be precipitated by oxidation. Oxidation of the soluble metals may be accomplished by aeration, chlorination, ozonation, or chemical oxidation with potassium permanganate or hydrogen peroxide. Chemical oxidation is the most common method of iron removal. However, potassium permanganate is the oxidant of choice for these reasons:

- The elimination of aeration reduces the volume of off-gas generated, and hence, reduces the cost for off-gas treatment more significantly than does the savings cost per pound of O_2 delivered by aeration.
- Potassium permanganate has been proposed for *in situ* treatment of the source VOCs in the groundwater plume, hence, it has the potential to oxidize VOCs above ground in a continuous stirred tank reactor.
- Dry $KMnO_4$ is safer and easier to handle and store than hydrogen peroxide.

This process also alters the chemical equilibrium shifting the equilibrium to the solid phase. As with softening, agglomerated particles are separated from the liquid phase by sedimentation and/or filtration. Sedimentation is defined as the gravitational separation of particles from water. The primary purpose of sedimentation in groundwater treatment is to produce a clarified effluent for either discharge or further treatment. The removal of suspended particles by gravitational settlement is low cost and energy efficient. Sedimentation may be performed in sedimentation basins, plate separators, tube settlers, or clarifiers. To economize on space in the building, the most cost-effective sedimentation equipment is the inclined plate clarifier. These units are readily available and typically, there is suspended solids carryover of approximately 5 to 10 mg/L in the clarified water. Thus, filtration is required to remove the carryover solids to protect the downstream equipment from fouling.

Filtration is a physical process where suspended solids are removed from the liquid phase by passing the liquid through a porous media. Granular filtration is the most typical type of filtration. The filter media generally consists of a bed of granular particles, such as sand or sand with anthracite, supported by an underdrain within an enclosed vessel. The liquid passes through the filter media and is drawn off the bottom. The suspended particles are trapped on and within the filter media. The entrainment of particles within the bed reduces the filtration rate, thereby increasing the amount of pressure needed to force the liquid through the filter. In order to prevent plugging of the filter, the filter is backwashed at a high velocity to dislodge the particles. The backwash water then flows through a sludge dewatering system for final disposal. Filtration units typically require a large amount of space. Because of the anticipated space limitation in the groundwater treatment plant, the technology will be used to process carry over of solids but will not be retained for dewatering the metal sludge.

Another type of filtration, bag filtration, uses a fabric or non-woven material to remove micron sized particles. In general these filters are used in line or in series as polishing unit operation. This technology is being used as an effluent stream polishing step.

In summary, metals removal will be achieved by designing unit operations and process equipment that will raise the pH of the influent water and chemically oxidize the dissolved metals into metal hydroxide sludge. Caustic Soda (25% NaOH) is commonly used to raise the pH of influent groundwater and similarly, chemical oxidation via Potassium Permanganate has been selected for the site because it is effective, economical to use, and readily available.

Volatile Organic Compounds Removal

Mass Transfer – Air Stripping

Air stripping is a proven mass transfer technology for removing volatile organic compounds (VOCs) from groundwater. In an air stripping unit, the liquid is passed down over packing or trays while air is blown up through the liquid (countercurrent). The contaminants are transferred from the liquid phase to the gaseous phase as the air makes contact with the liquid. The packing or trays are used to increase the mass transfer between the air and liquid. Treated groundwater flows out of the bottom of the unit while the effluent gas is vented out of the top of the unit. The effluent gas may be vented to the atmosphere or to further treatment depending on contaminant concentrations. Air stripping is a cost effective and efficient means of removing contaminants with a Henry's Law Constant greater than 3E-3 atmosphere-cubic meters per mole (atm-m^3/mole). The Henry's Law Constants for the site-related contaminates are as follows: 1,1-Dichloroethene (0.19 atm-m^3/mole), 1,2-Dichloroethene (6.7E-2 atm-m^3/mole), 1,2-Dichloroethane (9.1E-4 atm-m^3/mole), 1,1,1-Trichloroethane (0.03 atm-m^3/mole), Vinyl Chloride (8.1E-2 atm-m^3/mole), Trichloroethene (9.1E-2 atm-m^3/mole), Tetrachloroethene (1.53E-2 atm-m^3/mole). The primary compounds of concern, PCE, 1,2-DCE and TCE all have favorable gas constants indicative of good removal using air stripping. The compound exhibiting the least favorable gas constant, 1,2-DCA, will still strip, but not as well as the other compounds listed. Based on reported influent concentrations both on site and off site, 1,2-DCA is below the discharge standards and is thus not a primary compound of concern, (see **Appendix E, Tab 2**).

A low-profile tray stripper is preferred over the packed column to minimize the height of the building. Moreover, the trays are designed to accept a higher solids loading before fouling interferes with VOC removal and to ease the maintenance requirements for cleaning once fouled compared to the packed column stripper.

Adsorption – Granular Activated Carbon

Granular activated carbon (GAC) is effective in removing a wide range of organic compounds. The activated carbon selectively adsorbs organics from the liquid phase by a surface attraction phenomenon (Van der Walls theory) in which organic molecules are attracted to the internal micropores of the carbon granules. The adsorption rate is controlled by the molecular attraction between the adsorbate and adsorbent, the molecular weight of the adsorbate, and the surface area of the carbon. **Appendix E, Tab 3** provides the supporting information and calculations that demonstrates the viability of utilizing GAC to remove the site-related contaminants (adsorbate).

GAC units operate in series or in parallel configurations. Operating the units in series is generally the most cost effective configuration and produces the lowest effluent concentrations compared to a parallel configuration. Once the GAC surface is equilibrated with the dissolved influent contamination concentrations, the carbon is considered "spent" and must be replaced or regenerated. Off-site regeneration is the preferred method. The time to reach "breakthrough" is a function of the adsorptive capacity of the carbon and influent concentration. Pretreatment steps such as air stripping can greatly enhance the carbon's life and reduce the need for frequent carbon replacement. This technology is retained as a polishing treatment for the primary VOC treatment, air stripping.

<u>Oxidation – Ultraviolet Light/Peroxide System</u>

An ultraviolet light/peroxide system uses hydrogen peroxide to oxidize the contaminants with ultraviolet light acting as the catalyst. The UV light converts the hydrogen peroxide into hydroxyl radicals, which are a strong oxidant. The hydroxyl radical then oxidizes the VOC contaminants into inert compounds. Process variables include UV energy dose, hydrogen peroxide dose, pH level, temperature, and mixing efficiency. Bench-scale studies are generally required to estimate these quantities and the size of the reactor.

In this process, water is pumped through a heat exchanger that regulates the inlet temperature. Hydrogen peroxide is injected into the line as the water enters the reactor, which is equipped with UV light lamps. As the water passes through the reactor, the contaminants are destroyed and the effluent is discharged. The operational costs associated with a UV/peroxide system are high due to the great amount of energy required to operate the system. Metals are also damaging to the system, therefore, significant metals pretreatment would be required. In addition, suspended solids limit the effectiveness of the UV lamps over time by coating them. Due to these reasons, this unit operation is not retained.

Off-Gas Treatment

<u>Carbon Adsorption</u>

Carbon adsorption is one of the most commonly used and cost effective off-gas treatments for the reduction of VOC emissions, with granular activated carbon the most widely used form of carbon. As with the liquid phase carbon adsorption system, the physical principal behind the carbon adsorption is the Van der Walls attractive potential between the adsorbate and the adsorbent. Again, as with the liquid phase system, the adsorption rate is controlled by the molecular attraction between the adsorbate and adsorbent, the molecular weight of the adsorbate, and the surface area of the carbon. For gas phase carbon adsorption, contaminants must have a molecular weight between 50 to 200 grams per gram-mole for efficient adsorption. Generally, if the influent gas stream concentration of total VOCs is more than 1,000 parts per million volume (ppmv) then other thermal or catalytic oxidation systems may be more cost effective.

GAC units typically operate either in series or in parallel configurations. Operating the units in series is generally the most cost effective configuration and produces the lowest effluent concentrations compared to a parallel configuration. Once the micropores are saturated, the carbon is considered "spent" and must be replaced or regenerated. Off-site regeneration is the preferred method. The time to reach "breakthrough" is a function of the adsorptive capacity of the carbon and influent concentration.

The carbon technology is retained for VOC emission control.

Catalytic Oxidation

Catalytic oxidation, also known as catalytic incineration, is a commonly applied combustion technology for controlling VOC emissions from waste streams. In catalytic oxidation a contaminant laden waste stream is heated with auxiliary fuel to between 600 and 900° F. The waste gas is then passed across a catalyst where the VOC contamination reacts with oxygen to form carbon dioxide, water, and hydrochloric acid. The effluent gas is then passed through a heat exchanger and hydrogen chloride scrubber to reduce the gas temperature and remove hydrochloric acid prior to discharge. This option is a cost effective and efficient method for treating high VOC concentration streams. This technique has been eliminated during the Final design phase.

6.2 Summary and Selection of Chosen Groundwater Treatment Process Options

Based on the review and evaluation performed in the previous section and considering the remedial objectives and the design basis/criteria established, the following process equipment options were selected for the groundwater treatment systems that primarily consist of Metals Removal (M), VOC Removal (V) and Polishing/Discharge/Residuals Management (P/D/R) unit operations.

- Chemical Oxidation with a chemical oxidant for iron and heavy metals removal (M)
- Clarification and Sedimentation (M)
- Filtration for removal of solids before air stripping process (M and R)
- Air Stripping for VOC removal (V)
- Bag filtration to protect downstream equipment (M and V and R)
- Granular Activated Carbon for air stripper effluent polishing prior to discharge (P and D)
- Carbon adsorption for air stripper off-gases (D and R) – (off-site only)

- Off-site disposal of the generated metal sludges (R)

7.0 FINAL GROUNDWATER TREATMENT SYSTEM DESIGN

The groundwater extraction rate for the on-site system was designed for a nominal flow rate of 100 gpm and a maximum design flow rate of 120 gpm for some of the equipment, while the off-site system extraction rate was estimated at 500 gpm and the equipment was sized appropriately for that flow. These extraction rates are 150% of the calculated extraction needed to contain the plume. This allows for system flexibility should the system need to be updated in the future. The influent contaminant concentrations used are those presented in **Section 4.3.**

In order to eliminate long transmission pipe runs, the need for additional pump stations, and the commingling of waters with significantly different chemical/treatment demands, the extracted groundwater will be processed through two separate treatment plants. One plant will be located on-site to treat the on-site contaminant plume. The second system will be located off-site at the downgradient edge of the off-site plume to treat the off-site contaminant plume. Treated groundwater from the on-site system will be discharged to a town sump and the discharge from the off-site system is proposed to go to a recharge basin to be constructed on the Suffolk County Water Authority property. The locations of the on-site treatment building, recovery wells and discharge point are shown on **Figure 4-3. Figures 4-2** and **4-4** show location of the treatment building, recovery wells and discharge point for the off-site system.

Calculations that show the size of a new recharge basin required for the off-site discharge are presented as **Appendix E, Tab 1.4**

The sections that follow describe the unit processes that will be used based on the anticipated influent concentrations, assumed discharge limits, the other design criteria and design basis established from **Section 4.4,** and equipment selection criteria from **Section 6.1.**

7.1 Unit Processes

An overview of the on-site and off-site extraction and treatment system unit processes are illustrated in the Process Flow Diagrams (PFDs) **Figures 7-1, 7-2** and **7-3** for the on-site treatment system and **Figures 7-4, 7-5** and **7-6** for the off-site treatment system. The following groundwater treatment system unit processes are common to the on-site and off-site systems:

- Groundwater Extraction (2 wells for on-site treatment, and 3 wells for off-site treatment)
- Equalization
- Metals removal consisting of: pH adjustment, chemical oxidation, filtration
- Multi-media filtration
- Air Stripping
- Bag Filtration
- Liquid-Phase GAC adsorption
- Discharge to a town sump (on-site) and a recharge basin (off-site)
- Off-gas treatment (off-site system only)
- Sludge storage, dewatering and disposal

The major equipment components involved in each unit operation (100 and 500 gpm) are summarized as follows:

1. Electric submersible pumps, buried pipe, and pipe manifold.
2. HDPE Equalization tank with a mixer for 100 gpm system and gravity feed to an oxidation tank. (Two Equalization Tanks for 500 gpm system)
3. HDPE Oxidation tank with mixer with gravity overflow to the Inclined Plate Clarifier, and chemical metering pumps for delivery systems for caustic and potassium permanganate.
4. Inclined Plate Clarifier (IPC), sludge pump and cone-bottom sludge storage tank with clarified gravity overflow to a surge tank.
5. Polymer Feed System for coagulation and precipitation of metal hydroxides in the IPC.
6. Pressure Filter to remove carryover solids before the air stripper.
7. Low profile tray-type air stripper with a blower and discharge pump for 100 gpm system (Two strippers in parallel for 500 gpm off-site system).
8. Bag Filter Assemblies for removal of carried over suspended solids.
9. Discharge stack for the on-site treatment system and Granular Activated Carbon (GAC) Adsorbers for polishing the air stripper off-gas for the 500-gpm system. (Note: Emissions from the 100-gpm system do not require carbon system.)
10. Treated Water HDPE Storage Tank with backwash supply pump, backwash hold tank and backwash transfer pump for 100 gpm system. (Two Treated Water HDPE tanks for 500-gpm off-site.)
11. One discharge pump and buried piping to the town sump for the on-site treatment system and to the SCWA recharge basin for the off-site treatment system.

The unit processes selected in this Final Design are low maintenance, field-proven, standard unit processes, for which there is significant performance data available for the capital equipment selected. The following subsections provide a description of the equipment components needed for these unit processes, identify key design parameters needed, and present the rational for the selection of a particular type of process equipment for the on-site system. **Appendix E, Tab 5** contains the calculations performed to select the various process equipment. The equipment descriptions follow the PFD drawings, **Figures 7-1, 7-2** and **7-3** for the on-site process and **Figures 7-4, 7-5,** and **7-6** for the off-site system. Equipment sizes, type, capacities, Materials of Construction (MOC), etc, are shown on the P&IDs, **Figures 7-8, 7-9, 7-10** for the on-site system and **Figures 7-11, 7-12** and **7-13** for the off-site system.

7.1.1 Groundwater Extraction

The on-site extraction system will consist of two extraction wells placed at the downgradient edge of the on-site plume (See **Figure 4-3**). These wells will each have a pumping capacity of 50 gallons per minute (gpm).

The off-site extraction system will consist of three extraction wells. One well will be installed along Benjoe Drive (125 gpm), just west of the Albany Avenue Field, and two wells (125 gpm and 250 gpm) will be positioned along Albany Avenue (**Figures 4-2** and **4-4**).

Optimum pipe sizes for this flow configuration of well laterals and headers were calculated and the calculations for each system are included in **Appendix E, Tab 6** for 100-gpm and 500-gpm systems. For the 100 gpm system, the laterals from individual extraction wells will be 2". For the 500 gpm system, the laterals from the 125 gpm and 250 gpm extraction wells will be 3" and 4", respectively. The configuration also economizes on the trenching requirements to convey, via buried pipe, extracted groundwater to the treatment building that will house the process equipment. Extraction well details and cross sections of the extraction and discharge trenching are shown in **Figures 7-14** and **7-15** for on-site and off-site systems.

Each extraction well will be equipped with a submersible pump sized to provide the design well yield at the required total dynamic head, plus reserve capacity. Each well will be capable of meeting design flow rates with sufficient head to discharge to the groundwater treatment system without in-line boost pumps (see **Appendix E, Tab 7**).

Each well will be metered with an automatic, continuous recording device that will measure to within + or - five percent of actual flow, as required by the necessary permits. Each well will be equipped with a manual flow control valve and readily accessible capped ports and drop pipes so that water levels may be measured under all conditions, as required.

7.1.2 Equalization

The purpose of the equalization tank(s) in each system is to: (1) dampen any flow variations resulting from changes in groundwater extraction rates, and (2) blend the groundwater extracted from different wells at the site and other waste streams (building sump, off-spec treated water, etc.) such that the concentration of contaminants is uniform to the subsequent unit processes, and (3) begin the pH adjustment and oxidation reactions by introducing chemicals to this tank.

The equalization tank will allow for a minimum of 30 minutes of residence time for attenuation and reaction. The equalization tanks for the on-site and off-site systems were designed with a 1.1 safety margin. The residence time calculations are found in **Appendix E, Tab 4**.

A tank agitator has been added to each tank to promote mixing of well water with the chemical additions. By adding the third function and the tank agitator, the reaction (oxidation) tank has been downsized. The equalization tank will be sealed and vented to minimize the emissions of VOCs into the treatment compound.

A second equalization tank for the off-site treatment system is needed to lower the overall hydraulic profile, and hence, the overall height of the off-site pre-engineered metal building.

7.1.3 Metals Removal

An oxidation/sedimentation process has been selected and designed that involves adding an oxidant source, $KMnO_4$, and raising the pH of the influent water using caustic soda (25%) for metal hydroxide precipitation of the dissolved iron and manganese. The Process Flow Diagram (PFD) indicates the use of metering pumps for the addition of NaOH to raise the pH to between 6.3 to 8.2, and a solution of $KMnO_4$.

To achieve the desired oxidation/sedimentation, oxidant and caustic are added and mixed by a tank agitator at the Equalization Tank. The Equalization Tank working volume of 4,000 gallons for the on-site system provides approximately 40 minutes of residence time at 100 gpm flow, which is sufficient to complete the reactions and attenuate the well waters. A total working volume of 18,000 gallons for the off-site system provides 36 minutes of residence time to complete the reactions and attenuate the off-site well water. To ensure complete pH adjustment and reaction, the residence time has been increased for both on site and off site systems by using an additional, small reaction tank, as a surge (oxidation) tank ahead of the IPC. At the Oxidation Tank, the residence time has been calculated at 5 minutes, and thus, the total reaction time for oxidation is 45 and 41 minutes. The reaction time for the off-site Equalization Tank and the Oxidation Tank has been calculated to be approximately 36 minutes. **Appendix E, Tab 4** provides the calculations used to determine the tank size for the desired residence times for the equalization and oxidation tanks. The Equalization and Oxidation Tanks will be supplied with stainless steel offset angle type of mixers.

There are two chemicals fed into each Equalization Tank: potassium permanganate ($KMnO_4$) and 25% sodium hydroxide (NaOH) solution. $KMnO_4$ solution is pumped from the $KMnO_4$ storage tank with a chemical metering pump. The 25% NaOH solution is pumped from a 120-gallon tote and 330-gallon tote for the on-site and off-site systems, respectively. There are two stackable totes for each system providing 240 and 660 gallons of the chemical for each system. The bottom tote is stationary and the top tote is replaced when empty.

The $KMnO_4$ tank capacities for the on-site (100 gpm) and off-site (500 gpm) treatment systems have been calculated to be 300 and 1,500 gallons, respectively. The metering pumps have been designed to pump at a maximum rate of 3.0 and 9.0 gallons per hour for the 100 gpm and 500 gpm systems, respectively

Based on the maximum 25% caustic feed rate of 5.6 gallons per day, the chemical stored in two 120-gallon totes will provide approximately 42 days of capacity. For the off-site system, which requires a maximum caustic feed rate of 30 gallons per day, the chemical will be delivered in 330- gallon totes (660 gallons total) to provide approximately 22 days of supply.

All metals removal calculations are located in **Appendix E, Tab 8**. The basis for influent metals concentrations used in the metals removal process is presented as **Table 7-1**.

7.1.4 Inclined Plate Clarifier

Reacted groundwater is pumped from the metals treatment process to an inclined plate clarifier (IPC) where coagulant and flocculent aids are added and mixed in flash/floc tanks ahead of the incline plate clarifier. IPCs are ideal for large GWPT systems because angled plates take up much less floor space than a typical, round clarifier in projecting the same square footage of collection area. The IPC selected for 100-gpm system is 7'-1"' W x 15'-6" L x 8' H. The IPC selected for the 500-gpm system has dimensions of 8'-6"' W x 26' L x 13' H. Additional height is required for removal of the plates for cleaning. Each IPC is equipped with three small tanks: 500-gallon (ON-SITE) and 2,500-gallon (OFF-SITE) oxidation, flash mix and floc tanks. The three ON-SITE and OFF-SITE tanks have dimensions of 7'-1"W x 6'-0"L x 9'-0"H and 8'-6""W x 18'-0"L x '-13'-0"H, respectively. Additional $KMnO_4$ is added to the oxidation tank to ensure complete oxidation of dissolved metals. The neat polymer is added at a 5-ppm dosage to the flash mix tank at a rate of 0.6 gallons per day for the 100-gpm system and 3.0 gallons per day for the 500-gpm system. The actual type of polymer and dosage will be determined during the system startup by performing jar tests. The Flash Mix and Floc tanks are designed for a minimum of 5-minute residence time.

Sedimentation of the metal hydroxides (along with solids) is promoted by these agents. Optimum types and dosage of polymer is achieved through jar testing of representative groundwater samples or during startup of the extraction and treatment system. Generally, for adequate flocculation of metal hydroxides, anionic polyacrylamide polymers are used in the range of 2 – 20 ppm depending upon groundwater (influent) characteristics. For sizing purposes in the final design, 5 ppm polymer was chosen. The metering pumps used to inject pre-diluted polymer have turndown ratios of up to 100:1 and can readily handle a 2 – 20 ppm (or greater) range of polymer treatment.

The resultant metal hydroxide floc drops to the bottom chamber of the IPC as sludge for collection and residuals management. Clarified water, with the dissolved metals of concern removed, overflows by gravity to a 1,700-gallon or 7,500-gallon IPC Surge Tank (for 100-gpm and 500 gpm systems, respectively), located after the IPC, and then is pumped to the next unit process operation – VOC removal.

Thus, a potassium permanganate reaction tank with agitator, flash mix tank, and floc tank, followed by the Inclined Plate Clarifier as a packaged unit have been sized for the removal of iron (and manganese) to levels below the discharge limits and for reliable operation of the VOC removal equipment at 100 gpm and at 500 gpm. The Inclined Plate Clarifier will be sealed and vented to minimize the emissions of VOCs into the treatment compound.

The calculations provided in **Appendix E, Tab 8** include the rate of chemical addition for the total $KMnO_4$, polymer and caustic feeds for the 100 gpm and 500 gpm clarifiers.

7.1.5 Multi Media Filter

A multi media filter will be placed in line between the inclined plate clarifier and the VOC removal system. This filter has been sized to remove any carryover solids from the clarifier and provide minimum pressure drop across the system. Each sand filter is 48 inches in diameter by 6 feet high for the 100-gpm system and 54" diameter by 10 feet 8 inches high for the 500-gpm system. Each filter system requires a periodic backwash cycle. Both filter assemblies will be skid mounted and pre-piped. Multi media filter technical information and product literature is included in **Appendix E, Tab 5**.

The backwash cycle for the 100 gpm system involves dual filter vessels: one is always on line during a backwash cycle of the dirtiest filter vessel. Backwash water is supplied from the treated water storage tank and backwash pumps. Refer to the P&IDs. Regular treatment operation continues with filtration occurring in the "standby" cleaner filter vessel and subsequent VOC removal proceeds normally after the vessel switch is made.

The backwash cycle for the 500 gpm system involves triple filter vessels filtering 165 gpm of water each. When the dirtiest filter reaches its differential pressure set point the backwash cycle begins. The automatic valves switch out the dirty vessel for backwash and feed forward filtered water is split between the filter vessel to be backwashed and the air stripper. The split is approximately 50/50. Thus, 250 gpm of water is remediated of VOCs (uninterrupted) and 250 gpm of filtered water is used for backwash.

7.1.6 Air Stripping

A low-profile air stripper will transfer the VOCs in the groundwater to an air stream created by the stripper blower. The air stripper selected for the 100 gpm system is designed for 53 to 1 air to water ratio to remove the VOCs in the liquid stream to below the discharge criteria. Two air strippers in parallel are needed to handle the 500 gpm design flow. Each of the two air strippers for the 500-gpm plant is designed to handle 250 gpm at an air to water ratio of approximately 54 to 1. The mass balance calculations performed for the ON-SITE and OFF-SITE systems are based on the influent contaminant concentrations as listed in Table 4-1 and the discharge criteria listed in Table 4-2. QED Environmental Inc. 6-tray air stripper (QED) and two North East Environmental Products (NEEP) 5-tray air strippers (for on-site and off-site, respectively), will reduce the VOCs in the liquid stream to levels below the water discharge permit requirements.

Calculations of the off-gas VOC concentrations for the 100-gpm air stripper, and the pair of 250-gpm strippers, indicate that no additional off-gas treatment is necessary. For the discharge air permit calculations, it is assumed that all of the VOCs are stripped from the water to the off-gas stream. Two vapor phase carbon vessels placed in a series arrangement were added to the 500-gpm air stripper off-gas discharge to remove VOCs prior to the discharge to the atmosphere at the request of the SCWA. VOC-laden off-gas will be directed to the off-gas treatment units described in **Section 7.4**.

All calculations and supporting documentation utilized to finalize the number of trays, air to liquid ratios, and operating parameters for the 100-gpm and 500-gpm air strippers can be referenced in **Appendix E, Tab 2**.

7.1.7 Filtration

To protect the liquid GAC vessels from fouling, the air stripper effluent is first pumped through bag filters to remove additional solids generated by aeration or pH changes. Two duplex bag filter assemblies are recommended for continuous operation of the treatment train for the 100-gpm system. Only one set of two bag filters arranged in series will be on line at a time. The bags will be changed periodically.

The filter housing holds standard 30-inch long bags. Thus, each dual assembly (two bags) will provide approximately 8.8 ft^2 of filtration surface area. The optimize bag micron size will be determined during and after start-up to balance particulate removal with O&M bag change out frequency.

Rosedale Duplex Model 22 bag filter (or equal) with automatic sequenced backwashing was selected as the most representative process option for filtration equipment in the 500-gpm system. Each bag filter assembly is designed to process up to 800 gpm and contains four filter bags. The 30-inch standard bag size provides 17.6 ft^2 of filtration area per filter housing. The two filters will be run in parallel. When the bags in one filter assembly become dirty and need to be changed, the total flow of 500 gpm can be processed through one bag filter., The optimized bag micron size will be determined during and after start-up to balance particulate removal with O&M bag change out frequency. For more information on the bag filter selection see **Appendix E, Tab 5**.

7.1.8 Process Pumps

Per the P&ID figures, the calculation set was performed to size and select other process pumps for both the on-site and off-site treatment systems (see **Appendix E, Tab 9**). Total dynamic heads (TDHs) and motor sizes for these transfer pumps are summarized in a table at the end of **Appendix E, Tab 9.**

7.1.9 Liquid Phase Carbon Polishing

To ensure complete compliance with substantive surface and groundwater discharge permit requirements, carbon filters serve as final polishing units. Should there be a stripper upset or shutdown for minor repairs/cleaning, the carbon will continue to remove VOCs. In the polishing mode, carbon filters installed in a lead-lag, reversible arrangement of two carbon filters in series works most effectively. When there is evidence of breakthrough in the lead vessel, the carbon filters are reversed before the carbon change out occurs. When the carbon is changed, the filters will be reversed again once breakthrough is monitored after the lead vessel.

For the 100-gpm system, each carbon vessel is filled with approximately 3,000 lbs of carbon. The two carbon vessels selected for the 500-gpm system contain approximately 10,000 lbs of carbon per vessel. Liquid phase carbon usage calculations are located in **Appendix E, Tab 3.**

7.2 Pre-Engineered Metal Buildings

The pre-engineered metal buildings for the on-site and off-site treatment systems will house all the process equipment to provide freeze protection. Each building shall include, at a minimum, the structural frame, foundation, metal walls, sloped roof system including gutters, trims, flashing and downspouts, vents, interior and exterior doors and windows, electric space heating system, internal and external lighting system, cables, conduits, switches and power distribution systems, and building exhaust units. The height of each treatment building has been established by the tallest equipment component. This is illustrated in the hydraulic profiles developed for the 100 and 500-gpm treatment systems, **Figures 7-16 and 7-17.**

The control room area (office space) will be equipped with a unit air conditioner, baseboard heat, ventilation, window and lighting. HVAC system for both treatment buildings' main floor areas have been designed for proper ventilation and sufficient heat for freeze protection. Only the office area will be heated and air conditioned to office conditions (see **Appendix E, Tab 12** for building heat calculations). For the 100-gpm system, the electric motors are of small enough size to combine the motor control center and the process controls into one Main Control Panel (MCP). The MCP will consist of appropriately sized motor starters and the Programmable Logic Controller (PLC). For the 500-gpm system, the larger electric motors in this system require a Motor Control Center for power distribution to the motors.

Equipment arrangement/plant layouts are shown in **Figures 7-18** and **7-19** for the on-site and off-site systems. Single line electrical diagrams are shown in **Figures 7-20** and **7-21,** respectively.

Roadworthy containers will be used to house the off-gas equipment associated with in-well stripping. Each modular container will be designed using the same HVAC guidelines as for ventilating and heating pre-engineered buildings. If space allows, there will be a separate area divided off in the container for the system controls and to serve as an office area for one person with heating and cooling.

7.3 Residuals Management

Sludge from the bottom of the IPC units will be pumped out periodically using an air-operated diaphragm pump. Evacuated sludge from the 100-gpm IPC will fill a 2,500-gallon cone bottom Sludge Holding Tank and a 7,500-gallon tank will collect sludge from the 500-gpm IPC located at the off-site facility. The sludge for disposal may contain residual VOCs and will need to be tested to determine the type of waste. The sludge holding tank has been sized to fit within the treatment compound and afford up to 7 days of storage time for the on-site facility and 5 days for the off-site system. The sludge from each sludge holding tank will be disposed of off site using a truck service. While the sludge settles in this tank, water will be decanted continuously by gravity for recycling to the Equalization tank. The sludge holding tank will also receive GAC and sand filter backwash water from the backwash holding tank when these units are periodically backwashed. Space has been reserved for the addition of a filter press at the off-site treatment compound because its use could be justified by lower disposal costs if the volume of sludge is reduced. This would be evaluated as part of the startup or acceptance of the installed treatment systems.

7.4 Off-Gas Treatment

Based on air modeling performed for the on-site and off-site treatment systems, the air discharge stripper concentrations are low enough to be discharged directly into the atmosphere without any additional treatment. However, the off-site system will require an off-gas treatment system, at the request of the SCWA. The off-gas treatment system will consist of two vapor phase carbon vessels placed in a series arrangement. The carbon vessels are designed to treat combined emissions from the process vents and off-gas from two air strippers. The combined stream will be characterized by mass balance calculations for 25% of the maximum VOC concentrations as a minimum threshold and at maximum (100%) concentrations at the same flow conditions.

Each carbon vessel selected for the 500-gpm system contains 8,000 pounds of activated carbon. Based on the carbon usage calculations, shown in **Appendix E, Tab 3,** 8,000 pounds of carbon should last approximately 41 days (or 82 days for 16,000 pounds total) before it is spent and needs to be replaced.

EPA Screen3 was utilized to perform air discharge modeling for the on-site and off-site treatment systems. This model incorporates input parameters including but not limited to stack height, distance to receptor, treatment building height, stack exit velocity and urban/rural dispersion option. Based on the air modeling, the on-site system will not require carbon for air discharge polishing. NYSDEC air emission standards will be met by utilizing a 1 ft. diameter stack with a total height of 26 ft. Air modeling performed for the off-site system indicated that air discharge polishing would not be required, depending upon the selection of the discharge stack height. However, air discharge polishing has been incorporated into the design of the request of the SCWA. The use of carbon for air discharge polishing resulted in a discharge stack height of 30 ft according to air modeling. Air model runs and input parameters are included in **Appendix E Tab 11.**

7.5 Process Control Description

This section provides a preliminary description of the process controls and PLC system for the groundwater extraction and treatment systems. The goals of the system process control and automation are to minimize the operator's daily routine and to minimize the operator time on site. The system automation provided will help define the degree of operator attention required and the extent of on-site and remote data handling. The degree of operator attention is discussed in the following subsection. An overview of the Final design and the process controls is illustrated in the Process and Instrumentation Diagrams (P&IDs), **Figures 7-8, 7-9** and **7-10** for the 100 gpm system and **Figures 7-11, 7-12** and **7-13** for the 500-gpm treatment system.

7.5.1 General

The process controls will be similar for the on-site and off-site treatment systems because they differ only in scale. The work related to the process control systems is beyond the scope of this final design report, but will include (but not be limited to) the supply, complete installation, and testing of:

- A microprocessor-based control system PLC to control and monitor the overall treatment system from the well fields to the final discharge of treated water.
- The specific control and data equipment to be used as shown in the final P&IDs.

7.5.2 Major Equipment Controls

A summary of the process control description is shown on the P&IDs for the Final design of the on-site and off-site extraction/treatment systems. Included in these details are the specifications for instrumentation, unit process alarms and safeguards, flow monitoring, feed rate adjustments, and interfaces with the PLC and autodialer.

7.6 Degree of Operator Attention

The following is a preliminary description of required operator attention for the major unit process operations as presented in this design.

Extraction/Collection System

Flow from the groundwater collection system (pump on/off operation) will be controlled automatically. Flow adjustments at each well will be controlled with manual valves.

Equalization, pH Adjustment, and Chemical Precipitation

Equalization requires operator attention to maintain the correct chemistry for the metals removal process. The chemical feed pumps will be automatically adjusted based on flow rate. However, if the water quality varies the operator must recheck the pH and oxidation dosages for optimum, cost-effective performance. In addition, the operator will also need to periodically check all of the chemical feed pumps, which will be controlled automatically through the use of controllers, using manual calibration techniques and routine maintenance, as well as routine maintenance to check the mixer operations.

Other tasks requiring operator attention include:

- Refilling the chemical storage day tanks will be arranged by the operator
- Premixing of potassium permanganate solution, polymer drum deliveries and disposal will be arranged by the operator.

- Scheduling delivery of the 25% NaOH solution in totes.

Flocculation and Clarification
The variable speed drive on the flocculating mixer requires manual adjustment to be set.

Air Stripping
Air stripping is fully automatic requiring minimal operator attention. A pressure wash of a removed tray will be required periodically. For the larger strippers, a dilute acid wash may be required after several pressure washes.

Sand Filter
The multi-media unit will have its own local controls for automatic operations including backwashing and vessel sequencing. The operator is to confirm that there is an adequate amount of treated water in the treated water holding tank and adequate storage in the sludge holding tanks before sand filter backwashing.

Bag Filters
Bag filtration is fully automatic requiring minimal operator attention. Bag filter replacements will be the responsibility of the operator.

Liquid and Vapor-Phase GAC Adsorbers
Spent carbon change outs will be the responsibility of the operator. Backwashing of the liquid GAC will be operator-initiated and manually controlled. The operator is to confirm that there is an adequate amount of treated water in the treated water holding tank and adequate storage in the Backwash Holding and Sludge Holding tanks before initiating GAC backwashing.

Discharge System
The discharge system is fully automated requiring minimal operator attention. Liquid phase carbon may raise the pH of the polished water. To handle potential pH adjustment requirements, an automated acid feed system is included in the system as shown on the P&IDs (**Figures 7-10** and **7-13** for the on-site and off-site systems, respectively). The operator is to manage the inventory of acid (supplied in drums).

7.7 Residual Wastes Management

Metals removal via oxidation/sedimentation is the most labor-intensive operation of the groundwater extraction and treatment systems describe in the previous sections. The sludge holding tanks have been sized to hold approximately ten and eight days of metal sludge for the 100 and 500 gpm systems, respectively. Filter bag changeouts by the operator would occur during any site visit. This will be less when sand filter and GAC backwashing occur. GAC backwashing will occur infrequently, but there will be daily backwashing volume from the sand filters. The operator must carefully monitor and manage the sludge holding operation of filling, decanting, and evacuation. The operator frequency schedule described for Equalization, pH adjustments, etc., would be the same as described in **Section 7.6**, above; however, it may take longer to reach state or to convert from daily to weekly scheduling for the waste management operations. Furthermore, it may take an operator more than 8 hours per day at the start of operation to carry out metals removal along with the other standard operations.

7.8 Monitoring

Existing and proposed monitor wells will be used to monitor the performance of the extraction systems and document compliance with the groundwater quality objectives. The identification of existing wells and placement of proposed wells will be sufficient to monitor upgradient and down gradient water quality at each extraction system location.

At the National Heatset property, existing monitor wells will be used upgradient of the area of influence of the extraction system wells. A new monitoring well will be placed downgradient of the extraction system wells, as shown in **Figure 4-1** and **4-3**. For the off-site treatment system, one monitor well will be placed upgradient of the extraction system wells and two monitor wells will be placed downgradient of the extraction system wells, as shown in **Figures 4-2** and **4-4**.

Monitor wells will be sampled quarterly for volatile organics and results will be reported to the NYSDEC.

8.0 SPECIFICATIONS LIST AND PROJECT SCHEDULE FOR DETAILED DESIGN

8.1 List of Specifications for Detailed Design

A list of the specification sections that are required for completion of the contract documents and to bid the construction of the groundwater extraction, treatment, and discharge systems are shown in **Table 8-1**. These specification sections have been selected based on the Construction Specification Institute Master Format™, 1995 edition. Each section is marked as applicable:

- to in-well stripping,
- to extraction and treatment (GW Pump and Treat)
- by building trade or craft (general, mechanical, plumbing or electrical) or

8.2 Project Schedule

The proposed implementation schedule is illustrated for the on site and off site extraction and treatment systems in **Figures 8-1 and 8-2,** respectively and for the in-well stripping system in **Figure 8-3**. The significant scheduling differences between the two approaches arise from the need to pilot test in-well stripping, and, the significantly longer construction schedule for extraction/treatment. Pre-construction activities/deliverables are included in the implementation schedules.

9.0 REFERENCES

Duffield, G. M., 1998 AQTESOLV for Windows User's Guide. Hydrosolve, Inc. Reston, VA.

Erdmann, J. B., 2000. On capture width and capture zone gaps in multiple well systems. *Groundwater* 38:4:497-504.

Jensen, H. M. and J. Soren, 1974. Hydrogeology of Suffolk County, Long Island, New York. Hydrologic Investigations Atlas HA-501. U. S. Geological Survey. Washington, DC.

Keely, J. F. and C-F. Tsang, 1983. Velocity plots and capture zones of pumping centers for ground-water investigations. *Groundwater* 21:6:701-714.

Neuman, S. P. 1974. Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response. *Water Resources Research*, 10:303-312.

TABLES

Table 3-1
Summary of Aquifer Pump Test Analysis Results
National Heatset Printing
Babylon, New York

Monitoring Well	Maximum Drawdown (feet)	Estimated Transmissivity (feet^2/day)	Estimated Hydraulic Conductivity[1] (feet/day)	Estimated Specific Yield	Curve Fit Data Quality
MW-2A	0.348	10,260	147	0.23	Good
MW-3A	0.339	8,764	125	0.23	Good
MW-4A	0.302	9,759	139	0.08	Fair
MW-9	0.727	777	11	0.20	Poor
Average Values:		9,594	137	0.18	
Median Values:		9,759	139	0.23	
Geometric Mean:		9,574	137	0.16	

Notes:

[1] Hydraulic Conductivity (Kh) = Transmissivity (T)/ Aquifer Thickness (b)

Transmissivity solved by AQTESOLV computer program.

Hydraulic conductivity calculated based on average aquifer thickness of 70 feet.

Specific yield was determined by the AQETSOLV program.

Drawdown was recorded by the installation of transducers in each well.

Data quality of fair or better was used in the calculation of average values.

Table 3-2
Calculation of Pumping Rate for Groundwater Extraction System Design
National Heatset Printing Site
Babylon, New York

On-Property Treatment System

Gradient	Average Hydraulic Conductivity (feet/day)	Capture Width at Recovery Well (feet)	Saturated Thickness (feet)	Pumping Rate (ft^3/day) [1]	Pumping Rate (gpm)	Upgradient Capture Width (feet)[2]	Downgradient Capture Distance (feet)[2]
0.00147	164	450	70	15,188	**79**	900	143

Notes:
Gradient is average site gradient as determined by site gauging data.
Hydraulic conductivity value provided from Table 3-1.
Hydraulic conductivity is high range of conductivities calculated from pump test analysis.
Capture width desired determined by width of property boundary.
Aquifer thickness of site averages 70 feet.
[1] [Gradient x Hyd. Conductivity (ft/dy) x Capture Width (ft) x Sat. Thickness (ft)] x 2= Pumping Rate (cubic ft/dy)
[2] Parameter not used in design of system.
Calculation of capture zone was performed using complex flow potential methodology (Keely & Tsang, 1983 and Erdman, 2000).
The capture width at an infinitely upgradient point is twice that predicted at the recovery well.
The capture width downgradient of the recovery well is equivalent to the upgradient width/2

Downgradient Treatment System

Gradient	Average Hydraulic Conductivity (feet/day)	Capture Width at Recovery Well (feet)	Saturated Thickness (feet)	Pumping Rate (ft^3/day)	Pumping Rate (gpm)[1]	Maximum Well Spacing (feet)[2]	Upgradient Capture Width (feet)	Downgradient Capture Distance (feet)
0.0018	164	1,520	70	62,972	**327**	395	3,040	484

Notes:
Gradient according to 2001 gauging data.
Hydraulic conductivity value provided from Table 3-1.
Hydraulic conductivity is high range of conductivities calculated from pump test analysis.
Aquifer thickness of site averages 70 feet.
[1] [Gradient x Hyd. Conductivity (ft/dy) x Capture Width (ft) x Sat. Thickness (ft)] x 2= Pumping Rate (cubic ft/dy)
[2] Distance between wells along Albany Avenue, based on angle of 30 degrees betweem Albany Avenue and the direction of flow.
Width of site was assumed to be the maximum width of the 1.0 mg/L isopleth for total VOCs in groundwater at 75 - 85 feet bgs. (H2M,1999; Figure 4.3)
Calculation of capture zone was performed using complex flow potential methodology (Keely & Tsang, 1983 and Erdman, 2000).
Upgradient capture width and downgradient capture distance are presented to illustrate predicted extent of capture zone.

Table 3-2
Calculation of Pumping Rate for Groundwater Extraction System Design
National Heatset Printing Site
Babylon, New York

Downgradient Treatment System (2002 Data)

Gradient	Average Hydraulic Conductivity (feet/day)	Capture Width at Recovery Well (feet)	Saturated Thickness (feet)	Pumping Rate (ft^3/day)	Pumping Rate (gpm)[1]	Maximum Well Spacing (feet)	Upgradient Capture Width (feet)	Downgradient Capture Distance (feet)
0.0018	164	1,100	70	45,461	**236**	370	2,200	350

Notes:
Gradient according to 2001 gauging data.
Hydraulic conductivity value provided from Table 3-1.
Hydraulic conductivity is high range of conductivities calculated from pump test analysis.
Aquifer thickness of site averages 70 feet.
[1] [Gradient x Hyd. Conductivity (ft/dy) x Capture Width (ft) x Sat. Thickness (ft)] x 2= Pumping Rate (cubic ft/dy)
Width of site was assumed to be the maximum width of the 1.0 mg/L isopleth for total VOCs in groundwater at 75 - 85 feet bgs. (H2M,1999; Figure 4.3)
Calculation of capture zone was performed using complex flow potential methodology (Keely & Tsang, 1983 and Erdman, 2000).
Upgradient capture width and downgradient capture distance are presented to illustrate predicted extent of capture zone.

Table 3-3
Maximum Capacity of Aquifer within Groundwater Extraction System Capture Zone
National Heatset Printing
Babylon, New York

Distance to Upgradient Divide[1]	Width of Plume	Recharge Rate	Available Flow to Well	
(feet)	(feet)	(inches/year)	(ft^3/day)	(gpm)
28,000	450	25	71,918	374
28,000	1,520	25	242,922	1,262

Notes:
[1] Taken from USGS, 1974.
[Dist. To Upgradient Divide (ft) x Plume Width (ft) x Recharge Rate (in/yr)] x [1 (ft)/12 (in)] x [1(yr)/365 (dy)] = Flow to Well (cubic feet/day)

Table 4-1
Estimated Influent Concentrations
National Heatset
Babylon, New York

CHEMICAL OF CONCERN	ON-SITE ESTIMATED INFLUENT CONCENTRATION (UG/L)	OFF-SITE ESTIMATED INFLUENT CONCENTRATION (UG/L)	OFF-SITE ESTIMATED INFLUENT CONCENTRATION 2002 (UG/L)
1,1-Dichloroethene	-	1.3	---
1,2-Dichloroethene*	3,500	330	100
1,2-Dichloroethane	-	-	---
1,1,1-Trichloroethane	-	4	---
Vinyl Chloride	-	32.4	---
Trichloroethene	650	103	41
Tetrachloroethene	1,400	11,900	680

On-site concentrations are estimated using the maximum concentrations detected during the July 26, 2001 sampling event. The off-site concentrations are estimated using the maximum concentrations detected as reported in the 1999 Record of Decision.

Table 4-2
Clean-up Criteria for Groundwater
National Heatset
Babylon, New York

CHEMICAL OF CONCERN	NYS WATER QUALITY STANDARDS 6 NYCRR 703.5 (UG/L)
1,1-Dichloroethene	5
1,2-Dichloroethene*	5
1,2-Dichloroethane	0.6
1,1,1-Trichloroethane	5
Vinyl Chloride	2
Trichloroethene	5
Tetrachloroethene	5

NA – Not Available
*- Values presented are for the trans 1,2-DCE isomer
Shading indicates chosen clean-up criteria

Table 4-3
Off-gas Discharge Requirements
National Heatset
Babylon, New York

CHEMICAL OF CONCERN	SGS SHORT TERM GUIDELINE CONCENTRATIONS NYSDEC DAR-1 (UG/M^3)	AGC ANNUAL GUIDELINE CONCENTRATIONS NYSDEC DAR-1 (UG/M^3)
1,1-Dichloroethene	NA	0.02
1,2-Dichloroethene*	NA	1,900
1,2-Dichloroethane	NA	0.038
1,1,1-Trichloroethane	NA	NA
Vinyl Chloride	180,000	0.02
Trichloroethene	54,000	0.45
Tetrachloroethene	1000	1.0
Hydrogen Chloride	150	20

Table 7-1
Influent Metals Concentrations Utilized in Metals Removal for Groundwater Treatment System
National Heatset Printing
Babylon, New York

Data Source/Well ID.	Iron Concentration (ppm)	Manganese Concentration (ppm)
Design Report	7.27	0.746
RI Data		
Table 4.30		
MW-7	5.07	1.4
MW-9	1.8	1.7
MW-14	2.6	1.9
Table 4.26		
MW-7	2.2	0.07
MW-7A	0.8	0.04
Suffolk County Data		
Albany Ave Well No. 4A	0.53	0.01
Albany Ave Well No. 5	0.53	0.01
Albany Ave Well No. 6	0.92	0.03

Notes:
Iron concentration utilized in Design Report was determined by applying a 1.4 multiplier to the highest iron concentration observed in previous data.
Manganese concentration utilized in Design Report was determined by applying a 1.15 multiplier to the average manganese concentration observed in previous data.

Table 8-1 National Heatset
Table of Contents
Supplemental Specifications

	Specification Title/Technology Description	In-Well Stripping	GW Pump & Treat: General Contract	GW Pump & Treat: Electrical Contract**	GW Pump & Treat: Mechanical Contract	GW Pump & Treat: Plumbing Contract
DIVISION 1	GENERAL INFORMATION					
Section 01010	Summary of Work	X	X	X	X	X
Section 01036	Decontamination	X	X			
Section 01045	Cutting and Patching	X	X			X
Section 01051	Survey	X	X			X
Section 01060	Regulatory Requirements	X	X			
Section 01090	Reference Standards	X	X	X	X	X
Section 01110	Environmental Protection	X	X			X
Section 01120	Site Maintenance	X	X			
Section 01200	Health and Safety	X	X			
Section 01202	Progress Meetings	X	X			
Section 01300	Submittals	X	X	X	X	X
Section 01400	Quality Control	X	X	X	X	X
Section 01410	Sampling and Analysis	X	X			
Section 01590	Field Offices	X	X	X		
Section 01600	Material Storage and Equipment	X	X	X	X	X

Table 8-1 National Heatset Table of Contents Supplemental Specifications						
	Specification Title/Technology Description	**In-Well Stripping**	**GW Pump & Treat: General Contract**	**GW Pump & Treat: Electrical Contract****	**GW Pump & Treat: Mechanical Contract**	**GW Pump & Treat: Plumbing Contract**
Section 01700	Contract Close-Out	X	X			
Section 01710	Site Restoration	X	X			
DIVISION 2	**SITE WORK**					
Section 02110	Clearing and Grubbing	X	X			
Section 02111	Excavation and Handling of Contaminated Material	X	X			
Section 02200	Earthwork Terms	X	X			X
Section 02220	Excavation and Subgrade Preparation	X	X			X
Section 02223	Transportation and Disposal	X	X			
Section 02225	Trenching	X	X	X		
Section 02227	Waste Material Disposal	X	X			X
Section 02350	Sheeting and Shoring	X	X			X
Section 02401	Dewatering	X	X			X
Section 02415	Wastewater/Stormwater Management	X	X			
Section 02444	Chain Link Fence and Gates	X	X			
Section 02450	Soil Erosion and Sediment Control	X	X			
Section 02480	Topsoil and Seeding	X	X			
Section 02513	Hot Mix Asphalt Concrete Pavements	X	X			

Table 8-1 National Heatset Table of Contents Supplemental Specifications						
	Specification Title/Technology Description	**In-Well Stripping**	**GW Pump & Treat: General Contract**	**GW Pump & Treat: Electrical Contract****	**GW Pump & Treat: Mechanical Contract**	**GW Pump & Treat: Plumbing Contract**
Section 02605	Underground Piping - General	X	X	X		
Section 02685	Extraction Wells		X	X		
Section 02686	Re-circulation Wells	X				
Section 02687	Monitoring Wells	X	X			
Section 02688	Infiltration Basin		X			
DIVISION 3	**CONCRETE**					
	Refer to the Contract Document: Standard Specifications					
DIVISION 8	**DOORS AND WINDOWS**					
See Section 13120	Pre-assembled Metal Door and Frame Units	*	X			
See Section 13120	Overhead Doors	•	X			
See Section 13120	Steel Windows	*	X			
DIVISION 9	**FINISHES**					
Section 09250	Gypsum Drywall	*	X			
Section 09910	Paints/Interior and Exterior	*	X			
DIVISION 10	**SPECIALTIES**					
	NOT USED					

Table 8-1 National Heatset
Table of Contents
Supplemental Specifications

	Specification Title/Technology Description	In-Well Stripping	GW Pump & Treat: General Contract	GW Pump & Treat: Electrical Contract**	GW Pump & Treat: Mechanical Contract	GW Pump & Treat: Plumbing Contract
DIVISION 11	**EQUIPMENT**					
Section 11205	Process Tanks		X	X		
Section 11210	Process Pumps – Centrifugal Pumps		X	X		
Section 11211	Sludge Pumps – Air-Operated Diaphragm		X			
Section 11212	Vertical Sump Pump		X	X		
Section 11214	Submersible Well Pumps		X	X		
Section 11220	Mixers		X	X		
Section 11225	Inclined Plate Clarifier		X			
Section 11240	Chemical Feed and Storage Systems		X	X		
Section 11241	Polymer Feed System		X	X		
Section 11246	Sand Filters		X	X		
Section 11302	Startup & Testing of the Extraction and Treatment Systems		X	X	X	X
Section 11303	Operation and Maintenance of the Extraction & Treatment Systems and In-Well Stripping Systems	X	X			
Section 11308	Bag Filtration System		X			
Section 11346	Carbon Adsorption System		X			
Section 11347	Vapor Phase Carbon Adsorption System	X	X			

Table 8-1 National Heatset
Table of Contents
Supplemental Specifications

	Specification Title/Technology Description	In-Well Stripping	GW Pump & Treat: General Contract	GW Pump & Treat: Electrical Contract**	GW Pump & Treat: Mechanical Contract	GW Pump & Treat: Plumbing Contract
Section 11405	Low Profile Air Stripper System		X	X		
Section 11700	Compressed Air System	X	X	X		
Section 11800	In-well Stripping System(s)	X				
DIVISION 13	**SPECIAL CONSTRUCTION**					
Section 13120	Pre-Engineered Metal Building (including doors and windows from Div. 08 and Louvers from Div. 10)	*	X	X	X	X
Section 13121	Lightning Protection			X		
Section 13301	Remediation Sites with Containerized Treatment Systems	X*				
Section 13420	Instrumentation	X	X	X		
DIVISION 15	**MECHANICAL**					
Section 15001	General Requirements for Plant Piping Systems	X	X			X
Section 15050	Piping Installation	X	X			X
Section 15060	Pipe and Pipe Fittings	X	X			X
Section 15064	High Density Polyethylene (HDPE) Pipe and Fittings	X	X			
Section 15080	Pipe Couplings and Expansion Joints	X	X			X
Section 15100	Valves, Flowmeters and Accessories	X	X			X

Table 8-1 National Heatset Table of Contents Supplemental Specifications						
	Specification Title/Technology Description	**In-Well Stripping**	**GW Pump & Treat: General Contract**	**GW Pump & Treat: Electrical Contract****	**GW Pump & Treat: Mechanical Contract**	**GW Pump & Treat: Plumbing Contract**
Section 15140	Supports, Anchors and Seals	X	X			X
Section 15763	Heating, Ventilating, and Air Conditioning	X*			X	
DIVISION 16	**ELECTRICAL**					
Section 16100	General Electrical Requirements	X	X	X		
Section 16192	Programmable Logic Controller		X	X		
Section 16400	Service and Distribution - Motor Control Centers		X	X		
Section 16510	Lighting Systems	X		X		

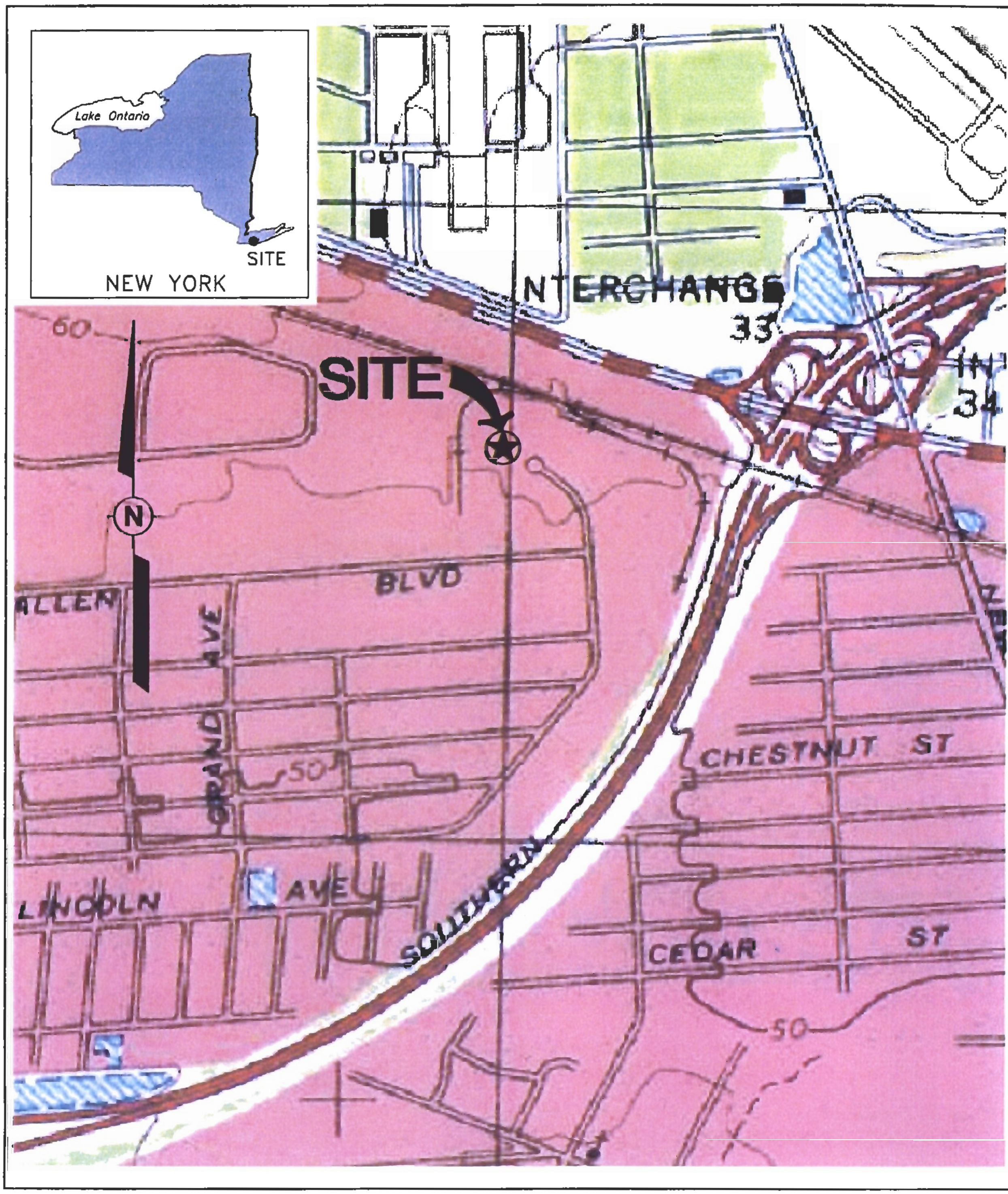
* In well stripping treatment contractors are forbidden to use pre-engineered or other types of permanent buildings, and shall use other more modular structures, e.g., sheds, sea-land containers, etc, to house above ground equipment components.

** The electrical contractor shall be responsible for the entire electrical installation.

FIGURES

OFFICE Trenton, NJ

DRAWING NUMBER 802901-A2-A



SITE LOCATION MAP

FIGURE 1-1

REFERENCE:

USGS TOPOGRAPHIC MAP OF BABYLON, NEW YORK
DATED AUGUST 1978.

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	DL	EW	EW	100% DESIGN ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
0	12/8/03	DL	EW	EW	95% DESIGN ON-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: --

DRAWN BY: C. Agabiti

CHECKED BY: E. Weinberg

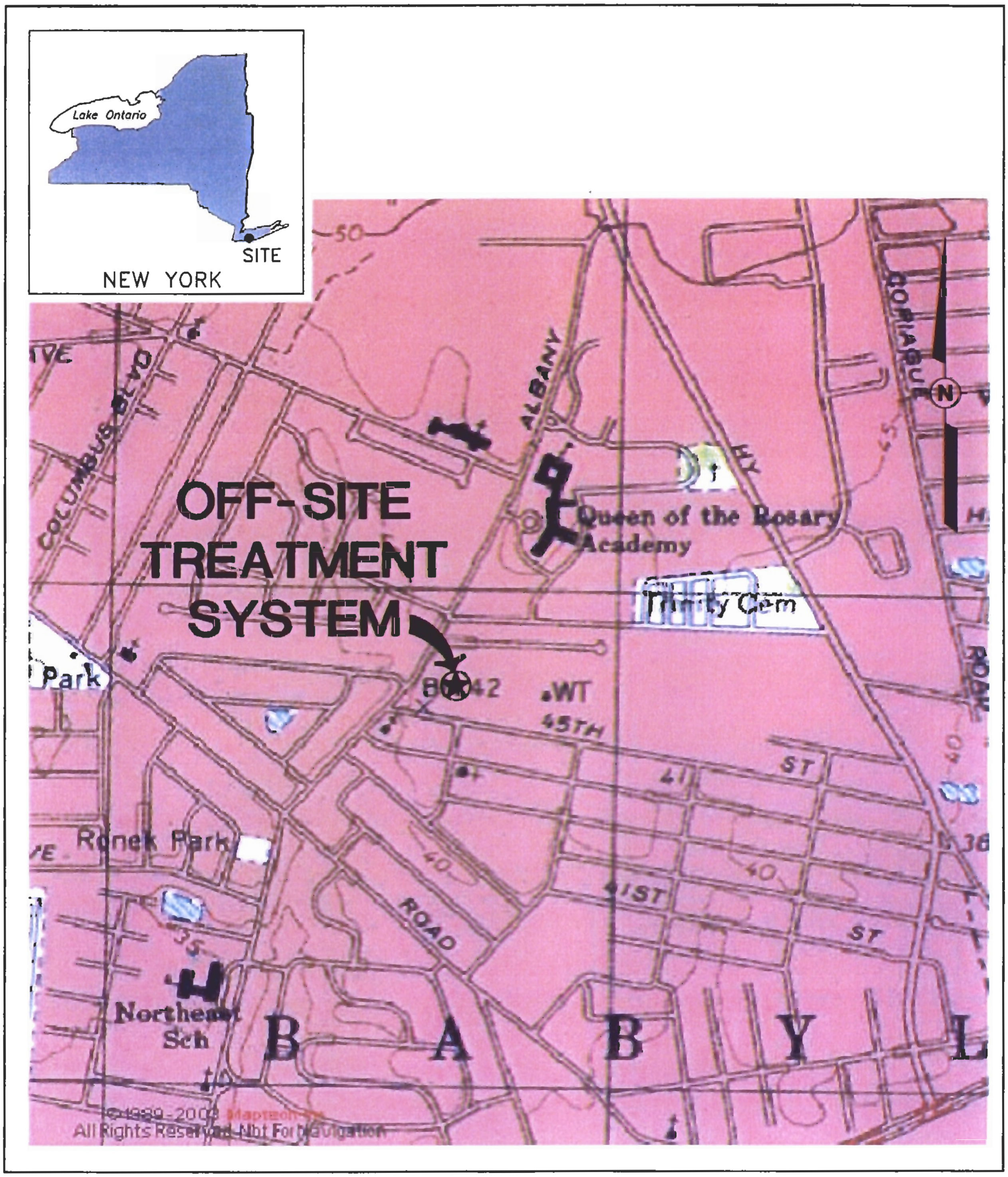
APPROVED BY: EW

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
SITE LOCATION MAP
NATIONAL HEATSET SITE (ON-SITE)

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
11/03	NTS	802901-A2-A		4

DWG FullPath: K:\PROJECT\802901\Construct Bid 8-04 On-Site\802901-A2-A.dwg
Plot Date/Time: 09/08/04 09:00am
Image:babylonUSGSOS



SITE LOCATION MAP

FIGURE 1-2

REFERENCE:

USGS TOPOGRAPHIC MAP OF BABYLON, NEW YORK
DATED AUGUST 1978.

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	DL	EW	EW	100% DESIGN ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
0	12/8/03	DL	EW	EW	95% DESIGN ON-SITE

Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: --

DRAWN BY: C. Agabiti

CHECKED BY: E. Weinberg

APPROVED BY: EW

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
SITE LOCATION MAP - SCWA SITE (OFF-SITE)

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/8/03	NTS	802901-A3-A		4

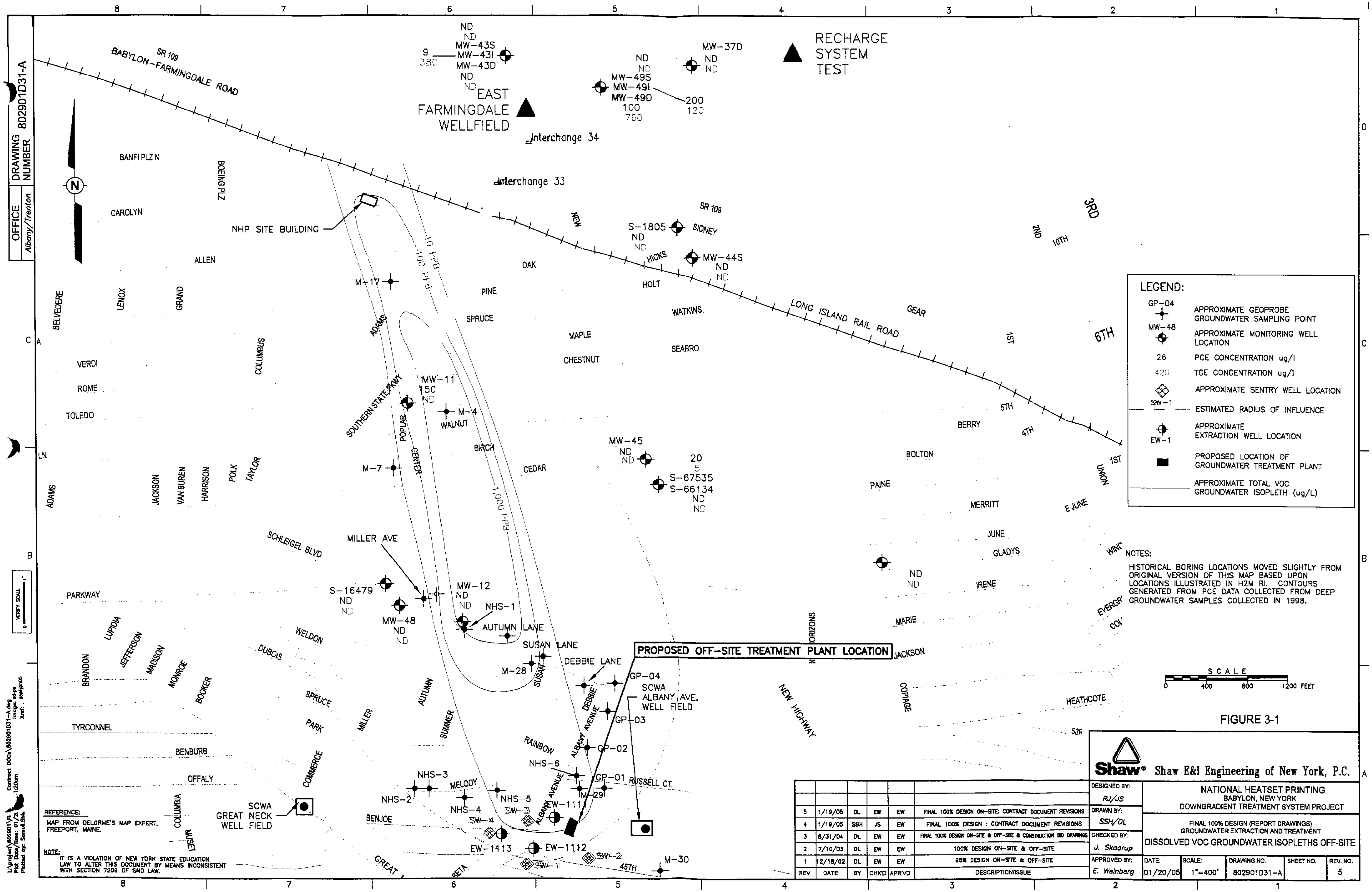
OFFICE Trenton, NJ

DRAWING NUMBER 802901-A3-A

DWG path: K:\PROJECT\802901\Construct Bid 8-04 On-Site\802901-A3-A.dwg

Plot Date/Time: 09/08/04 09:04am

Image:babylonUSGSOS



OFFICE Albany/Trenton
DRAWING NUMBER 802901D31-A
BABYLON-FARMINGDALE ROAD
SR 109
EAST FARMINGDALE WELLFIELD
RECHARGE SYSTEM TEST
Interchange 34
Interchange 33
NHP SITE BUILDING
LONG ISLAND RAIL ROAD
10 PPB
100 PPB
1,000 PPB
MW-43S
MW-43I
MW-43D
MW-37D
MW-49S
MW-49I
MW-49D
S-1805
MW-44S
M-17
MW-11
M-4
M-7
MW-45
S-67535
S-66134
S-16479
MW-48
MW-12
NHS-1
M-28
GP-04
GP-03
GP-02
GP-01
NHS-6
M-29
NHS-3
NHS-2
NHS-4
NHS-5
SW-3
SW-4
SW-1
SW-2
EW-1111
EW-1112
EW-1113
M-30
MILLER AVE
AUTUMN LANE
SUSAN LANE
DEBBIE LANE
ALBANY AVENUE
RUSSELL CT.
PROPOSED OFF-SITE TREATMENT PLANT LOCATION
SCWA ALBANY AVE. WELL FIELD
SCWA GREAT NECK WELL FIELD
SOUTHERN STATE PKWY
NEW HIGHWAY
LEGEND:
GP-04 APPROXIMATE GEOPROBE GROUNDWATER SAMPLING POINT
MW-48 APPROXIMATE MONITORING WELL LOCATION
26 PCE CONCENTRATION ug/l
420 TCE CONCENTRATION ug/l
SW-1 APPROXIMATE SENTRY WELL LOCATION
ESTIMATED RADIUS OF INFLUENCE
EW-1 APPROXIMATE EXTRACTION WELL LOCATION
PROPOSED LOCATION OF GROUNDWATER TREATMENT PLANT
APPROXIMATE TOTAL VOC GROUNDWATER ISOPLETH (ug/L)
NOTES:
HISTORICAL BORING LOCATIONS MOVED SLIGHTLY FROM ORIGINAL VERSION OF THIS MAP BASED UPON LOCATIONS ILLUSTRATED IN H2M RI. CONTOURS GENERATED FROM PCE DATA COLLECTED FROM DEEP GROUNDWATER SAMPLES COLLECTED IN 1998.
SCALE 0 400 800 1200 FEET
FIGURE 3-1
REFERENCE: MAP FROM DELORME'S MAP EXPERT, FREEPORT, MAINE.
NOTE: IT IS A VIOLATION OF NEW YORK STATE EDUCATION LAW TO ALTER THIS DOCUMENT BY MEANS INCONSISTENT WITH SECTION 7209 OF SAID LAW.
Shaw E&I Engineering of New York, P.C.
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT
FINAL 100% DESIGN (REPORT DRAWINGS)
GROUNDWATER EXTRACTION AND TREATMENT
DISSOLVED VOC GROUNDWATER ISOPLETHS OFF-SITE
DESIGNED BY: RJ/JS
DRAWN BY: SSH/DL
CHECKED BY: J. Skaarup
APPROVED BY: E. Weinberg
DATE: 01/20/05
SCALE: 1"=400'
DRAWING NO. 802901D31-A
REV. NO. 5
5 1/19/05 DL EW EW FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4 1/19/05 SSH JS EW FINAL 100% DESIGN : CONTRACT DOCUMENT REVISIONS
3 8/31/04 DL EW EW FINAL 100% DESIGN ON-SITE & OFF-SITE & CONSTRUCTION BID DRAWINGS
2 7/10/03 DL EW EW 100% DESIGN ON-SITE & OFF-SITE
1 12/18/02 DL EW EW 95% DESIGN ON-SITE & OFF-SITE
REV DATE BY CHK'D APPR'VD DESCRIPTION/ISSUE

LEGEND

- DEEP MONITORING WELL
- SHALLOW MONITORING WELL
- SENTRY WELL LOCATION (PROPOSED)
- IN-WELL STRIPPING TREATMENT AREA
- EXTRACTION WELL LOCATIONS (PROPOSED)
- SEDIMENT SAMPLE
- GEOPROBE POINT
- EDGE OF PAVEMENT
- CONCRETE
- CURB
- DROP CURB
- BOLLARD
- WALL
- RAILROAD
- CHAIN LINK FENCE
- UTILITY POLE
- ANCHOR
- OVERHEAD WIRES
- STANDPIPE
- CATCH BASIN FIELD INLET (DW=DRY WELL)
- MANHOLE
- SEWER MANHOLE
- UNDERGROUND SEWER (PAINT MARK)
- GAS METER
- UNDERGROUND GAS LINE (PAINT MARK)
- HYDRANT
- WATER VALVE
- UNDERGROUND WATER LINE (PAINT MARK)
- UNDERGROUND ELECTRIC LINE (PAINT MARK)
- CONTOUR LINE (0.5' INTERVAL)

WELL ELEVATION TABLE (in feet)

I.D. NO.	GROUND	TOP OUTER CASING	TOP INNER CASING
MW-1	56.88	56.88	56.60
MW-2A	58.40	58.40	58.00
MW-3A	58.36	58.36	57.95
MW-4A	58.24	58.24	57.94
MW-5	56.95	56.98	56.56
MW-6	59.00	59.03	58.61
MW-7	58.48	58.49	58.19
MW-8	58.08	58.08	57.75
MW-9	57.24	57.24	56.93
MW-10	58.32	58.32	58.00
MW-11	51.00	51.00	50.70
MW-12	44.35	44.35	44.04
I.D.NO	GROUND	TOP PVC	TOP CASING
MW-A	59.34	59.11	59.34
MW-B	59.13	58.76	59.13
MW-C	59.56	59.28	59.56
MW-E	59.52	59.24	59.52
MW-F	59.50	58.99	59.50
MW-G	59.63	59.39	59.63
MW-H	58.04	57.77	58.04

NOTE:
MW-11 IS ABOUT 1792' SOUTH AND 418' EAST OF SOUTHERN MOST PLOTTED POINT.
MW-12 IS ABOUT 3665' SOUTH AND 468' EAST OF SOUTHERN MOST PLOTTED POINT.

PROPOSED RECOVERY WELL TABLE

I.D. NO.	EASTING	NORTHING
RW-5110	1146951.54	201280.16
RW-5120	1146872.43	201184.25

PROPOSED SENTRY WELL TABLE

I.D. NO.	EASTING	NORTHING
SW-A	1146902.3	201150.0

NOTES:

1) HORIZONTAL DATUM: N.Y.S. PLANE COORDINATE SYSTEM, NAD 83, LONG ISLAND ZONE

2) VERTICAL DATUM: NGVD 1929

3) DATE OF FIELD SURVEY: 6/25/97, 12/1/99, 4/18/01

4) ALL INVERT AND PIPE ELEVATIONS SHOWN MEASURED AS VISIBLE AT TIME OF SURVEY. DIRECTION AND DESTINATION OF SOME PIPES NOT KNOWN OR DETERMINABLE FROM SURFACE OBSERVATIONS

5) NO BENCHMARK IN VICINITY AVAILABLE WITH NAVD 88 ELEVATIONS

6) SURVEY COMPLETED BY YEC, INC.

SCALE 0 30 60 90 FEET

FIGURE 4-1

REFERENCE:
BASE MAP SOURCE: YEC, INC.

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	DL	EW	EW	95% DESIGN ON-SITE, RELOCATED TREATMENT BLDG; DISCHARGE TO RETENTION BASIN

Shaw™ Shaw Environmental & Infrastructure, Inc.

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

EXTRACTION WELL LOCATIONS AND IN-WELL STRIPPING TREATMENT AREA - ON-SITE

DESIGNED BY:	DRAWN BY:	CHECKED BY:	APPROVED BY:	DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
R. Josoitis	HD / DL	E. Weinberg	E. Weinberg	12/6/02	AS SHOWN	802901-D30-A		5

K:\PROJECT\802901\Construct Bid 8-04 On-Site\802901D30-A.dwg
Plot Date/Time: 01 11:17am
Plotted by: david.li

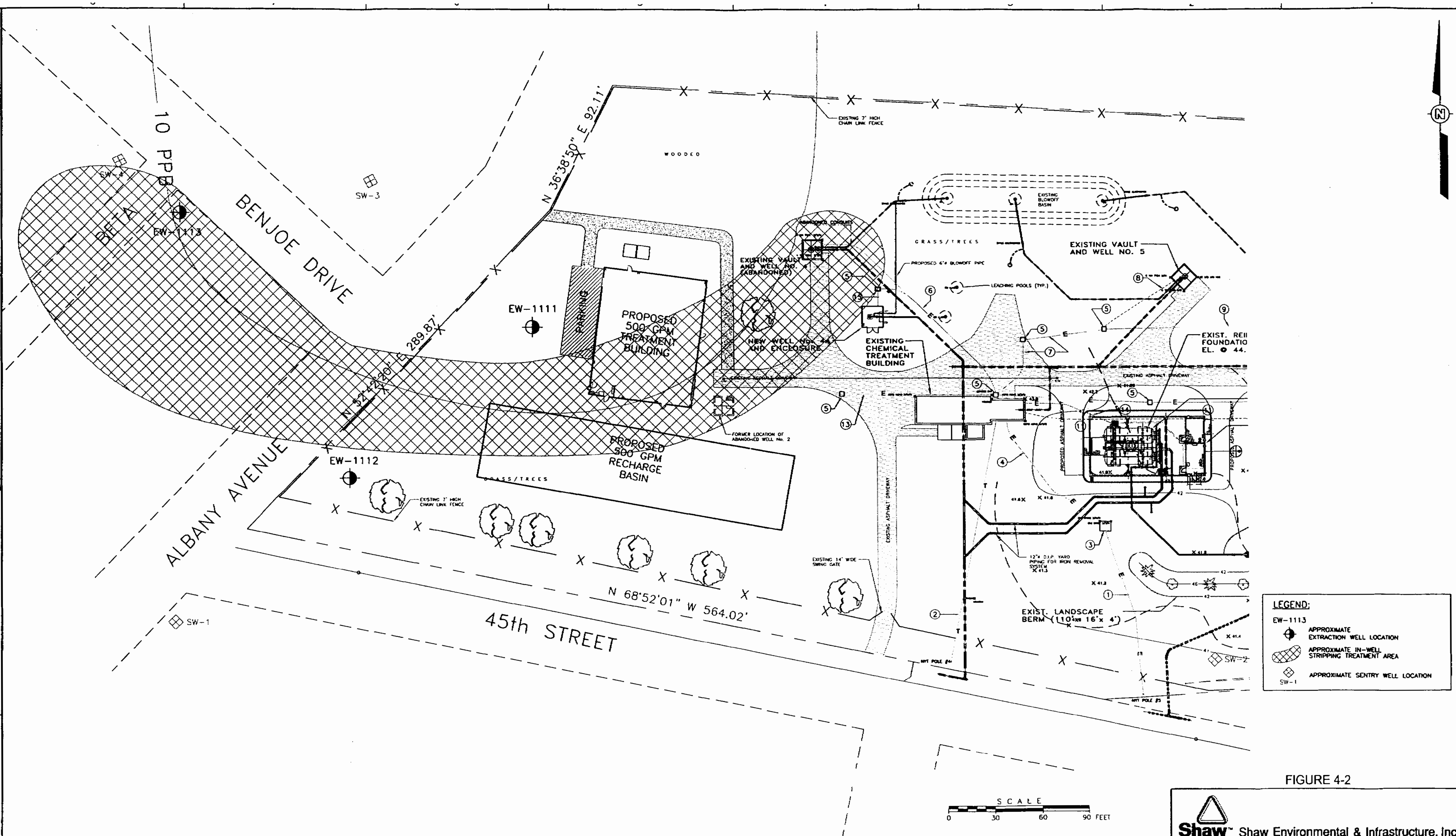


FIGURE 4-2

GENERAL NOTES:

1. THIS DRAWING WAS COMPILED FROM DRAWING NO. XAM-638-1 NORTH AMITYVILLE, TOWN OF BABYLON." PREPARED BY ALBERT F. TAGUE JR. LAND SURVEYOR, 1035-A MERRICK ROAD, COPAIGUE, N.Y.
2. ALL ELEVATIONS REFER TO USC AND GS DATUM
3. RE-CIRCULATION WELL LOCATIONS TO BE DETERMINED BY CONTRACTOR AND APPROVED BY NYSDEC

REFERENCE:

BASE MAP SOURCE:
SUFFOLK COUNTY WATER AUTHORITY.

REV	DATE	BY	CHK'D	APPR'VD	DESCRIPTION/ISSUE
5	1/21/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	SSH	JS	EW	100% FINAL DESIGN: OFF-SITE
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	50% DESIGN OFF-SITE

Shaw Environmental & Infrastructure, Inc.

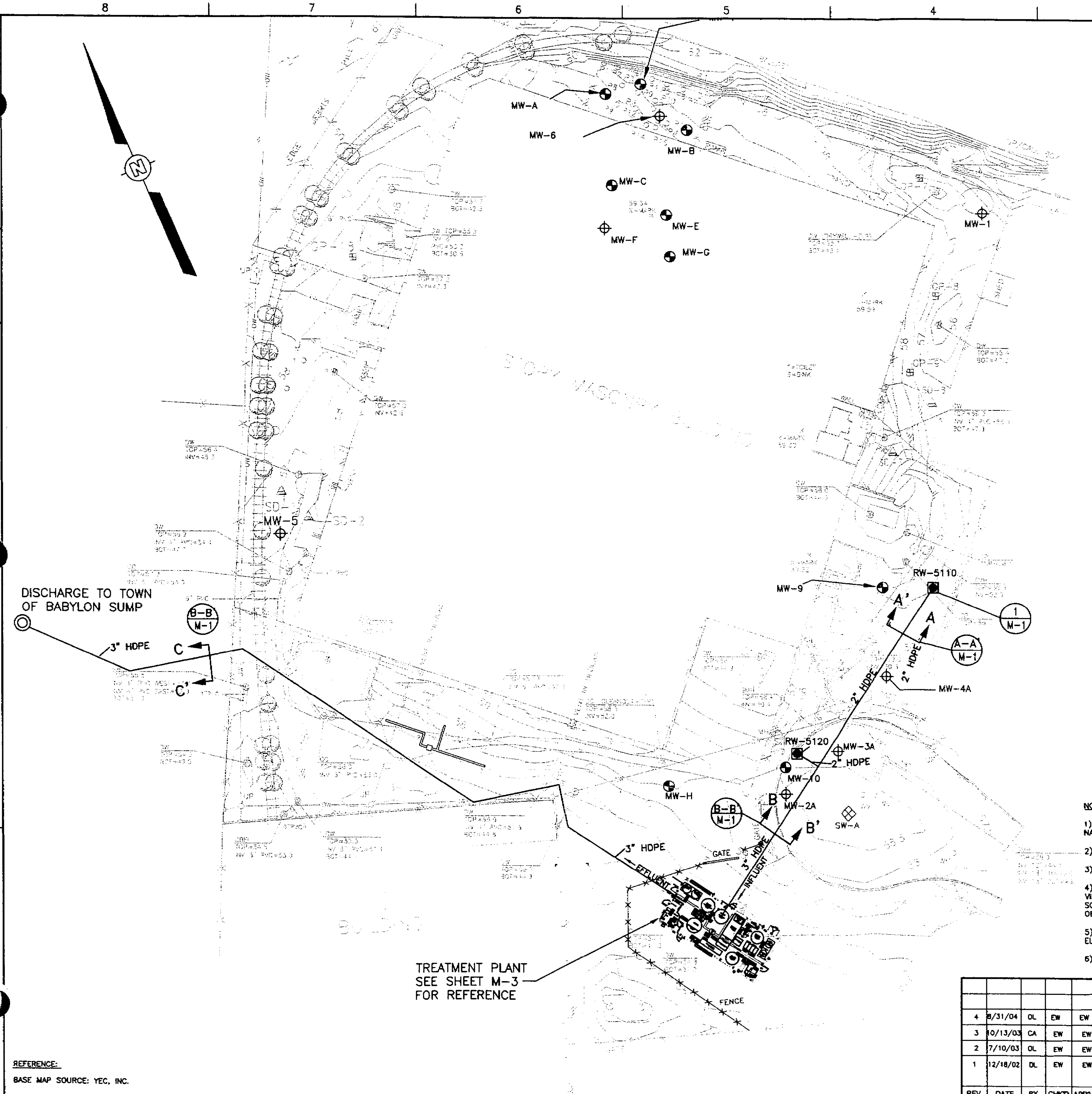
DESIGNED BY: J. Skaarup, R. Jasoitis
DRAWN BY: C. Agabiti
CHECKED BY: J. Skaarup
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
EXTRACTION WELL LOCATIONS AND
IN-WELL STRIPPING TREATMENT AREA (OFF-SITE)

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D102	C-3	5

OFFICE Trenton, NJ
DRAWING NUMBER 802-102



LEGEND

- DEEP MONITORING WELL
- SHALLOW MONITORING WELL
- PROPOSED SENTRY WELL LOCATION
- SEDIMENT SAMPLE
- GEOPROBE POINT
- EDGE OF PAVEMENT
- CONCRETE
- CURB
- DROP CURB
- BOLLARD
- WALL
- RAILROAD
- CHAIN LINK FENCE
- UTILITY POLE
- ANCHOR
- OVERHEAD WIRES
- STANDPIPE
- CATCH BASIN FIELD INLET (DW=DRY WELL)
- MANHOLE
- SEWER MANHOLE
- UNDERGROUND SEWER (PAINT MARK)
- GAS METER
- UNDERGROUND GAS LINE (PAINT MARK)
- HYDRANT
- WATER VALVE
- UNDERGROUND WATER LINE (PAINT MARK)
- UNDERGROUND ELECTRIC LINE (PAINT MARK)
- CONTOUR LINE (0.5' INTERVAL)
- EXTRACTION WELL, PROPOSED LOCATIONS
- GROUNDWATER TREATMENT PLANT PROPOSED LOCATION

WELL ELEVATION TABLE (in feet)

I.D. NO.	GROUND	TOP OUTER CASING	TOP INNER CASING
MW-1	56.88	56.88	56.60
MW-2A	58.40	58.40	58.00
MW-3A	58.36	58.36	57.95
MW-4A	58.24	58.24	57.94
MW-5	56.95	56.98	56.56
MW-6	59.00	59.03	58.61
MW-7	58.48	58.49	58.19
MW-8	58.08	58.08	57.75
MW-9	57.24	57.24	56.93
MW-10	58.32	58.32	58.00
MW-11	51.00	51.00	50.70
MW-12	44.35	44.35	44.04
I.D.NO	GROUND	TOP PVC	TOP CASING
MW-A	59.34	59.11	59.34
MW-B	59.13	58.76	59.13
MW-C	59.56	59.28	59.56
MW-E	59.52	59.24	59.52
MW-F	59.50	58.99	59.50
MW-G	59.63	59.39	59.63
MW-H	58.04	57.77	58.04

NOTE:
MW-11 IS ABOUT 1792' SOUTH AND 418' EAST OF SOUTHERN MOST PLOTTED POINT.
MW-12 IS ABOUT 3665' SOUTH AND 468' EAST OF SOUTHERN MOST PLOTTED POINT.

PROPOSED RECOVERY WELL TABLE

I.D. NO.	EASTING	NORTHING
RW-5110	1146951.54	201280.16
RW-5120	1146872.43	201184.25

PROPOSED SENTRY WELL TABLE

I.D. NO.	EASTING	NORTHING
SW-A	1146902.3	201150.0

NOTES:

1) HORIZONTAL DATUM: N.Y.S. PLANE COORDINATE SYSTEM, NAD 83, LONG ISLAND ZONE

2) VERTICAL DATUM: NGVD 1929

3) DATE OF FIELD SURVEY: 6/25/97, 12/1/98, 4/18/01

4) ALL INVERT AND PIPE ELEVATIONS SHOWN MEASURED AS VISIBLE AT TIME OF SURVEY. DIRECTION AND DESTINATION OF SOME PIPES NOT KNOWN OR DETERMINABLE FROM SURFACE OBSERVATIONS

5) NO BENCHMARK IN VICINITY AVAILABLE WITH NAVD 88 ELEVATIONS

6) SURVEY COMPLETED BY YEC, INC.

SCALE 0 30 60 90 FEET

FIGURE 4-3

REFERENCE:
BASE MAP SOURCE: YEC, INC.

OFFICE Trenton, NJ | DRAWING NUMBER 80290 5-A

REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	DL	EW	EW	95% DESIGN ON-SITE, RELOCATED TREATMENT BLDG; DISCHARGE TO RETENTION BASIN

Shaw Environmental & Infrastructure, Inc.

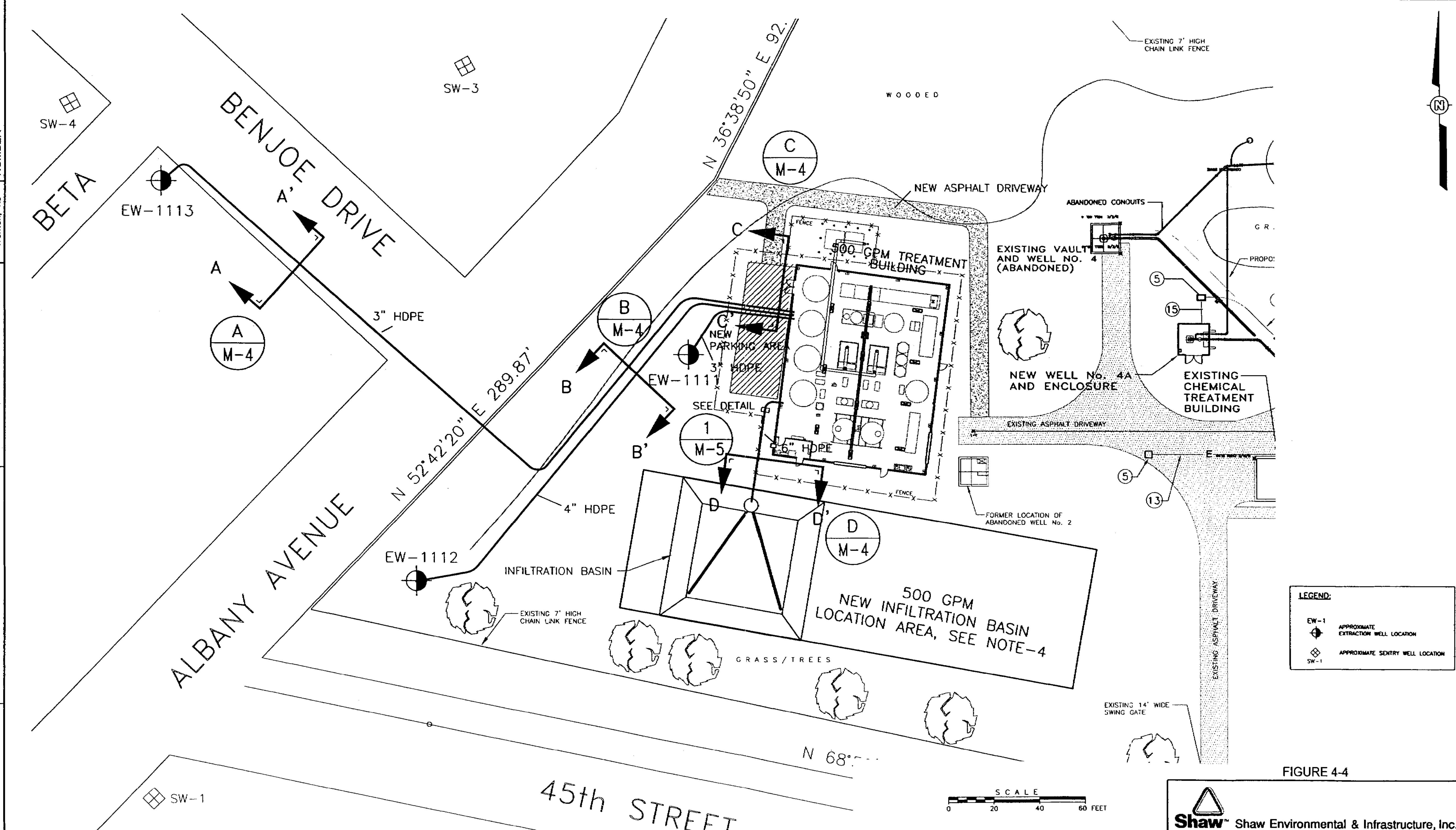
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

REMEDIATION SITE PLAN - ON-SITE

DESIGNED BY:	MJ/RJ/EW
DRAWN BY:	HD / DL
CHECKED BY:	E. Weinberg
APPROVED BY:	E. Weinberg

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	AS SHOWN	802901-D45-A		4



GENERAL NOTES:

1. THIS DRAWING WAS COMPILED FROM DRAWING NO. KAM-638-1 NORTH AMITYVILLE, TOWN OF BABYLON" PREPARED BY ALBERT F. TAGUE JR. LAND SURVEYOR, 1035-A MERRICK ROAD, COPAIGUE, N.Y.
2. ALL ELEVATIONS REFER TO USC AND GS DATUM
3. SENTRY WELL SW-2 NOT SHOWN, SEE FIGURE 4-2
4. FINAL LOCATION OF THE BASIN SHALL BE WITHIN THE AREA OUTLINED

REFERENCE:

BASE MAP SOURCE:
SUFFOLK COUNTY WATER AUTHORITY.

FIGURE 4-4

Shaw Environmental & Infrastructure, Inc.

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
3	10/01/03	DL	MJ	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	50% DESIGN OFF-SITE

DESIGNED BY: J. Skaarup, E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: J. Skaarup
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
REMEDIATION SITE PLAN - OFF-SITE

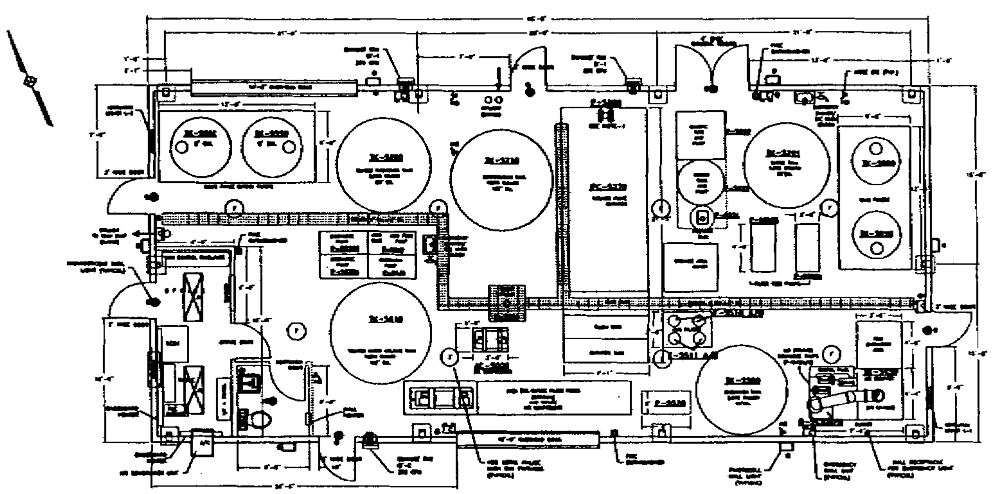
DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D101		5

OFFICE: Trenton, NJ
DRAWING NUMBER: 80290■D101

K:\PROJECT\802901' Bid 8-04 Off-Site\802901-0101-A.dwg
Plot Date/Time: 01, 7pm Image: .
Plotted by: david.lee Xref: .

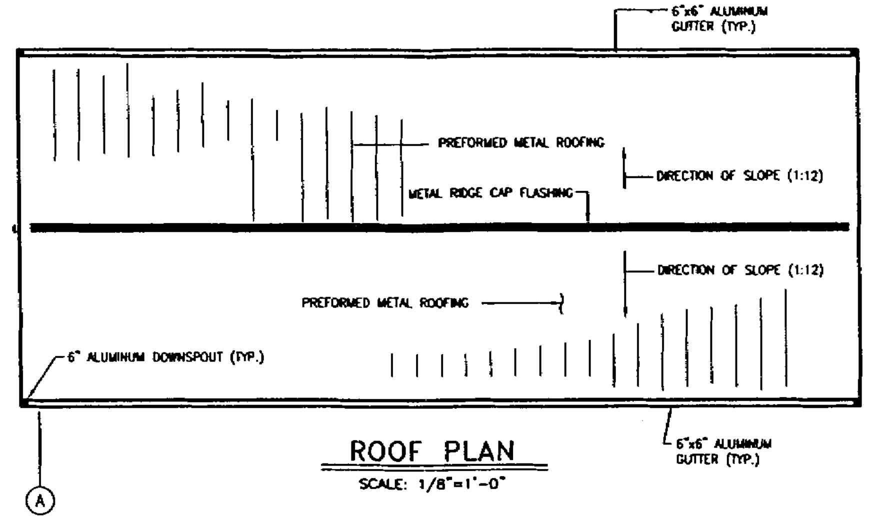
OFFICE Trenton, NJ

DRAWING NUMBER 8029[illegible]D32-A



PLAN VIEW

SEE SHEET M-3 FOR EQUIPMENT GENERAL ARRANGEMENT

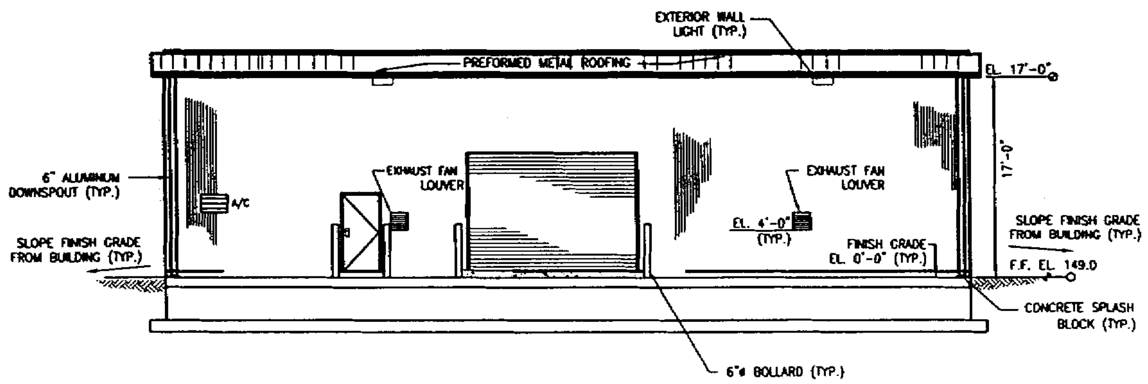


ROOF PLAN

SCALE: 1/8"=1'-0"

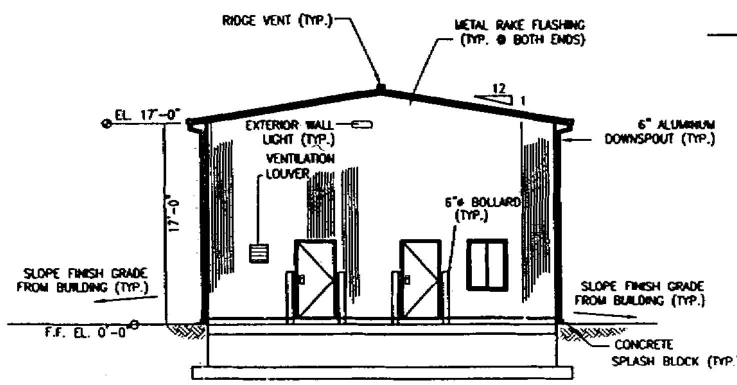
NOTES:

1. BUILDING COMPONENTS SHALL BE DESIGNED BASED ON APPLICABLE SECTIONS OF THE CURRENT EDITION OF AISC OR AISI SPECIFICATIONS AND MBMA RECOMMENDED DESIGN PRACTICE MANUAL. METAL BUILDING DETAILS SHOWN ARE BASED UPON STANDARD INDUSTRY PRACTICE. CONSTRUCTION DETAILS WILL VARY AMONG METAL BUILDING MANUFACTURERS. CONTRACTOR SHALL COORDINATE NON-STANDARD DETAILS WITH BUILDING MANUFACTURER.
2. ALL STRUCTURAL MILL SECTIONS AND WELDED PLATE SECTIONS SHALL BE DESIGNED IN ACCORDANCE WITH AISC'S LATEST "SPECIFICATION FOR THE DESIGN, FABRICATION AND ERECTION OF STRUCTURAL STEEL FOR BUILDINGS."
3. ALL COLD FORMED STEEL STRUCTURAL MEMBERS SHALL BE DESIGNED IN ACCORDANCE WITH AISI'S LATEST "SPECIFICATION FOR THE DESIGN OF COLD-FORMED STEEL STRUCTURAL MEMBERS."
4. SNOW LOADS APPLIED ON THE HORIZONTAL ROOF PROJECTION AND DESIGN CONSIDERATIONS SHALL BE IN ACCORDANCE WITH MBMA RECOMMENDED DESIGN PRACTICES MANUAL.
5. ALL FRAMING MEMBERS SHALL BE SHOP FABRICATED FOR FIELD ASSEMBLY. THE SURFACES OF THE BOLTED CONNECTIONS SHALL BE SMOOTH AND FREE FROM BURRS AND DISTORTIONS.
6. ALL SHOP CONNECTIONS SHALL BE IN ACCORDANCE WITH THE AMERICAN WELDING SOCIETY CODE FOR BUILDING CONSTRUCTION.
7. ALL UNCOATED STRUCTURAL STEEL AND LIGHT GAUGE STEEL MEMBERS SHALL BE CLEANED OF ALL FOREIGN MATTER AND LOOSE SCALE AND GIVEN A RED PRIMER COATING IN ACCORDANCE WITH THE BUILDING MANUFACTURERS RECOMMENDATIONS.
8. STEEL FOR PRIMARY FRAMING SHALL CONFORM TO THE REQUIREMENTS OF ASTM SPECIFICATION A-36.
9. STEEL FOR ALL BUILT UP SECTIONS SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS OF ASTM A572 GRADE 50 FOR PLATES AND ASTM A607 GRADE 50 PER SHEET AND STRIP. MINIMUM YIELD STRESS SHALL BE 50,000 PSI.
10. ALL BASE PLATES, SPLICE PLATES, CAP PLATES AND STIFFENERS SHALL BE FACTORY WELDED INTO PLACE ON THE STRUCTURAL MEMBERS.
11. ALL BASE PLATES, SPLICE PLATES AND FLANGES SHALL BE SHOP FABRICATED TO INCLUDE BOLT CONNECTION HOLES.
12. SECONDARY FRAMING SHALL CONSIST OF ALL SUBGIRTS, STRUTS, FLANGE BRACES, ETC. SECONDARY FRAMING MEMBERS SHALL BE COMPARABLE TO OR EXCEEDING THE REQUIREMENTS OF ASTM GRADE 55. MINIMUM YIELD STRESS SHALL BE 55,000 PSI.
13. WALL EXTERIOR PANELS SHALL BE ROLL FORMED WITH INTERLOCKING RIBS AT SIDE JOINTS. THE EXTERIOR PANELS SHALL BE OF SUFFICIENT LENGTHS TO ELIMINATE HORIZONTAL JOINTS. THE PANELS SHALL BE FASTENED USING STAINLESS STEEL FASTENERS WITH MATCHING COLOR CAPS OR PAINTED HOODS. THE FACE PANEL SHALL BE A MINIMUM OF 26 GAUGE COMMERCIAL GALVANIZED STEEL.
14. ROOF PANELS SHALL BE A CONTINUOUS RIB SPACED ON A MINIMUM 24 INCH CENTER. PANELS SHALL BE JOINED AT THE SIDELAPS WITH AN INTERLOCKING SEAM. THE PANEL FACE SHALL BE 24 GAUGE COMMERCIAL GALVANIZED STEEL.
15. ALL WALL PANELS SHALL BE CONTINUOUS FROM SILL TO ROOF LINE AND ALL ROOF PANELS SHALL BE CONTINUOUS FROM EAVE TO RIDGE EXCEPT WHERE LENGTH BECOMES PROHIBITED FOR HANDLING PURPOSES. ALL END LAPS SHALL BE AT LEAST 6 INCHES ON THE ROOF AND 4 INCHES ON THE WALLS.
16. REFER TO STRUCTURAL PLAN FOR FLOOR ELEVATION AND STRUCTURAL DETAILS.
17. CONTRACTOR RESPONSIBLE FOR CONTAINMENT CURB LAYOUT, EQUIPMENT PAD LOCATIONS AND TRENCH DRAIN LOCATION. SEE SECTION "A", AND PLAN VIEW OF THIS DRAWING.



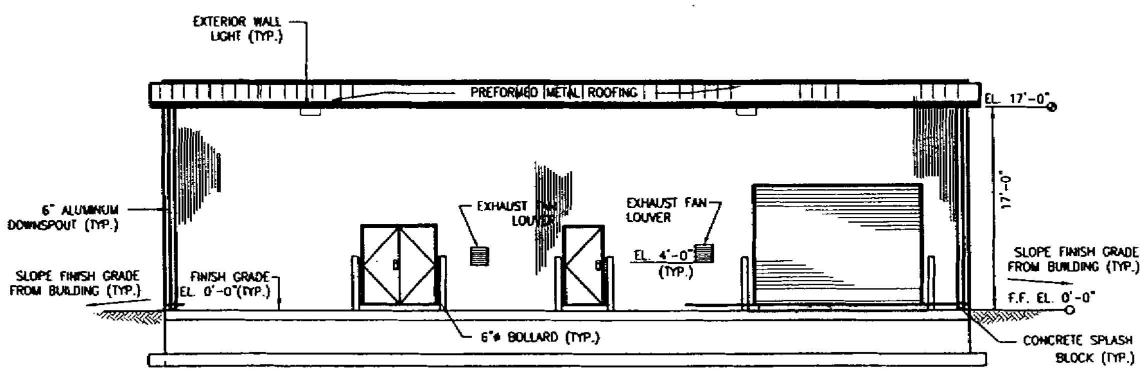
SOUTH ELEVATION

SCALE: 1/8"=1'-0"



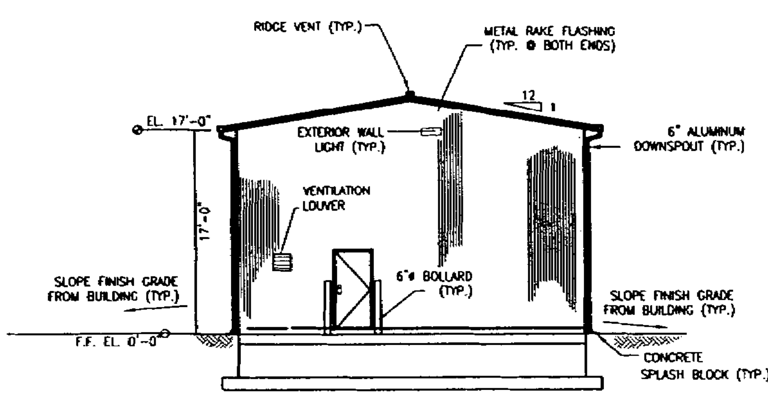
WEST ELEVATION

SCALE: 1/8"=1'-0"



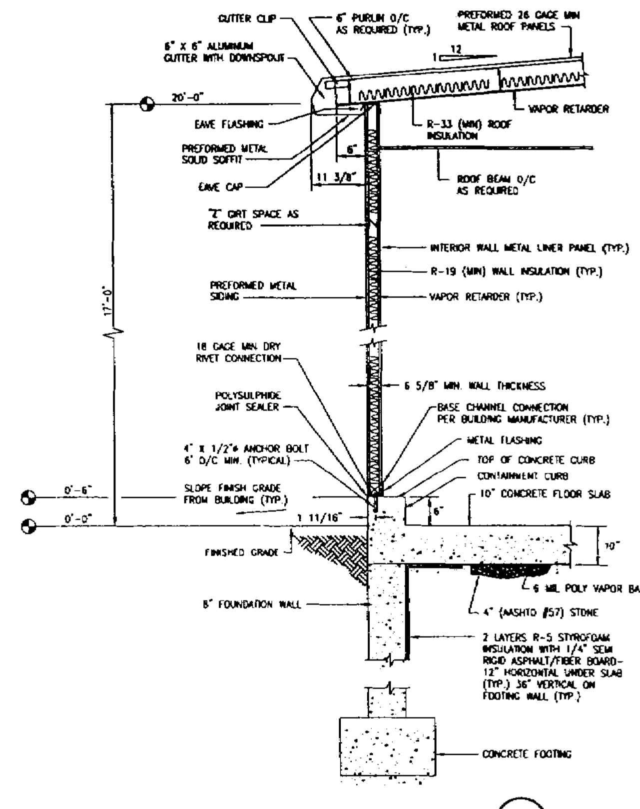
NORTH ELEVATION

SCALE: 1/8"=1'-0"



EAST ELEVATION

SCALE: 1/8"=1'-0"



TYPICAL SECTION A

NTS

FIGURE 4-5

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE; REPLACED TK-5310 WITH COMBINATION IPC-5270 FOR OXIDATION REACTION

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: MJ/EW

DRAWN BY: D. Leech

CHECKED BY: E. Weinberg

APPROVED BY: E. Weinberg

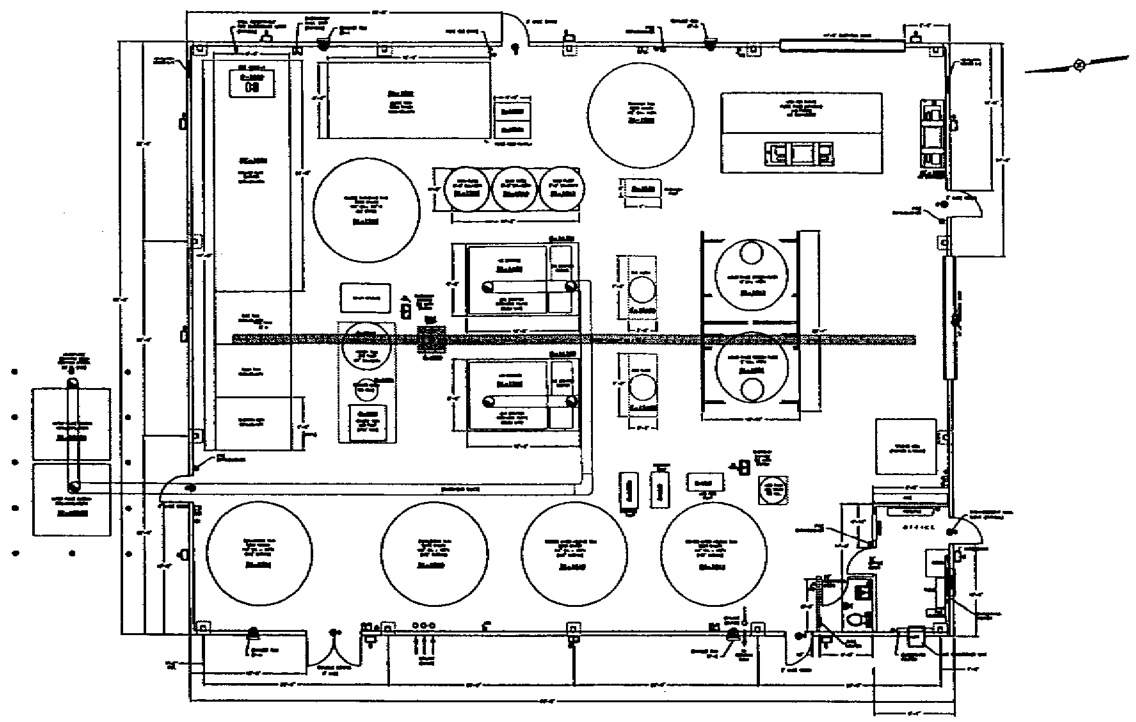
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

ON-SITE TREATMENT BUILDING
ELEVATION AND DETAILS

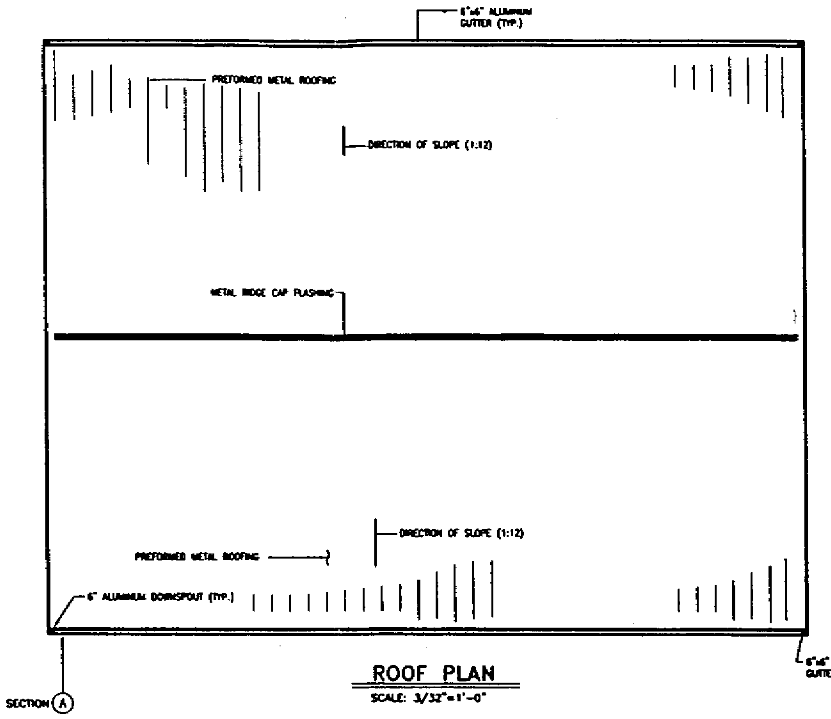
DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D32-A		5

K:\PROJECT\802901 ... Bid 8-04 On-Site\802901-D32-A.dwg
Plot Date/Time: 01 ... 1:27am
Plotted by: david.lee...



PLAN VIEW

SCALE: 3/32"=1'-0"

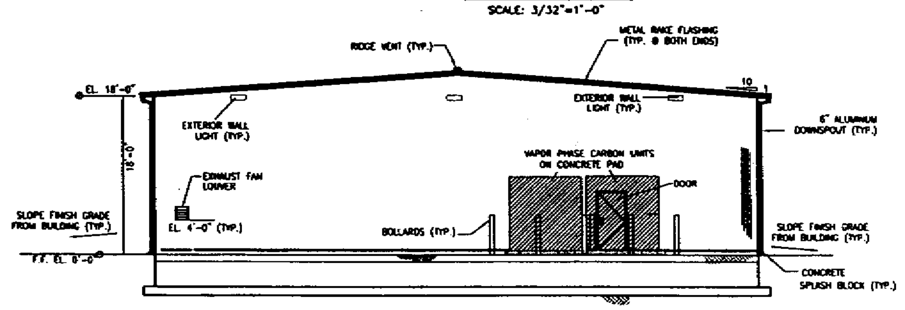


ROOF PLAN

SCALE: 3/32"=1'-0"

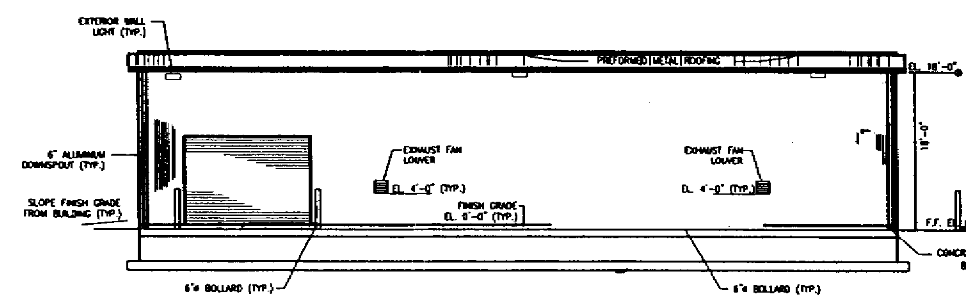
NOTES:

1. BUILDING COMPONENTS SHALL BE DESIGNED BASED ON APPLICABLE SECTIONS OF THE CURRENT EDITION OF AISC OR AISI SPECIFICATIONS AND MBMA RECOMMENDED DESIGN PRACTICE MANUAL. METAL BUILDING DETAILS SHOWN ARE BASED UPON STANDARD INDUSTRY PRACTICE. CONSTRUCTION DETAILS WILL VARY AMONG METAL BUILDING MANUFACTURERS. CONTRACTOR SHALL COORDINATE SPEC SECTION 13120 AND NON-STANDARD DETAILS WITH BUILDING MANUFACTURER. DETAILS WITH BUILDING MANUFACTURER.
2. ALL STRUCTURAL WALL SECTIONS AND WELDED PLATE SECTIONS SHALL BE DESIGNED IN ACCORDANCE WITH AISC'S LATEST "SPECIFICATION FOR THE DESIGN, FABRICATION AND ERECTION OF STRUCTURAL STEEL FOR BUILDINGS."
3. ALL COLD FORMED STEEL STRUCTURAL MEMBERS SHALL BE DESIGNED IN ACCORDANCE WITH AISI'S LATEST "SPECIFICATION FOR THE DESIGN OF COLD-FORMED STEEL STRUCTURAL MEMBERS."
4. SNOW LOADS APPLIED ON THE HORIZONTAL ROOF PROJECTION AND DESIGN CONSIDERATIONS SHALL BE IN ACCORDANCE WITH MBMA RECOMMENDED DESIGN PRACTICES MANUAL.
5. ALL FRAMING MEMBERS SHALL BE SHOP FABRICATED FOR FIELD ASSEMBLY. THE SURFACES OF THE BOLTED CONNECTIONS SHALL BE SMOOTH AND FREE FROM BURRS AND DISTORTIONS.
6. ALL SHOP CONNECTIONS SHALL BE IN ACCORDANCE WITH THE AMERICAN WELDING SOCIETY CODE FOR BUILDING CONSTRUCTION.
7. ALL UNCOATED STRUCTURAL STEEL AND LIGHT GAUGE STEEL MEMBERS SHALL BE CLEANED OF ALL FOREIGN MATTER AND LOOSE SCALE AND GIVEN A RED PRIMER COATING IN ACCORDANCE WITH THE BUILDING MANUFACTURERS RECOMMENDATIONS.
8. STEEL FOR PRIMARY FRAMING SHALL CONFORM TO THE REQUIREMENTS OF ASTM SPECIFICATION A-36.
9. STEEL FOR ALL BUILT UP SECTIONS SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS OF ASTM A572 GRADE 50 FOR PLATES AND ASTM A607 GRADE 50 PER SHEET AND STRIP. MINIMUM YIELD STRESS SHALL BE 50,000 PSI.
10. ALL BASE PLATES, SPLICE PLATES, CAP PLATES AND STIFFENERS SHALL BE FACTORY WELDED INTO PLACE ON THE STRUCTURAL MEMBERS.
11. ALL BASE PLATES, SPLICE PLATES AND FLANGES SHALL BE SHOP FABRICATED TO INCLUDE BOLT CONNECTION HOLES.
12. SECONDARY FRAMING SHALL CONSIST OF ALL SUBGIRTS, STRUTS, FLANGE BRACES, ETC. SECONDARY FRAMING MEMBERS SHALL BE COMPARABLE TO OR EXCEEDING THE REQUIREMENTS OF ASTM GRADE 55. MINIMUM YIELD STRESS SHALL BE 55,000 PSI.
13. WALL EXTERIOR PANELS SHALL BE ROLL FORMED WITH INTERLOCKING RIBS AT SIDE JOINTS. THE EXTERIOR PANELS SHALL BE OF SUFFICIENT LENGTHS TO ELIMINATE HORIZONTAL JOINTS. THE PANELS SHALL BE FASTENED USING STAINLESS STEEL FASTENERS WITH MATCHING COLOR CAPS OR PAINTED HOODS. THE FACE PANEL SHALL BE A MINIMUM OF 26 GAUGE COMMERCIAL GALVANIZED STEEL.
14. ROOF PANELS SHALL BE A CONTINUOUS RIB SPACED ON A MINIMUM 24 INCH CENTER. PANELS SHALL BE JOINED AT THE SIDELAPS WITH AN INTERLOCKING SEAM. THE PANEL FACE SHALL BE 24 GAUGE COMMERCIAL GALVANIZED STEEL.
15. ALL WALL PANELS SHALL BE CONTINUOUS FROM SILL TO ROOF LINE AND ALL ROOF PANELS SHALL BE CONTINUOUS FROM EAVE TO RIDGE EXCEPT WHERE LENGTH BECOMES PROHIBITED FOR HANDLING PURPOSES. ALL END LAPS SHALL BE AT LEAST 6 INCHES ON THE ROOF AND 4 INCHES ON THE WALLS.
16. REFER TO STRUCTURAL PLAN FOR FLOOR ELEVATION AND STRUCTURAL DETAILS.
17. CONTRACTOR RESPONSIBLE FOR CONTAINMENT CURB LAYOUT, EQUIPMENT PAD LOCATIONS AND TRENCH DRAIN LOCATION. SEE SECTION "A", AND PLAN VIEW OF THIS DRAWING.



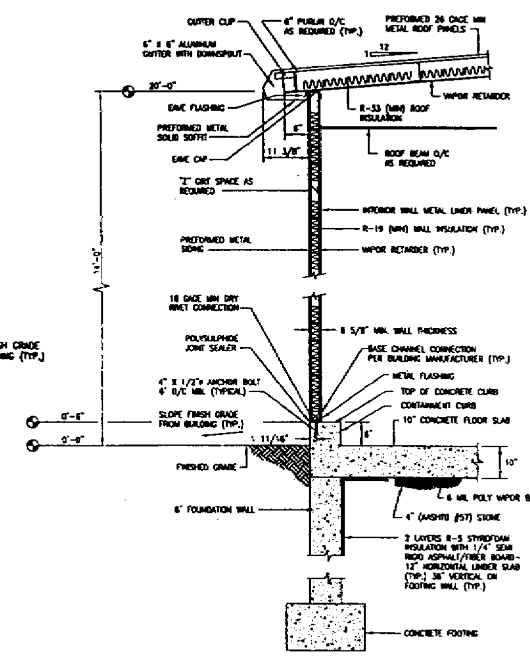
NORTH ELEVATION

SCALE: 3/32"=1'-0"



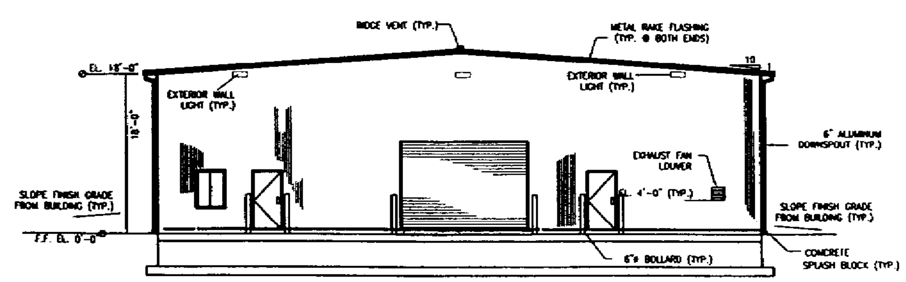
EAST ELEVATION

SCALE: 3/32"=1'-0"



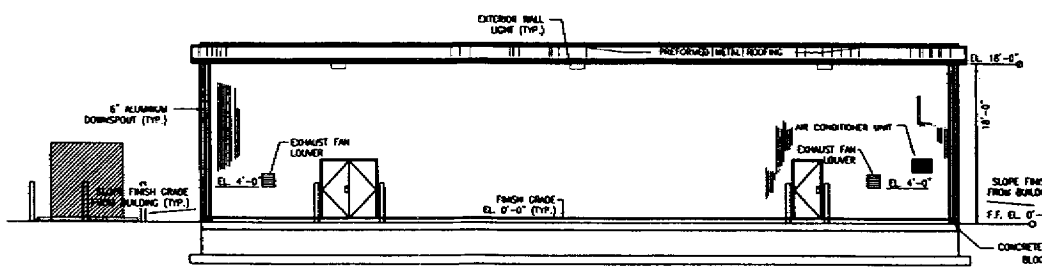
TYPICAL SECTION A

NTS



SOUTH ELEVATION

SCALE: 3/32"=1'-0"



WEST ELEVATION

SCALE: 3/32"=1'-0"

FIGURE 4-6

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT RIVISIONS
3	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

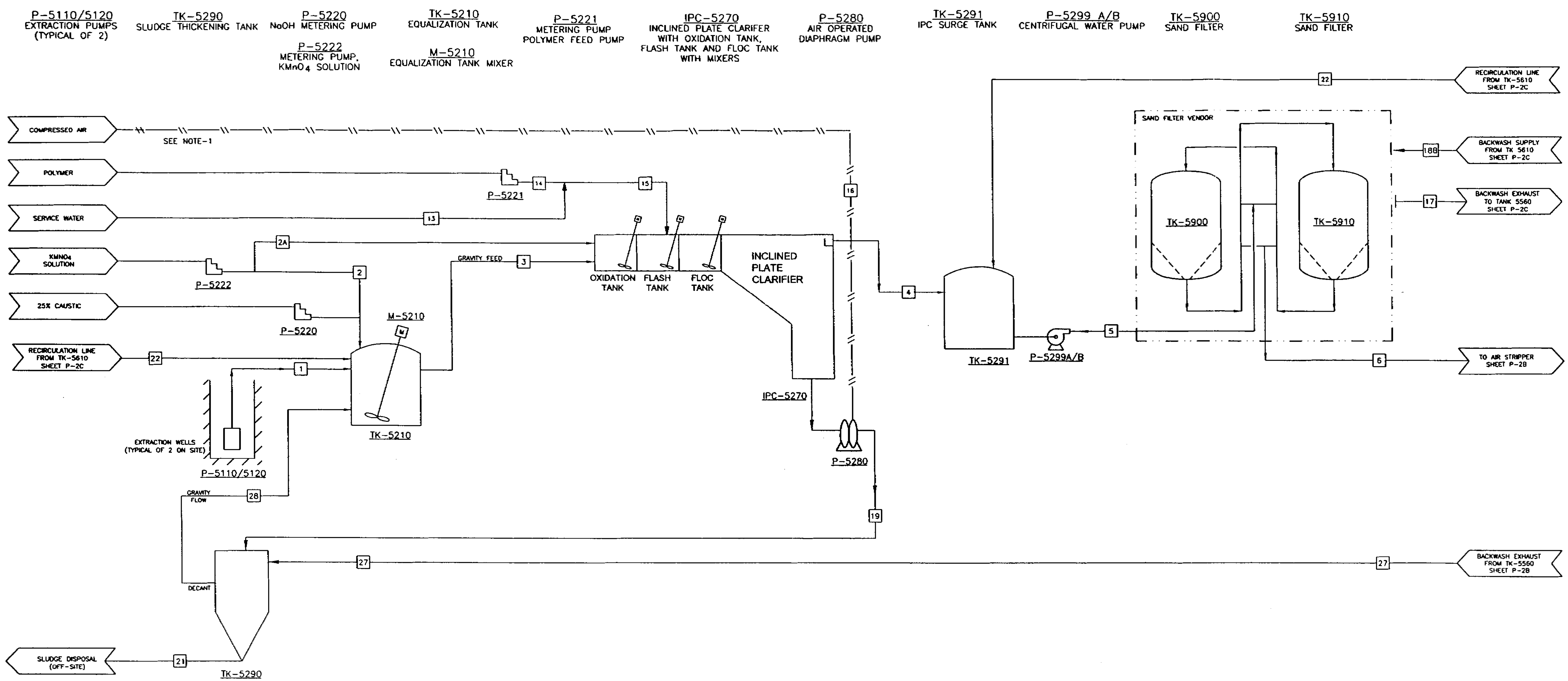
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
OFF-SITE TREATMENT BUILDING ELEVATION AND DETAILS

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D109-A		4

OFFICE	DRAWING NUMBER
Trenton, NJ	802901-D22



NOTES:

1. AIR COMPRESSOR NOT SHOWN. SEE P&ID SHEET NO. P-3.
2. BUILDING SUMP AND PUMP NOT SHOWN. SEE P&ID, SHEET NO. P-3.
3. RECIRCULATION OF (OFF-SPEC) TREATED WATER TO EQUALIZATION TANK OR IPC SURGE TANK. (STREAM I.D. NO. 22)
4. PROCESS VENTS SHOWN ON P&ID SHEETS.

DESIGN BASIS:

100 GPM

DISCHARGE CRITERIA:		INFLUENT WATER QUALITY:
1,1 - DICHLOROETHENE	5 ug/L	--
TRANS 1,2 - DICHLOROETHENE	5 ug/L	--
1,2 - DICHLOROETHENE	0.6 ug/L	3,500 ug/L
1,1,1, - TRICHLOROETHENE	5 ug/L	--
VINYL CHLORIDE	2 ug/L	--
TRICHLOROETHENE	5 ug/L	650 ug/L
TETRACHLOROETHENE	5 ug/L	1,400 ug/L

FIGURE 7-1

Shaw Environmental & Infrastructure, Inc.

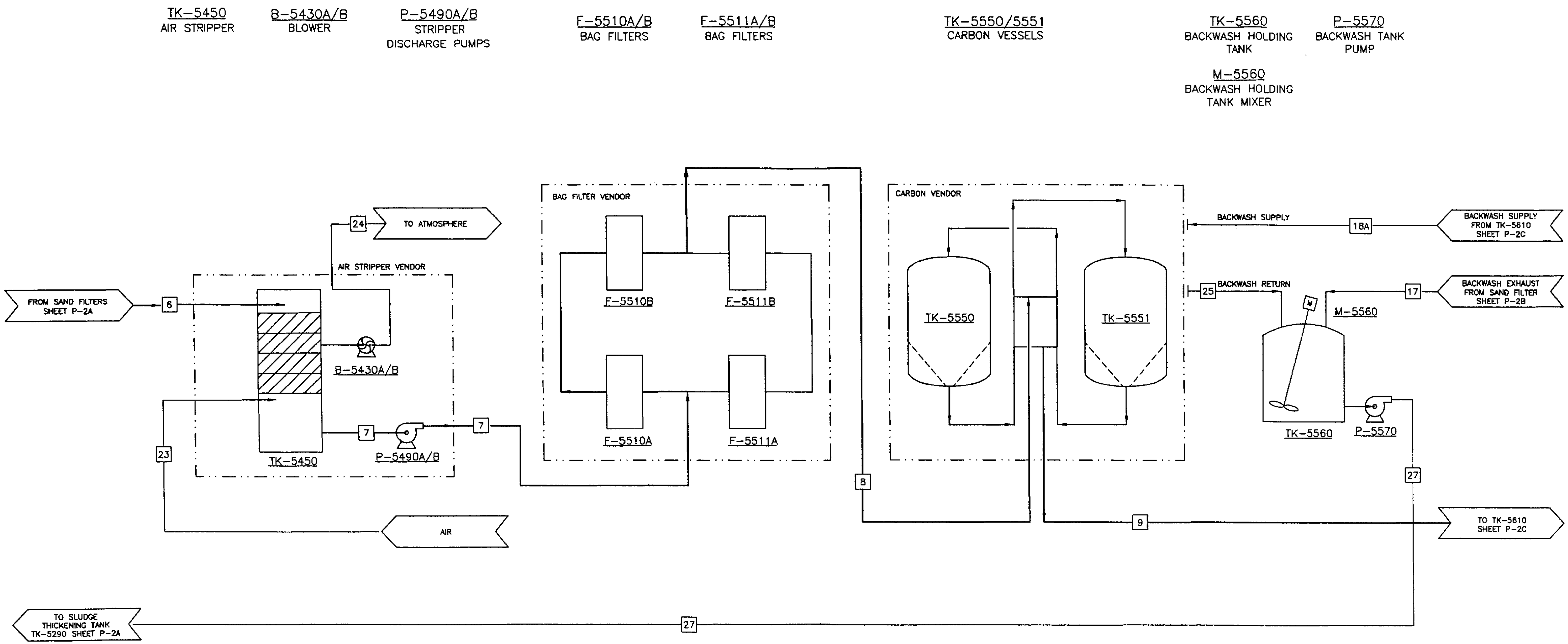
REV	DATE	BY	CHK'D	APPR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agobiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PROCESS FLOW DIAGRAM - ON-SITE
METALS PRETREATMENT

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D22		5



NOTE:

1. AIR STRIPPER PUMP P-5490B (SPARE) NOT SHOWN.

DESIGN BASIS:

100 GPM

DISCHARGE CRITERIA:		INFLUENT WATER QUALITY:
1,1 – DICHLOROETHENE	5 ug/L	--
TRANS 1,2 – DICHLOROETHENE	5 ug/L	--
1,2 – DICHLOROETHENE	0.6 ug/L	3,500 ug/L
1,1,1, – TRICHLOROETHENE	5 ug/L	--
VINYL CHLORIDE	2 ug/L	--
TRICHLOROETHENE	5 ug/L	650 ug/L
TETRACHLOROETHENE	5 ug/L	1,400 ug/L

FIGURE 7-2

REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

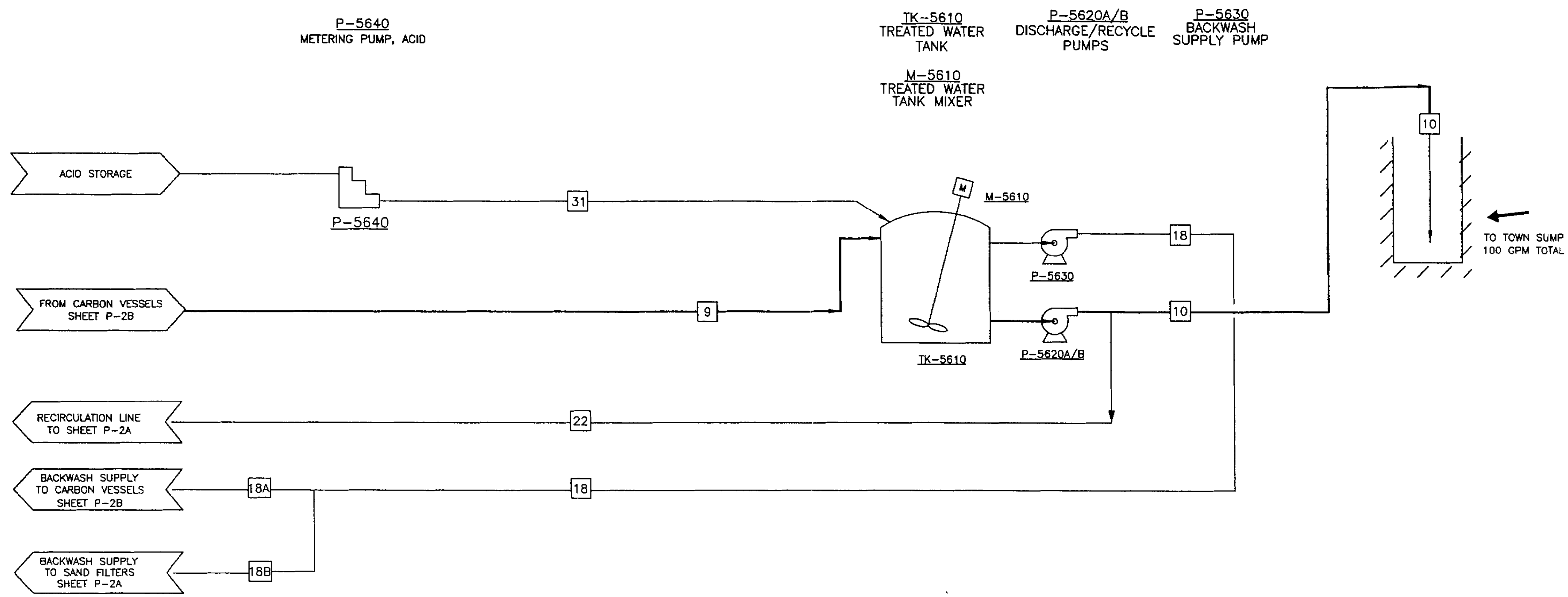
FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PROCESS FLOW DIAGRAM - ON-SITE
VOC REMOVAL

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D25		4

OFFICE Trenton, NJ
DRAWING NUMBER 802901-D25

VERIFY SCALE 0 1"

K:\PROJECT\802901\100% FINAL\802901-D25.dwg
Plot Date/Time: 10/22/03 11:50am
Plotted by: colette.o
Image:
Xref:



NOTES:

1. DISCHARGE PUMP P-5620B (SPARE) NOT SHOWN.

DESIGN BASIS:

100 GPM

DISCHARGE CRITERIA:		INFLUENT WATER QUALITY:
1,1 – DICHLOROETHENE	5 ug/L	--
TRANS 1,2 – DICHLOROETHENE	5 ug/L	--
1,2 – DICHLOROETHENE	0.6 ug/L	3,500 ug/L
1,1,1, – TRICHLOROETHENE	5 ug/L	--
VINYL CHLORIDE	2 ug/L	--
TRICHLOROETHENE	5 ug/L	650 ug/L
TETRACHLOROETHENE	5 ug/L	14,000 ug/L

FIGURE 7-3

Shaw Environmental & Infrastructure, Inc.

REV	DATE	BY	CHK'D	APRVD	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE, VGAC REMOVED
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PROCESS FLOW DIAGRAM - ON-SITE
DISCHARGE SYSTEMS

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D26		4

OFFICE Trenton, NJ
DRAWING NUMBER 80290_26

OFFICE	DRAWING NUMBER
Trenton, NJ	802901-D103-A

P-1111,1112,1113 EXTRACTION PUMPS (TYPICAL OF 3) (500 GPM TOTAL)

TK-1290 SLUDGE THICKENING TANK

TK-1222 KMnO4 SOLUTION TANK

M-1222 KMnO4 SOLUTION TANK MIXER

P-1220 NaOH METERING PUMP

P-1222 KMnO4 METERING PUMP SOLUTION

P-1221 POLYMER METERING PUMP

TK-1210 EQUALIZATION/REACTION TANK AND MIXER

TK-1211 EQUALIZATION/REACTION TANK AND MIXER

TK-1270A OXIDATION TANK

TK-1270B FLASH MIX TANK

TK-1270C FLOC TANK

IPC-1270 INCLINED PLATE CLARIFER

P-1280 AIR OPERATED DIAPHRAGM SLUDGE PUMP

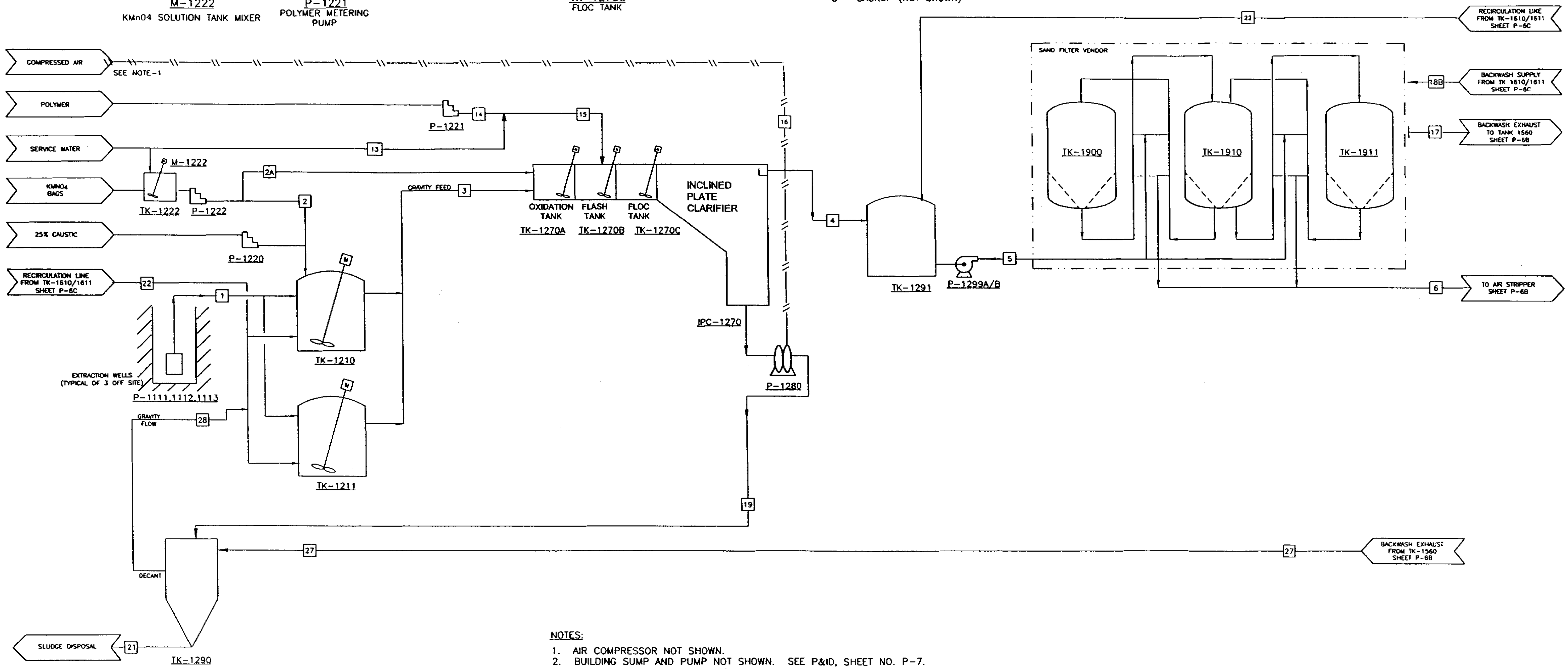
TK-1291 IPC SURGE TANK

P-1299 A/B CENTRIFUGAL WATER PUMP
A = PRIME
B = BACKUP (NOT SHOWN)

TK-1900 SAND FILTER

TK-1910 SAND FILTER

TK-1911 SAND FILTER



NOTES:

1. AIR COMPRESSOR NOT SHOWN.
2. BUILDING SUMP AND PUMP NOT SHOWN. SEE P&ID, SHEET NO. P-7.
3. RECIRCULATION OF (OFF-SPEC) TREATED WATER TO EQUALIZATION TANK OR IPC SURGE TANK. (SCREEN I.D. NO.22)
4. PROCESS VENTS SHOWN ON P&ID SHEETS.

DESIGN BASIS:

500 GPM

DISCHARGE CRITERIA:		INFLUENT WATER QUALITY:
1,1 - DICHLOROETHENE	5 ug/L	1.3 ug/L
TRANS 1,2 - DICHLOROETHENE	5 ug/L	330 ug/L
1,2 - DICHLOROETHENE	0.6 ug/L	--
1,1,1, - TRICHLOROETHENE	5 ug/L	4 ug/L
VINYL CHLORIDE	2 ug/L	32.4 ug/L
TRICHLOROETHENE	5 ug/L	103 ug/L
TETRACHLOROETHENE	5 ug/L	11,900 ug/L

FIGURE 7-4

REV	DATE	BY	CHK'D	APPR'VD	DESCRIPTION/ISSUE
4	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
3	10/15/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

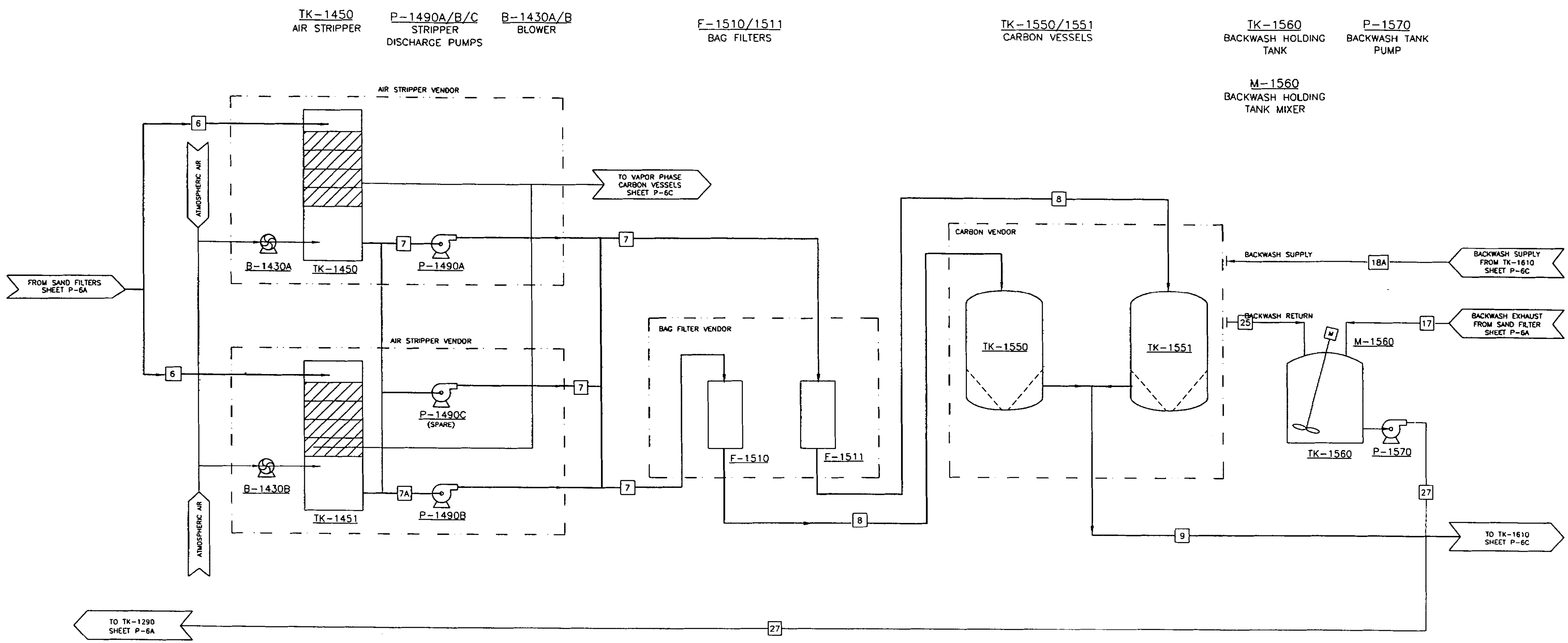
DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agobiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

CONSTRUCTION BID DRAWINGS (OFF-SITE)
GROUNDWATER EXTRACTION AND TREATMENT
PROCESS FLOW DIAGRAM - OFF SITE -
METALS PRETREATMENT

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D103		4

OFFICE	DRAWING NUMBER
Trenton, NJ	802901-D104



NOTES:

1. AIR COMPRESSOR NOT SHOWN.
2. BUILDING SUMP AND PUMP NOT SHOWN. SEE P&ID, SHEET NO. P-7.
3. RECIRCULATION OF (OFF-SPEC) TREATED WATER TO EQUALIZATION TANK OR IPC SURGE TANK. (STREAM I.D. NO.22)
4. PROCESS VENTS SHOWN ON P&ID SHEETS.

DESIGN BASIS:

500 GPM

	DISCHARGE CRITERIA:	INFLUENT WATER QUALITY:
1,1 - DICHLOROETHENE	5 ug/L	1.3 ug/L
TRANS 1,2 - DICHLOROETHENE	5 ug/L	330 ug/L
1,2 - DICHLOROETHENE	0.6 ug/L	--
1,1,1, - TRICHLOROETHENE	5 ug/L	4 ug/L
VINYL CHLORIDE	2 ug/L	32.4 ug/L
TRICHLOROETHENE	5 ug/L	103 ug/L
TETRACHLOROETHENE	5 ug/L	11,900 ug/L

FIGURE 7-5

REV	DATE	BY	CHK'D	APPR'VD	DESCRIPTION/ISSUE
3	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PROCESS FLOW DIAGRAM - OFF SITE - VOC REMOVAL

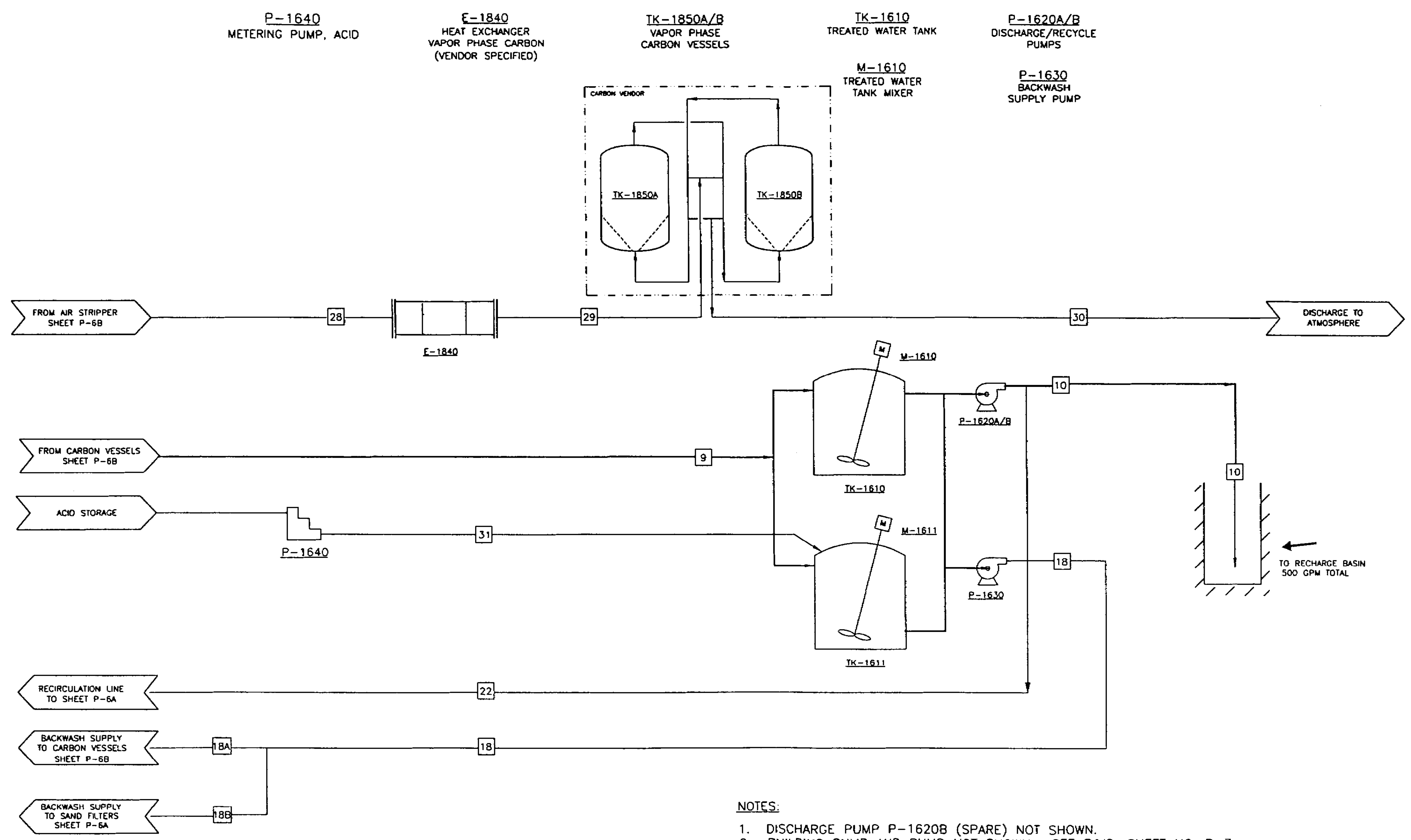
DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D104		4

K:\PROJECT\80290 ... INAL-OFFSITE\802901-D25.dwg
Plot Date/Time: 1... 4:38pm
Plotted by: colette...
Image: .
Xref: .

K:\PROJECT\80290[illegible] FINAL-OFFSITE\802901-D26.dwg
Plot Date/Time: 10/22/03 01:14pm
Plotted by: colette.agobil
Image: .
Xref: .

OFFICE	DRAWING NUMBER
Trenton, NJ	802901-D105-A

VERIFY SCALE 0 — 1"



NOTES:

1. DISCHARGE PUMP P-1620B (SPARE) NOT SHOWN.
2. BUILDING SUMP AND PUMP NOT SHOWN. SEE P&ID, SHEET NO. P-7.
3. RECIRCULATION OF (OFF-SPEC) TREATED WATER TO EQUALIZATION TANK OR IPC SURGE TANK. (STREAM I.D. NO.22)
4. PROCESS VENTS SHOWN ON P&ID SHEETS.

DESIGN BASIS:

500 GPM

DISCHARGE CRITERIA:		INFLUENT WATER QUALITY:
1,1 - DICHLOROETHENE	5 ug/L	1.3 ug/L
TRANS 1,2 - DICHLOROETHENE	5 ug/L	330 ug/L
1,2 - DICHLOROETHENE	0.6 ug/L	--
1,1,1, - TRICHLOROETHENE	5 ug/L	4 ug/L
VINYL CHLORIDE	2 ug/L	32.4 ug/L
TRICHLOROETHENE	5 ug/L	103 ug/L
TETRACHLOROETHENE	5 ug/L	11,900 ug/L

FIGURE 7-6

REV	DATE	BY	CHK'D	APPR'VD	DESCRIPTION/ISSUE
3	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PROCESS FLOW DIAGRAM - OFF-SITE -
DISCHARGE SYSTEMS

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D105-A		3

VALVE SYMBOLS

- ANGLE VALVE
- BALL VALVE
- CLOSED BALL VALVE
- GATE VALVE
- CLOSED GATE VALVE
- CHECK VALVE
- DIAPHRAGM VALVE
- BUTTERFLY VALVE
- GLOBE VALVE
- CLOSED GLOBE VALVE
- NEEDLE VALVE
- PLUG VALVE
- CLOSED PLUG VALVE
- ROTARY VALVE
- 3-WAY VALVE
- 4-WAY VALVE
- AIR RELEASE VALVE

CONTROL VALVES

- DIAPHRAGM ACTUATOR
- DIAPHRAGM ACTUATOR WITH POSITIONER
- ELECTRIC MOTOR ACTUATOR
- HYDRAULIC ACTUATOR
- PNEUMATIC ACTUATOR
- PNEUMATIC CYLINDER ACTUATOR
- REGULATOR WITH EXTERNAL TAP
- SELF CONTAINED REGULATOR
- 2-WAY SOLENOID
- 3-WAY SOLENOID
- 4-WAY SOLENOID

FC INDICATES "FAIL CLOSED"
FL INDICATES "FAIL LAST"
FO INDICATES "FAIL OPEN"

SAFETY RELIEF

- PRESSURE RELIEF VALVE (PRV)

NOTE: ALL SYMBOLS MAY NOT BE USED.

PIPING

- MAIN PROCESS PIPING
- SECONDARY PROCESS PIPING
- VENDOR SUPPLIED
- LINE BREAK, PIPING OR INSTRUMENTATION
- INSULATED PIPING
- FLANGED NOZZLE CONNECTION
- THREADED CAP OR CONNECTION
- TRAP
- AIR ELIMINATOR
- POP DRAIN
- VACUUM BREAKER
- SAMPLE PORT
- BLIND FLANGE/FLANGES
- THREADED PIPE CAP
- DIAPHRAGM SEAL
- DRAINS & VENTS (D.V. O.V.)
- EDUCTOR
- EXPANSION JOINT
- FLEXIBLE CONNECTION
- HOSE CONNECTION
- REDUCER (CONCENTRIC)
- REDUCER (ECCENTRIC)
- SLIP BLIND
- TIE-IN
- VENT STACK TO ATMOSPHERE
- "Y" STRAINER
- INLINE STRAINER
- COMPRESSED AIR LINE
- HOSE BIB
- PIPE UNION
- QUICK-DISCONNECT

INSTRUMENTS

- PANEL MOUNTED INSTRUMENT
- PANEL MOUNTED INSTRUMENT FOR PRIMARY (A)/ SPARE (B) EQUIPMENT
- REAR PANEL MOUNTED INSTRUMENT
- LOCALLY MOUNTED INSTRUMENT
- INSTRUMENT FURNISHED WITH EQUIPMENT BY VENDOR
- PLC CENTRAL
- PLC NON DISPLAY FUNCTION
- PLC BLIND FUNCTION
- PLC LOCAL\MANUAL BACKUP
- PLC H: HIGH ALARM L: LOW ALARM
- LEVEL GAUGE BOARD (WITH SEAL)
- LEVEL GAUGE BOARD (WITHOUT SEAL)
- ORIFICE PLATE
- RESTRICTING ORIFICE
- VORTEX SHEDDING FLOW TRANSMITTER
- ROTAMETER/PURGE METER
- TARGET FLOW METER
- PITOT TUBE (OR ANNUBAR)
- TURBINE OR PROPELLER FLOW SENSOR
- MAGNETIC FLOW METER (SENSOR ELEMENT)
- PARSHALL FLUME
- VENTURI FLOW ELEMENT

INSTRUMENTS

- WEIR
- POSITIVE DISPLACEMENT FLOW TOTALIZING INDICATOR
- SONIC FLOW TRANSMITTER (DOPPLER OR TRANSIT TIME)
- SONIC FLOW TRANSMITTER (DOPPLER OR TRANSIT TIME)
- FLOW STRAIGHTENING VANE
- PRESSURE GAUGE
- INTERLOCK LOGIC IN PLC
- LOGIC FUNCTION S – SUM
- TRANSDUCER FUNCTION
  - R – RESISTANCE
  - I – CURRENT
  - P – PNEUMATIC
  - MV – MILLIVOLTS

S/S	START/STOP
E/S	ENABLE/STOP
HOA	HAND OFF AUTOMATIC
PB	PUSH BUTTON EMERGENCY STOP
XO	ON/OFF
XXX	VARIABLE SPEED

EQUIPMENT/MISCELLANEOUS

- CENTRIFUGAL PUMP W/BASE OR BLOWER WITHOUT BASE
- POSITIVE DISPLACEMENT METERING PUMP
- CONTAINMENT PALLET
- OR
- CONTAINMENT DIKE
- EXTRACTION WELL WITH SUSMERSIBLE PUMP
- SUBMERSIBLE PUMP
- DIAPHRAGM PUMP
- TANK AGITATOR WITH MOTOR

INSTRUMENT FUNCTION IDENTIFICATION SYMBOLS

	1st LETTER	2nd LETTER	3rd LETTER	4th LETTER	LAST LETTER
A	ANALYZER	ALARM	ALARM	ALARM	ALARM
B	BURNER (FLAME)				
C	CONTROL (LOOP)	CONTROLLER	CONTROLLER	CONTROLLER	CONTROLLER
D	DENSITY	DIFFERENTIAL			DRIVE OPERATOR
E	VOLTAGE	ELEMENT			
F	FLOW	RATIO	FLOW	FLOW	
G	GAUGE	GAUGE			GLASS
H	HAND (MANUAL)		HIGH	HIGH	HIGH
I	AMPERES	INDICATOR			INDICATOR
J	POWER				MTR. PB & LCT.
K	TIME (COUNT)				
L	LEVEL	LEVEL	LOW	LOW	LOW
M	MOISTURE				METER
N	USER'S CHOICE				
O	OPERATIONAL	ORIFICE			
P	PRESSURE	PRESSURE	PRESSURE		PNEUMATIC
Q	SPECIAL	INTEGRATE	INTEGRATE	INTEGRATE	INTEGRATE
R	RESTRICTING	RECORDER	RECORDER	RECORDER	RECORDER
S	SPEED. SOLENOID	SAFETY/SWITCH	SWITCH	SWITCH	SWITCH
T	TEMPERATURE	TEMPERATURE	TEMPERATURE		TRANSMITTER
U	MULTIVARIABLE	MULTIVARIABLE			MULTIVARIABLE
V	VIBRATION	VALVE	VALVE	VALVE	VALVE
W	WEIGHT				WELL
X	UNCLASSIFIED				
Y	USER'S CHOICE				
Z	POSITION				COMPUTER
pH	pH				

INSTRUMENT SIGNALS

— — — — ELECTRICAL SIGNAL

EQUIPMENT DESIGNATION

M – 1 – 6 – 2

EQUIPMENT
UNIT OPERATION
COMPONENT SERIES
COMPONENT SEQUENCE

PIPING LINE DESIGNATIONS

6"-CS-GW

NOMINAL PIPING SIZE
PIPE MATERIAL
PIPE SCHEDULE

PIPE MATERIAL

SYMBOL	SERVICE
CS	CARBON STEEL
PE	POLYETHYLENE
PVC	POLYVINYL CHLORIDE
RH	RUBBER HOSE
SS	STAINLESS STEEL
HDPE	HIGH DENSITY POLYETHYLENE

EQUIPMENT DESIGNATIONS

SYMBOL	EQUIPMENT
F	BAG FILTER
P	PUMP
TK	TANK
M	MIXER
IPC	INCLINED PLATE CLARIFIER
AC	AIR COMPRESSOR

FIGURE 7-7

Shaw™ Shaw Environmental & Infrastructure, Inc.

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE & OFF SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE & OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

DESIGNED BY: --
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

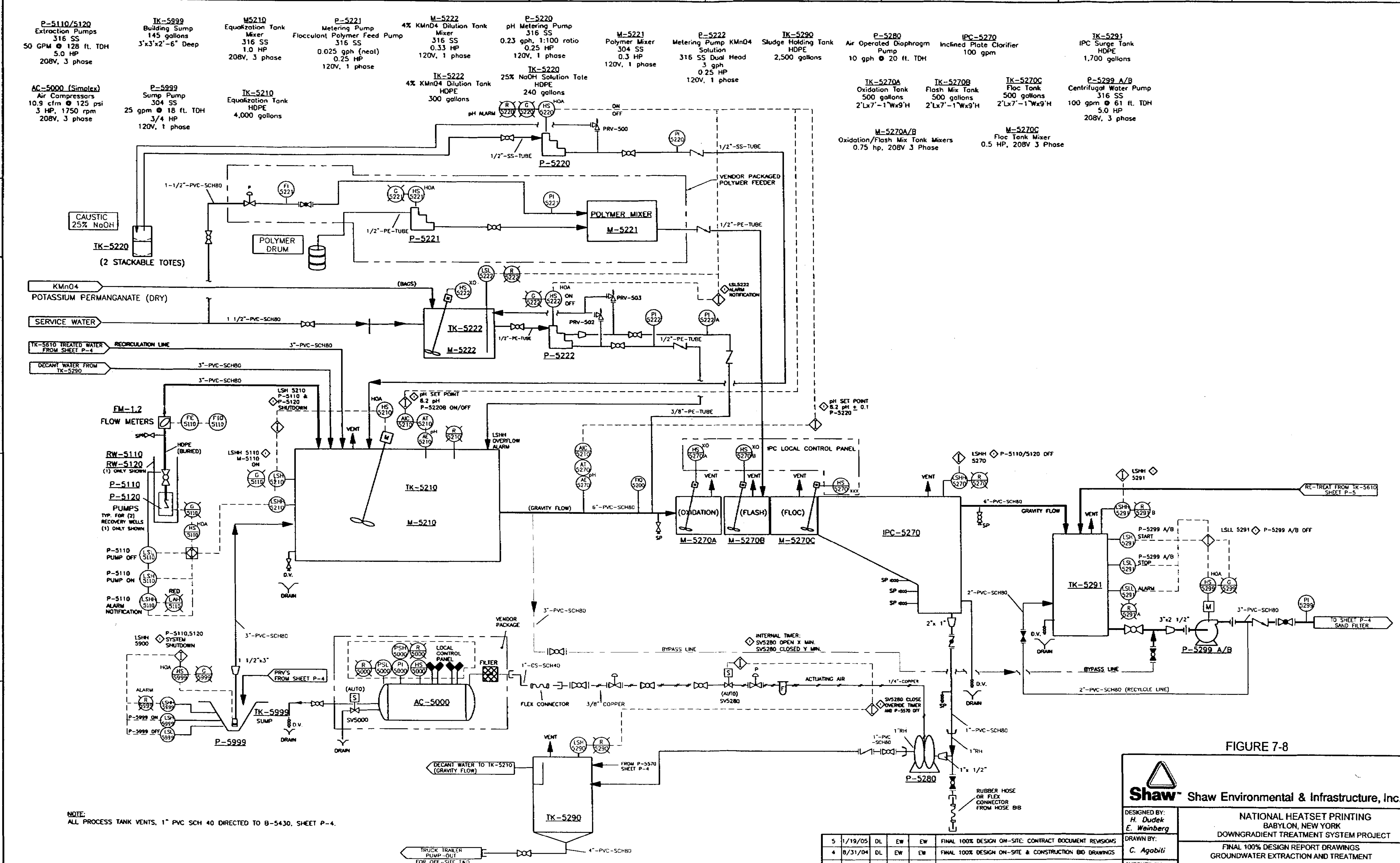
PROCESS & INSTRUMENTATION LEGEND

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D27-A		4

OFFICE Trenton, NJ
DRAWING NUMBER 802901-D27-A

VERIFY SCALE

OFFICE: Trenton, NJ
DRAWING NUMBER: 802901-D24



NOTE:
ALL PROCESS TANK VENTS, 1" PVC SCH 40 DIRECTED TO B-5430, SHEET P-4.

FIGURE 7-8

REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE; REPLACED TK-5310 WITH COMBINATION IPC-5270 FOR OXIDATION REACTION

Shaw Environmental & Infrastructure, Inc.

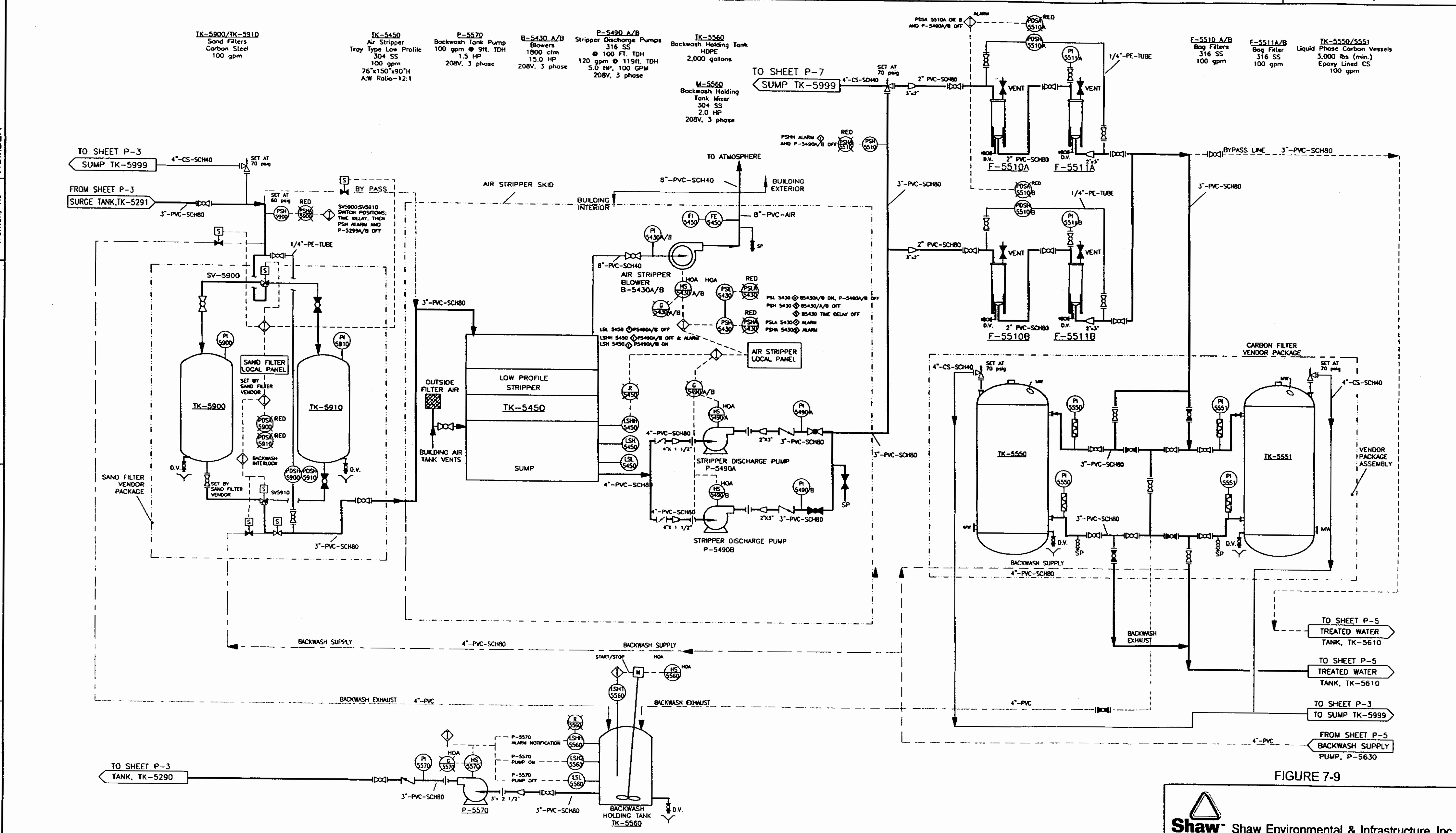
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PIPING & INSTRUMENTATION DIAGRAM - ON-SITE
METALS PRETREATMENT

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: C. Agobiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D24		5

OFFICE Trenton, NJ | DRAWING NUMBER 802901-D23



NOTE: P&ID SHOWS TK-5900 SAND FILTER IN FEED FORWARD MODE; TK-5910 IN STANDBY

FIGURE 7-9

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: D. Leech
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PIPING & INSTRUMENTATION DIAGRAM - ON-SITE
VOC REMOVAL

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D23-A		5

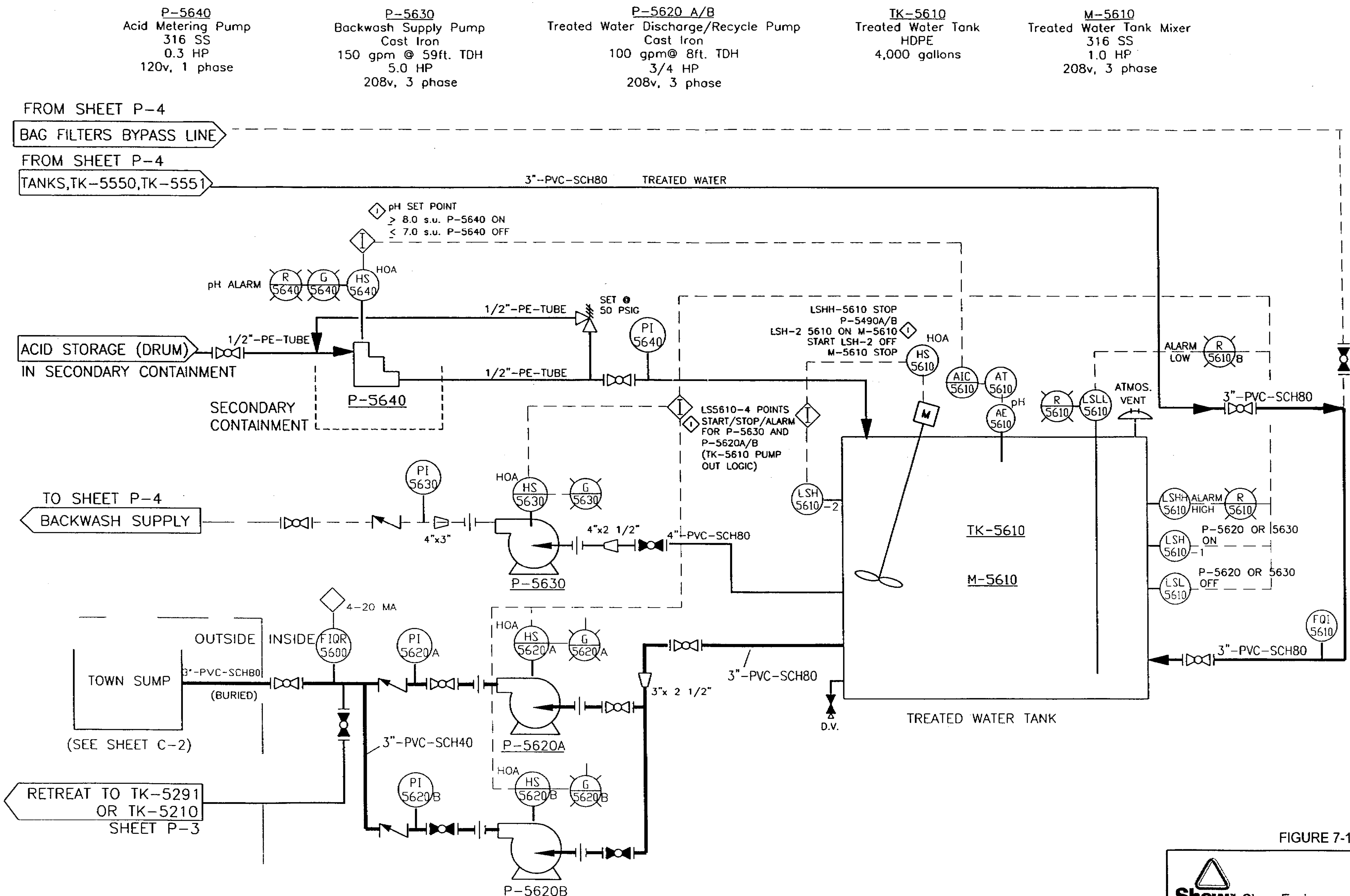


FIGURE 7-10

REV	DATE	BY	CHK'D	APPR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	CA	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: E. Weinberg
DRAWN BY: D. Leech
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

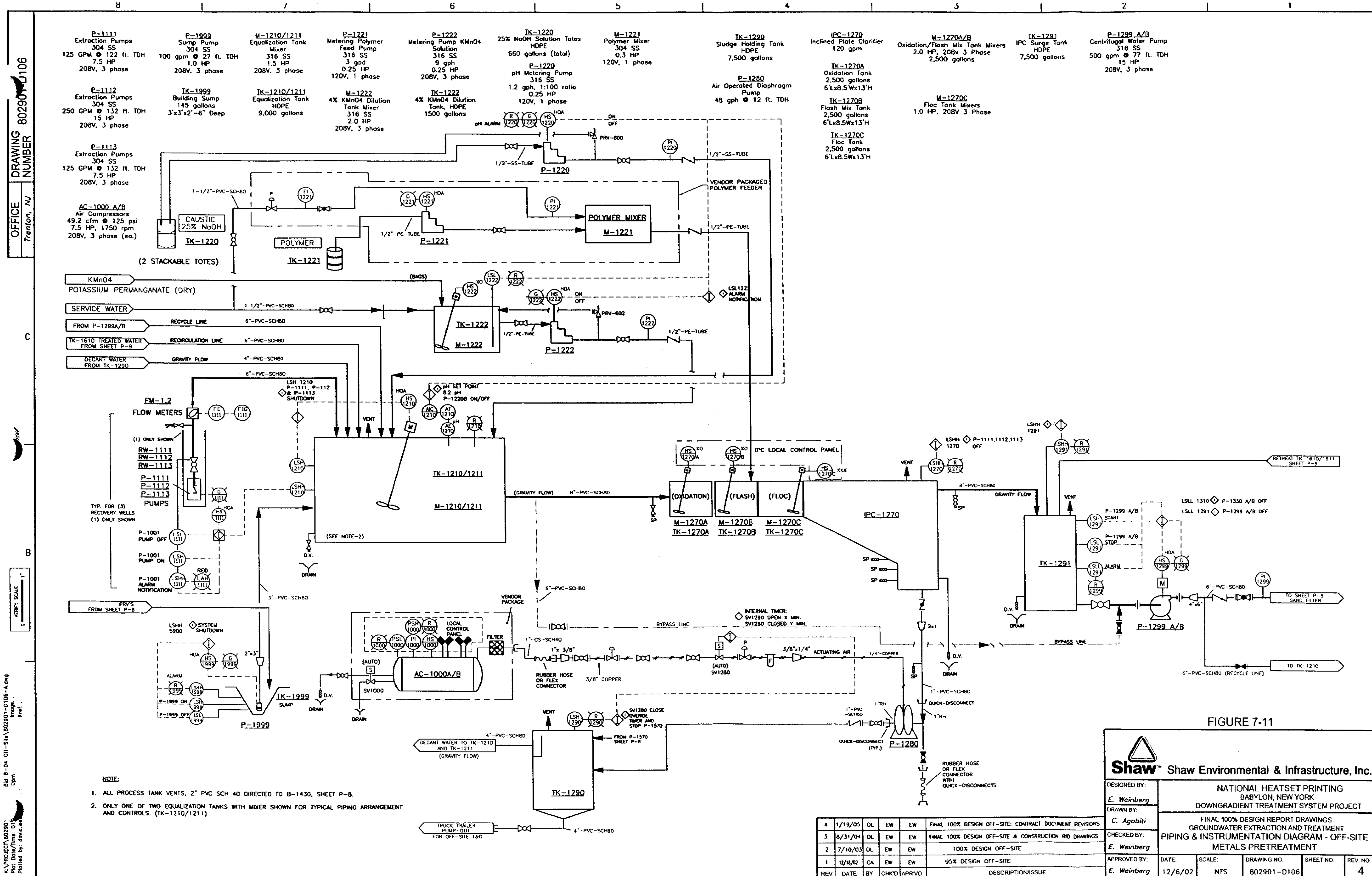
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

PIPING & INSTRUMENTATION DIAGRAM - ON-SITE DISCHARGE SYSTEMS

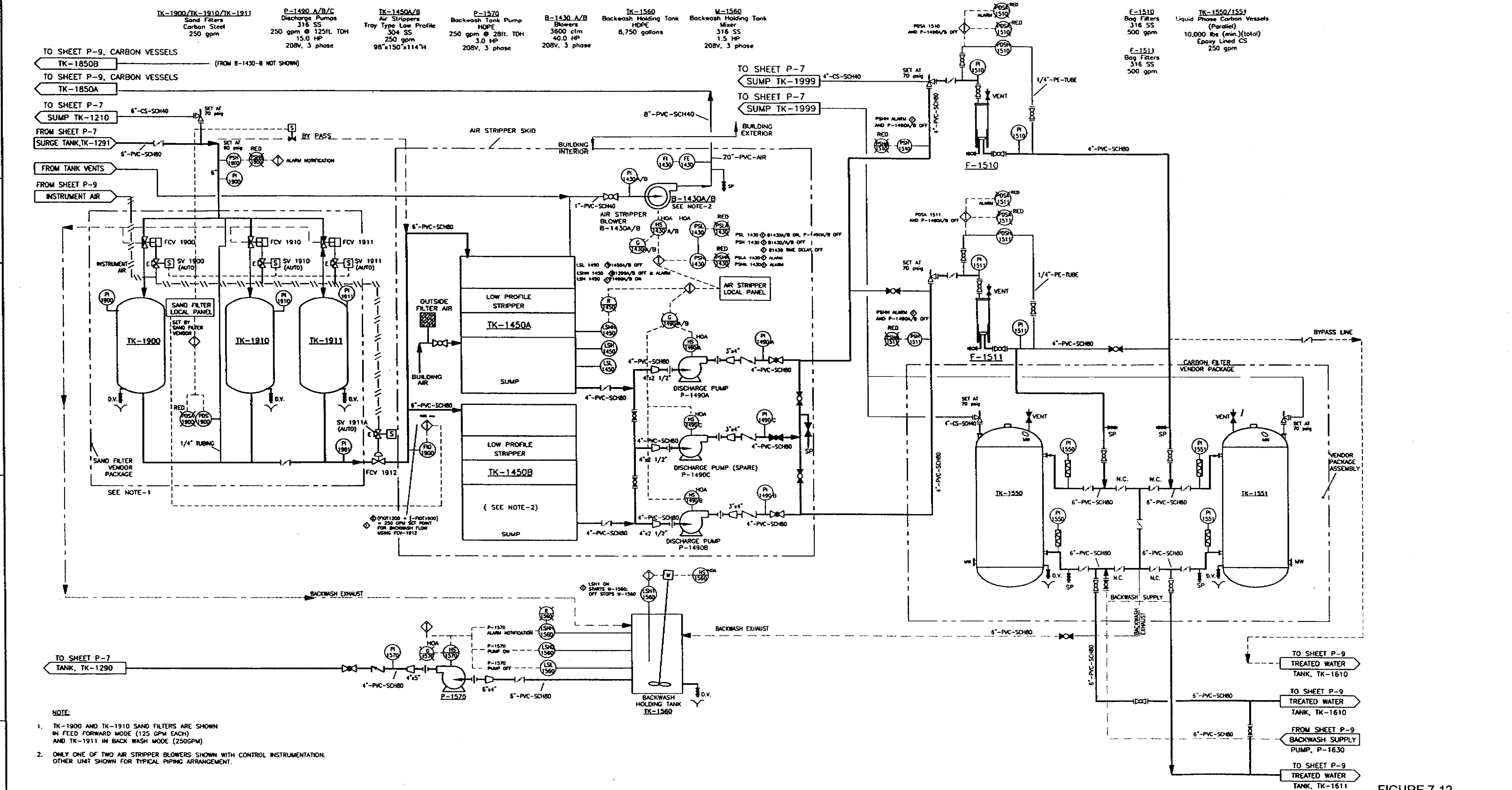
DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D28		5

OFFICE Trenton, NJ
DRAWING NUMBER 8029[illegible]D28



P-1111
Extraction Pumps
304 SS
125 GPM @ 122 ft. TDH
7.5 HP
208V, 3 phase
P-1112
Extraction Pumps
304 SS
250 GPM @ 132 ft. TDH
15 HP
208V, 3 phase
P-1113
Extraction Pumps
304 SS
125 GPM @ 132 ft. TDH
7.5 HP
208V, 3 phase
AC-1000 A/B
Air Compressors
49.2 cfm @ 125 psi
7.5 HP, 1750 rpm
208V, 3 phase (ea.)
P-1999
Sump Pump
304 SS
100 gpm @ 27 ft. TDH
1.0 HP
208V, 3 phase
TK-1999
Building Sump
145 gallons
3'x3'x2'-6" Deep
M-1210/1211
Equalization Tank Mixer
316 SS
1.5 HP
208V, 3 phase
TK-1210/1211
Equalization Tank
HDPE
9,000 gallons
P-1221
Metering Polymer Feed Pump
316 SS
3 gpd
0.25 HP
120V, 1 phase
M-1222
4% KMn04 Dilution Tank Mixer
316 SS
2.0 HP
208V, 3 phase
P-1222
Metering Pump KMn04 Solution
316 SS
9 gph
0.25 HP
208V, 3 phase
TK-1222
4% KMn04 Dilution Tank, HDPE
1500 gallons
TK-1220
25% NaOH Solution Totes
HDPE
660 gallons (total)
P-1220
pH Metering Pump
316 SS
1.2 gph, 1:100 ratio
0.25 HP
120V, 1 phase
M-1221
Polymer Mixer
304 SS
0.3 HP
120V, 1 phase
TK-1290
Sludge Holding Tank
HDPE
7,500 gallons
P-1280
Air Operated Diaphragm Pump
48 gph @ 12 ft. TDH
IPC-1270
Inclined Plate Clarifier
120 gpm
TK-1270A
Oxidation Tank
2,500 gallons
6'Lx8.5'Wx13'H
TK-1270B
Flash Mix Tank
2,500 gallons
6'Lx8.5Wx13'H
TK-1270C
Floc Tank
2,500 gallons
6'Lx8.5Wx13'H
M-1270A/B
Oxidation/Flash Mix Tank Mixers
2.0 HP, 208V 3 Phase
2,500 gallons
M-1270C
Floc Tank Mixers
1.0 HP, 208V 3 Phase
TK-1291
IPC Surge Tank
HDPE
7,500 gallons
P-1299 A/B
Centrifugal Water Pump
316 SS
500 gpm @ 77 ft. TDH
15 HP
208V, 3 phase
CAUSTIC 25% NaOH
TK-1220
(2 STACKABLE TOTES)
POLYMER
TK-1221
POLYMER MIXER
M-1221
VENDOR PACKAGED POLYMER FEEDER
KMn04
POTASSIUM PERMANGANATE (DRY)
SERVICE WATER
FROM P-1299A/B
TK-1610 TREATED WATER FROM SHEET P-9
DECANT WATER FROM TK-1290
RECYCLE LINE
RECIRCULATION LINE
GRAVITY FLOW
FM-1,2
FLOW METERS
RW-1111
RW-1112
RW-1113
P-1111
P-1112
P-1113
PUMPS
TYP. FOR (3) RECOVERY WELLS (1) ONLY SHOWN
P-1001 PUMP OFF
P-1001 PUMP ON
P-1001 ALARM NOTIFICATION
TK-1210/1211
M-1210/1211
(SEE NOTE-2)
OXIDATION
FLASH
FLOC
M-1270A TK-1270A
M-1270B TK-1270B
M-1270C TK-1270C
IPC LOCAL CONTROL PANEL
IPC-1270
TK-1291
P-1299 A/B
RETREAT TK-1610/1611 SHEET P-9
TO SHEET P-8 SAND FILTER
TO TK-1210
BYPASS LINE
PRV'S FROM SHEET P-8
TK-1999
P-1999
VENDOR PACKAGE
LOCAL CONTROL PANEL
FILTER
AC-1000A/B
RUBBER HOSE OR FLEX CONNECTOR
ACTUATING AIR
P-1280
DECANT WATER TO TK-1210 AND TK-1211 (GRAVITY FLOW)
FROM P-1570 SHEET P-8
TK-1290
TRUCK TRAILER PUMP-OUT FOR OFF-SITE T&D
NOTE:
1. ALL PROCESS TANK VENTS, 2" PVC SCH 40 DIRECTED TO B-1430, SHEET P-8.
2. ONLY ONE OF TWO EQUALIZATION TANKS WITH MIXER SHOWN FOR TYPICAL PIPING ARRANGEMENT AND CONTROLS. (TK-1210/1211)
Shaw Shaw Environmental & Infrastructure, Inc.
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT
FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PIPING & INSTRUMENTATION DIAGRAM - OFF-SITE
METALS PRETREATMENT
DESIGNED BY: E. Weinberg
DRAWN BY: C. Agabiti
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg
DATE: 12/6/02
SCALE: NTS
DRAWING NO. 802901-D106
REV. NO. 4
4 1/19/05 DL EW EW FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
3 8/31/04 DL EW EW FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2 7/10/03 DL EW EW 100% DESIGN OFF-SITE
1 12/18/02 CA EW EW 95% DESIGN OFF-SITE
REV DATE BY CHK'D APPR'VD DESCRIPTION/ISSUE
OFFICE Trenton, NJ
DRAWING NUMBER 802901-D106

FIGURE 7-11



NOTE:

1. TK-1900 AND TK-1910 SAND FILTERS ARE SHOWN IN FEED FORWARD MODE (125 GPM EACH) AND TK-1911 IN BACK WASH MODE (250GPM)
2. ONLY ONE OF TWO AIR STRIPPER BLOWERS SHOWN WITH CONTROL INSTRUMENTATION. OTHER UNIT SHOWN FOR TYPICAL PIPING ARRANGEMENT.

FIGURE 7-12

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE; CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

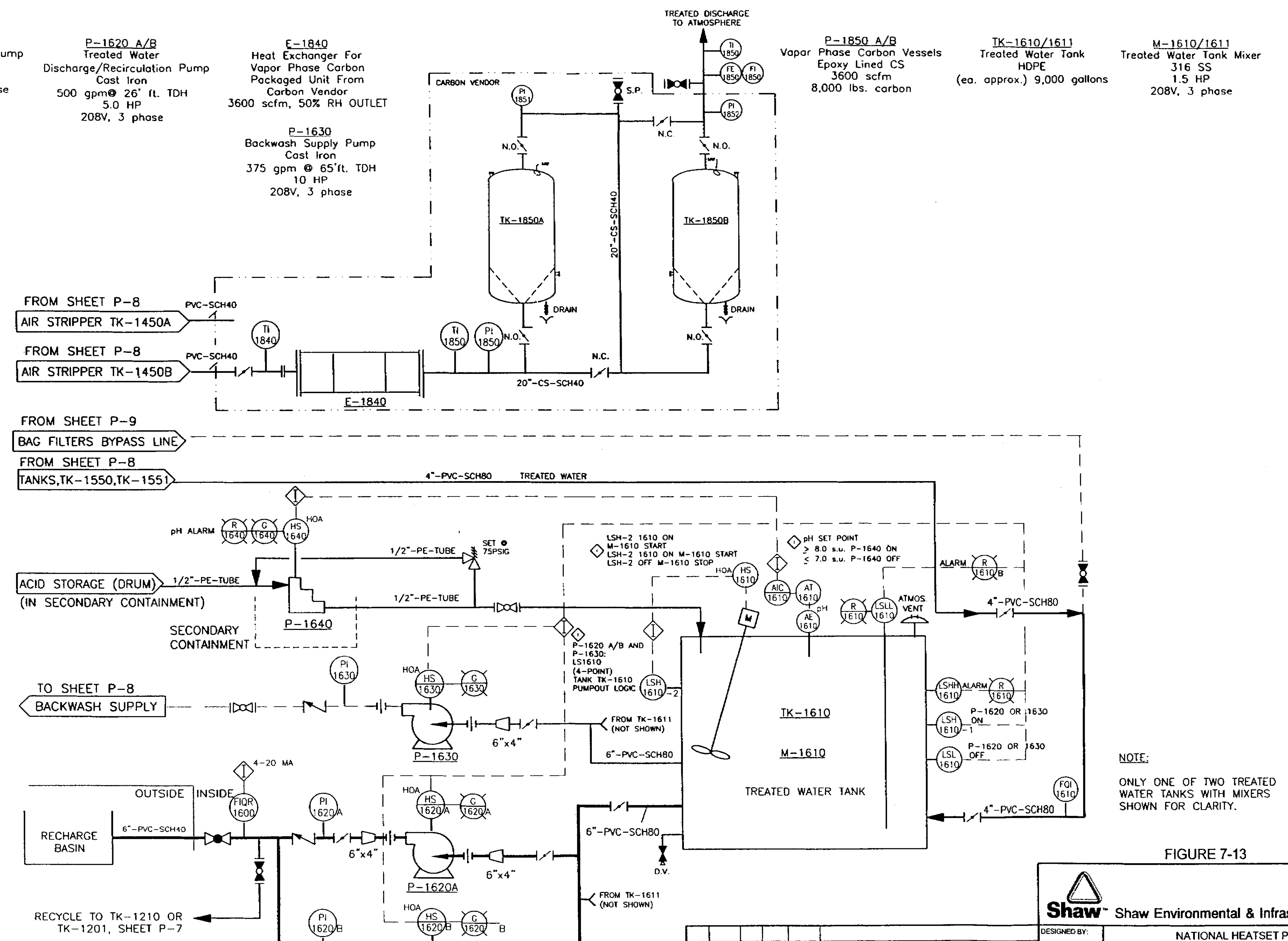
DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: D. Leech
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PIPING & INSTRUMENTATION DIAGRAM - OFF-SITE - VOC REMOVAL

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D107		5

FIGURE 7-13



REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
3	10/01/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw Environmental & Infrastructure, Inc.

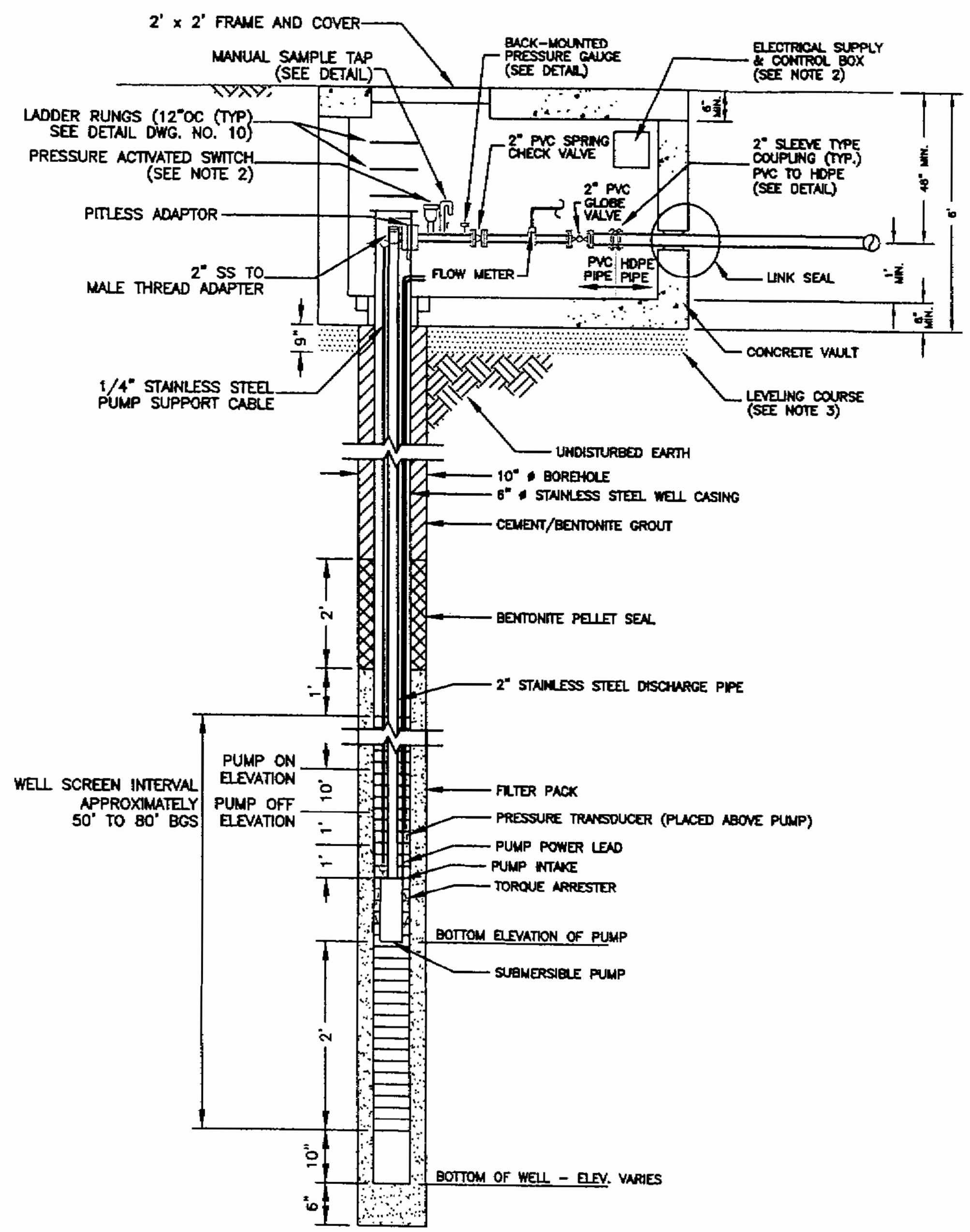
DESIGNED BY: E. Weinberg
DRAWN BY: D. Leech
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
PIPING & INSTRUMENTATION DIAGRAM - OFF-SITE - DISCHARGE SYSTEM

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D108		5

OFFICE Trenton, NJ
DRAWING NUMBER 802901-D108



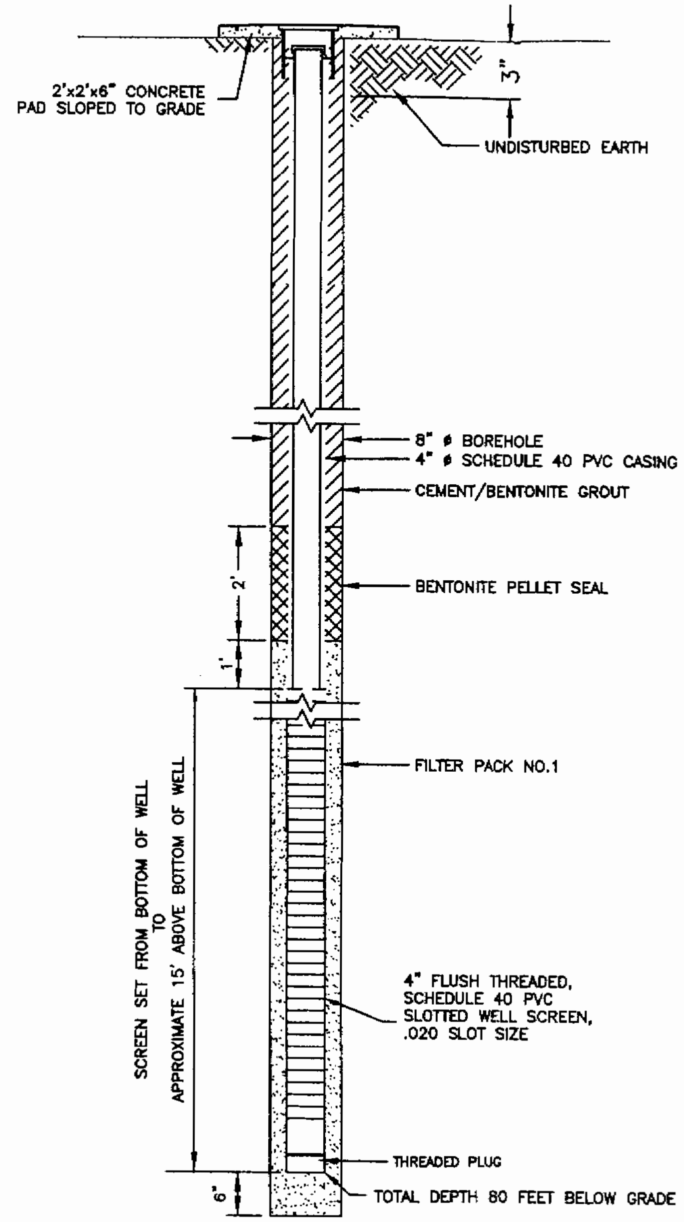
DETAIL 1 (1 / C-2)

TYPICAL OVERBURDEN EXTRACTION WELL WITH MANHOLE

N.T.S.

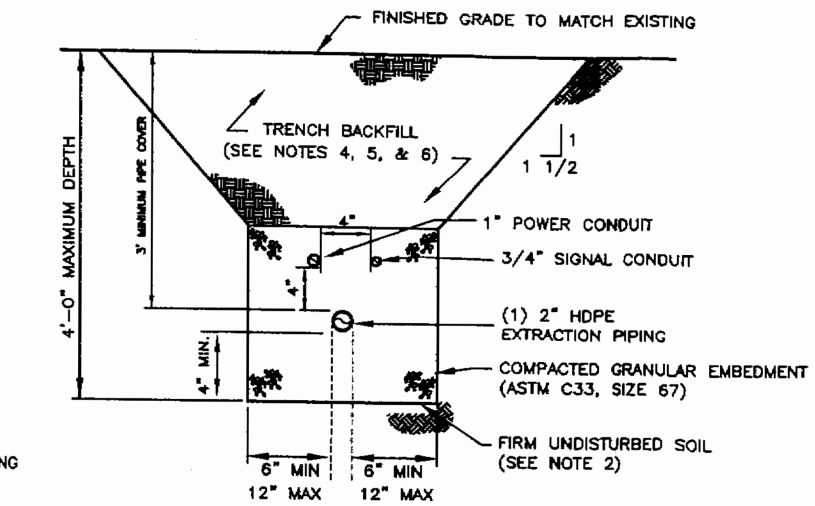
NOTE:

1) FLOW METER SHALL BE LOCATED SUCH THAT THERE ARE 10 PIPE DIAMETERS AHEAD, AND 5 PIPE DIAMETERS OF STRAIGHT PIPE AFTER METER.
2) CONTROLS SHALL INCLUDE A PRESSURE ACTIVATED SWITCH TO SWITCH PUMP "OFF" IN THE EVENT OF HIGH PRESSURE CONDITIONS. CONTROLS WILL ALSO REGULATE PUMP ACTIVATION AND DEACTIVATION BASED ON WATER LEVEL IN WELL.
3) LEVELING COURSE SHALL BE NYSDOT TYPE 3 STONE.



MONITORING WELL

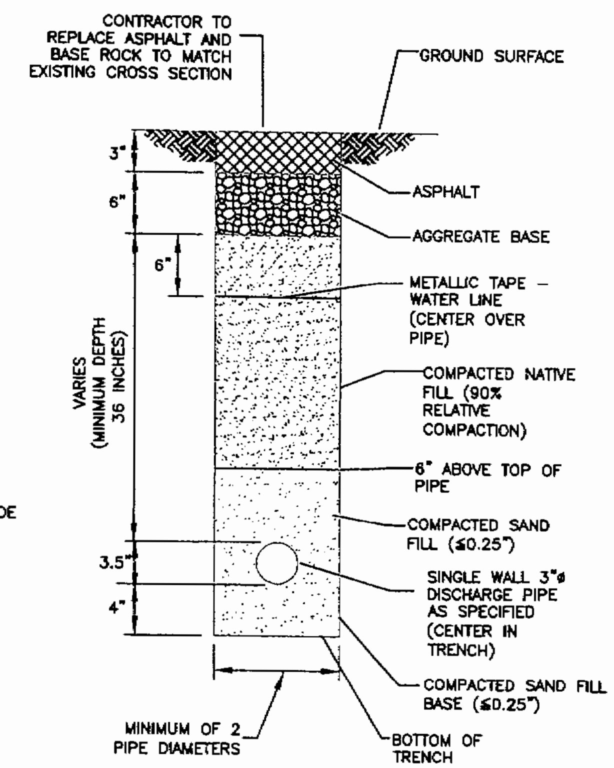
N.T.S.



SECTION A-A' (A-A / C-2)

TRENCH CONSTRUCTION (TYPICAL)

N.T.S.



SECTION B-B' (B-B / C-2)

DISCHARGE PIPELINE CROSS SECTION (TYPICAL)

N.T.S.

TRENCH NOTES:

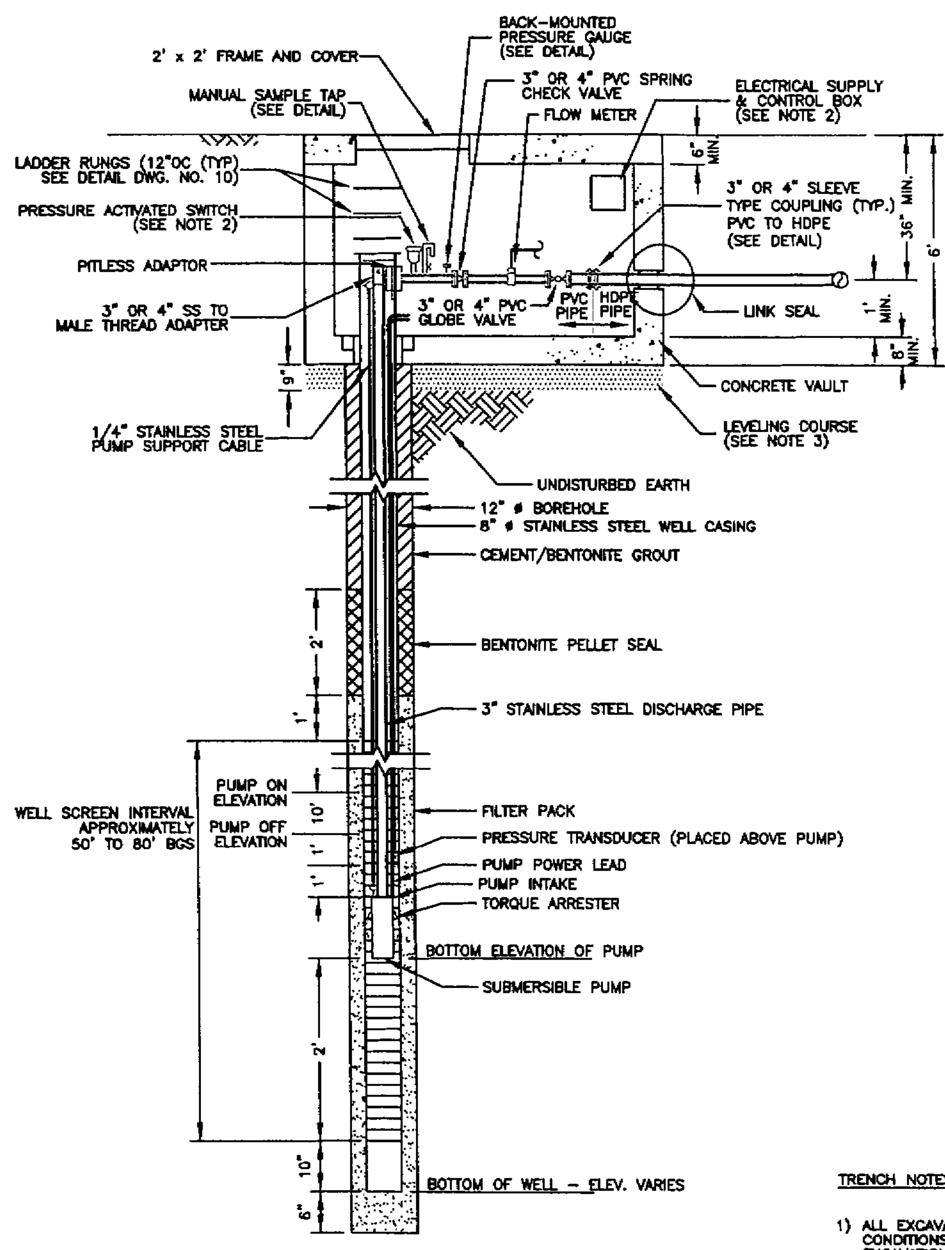
1) ALL EXCAVATION WILL BE PERFORMED IN ACCORDANCE WITH CALL ONDITIONS SET FORTH BY OSHA'S REVISED STANDARDS FOR EXCAVATIONS, 29 CFR 1926 SUBPART P.
2) TRENCH BOTTOM SHALL BE FIRM COMPACTED NON-FROZEN SOIL. CONTRACTOR SHALL VERIFY TRENCH BOTTOM SUITABILITY (IN ORDER TO AVOID EXCESSIVE SETTLEMENT) FOR PROJECT. PLACEMENT OF PIPE AND PIPE BEDDING MATERIAL SHALL NOT BE PERFORMED UNTIL APPROVAL OF TRENCH BOTTOM HAS BEEN RECEIVED.
3) PIPE BEDDING MATERIALS WILL BE PLACED BY HAND AND COMPACTED AS OUTLINED IN 6" (MAX) LIFTS, BANK TO BANK, TO 12" ABOVE THE PIPE SURFACE.
4) CONTAMINATED SOIL SHALL NOT BE USED AS BACKFILL WITHOUT WRITTEN AUTHORIZATION. NATIVE SOIL WILL BE FREE FROM ORGANIC MATTER, FROZEN SOIL, ROCKS IN EXCESS OF 4" ø , ROOTS OR DELETERIOUS COMPONENTS.
5) TRENCH BACKFILL BELOW PAVED AREAS SHALL BE NATIVE SOIL, COMPACTED WITH A VIBRATORY TAMPER TO A MINIMUM OF 95% STANDARD PROCTOR DENSITY.
6) TRENCH BACKFILL BELOW NON-PAVED AREAS WILL CONSIST OF NATIVE SOIL AND WILL BE COMPACTED WITH A VIBRATORY TAMPER TO A MINIMUM OF 90% STANDARD PROCTOR DENSITY.

FIGURE 7-14

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	7/28/03	SSH	JS	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	DL	EW	EW	95% DESIGN ON-SITE/ ADDED TRENCH CROSS SECTION FOR RECOVERY WELL PIPING

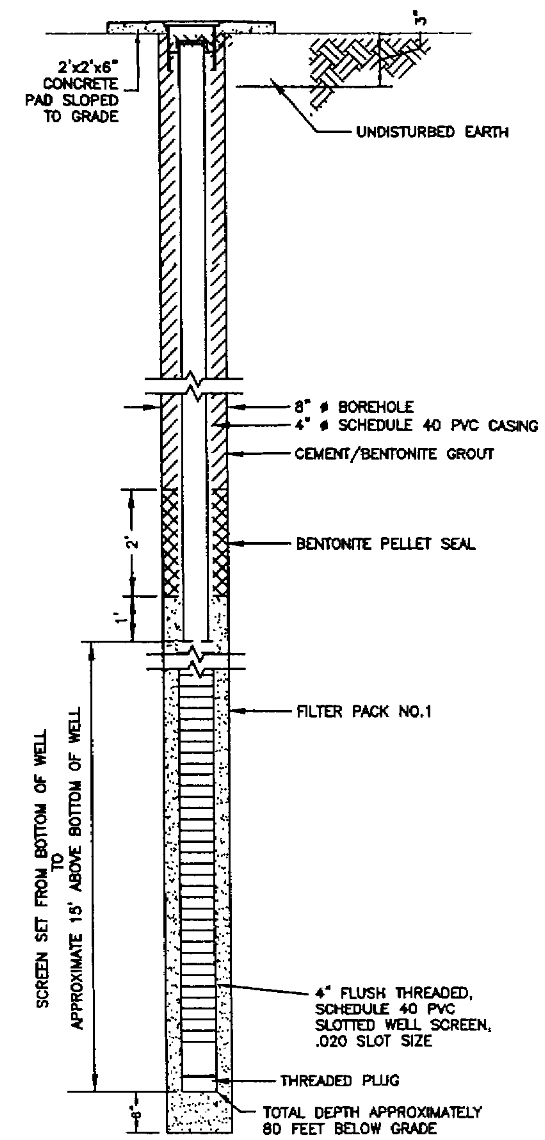
Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: J. Skaarup	NATIONAL HEATSET PRINTING BABYLON, NEW YORK DOWNGRADIENT TREATMENT SYSTEM PROJECT
DRAWN BY: D. Leech	FINAL 100% DESIGN REPORT DRAWINGS GROUNDWATER EXTRACTION AND TREATMENT
CHECKED BY: J. Skaarup	EXTRACTION WELL AND TRENCHING DETAILS - ON-SITE
APPROVED BY: E. Weinberg	DATE: 12/16/02 · SCALE: NTS · DRAWING NO. 802901-D8 · SHEET NO. · REV. NO. 4



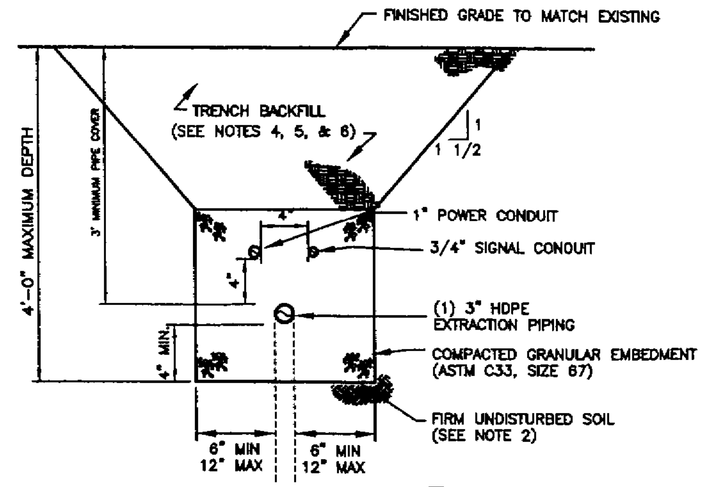
TYPICAL OVERBURDEN EXTRACTION WELL WITH MANHOLE

N.T.S.



MONITORING WELL

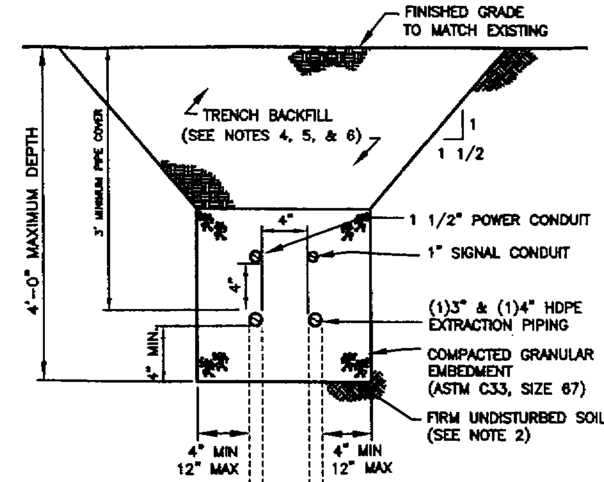
N.T.S.



SECTION A–A (A–A / C-4)

N.T.S.

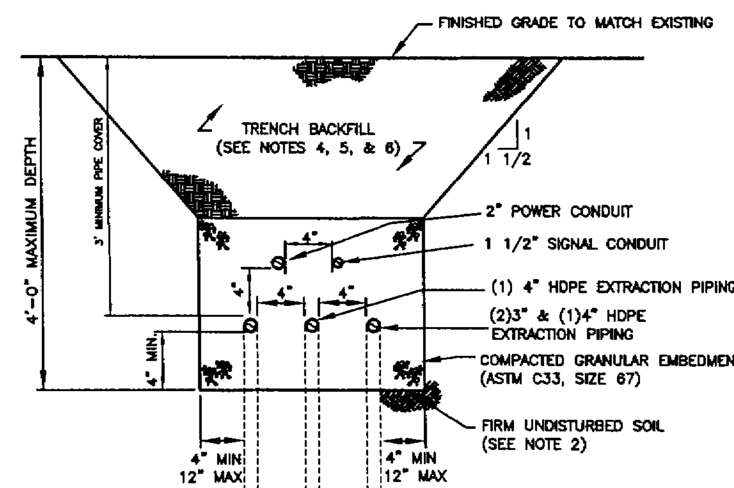
SINGLE PIPE TRENCH CONSTRUCTION (TYPICAL)



SECTION B–B (B–B / C-4)

N.T.S.

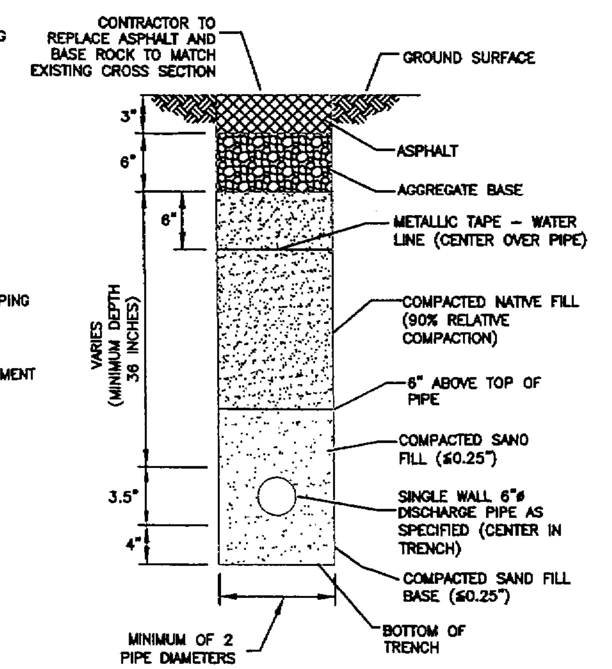
DOUBLE PIPE TRENCH CONSTRUCTION (TYPICAL)



SECTION C–C (C–C / C-4)

N.T.S.

TRIPLE PIPE TRENCH CONSTRUCTION (TYPICAL)



SECTION D–D (D–D / C-4)

N.T.S.

DISCHARGE PIPELINE CROSS SECTION (TYPICAL)

NOTE:

1) FLOW METER SHALL BE LOCATED SUCH THAT THERE ARE 10 PIPE DIAMETERS AHEAD, AND 5 PIPE DIAMETERS OF STRAIGHT PIPE AFTER METER.
2) CONTROLS SHALL INCLUDE A PRESSURE ACTIVATED SWITCH TO SWITCH PUMP "OFF" IN THE EVENT OF HIGH PRESSURE CONDITIONS. CONTROLS WILL ALSO REGULATE PUMP ACTIVATION AND DEACTIVATION BASED ON WATER LEVEL IN WELL.
3) LEVELING COURSE SHALL BE NYSDOT TYPE 3 STONE.

TRENCH NOTES:

1) ALL EXCAVATION WILL BE PERFORMED IN ACCORDANCE WITH ALL CONDITIONS SET FORTH BY OSHA'S REVISED STANDARDS FOR EXCAVATIONS, 29 CFR 1926 SUBPART P.
2) TRENCH BOTTOM SHALL BE FIRM COMPACTED NON-FROZEN SOIL. CONTRACTOR SHALL VERIFY TRENCH BOTTOM SUITABILITY (IN ORDER TO AVOID EXCESSIVE SETTLEMENT) FOR PROJECT. PLACEMENT OF PIPE AND PIPE BEDDING MATERIAL SHALL NOT BE PERFORMED UNTIL APPROVAL OF TRENCH BOTTOM HAS BEEN RECEIVED.
3) PIPE BEDDING MATERIALS WILL BE PLACED BY HAND AND COMPACTED AS OUTLINED IN 6" (MAX) LIFTS, BANK TO BANK, TO 12" ABOVE THE PIPE SURFACE.
4) CONTAMINATED SOIL SHALL NOT BE USED AS BACKFILL WITHOUT WRITTEN AUTHORIZATION. NATIVE SOIL WILL BE FREE FROM ORGANIC MATTER, FROZEN SOIL, ROCKS IN EXCESS OF 4"ø, ROOTS OR DELETERIOUS COMPONENTS.
5) TRENCH BACKFILL BELOW PAVED AREAS SHALL BE NATIVE SOIL, COMPACTED WITH A VIBRATORY TAMPER TO A MINIMUM OF 95% STANDARD PROCTOR DENSITY.
6) TRENCH BACKFILL BELOW NON-PAVED AREAS WILL CONSIST OF NATIVE SOIL AND WILL BE COMPACTED WITH A VIBRATORY TAMPER TO A MINIMUM OF 90% STANDARD PROCTOR DENSITY.

FIGURE 7-15

Shaw™ Shaw Environmental & Infrastructure, Inc.

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
EXTRACTION WELL AND TRENCHING DETAILS - OFF-SITE

REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
3	7/28/03	SSH	JS	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
2	7/10/03	DL	EW	EW	100% DESIGN OFF-SITE
1	12/18/02	CA	EW	EW	50% DESIGN OFF-SITE

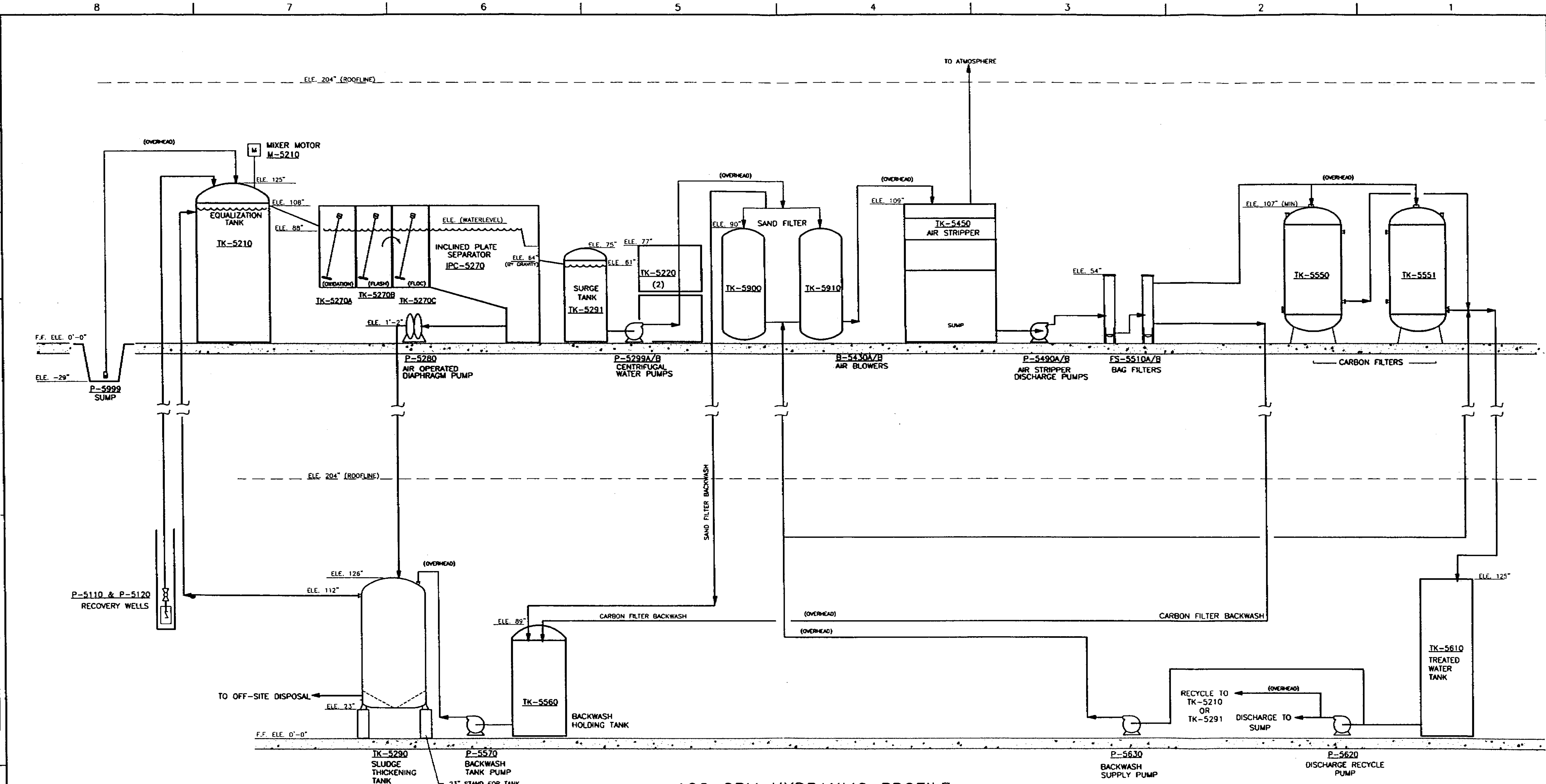
DESIGNED BY: J. Skaarup
DRAWN BY: C. Agabiti
CHECKED BY: R. Jasaitis
APPROVED BY: E. Weinberg

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/17/02	NTS	802901-D110		4

OFFICE Trenton, NJ
DRAWING NUMBER 80290_10

VERIFY SCALE 0 1"

PROJECT\802901\Construct Bid 8-04 Off-Site\802901-D110-A.dwg
Date/Time: 09/08/0_ 4pm
Image:
Plotted by: colette.ogeb
Xref:



100 GPM HYDRAULIC PROFILE

(NTS)

FIGURE 7-16

Shaw Environmental & Infrastructure, Inc.

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

DESIGNED BY: H. Dudek
DRAWN BY: C. Agabiti
CHECKED BY: R. Sinha, E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

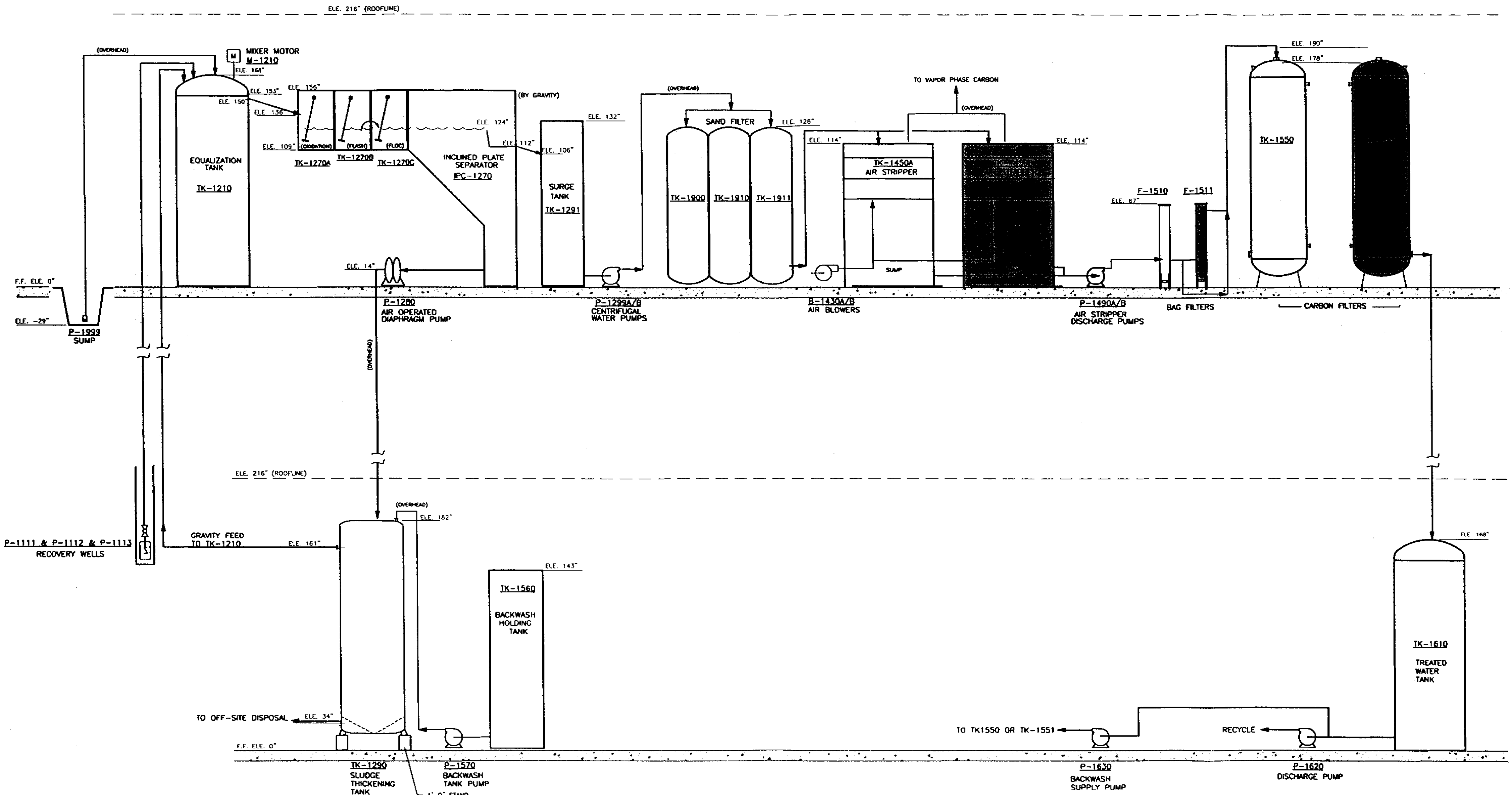
FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

EQUIPMENT HYDRAULIC PROFILE - ON-SITE

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D44-A		5

OFFICE Trenton, NJ
DRAWING NUMBER 802901-D44-A

OFFICE	DRAWING NUMBER
Trenton, NJ	80290[illegible]113-A



500 GPM HYDRAULIC PROFILE

(NTS)

FIGURE 7-17

NOTE:

1. PARALLEL AIR STRIPPERS, BAG FILTER HOUSINGS AND CARBON FILTERS SHOWN SIDE-BY-SIDE FOR CLARITY. SHADED UNITS ARE IN THE BACKGROUND.

REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
4	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
3	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: M. Jurusz
DRAWN BY: C. Agabiti
CHECKED BY: R. Sinha
APPROVED BY: E. Weinberg

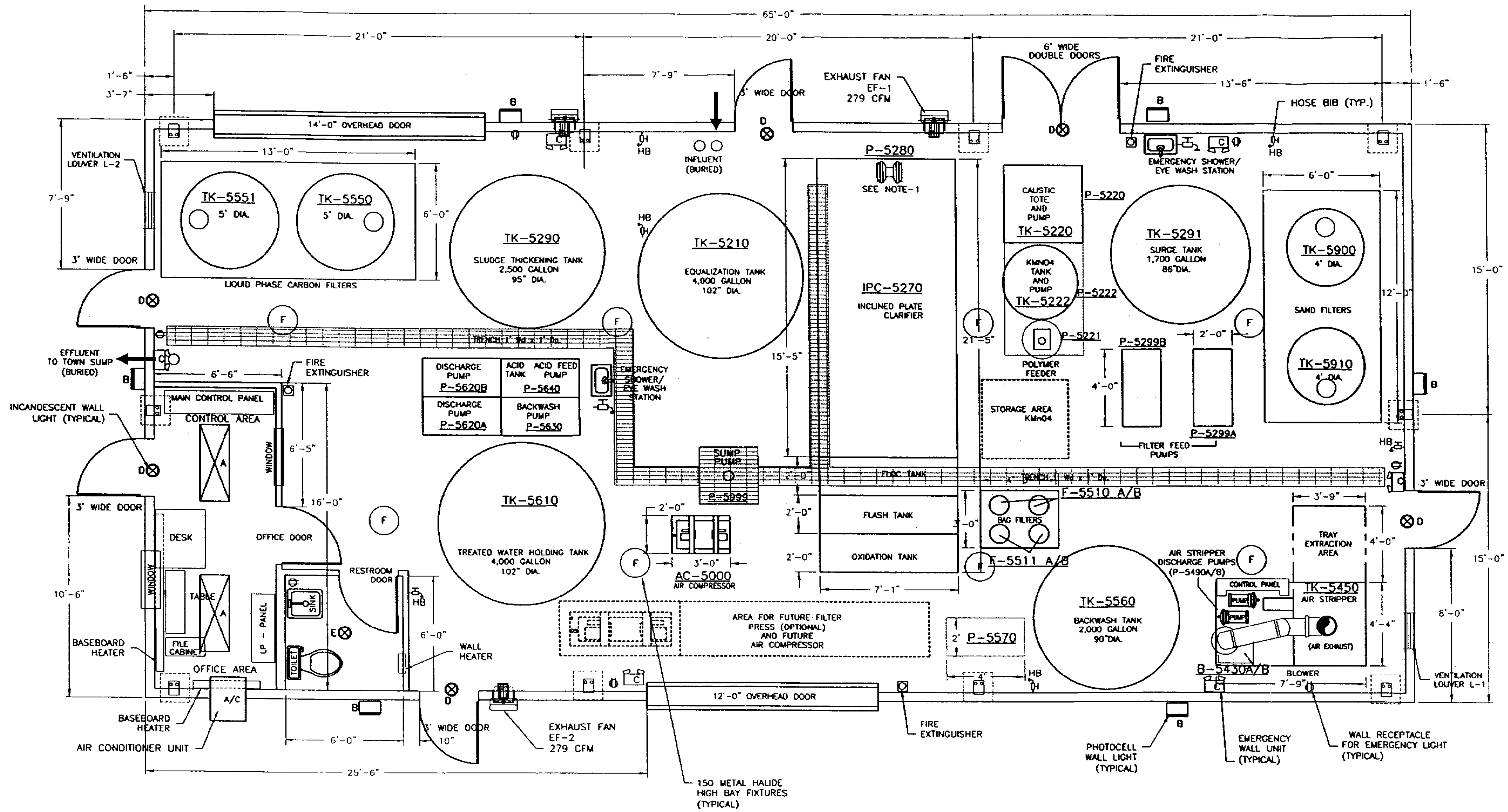
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

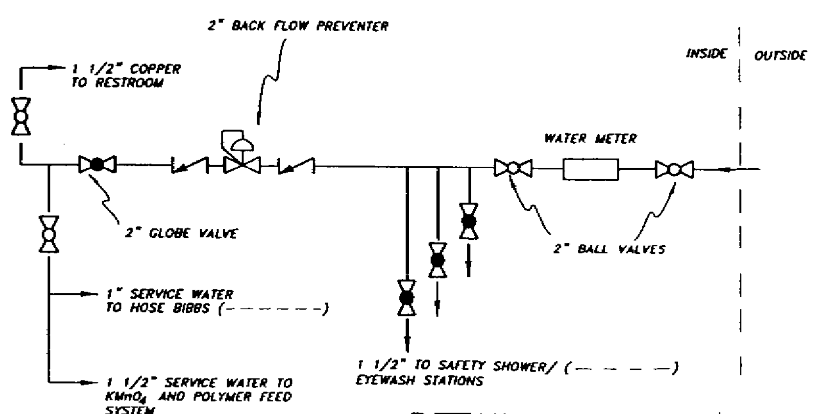
FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
EQUIPMENT HYDRAULIC PROFILE
OFF-SITE

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D113-A		4

K:\PROJECT\802901\C... d 8-04 Off-Site\802901-D113-A.dwg
Plot Date/Time: 01/2... pm
Plotted by: david.leec...
Image: .
Xref: .

VERIFY SCALE 0 1"





DETAIL 1
SERVICE WATER COMPONENTS
N. T. S.

LEGEND:

HB HOSE BIB

LIGHTING FIXTURE LEGEND

TYPE	LAMPS TYPE	MOUNTING	SYMBOLS
A	FLUORESCENT	HUNG FROM ROOF STRUCTURE OR CEILING	
B	PHOTO CELL	WALL	B
C	HALOGEN	WALL	C
D	INCAND.	WALL	D
E	INCAND.	CEILING	E
F	METAL HALIDE	PENDANT	F

SCALE 0 3' 6' 9' FEET

REV	DATE	BY	CHK'D	APPRVD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/15/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE; REPLACED TK-5310 WITH COMBINATION IPC-5270 FOR OXIDATION REACTION

FIGURE 7-18

Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: H. Dudek, E. Weinberg
DRAWN BY: D. Leech
CHECKED BY: R. Sinha, E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

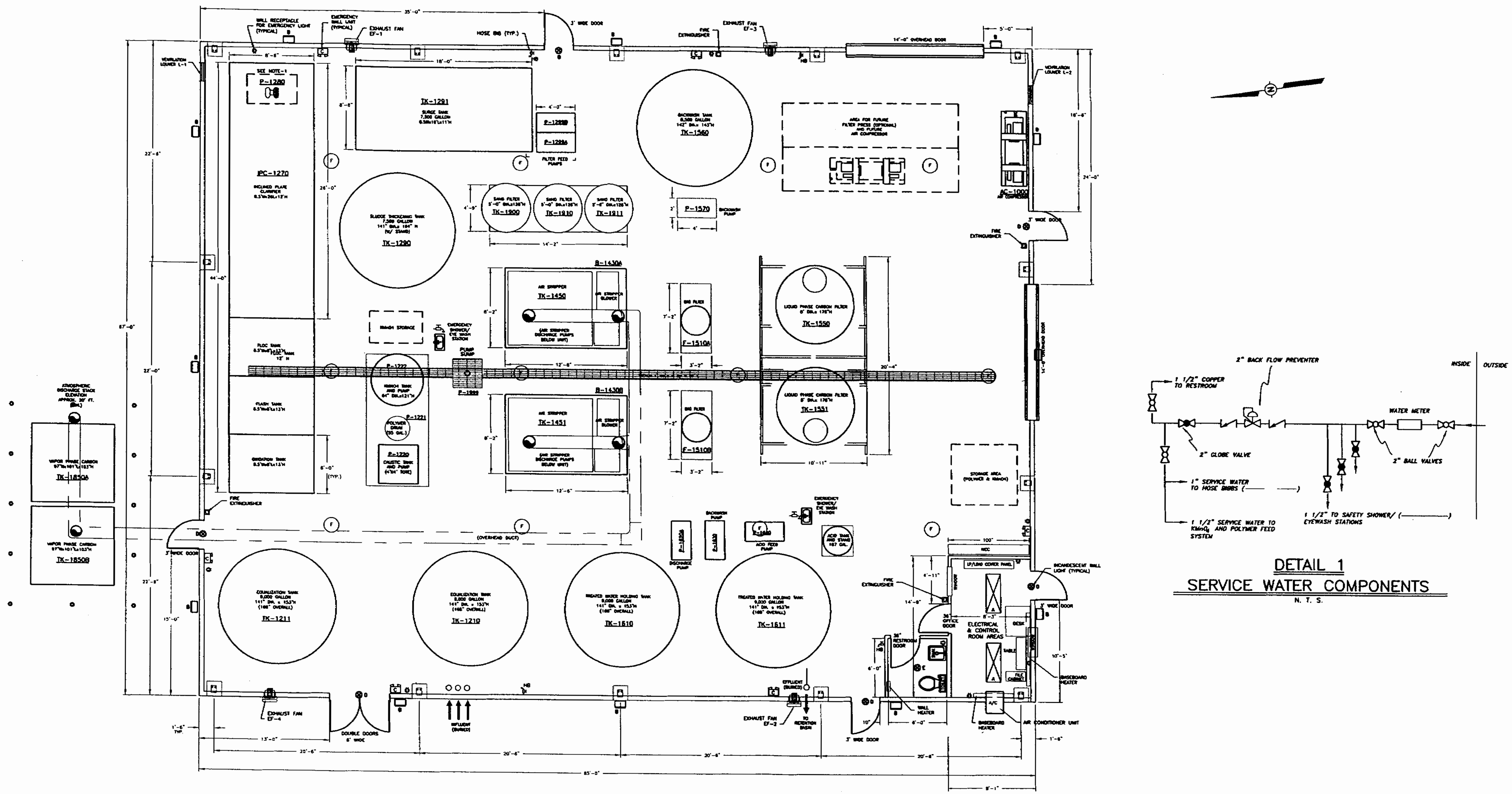
EQUIPMENT ARRANGEMENT, PLANT LAYOUT- ON-SITE

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D13-A		5

OFFICE Trenton, NJ
DRAWING NUMBER 80290_13-A

VERIFY SCALE 0 1"

K:\PROJECT\802901\Co... Bid 8-04 On-Site\802901-D13-A.dwg
Plot Date/Time: 01/2... 17am
Plotted by: david.leech



LEGEND

- PIPE BOLLARD
- HOSE BIB

LIGHTING FIXTURE LEGEND			
TYPE	LAMPS TYPE	MOUNTING	SYMBOLS
A	FLOURESCENT	HUNG FROM ROOF STRUCTURE OR CEILING	
B	PHOTO CELL	WALL	
C	HALOGEN	WALL	
D	INCAND.	WALL	
E	INCAND.	CEILING	
F	METAL HALIDE	CEILING	

FIGURE 7-19

REV	DATE	BY	CHK'D	APRVD	DESCRIPTION/ISSUE
4	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
3	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: E. Weinberg
DRAWN BY: C. Agabili
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
EQUIPMENT ARRANGEMENT,PLANT LAYOUT
OFF-SITE

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D112-A		4

OFFICE Trenton, NJ | DRAWING NUMBER 802901-D112-A

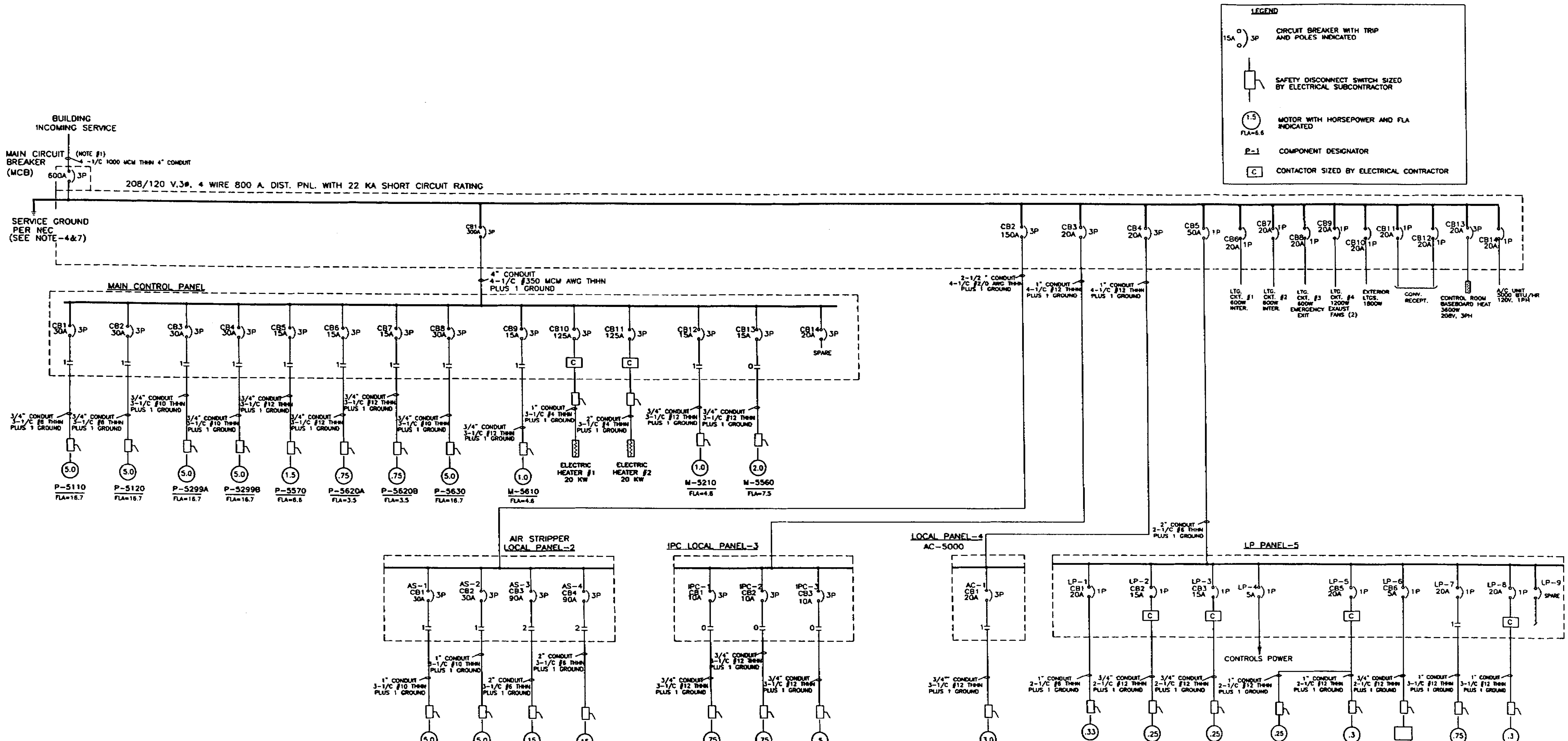
K:\PROJECT\802901\Con[...]Bid 8-04 Off-Site\802901-D112-A.dwg
Plot Date/Time: 01/20/05 12:28pm
Plotted by: david.leach
Image: .
Xref: .

VERIFY SCALE 0 1"

K:\PROJECT\802901\[redacted] Bid 8-04 On-Site\802901-D33-A.dwg
Plot Date/Time: 01/20/[redacted]1:57am
Plotted by: david.leech
Image: .
Xref: .

OFFICE	DRAWING NUMBER
Trenton, NJ	802901-D26

VERIFY SCALE 0 — 1"



Notes:

1. Contractor to confirm existing services available and coordinate installation with LILCO and the owner.
2. All electrical wiring and equipment installation shall be performed in accordance with the national electrical code (NEC 2002) and other applicable codes. All workmanship shall be performed in a professional manor.
3. The panel shall be rated for "for use as service equipment" per NEC 230.66.
4. All raceways and equipment shall be grounded per NEC 250.122.
5. All asphalt, concrete, grass and other areas disturbed by electric service shall be restored by contractor to original condition.
6. Area classification within and outside the treatment compound is non-hazardous, unclassified.
7. The panel neutral bus shall be connected to a grounding electrode system per NEC 250.52. The ground electrode conductor shall be sized and installed per NEC 250.66.
8. Temperature ratings for electrical equipment shall be 75 ° C.
9. Motor sizes or electric loads are subject to change pending final approvals, hence, electrical subcontractor to finalize total connected, operating loads for all panels and transformers and all overload or current protection devices. (FLA per 2002 NEC Tables 430.148 & 430.150)
10. Short circuit rating to be verified after incoming supply electrical ratings are known.
11. Main circuit breaker to have long time, short time & ground fault protection.

FIGURE 7-20

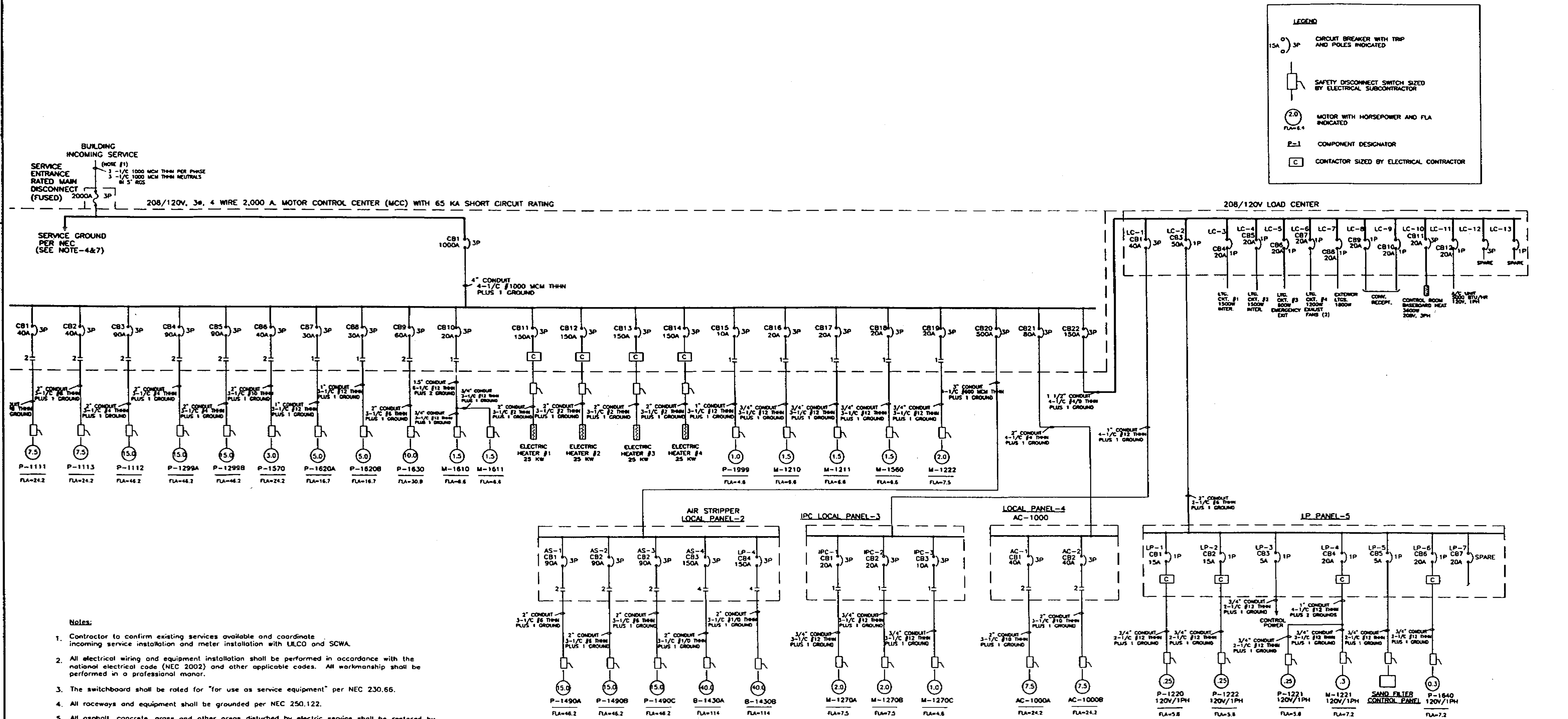
Shaw™ Shaw Environmental & Infrastructure, Inc.

REV	DATE	BY	CHK'D	APRVD	DESCRIPTION/ISSUE
5	1/19/05	DL	EW	EW	FINAL 100% DESIGN ON-SITE: CONTRACT DOCUMENT REVISIONS
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE, VGAC REMOVED
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

DESIGNED BY: EW / MS
DRAWN BY: C. Agobili
CHECKED BY: E. Weinberg
APPROVED BY: EW / MS

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT
FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
ELECTRICAL SINGLE LINE DIAGRAM - ON-SITE

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D33-A		5



Notes:

1. Contractor to confirm existing services available and coordinate incoming service installation and meter installation with LILCO and SCWA.
2. All electrical wiring and equipment installation shall be performed in accordance with the national electrical code (NEC 2002) and other applicable codes. All workmanship shall be performed in a professional manor.
3. The switchboard shall be rated for "for use as service equipment" per NEC 230.66.
4. All raceways and equipment shall be grounded per NEC 250.122.
5. All asphalt, concrete, grass and other areas disturbed by electric service shall be restored by contractor to original condition.
6. Area classification within and outside the treatment compound is non-hazardous, unclassified.
7. The panel/switchboard neutral bus shall be connected to a grounding electrode system per NEC 250.52. The ground electrode conductor shall be sized and installed per NEC 250.66.
8. Temperature ratings for electrical equipment shall be 75 ° C.
9. Motor sizes or electric loads are subject to change pending final approvals, hence, electrical subcontractor to finalize total connected, operating loads for all panels and transformers and all overload or current protection devices. (FLA per 2002 NEC Tables 430.148 & 430.150)
10. Short circuit rating to be verified after incoming supply electrical ratings are known.
11. Main circuit breaker to have long time, short time & ground fault protection.

FIGURE 7-21

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
3	6/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw™ Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: M.S. E.W.
DRAWN BY: D. Leech
CHECKED BY: E. Weinberg
APPROVED BY: M.S. E.W.

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

ELECTRICAL SINGLE LINE DIAGRAM - OFF-SITE

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/8/02	NTS	802901-D114-A		4

PANEL NO. MAIN POWER DISTRIBUTION PANEL
SERVICE 208/120V PH 3 W 4 NEUT SOLID
BUS RATING 800 AMPERES SHORT CIRCUIT RATING 22KA

LOCATION NATIONAL HEATSET, ON-SITE
MAIN 600A MAIN CIRCUIT BREAKER CONNECTION TOP
MOUNTING SURFACE NEMA 1 FEEDER SIZE 4-1/C1000MCM

SERVICE	CB NO	LOAD ØA	LOAD ØB	LOAD ØC	AMP			AMP	LOAD ØA	LOAD ØB	LOAD ØC	CB NO	SERVICE
MAIN CONTROL PANEL	1	25.9	25.9	25.9	300	1, 3, 5	2, 4, 6	150	11.2	11.2	11.2	2	AIR STRIPPER PANEL-2
IPC LOCAL PANEL-3	3	.7	.7	.7	20	7, 9, 11	8, 10, 12	20	.9	.9	.9	4	LOCAL PANEL-4 AC 5000
LP PANEL-5	5	2.8			50	13	14	20	.6			6	LIGHTING CIRUIT #1 (INTERIOR)
LIGHTING CIRCUIT #2 (INTERIOR)	7		.6		20	15	16	20		0.6		8	LIGHTING CIRCUIT #3 (EMERG. EXIT)
LIGHTING CIRCUIT #4 (EXH. FANS)	9			1.2	20	17	18	20			1.8	10	EXTERIOR LIGHTS
CONVENIENCE RPCT. CIRCUIT #1	11	1.2			20	19	20	20	1.2			12	CONVENIENCE RCPT. CIRCUIT #2
BASEBOARD HEATER	13	1.2	1.2	1.2	20	21	22	20		1.5		14	AC/5000 Btu/hr. AIR CONDITIONER
						23	24	20					SPARE
						25	26						SPACE
SPARE						27	28						
SPARE						29	30						

A B C

CONNECTED LOAD: ØA 45.7 KW
ØB 42.6 KW
ØC 42.9 KW

TOTAL LOAD: 131.2 KW

NEUTRAL BUS

FIGURE 7-22

Shaw Environmental & Infrastructure, Inc.

NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT

LOAD CENTER / PANEL SCHEDULES - ON-SITE

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE
4	8/31/04	DL	EW	EW	FINAL 100% DESIGN ON-SITE & CONSTRUCTION BID DRAWINGS
3	10/13/03	CA	EW	EW	CONSTRUCTION BID DRAWINGS: ON-SITE
2	7/10/03	DL	EW	EW	100% DESIGN ON-SITE, VGAC REMOVED
1	12/18/02	CA	EW	EW	95% DESIGN ON-SITE

DESIGNED BY: E. Arnold
DRAWN BY: E. Arnold
CHECKED BY: W. Taubel
APPROVED BY: E. Weinberg

DATE:	SCALE:	DRAWING NO.	SHEET NO.	REV. NO.
12/6/02	NTS	802901-D34-A		4

OFFICE Trenton, NJ
DRAWING NUMBER 802901-D34-A

PANEL NO. 208120V LOAD CENTER
SERVICE 208/120V PH 3 W 4 NEUT SOLID
BUS RATING ____ SHORT CIRCUIT RATING ____ — FROM VENDOR
LOCATION NATIONAL HEATSET, OFF-SITE
MAIN MAIN LUGS ONLY CONNECTION TOP
MOUNTING SURFACE NEMA 1 FEEDER SIZE 4-1/C #4

SERVICE	CB NO	LOAD ØA	LOAD ØB	LOAD ØC	AMP		AMP	LOAD ØA	LOAD ØB	LOAD ØC	CB NO	SERVICE
LOCAL PANEL-3	1	2.1	2.1	2.1	40	1 / 2					2	
						3 / 4	20	1.5			4	LIGHTING CIRCUIT #1 (INTERIOR)
						5 / 6	20		0.6		6	LIGHTING CIRCUIT #3 (EMERG. EXIT)
LOCAL PANEL-5	3	2.2			50	7 / 8	20			1.8	8	EXTERIOR LIGHTS
LIGHTING CIRCUIT #2 (INTERIOR)	5		1.5		20	9 / 10	20	1.2			10	CONVENIENCE RCPT. CIRCUIT #2
LIGHTING CIRCUIT #4 (EXH. FANS)	7			1.2	20	11 / 12	20		1.5		12	AC/5000 Btu/hr AIR CONDITIONER
CONVENIENCE RPCT. CIRCUIT #1	9	1.2			20	13 / 14					14	SPARE
BASEBOARD HEATERS	11	1.2	1.2	1.2	20	15 / 16						
						17 / 18						
						19 / 20						
SPARE						21 / 22						
						23 / 24						
						25 / 26						
						27 / 28						
						29 / 30						

A B C

CONNECTED LOAD: ØA 9.4 KW
ØB 6.9 KW
ØC 6.3 KW
TOTAL LOAD: 22.6 KW

NEUTRAL BUS

PANEL NO. LP-5
SERVICE 120V/208 PH 1 W 3 NEUT SOLID
BUS RATING 100A SHORT CIRCUIT RATING 22KA
LOCATION NATIONAL HEATSET, OFF-SITE
MAIN MAIN LUGS ONLY CONNECTION TOP
MOUNTING SURFACE NEMA 1 FEEDER SIZE 2-1/C #6

SERVICE	CB NO	LOAD X1	LOAD X2	AMP		AMP	LOAD X1	LOAD X2	CB NO	SERVICE
P-1220	1	.19		15	1 / 2	15	.19		2	P-1221
CONTROL POWER	3		.6	5	3 / 4	20		.41	4	P-1222 & M-1221
SAND FILTER CONTROL PANEL	5	.6		5	5 / 6	20	.24		6	P-1640
SPARE	7			20	7 / 8					
					9 / 10					
					11 / 12					
					13 / 14					
					15 / 16					
					17 / 18					
					19 / 20					
					21 / 22					
					23 / 24					
					25 / 26					
					27 / 28					
					29 / 30					

X1 X2

CONNECTED LOAD: X1 1.22 KW
X2 1.01 KW
TOTAL LOAD: 2.23 KW

NEUTRAL BUS

FIGURE 7-23

REV	DATE	BY	CHK'D	APRV'D	DESCRIPTION/ISSUE
4	1/19/05	DL	EW	EW	FINAL 100% DESIGN OFF-SITE: CONTRACT DOCUMENT REVISIONS
3	8/31/04	DL	EW	EW	FINAL 100% DESIGN OFF-SITE & CONSTRUCTION BID DRAWINGS
2	7/10/03	DL	EW	EW	CONSTRUCTION BID DRAWINGS: OFF-SITE
1	12/18/02	CA	EW	EW	95% DESIGN OFF-SITE

Shaw Environmental & Infrastructure, Inc.

DESIGNED BY: W. Taubel, E. Weinberg
DRAWN BY: --
CHECKED BY: E. Weinberg
APPROVED BY: E. Weinberg

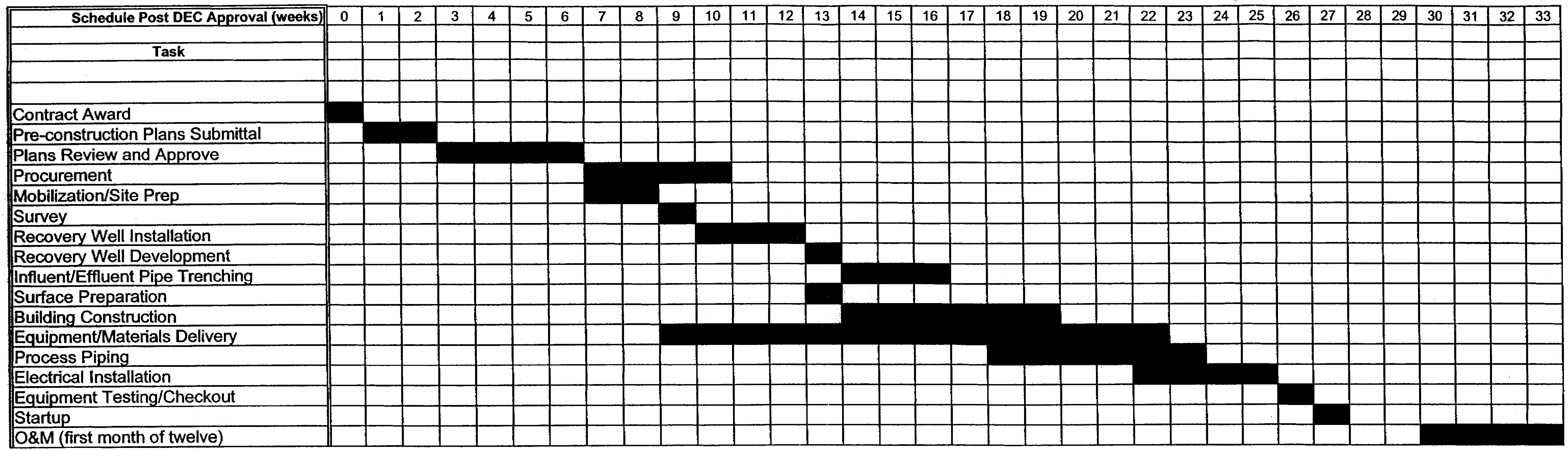
NATIONAL HEATSET PRINTING
BABYLON, NEW YORK
DOWNGRADIENT TREATMENT SYSTEM PROJECT

FINAL 100% DESIGN REPORT DRAWINGS
GROUNDWATER EXTRACTION AND TREATMENT
LOAD CENTER / PANEL SCHEDULES - OFF SITE

DATE: 8/22/04 SCALE: NTS DRAWING NO. 802901-D117-A SHEET NO. REV. NO. 4

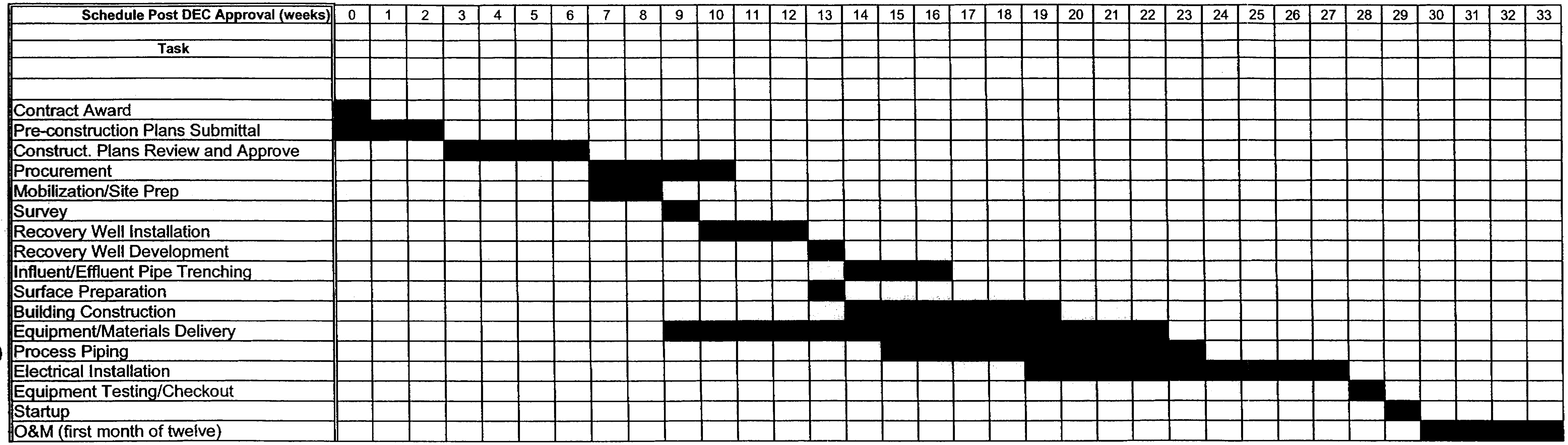
OFFICE Trenton, NJ DRAWING NUMBER 802901-D117-A

Figure 8-1
National Heat Set Downgradient Project
Implementation Schedule - On-Site - Extraction and Treatment
September 2004



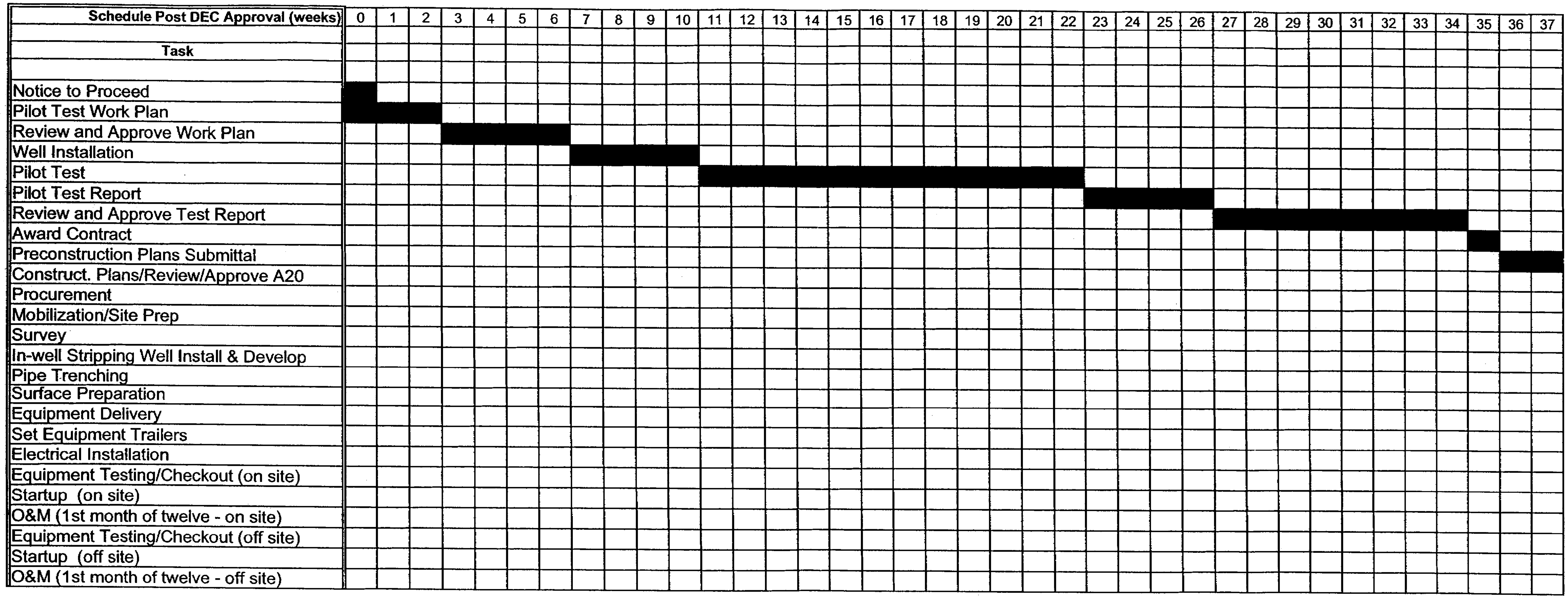
Note: 1. Off-site testing and startup is sequenced after on-site testing and startup because the same personnel will be involved in both sets of activities.
2. Substantial completion occurs after successful completion of Equipment testing and Checkout (week 27).

Figure 8-2
National Heat Set Downgradient Project
Implementation Schedule - Off-Site - Extraction and Treatment
September 2004



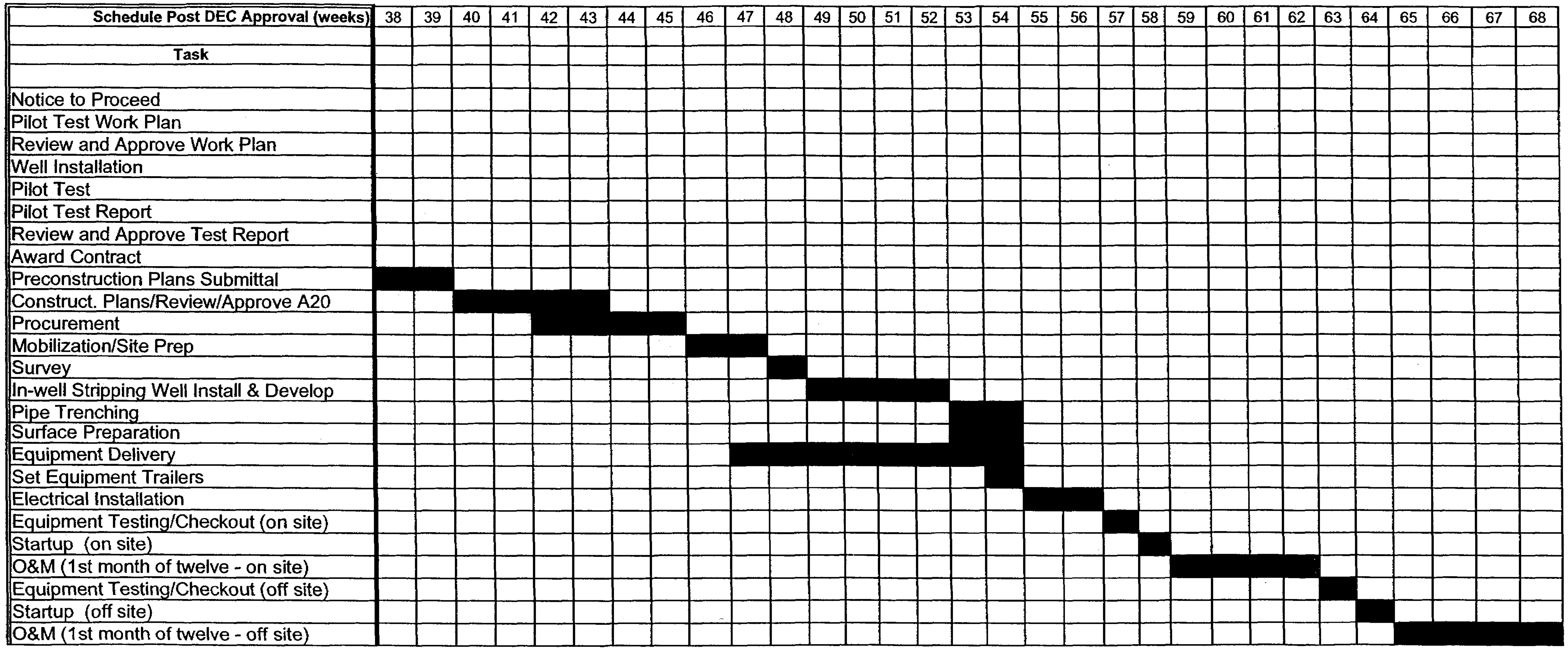
Note: 1. Off-site testing and startup is sequenced after on-site testing and startup because the same personnel will be involved in both sets of activities.
2. Substantial completion occurs after successful completion of Equipment testing and Checkout (week 28).

Figure 8-3
National Heat Set Downgradient Project
In Well Stripping - Implementation Schedule
September 2004



Note: 1. Off-site testing and startup is sequenced after on-site testing and startup because the same personnel will be involved in both sets of activities.
2. Substantial completion occurs after successful completion of Equipment testing and Checkout (week 57).

Figure 8-3
National Heat Set Downgradient Project
In Well Stripping - Implementation Schedule
September 2004



Note: 1. Off-site testing and startup is sequenced after on-site testing and startup because the same personnel will be involved in both sets of activities.
2. Substantial completion occurs after successful completion of Equipment testing and Checkout (week 57).

APPENDIX A

METEOROLOGICAL AND GAUGING DATA

Daily Climate Data

FRG April 2001 - FARMINGTON STATION

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR	AvSLP
1	42	37	40	25	34.0		0.00	F	100	6.1	110	12	10.0	100	73	1008.3
2	49	36	43	22	29.1		0.00		310	7.2	310	20	9.9	89	47	1013.1
3	52	34	43	22	29.7		0.00		330	7.0	340	22	5.6	78	39	1019.2
4	53	34	44	21	29.8		0.00		360	8.4	360	17	0.3	92	36	1025.0
5	61	36	49	16	29.7		0.00		240	7.0	350	22	0.0	92	24	1025.6
6	49	39	44	21	42.4	0.08	0.25	RF	220	6.6	210	16	6.0	100	65	1016.6
7	49	41	45	20	38.8	0.00	T	F	140	9.8	040	23	8.7	100	67	1022.2
8	46	40	43	22	40.1	0.08	0.15	RTF	130	8.5	120	15	10.0	100	67	1019.7
9	68	41	55	10	50.0	0.29	0.62	RTFH	180	7.1	020	21	4.9	100	67	1009.7
10	60	44	52	13	43.4	0.02	0.00	RTF	020	9.3	040	20	4.9	100	49	1016.9
11	52	43	48	17	42.6	0.04	0.12	RF	110	9.8	090	21	6.5	100	71	1025.0
12	60	48	54	11	50.7	0.04	0.15	RF	110	7.3	100	25	10.0	100	81	1016.5
13	72	48	60	5	43.7	0.01	T	RFH	310	8.7	290	22	4.1	100	25	1009.6
14	66	45	56	9	26.6		0.00		310	10.7	320	30	0.0	50	18	1012.2
15	62	41	52	13	34.7	0.02	0.03	R	180	5.5	200	13	2.0	96	37	1009.6
16	55	46	51	14	36.1	0.02	0.01	R	030	8.3	040	22	5.6	96	32	1006.6
17	50	42	46	19	42.5	0.03	0.04	R	010	6.0	240	13	8.2	100	71	1005.7
18	54	37	46	19	23.6	0.01	0.01	RS	330	13.4	010	31	4.5	96	23	1008.0
19	52	33*	43	22	25.3		0.00		310	7.5	220	22	0.1	96	31	1022.1
20	55	34	45	20	42.5		0.00	F	190	5.0	170	12	2.6	100	74	1027.6
21	61	49	55	10	50.0	0.10	0.18	RF	190	6.6	180	10	8.4	100	70	1026.9
22	76*	50	63	2	55.6	0.00	0.00	F	210	8.7	220	14	1.2	100	60	1022.0
23	73	54	64	1	51.6		0.00		150	7.0	140	14	0.4	96	41	1020.7
*24	75	53	64	1	51.8	0.01	0.02	R	200	11.6	290	32	1.0	96	32	1012.1
25	54	42	48	17	30.4		0.00		010	9.8	330	22	0.0	73	32	1022.2
26	61	40	51	14	28.9		0.00		070	9.0	080	20	0.0	79	22	1023.7
27	67	40	54	11	36.6		0.00		230	5.8	220	13	0.3	80	32	1015.8
28	61	48	55	10	27.7	0.00	T		350	11.3	340	32*	2.1	66	19	1022.0
29	57	42	50	15	30.4		0.00		220	8.8	200	16	0.0	89	31	1032.0
30	71	40	56	9	43.8		0.00		230	8.2	230	22	0.0	96	32	1025.7
mo	58.8	41.9	50.3	431	38.1		1.58			8.2			3.9			

Index

Dy - Day
MxT - Maximum Temp.
MnT - Minimum Temp.
Av T - Average Temp.
HDDay -
AvDP - Average Dew Point
1HrP - 1-Hour Precipitation
TPcpn - Total Precipitation

Daily Climate Data

ISP April 2001

Dy	MxT	MnT	AvT	HDDay	AvDP	1HrP	TPcpn	WxType	PDir	AvSp	Dir	MxS	SkyC	MxR	MnR	AvSLP
1	42	36	39	26	35.1		0.00		090	6.4	100	10	10.0	100	79	1009.4
2	46	36	41	24	31.0		0.00		300	9.5	310	15	10.0	79	62	1014.0
3	52	31	42	23	31.8		0.00		320	7.5	320	13	5.8	92	42	1020.2
4	52	33	43	22	31.8		0.00		360	8.7	360	20	0.0	100	41	1026.0
5	61	33	47	18	30.8		0.00		230	8.1	320	16	0.0	96	25	1026.6
6	49	41	45	20	42.8	0.07	0.26	RF	220	7.0	210	22	7.0	100	71	1017.6
7	48	40	44	21	36.4	0.01	T	TF	040	10.7	030	20	9.6	100	62	1023.3
8	46	35	41	24	39.4	0.05	0.11	LRTF	120	8.7	120	20	10.0	100	67	1020.7
9	70	40	55	10	48.0	0.26	0.71	RTF	260	7.0		32	4.9	100	51	1010.7
10	60	45	53	12	41.7	0.01	T	RF	030	8.8	010	16	5.2	100	46	1017.8
11	53	42	48	17	41.0	0.06	0.18	RF	110	10.7	120	17	5.7	96	63	1026.2
12	58	47	53	12	49.6	0.10	0.14	RF	110	8.8	100	26	10.0	100	83	1017.6
13	71	47	59	6	43.2	0.00	T	RFH	310	8.7	320	31	3.0	100	23	1010.4
14	65	44	55	10	26.0		0.00		330	10.3	290	24	0.0	60	17	1012.8
15	63	40	52	13	31.8	0.00	T	R	330	6.1		21	2.4	70	33	1010.5
16	55	44	50	15	35.0	0.00	T	R	030	8.5	050	15	6.2	86	40	1007.4
17	51	40	46	19	41.4	0.06	0.11	R	240	4.9	220	18	8.3	96	63	1006.7
18	55	36	46	19	24.0	0.06	0.13	RSF	330	15.3	010	33	4.4	96	19	1008.5
19	52	30*	41	24	23.2		0.00		300	8.8	320	22	0.0	92	25	1022.9
20	56	32	44	21	40.6	0.00	T	F	200	6.5	220	14	3.3	96	64	1028.9
21	63	49	56	9	49.0	0.18	0.28	RFH	160	7.2	200	12	8.2	100	58	1028.0
22	73	51	62	3	53.2	0.05	0.01	F	230	9.4	220	15	1.3	100	57	1023.0
23	74	43	59	6	49.6		0.00		150	7.2	140	15	0.7	90	39	1021.9
24	74*	54	64	1	51.4	0.00	T		220	13.3	350	30	2.2	93	29	1012.9
25	54	40	47	18	30.2		0.00		010	10.6	320	23	2.1	82	29	1022.8
26	62	38	50	15	27.2		0.00		040	8.4	040	24	0.0	89	17	1024.3
27	68	41	55	10	33.4		0.00		010	7.1	230	14	0.1	77	23	1016.5
28	61	45	53	12	27.4		0.00		350	11.6	330	33*	1.8	83	19	1022.7
29	59	40	50	15	27.6		0.00		010	8.9	220	14	0.2	86	22	1032.8
30	71	41	56	9	42.2		0.00		240	9.1	240	23	0.0	93	27	1026.5
mo	58.8	40.5	49.6	454	37.2		1.93			8.8			4.1			

Location ______ Date 4-23-01

Project / Client National Heat Set

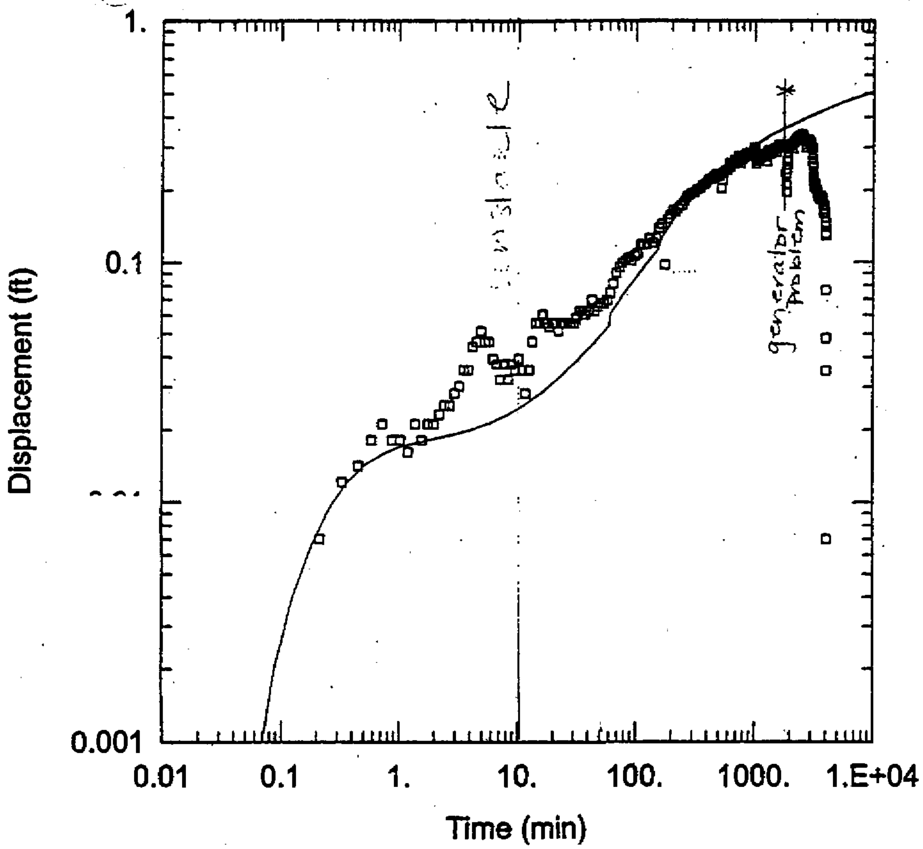
	4-23-01			4-23			
MW ID	DTW	TD	PRE START UP DTW	4/26	4/27 (7:00)	4-27 (16:00)
H	14.70	82.96	14.68		14.97	14.81
2A	14.97	25.53	14.95		15.20	15.09
1D	14.93	78.70	14.92			
3A	14.88	27.43	14.86		15.11	15.00
5	13.21				13.34	13.32
B	15.14				15.25	15.23
A	15.44				15.55	15.53
7	14.49			14.59	14.60	14.58
6	14.95			15.05	15.07	15.05
1	13.08				13.70	13.18
9	13.71		13.69		13.89	13.82
G	15.84				15.96	15.93
E	15.65					
F	15.42				15.55	15.53
C	15.66				15.79	15.76
4A	14.81	22.00	14.81		15.03	14.95

Location ______ Date ______

Project / Client ______

APPENDIX B

WELL TEST ANALYSIS / TIME-DRAWDOWN CURVES



WELL TEST ANALYSIS

Data Set: C:\MYDOCU~1\LATHAM~1\MW3ANUMN.AQT
Date: 06/18/01 Time: 14:33:30

PROJECT INFORMATION

Company: IT Corporation
Client: NYSDEC
Project: National Heatset
Test Location: Babylon, NY
Test Well: MW-10
Test Date: April 24, 2001

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman

T = 8764. ft^2/day
S = 0.001471
Sy = 0.2335
ß = 0.06

AQUIFER DATA

Saturated Thickness: 70. ft

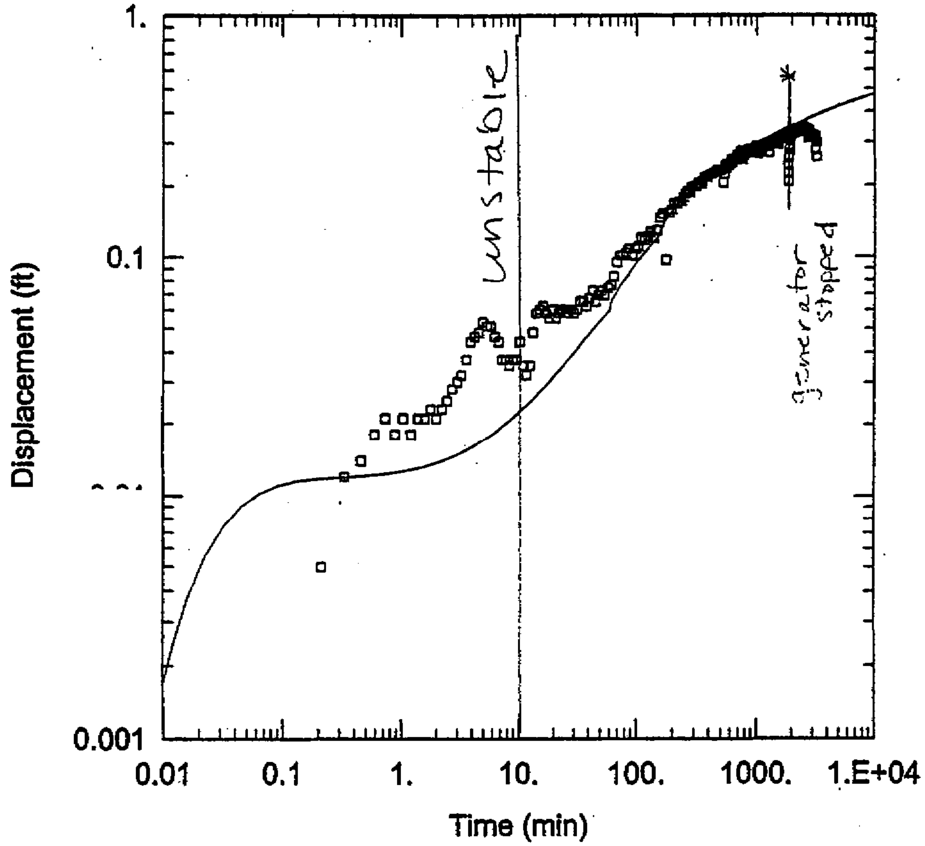
WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
MW10	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
▫ MW3A	18	0



WELL TEST ANALYSIS

Data Set: C:\MYDOCU~1\LATHAM~1\MW2ANUMN.AQT
Date: 06/18/01 Time: 14:32:16

PROJECT INFORMATION

Company: IT Corporation
Client: NYSDEC
Project: National Heatset
Test Location: Babylon, NY
Test Well: MW-10
Test Date: April 24, 2001

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman

T = 1.026E+04 ft^2/day
S = 0.0002463
Sy = 0.2256
ß = 0.1

AQUIFER DATA

Saturated Thickness: 70. ft

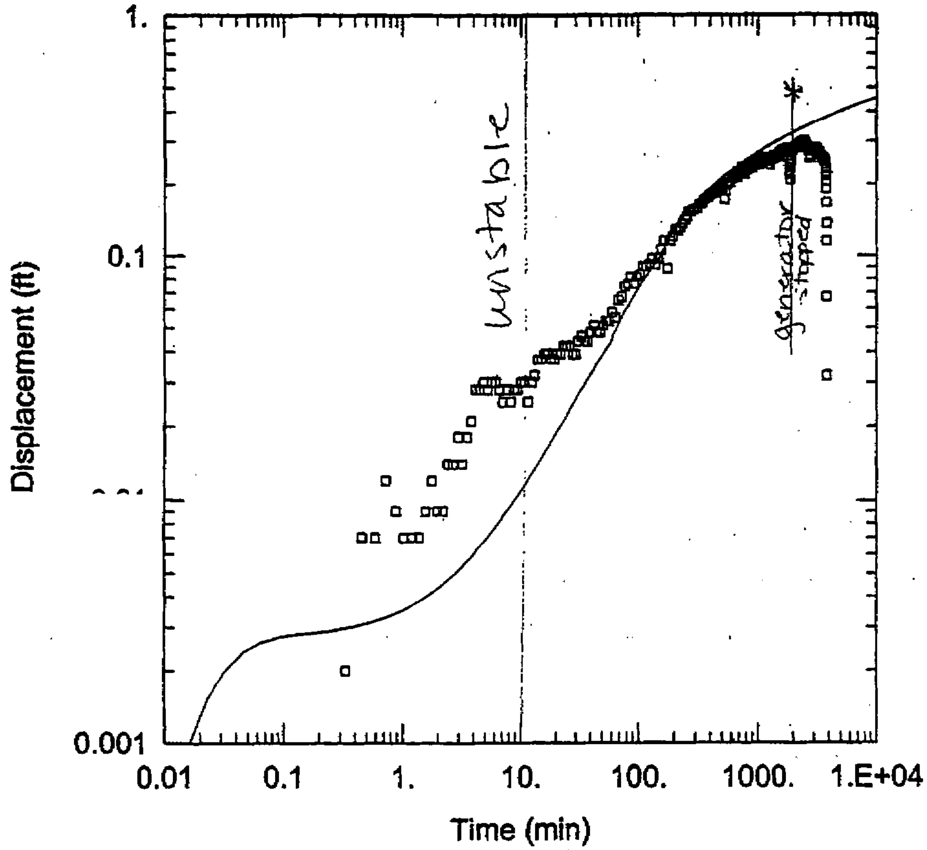
WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
MW10	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
□ MW2A	19	0



WELL TEST ANALYSIS

Data Set: C:\MYDOCU~1\LATHAM~1\MW4ANUMN.AQT
Date: 06/18/01 Time: 14:35:14

PROJECT INFORMATION

Company: IT Corporation
Client: NYSDEC
Project: National Heatset
Test Location: Babylon, NY
Test Well: MW-10
Test Date: April 24, 2001

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman

T = 9759. ft^2/day
S = 7.407E-05
Sy = 0.07517
ß = 1.

AQUIFER DATA

Saturated Thickness: 70. ft

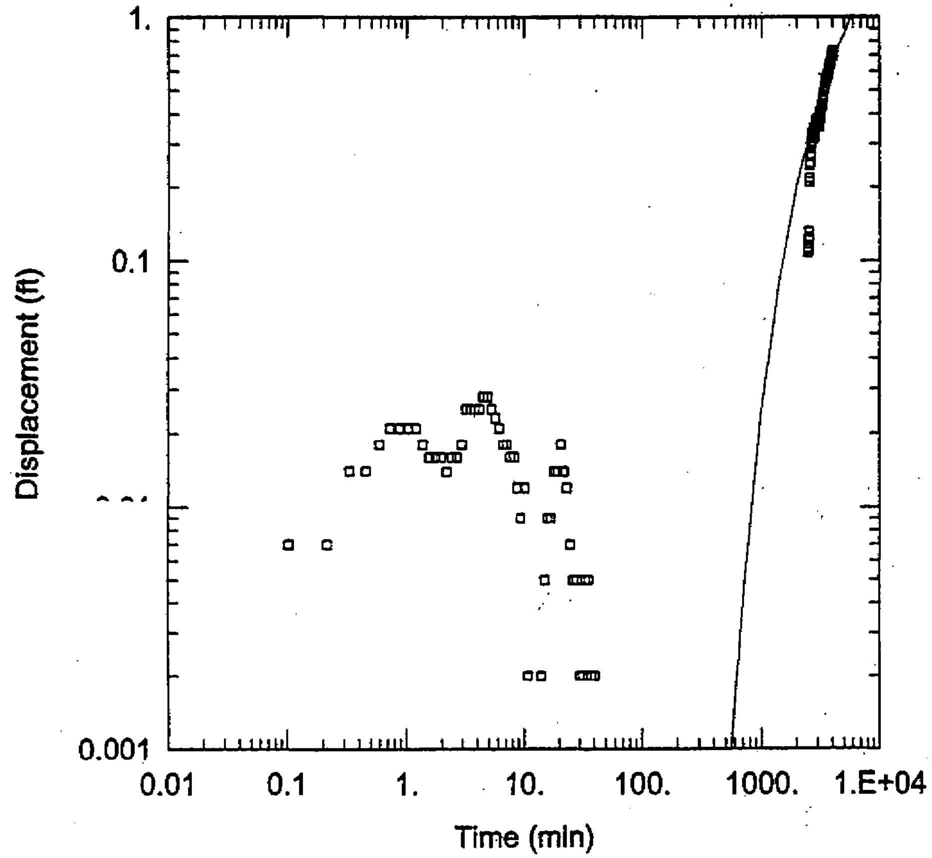
WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
MW10	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
▫ MW4A	75	0



WELL TEST ANALYSIS

Data Set: C:\MYDOCU~1\LATHAM~1\MW9NUMAN.AQT
Date: 06/18/01 Time: 16:53:21

PROJECT INFORMATION

Company: IT Corporation
Client: NYSDEC
Project: National Heatset
Test Location: Babylon, NY
Test Well: MW-10
Test Date: April 24, 2001

SOLUTION

Aquifer Model: Unconfined
Solution Method: Neuman

T = 777.4 ft^2/day
S = 0.475
Sy = 0.2
ß = 0.2

AQUIFER DATA

Saturated Thickness: 70. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
MW10	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
▫ MW9	120	0

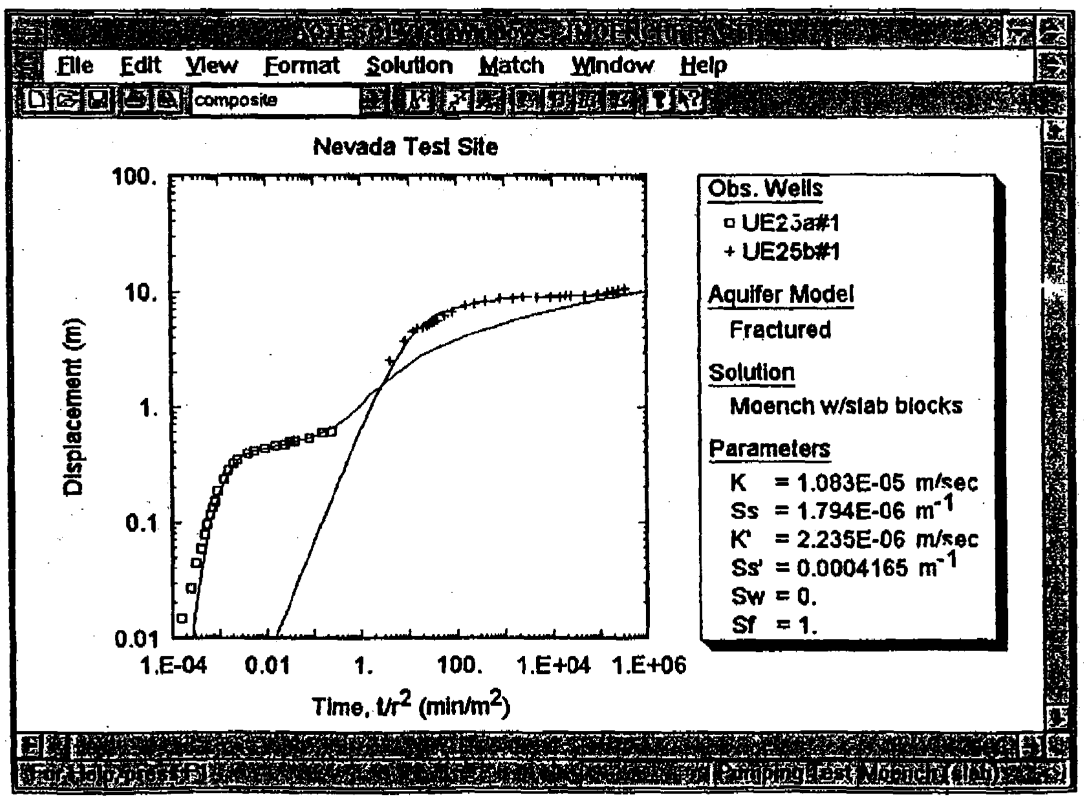
APPENDIX C

AQTESOLV USER'S GUIDE

AQTESOLV for Windows

User's Guide

By HydroSOLVE, Inc.



Software Developed By: Glenn M. Duffield, HydroSOLVE, Inc.
Manual Authored By: Glenn M. Duffield, HydroSOLVE, Inc.

HydroSOLVE, Inc.

HydroSOLVE, Inc.
2303 Horseferry Court
Reston, VA 20191-2739
Tel (703) 264-9024
Fax (703) 476-2318
gmd.hsi@ix.netcom.com
http://www.netcom.com/~gmd.hsi

1-Sep-98

Contents

Getting Started

AQTESOLV for Windows Features

AQTESOLV for Windows is a powerful yet easy-to-use tool for hydrogeologists that features a suite of analytical solutions for determining aquifer properties from pumping tests and slug tests. After first entering or importing data from an aquifer test, you can access visual and automatic curve matching methods for confined, unconfined, leaky and fractured aquifers. Visual curve matching is analogous to traditional methods of aquifer test analysis with graph paper and type curves. The sophisticated automatic curve matching feature enhances aquifer test analysis by providing greater objectivity and a detailed statistical evaluation of the results. AQTESOLV for Windows also features many options for obtaining report quality graphics to summarize the results of your analysis.

Data Management

AQTESOLV for Windows helps you manage aquifer test data with data management tools for entering, editing and importing data. Wizards guide you through the creation of data sets for pumping tests and slug tests. Error checking ensures consistent and complete data entry. Flexible specification of measurement units lets you enter data in English and metric systems. Retrieval of data from a pressure transducer is easy using the Import Wizard in AQTESOLV for Windows.

Visual Curve Matching

The visual curve matching feature in AQTESOLV for Windows lets you analyze aquifer tests using the traditional method of matching type curves or straight lines to time-displacement data measured during an aquifer test.

With a plot of the data displayed on the computer screen, you can match a type curve to your data in an interactive manner. By simply moving your mouse, you can move a type curve on the screen and watch AQTESOLV for Windows update the values of aquifer properties.

Automatic Curve Matching

The powerful automatic curve matching feature provided by AQTESOLV for Windows uses a nonlinear weighted least-squares parameter estimation algorithm to match type curves or straight lines to time-displacement data measured during an aquifer test.

The automatic curve matching feature minimizes the errors between the position of the type curve and your data and provides statistical measures of the type curve "fit" such as the precision of the estimated aquifer properties and error distributions.

Statistical Analysis

Automatic curve matching provides statistical criteria measuring the "fit" of a type curve to your data. The statistics give you an objective basis for comparing the match of several different solutions to the same set of data.

Automatic curve matching computes standard errors of the estimated parameters that allow you to evaluate the precision of the parameter estimates and to construct approximate confidence intervals. Statistics for the model errors provide a basis for choosing between different aquifer test solutions that produce similar visual matches.

Plots and Reports

AQTESOLV for Windows helps you visualize the results of your aquifer test analyses by providing seven graphical representations.

- displacement vs. time plot
- composite plot
- residuals vs. time plot
- residuals vs. simulated displacement plot
- normality test for residuals
- derivative vs. time plot
- discharge vs. time plot

In addition, AQTESOLV for Windows includes report options that document the contents of data sets and summarize the results of matching analytical solutions to data.

- complete aquifer test analysis report
- diagnostic statistics summary
- error log

The error log feature enables you to quickly identify any deficiencies or inconsistencies detected in your data set.

Installation

The AQTESOLV for Windows diskette provided with this manual contains an installation program that prompts you for the destination directory for the program files, the type of installation you are performing, and the Program Group for the AQTESOLV for Windows icons. To install the program, perform the following steps:

1. Insert the program diskette in a floppy drive (e.g., drive a:).
2. Select **Run...** from the **File** menu and enter the following command: **a:setup <enter>**
3. The installation program prompts you to close any applications that are currently running. Click **Continue** to proceed or **Exit Setup** to close any currently running applications.
4. When the installation program prompts you for a destination directory for the program files, choose the default path (**\aqtw**) or click **Change Directory...** to enter a different path. Click **Continue** when you have selected a destination directory.
5. When the installation program prompts you for the type of installation, click the **Typical** button to begin installing AQTESOLV for Windows.
6. After installation is complete, enter a name for the Program Group that will contain the AQTESOLV for Windows icons. Accept the default name (**AQTESOLV for Windows**) or enter a new name for the Program Group. Click the **OK** button install the icons in the Program Group.
7. After viewing last-minute information, close the viewer window. Start the application by double-clicking the AQTESOLV for Windows icon.

Uninstallation

To uninstall AQTESOLV for Windows, simply delete the Program Group (e.g., AQTESOLV for Windows) and the subdirectory (e.g., c:\aqtw) containing the program files. AQTESOLV for Windows does not modify any Windows system files, so no additional uninstallation is necessary.

Using Help

The **Help** menu provides you with options for exploring the AQTESOLV for Windows on-line User's Guide.

Index

Use **Index** in the **Help** menu to view the table of contents in the AQTESOLV for Windows help manual. Once you have entered Help, you can perform searches for specific topics using the **Search** button.

To obtain Help about a specific menu option or button, click ↖? on the toolbar. Release the mouse on the option or button for which you wish to obtain Help.

Using Help

Choose **Using Help** from the **Help** menu to view instructions for navigating the Windows help system.

About AQTESOLV

Choose **About AQTESOLV...** from the **Help** menu or click ? on the toolbar to display program copyright and version information for AQTESOLV for Windows.

Guided Tours

Overview

The "guided tours" provide you with step-by-step instructions illustrating the use of AQTESOLV for Windows in the analysis of pumping tests and slug tests. The tours show you how to perform visual and automatic curve matching, change between plot and report views, open multiple windows for the same data set, obtain printed output, and much more. Regardless of whether you are a novice or an expert in analyzing aquifer test data, it is recommended that you take the time to go through the guided tours to become familiar with AQTESOLV for Windows.

Analyzing a Pumping Test

The first stop in the guided tour shows you how to use AQTESOLV for Windows to analyze a constant-rate pumping test in a confined aquifer. This step-by-step example illustrates the use of visual and automatic curve matching to estimate the hydraulic properties of the aquifer.

Open a New Data Set

Open a new data set by choosing **New** from the **File** menu. In the **New Data Set** dialog box, choose **Guided Tour** from the list box to initialize the new data set with default values. AQTESOLV for Windows opens a new window with an Error Log view that reports any errors identified in the data set.

Enter Data for Pumping Test

Units

Choose **Units...** from the **Edit** menu to open the **Units** dialog box for selecting units of measurement for the data set.

1. Select **ft** (feet) for **Length**, **min** (minutes) for **Time**, **consistent** for **Pumping Rate** and **consistent** for **Hyd. Conductivity**.
2. Click the **OK** button to close the **Units** dialog box.

Consistent units

For this data set, consistent units for pumping rate are cubic feet-per-minute; consistent units for hydraulic conductivity are feet-per-minute.

Title

Choose **Title...** from the **Edit** menu to open a dialog box for editing the data set title.

1. Enter **Theis Verification** for the **Title**.
2. Click the **OK** button to close the dialog box.

Aquifer data

Choose **Aquifer Data...** from the **Edit** menu to open a dialog box for editing aquifer data.

1. Enter **100.0** for the value of **Saturated Thickness**.
2. Click the **OK** button to close the dialog box.

Pumping well data

Choose **Pumping Well/Edit...** from the **Edit** menu to open the **Pumping Well Data** dialog box for editing pumping well data.

1. Click the **Edit** button to open the **Pumping Period Data** dialog box for entering pumping rates.
2. In the **Time** and **Rate** edit controls, enter values of **0.0** and **3.14159** for time and rate, respectively, where time is in minutes and rate is in cubic feet-per-minute.

   TIPS
   Enter rates for a pumping test by entering a sequence of pumping periods. Define pumping periods by entering the starting time and pumping rate for the period. The first pumping period should have a time = 0.0. For recovery, enter a pumping period with the time when the pump was shut off and a pumping rate = 0.0.

3. Click the **<<Add** button to transfer the values from the edit controls to the list box.
4. Click **OK** to close the **Pumping Period Data** dialog box.
5. Click **OK** to close the **Pumping Well Data** dialog box.

Observation well data

Choose **Obs. Well/Edit...** from the **Edit** menu to open the **Observation Well Data** dialog box and edit data for the observation well.

1. Enter a value of **100.0** for the **X-Coordinate** location of the well.
2. Click the **Edit** button to open the **Observation Data** dialog box for entering observation data from the keyboard. All of the time values should be greater than the start of the first pumping period entered for the pumping well (i.e., > 0.0). All of the displacement values should be greater than zero.

   Enter the following 10 measurements into the edit controls for **Time** and **Displacement** (set all weights equal to 1.0):

Time	Displacement
0.5	0.0489
1	0.2194
[illegible]	[illegible]
10	1.823
[illegible]	[illegible]
100	4.038
[illegible]	[illegible]
1000	6.332
[illegible]	[illegible]
10000	8.633

2. Click the <<**Add** button to transfer values from the edit controls to the list box.
3. When you have finished entering the observations, click the **OK** button to close the **Observation Data** dialog box.
4. Click the **OK** button to close the **Observation Well Data** dialog box.

After you have completed the previous data entry steps, the **Error Log** displayed in the active window should show that the data set contains no errors. Now you are ready to display the data, choose a solution and estimate aquifer properties.

Save Data Set

Choose **Save As...** from the **File** menu to open a dialog box for saving the data you have entered into the current data set.

1. Enter **TOUR1.AQT** for the file name.
2. Click the **OK** button to close the dialog box and save the data set.

Display Plot in Window

Choose **Displacement-Time** from the **View** menu to display a plot of displacement vs. time in the active window. The window displays a plot of the observation well data on semi-logarithmic axes.

Choose Theis Solution

Choose **Confined...** from the **Solution** menu to open a dialog box with solutions for analyzing pumping tests in a confined aquifer.

1. Choose the **Theis (1935)** solution.
2. Click the **OK** button to close the dialog box.

After you have selected the Theis solution for a pumping test in a confined aquifer, AQTESOLV for Windows updates the window by plotting the data on double logarithmic axes, superimposing the Theis type curve on the plot, and adding the current values of transmissivity (T) and storage coefficient (S) to the legend.

For details concerning the Theis solution, see "Theis (1935) Solution for a Pumping Test in a Confined Aquifer" on page 40.

Perform Visual Matching with Theis

The Theis type curve solution computes drawdown in a confined aquifer using the following equations:

$$s=\frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}}{y}dy$$

$$u=\frac{r^2S}{4Tt}$$

where s is drawdown, Q is pumping rate, T is transmissivity, r is radial distance between pumping and observation wells, S is storage coefficient, and t is time.

Hydrogeologists commonly refer to the exponential integral in the drawdown equation as the *Theis well function*, abbreviated as w(u). Therefore, we can write the Theis drawdown equation in compact notation as follows:

$$s=\frac{Q}{4\pi T}w(u)$$

To analyze a pumping test using the Theis type curve method, one plots drawdown as a function of time on double logarithmic axes. By matching a type curve drawn by plotting w(u) as a function of 1/u, one can estimate the values of transmissivity and storage coefficient by visual analysis.

Choose **Visual** from the **Match** menu to perform visual curve matching of the Theis type curve to the observation well data.

1. To begin interactively moving the type curve, move the mouse cursor over the plot, click the left mouse button, and hold it down.
2. As you move the mouse, the type curve also moves. AQTESOLV for Windows updates the values of the aquifer properties, T and S, in the legend as the type curve position changes.
3. When you have finished matching the type curve to the observation well data, release the left mouse button to end visual curve matching.

Perform Automatic Matching with Theis

Choose **Automatic...** from the **Match** menu to open a dialog box for performing automatic matching of the Theis type curve solution to the observation well data.

AQTESOLV for Windows uses a nonlinear least-squares estimation procedure to match a solution to observation well data. The estimation procedure performs a sequence of iterations to minimize the residual sum of squares (RSS) criterion. The residuals are the errors between the computed and observed values of displacement.

1. Click the **Start** button to begin the automatic estimation procedure.
2. As the automatic estimation procedure completes iterations, the dialog box displays the changes in the residual sum of squares (RSS) criterion and the values of the aquifer properties. After the automatic estimation procedure finishes, AQTESOLV for Windows displays a message box containing residual summary statistics. Click the **OK** button to close the message box.
3. Click the **Close** button when the automatic estimation procedure has finished.

Print Results

Choose **Print...** from the **File** menu to print a copy of the type curve solution. To select a printer other than the default, click the **Setup...** button and choose a new printer. Click the **OK** button to print the type curve plot.

Open a New Window for a Diagnostic Plot

Choose **New Window** from the **Window** menu to open a second window for the active data set. The initial view in the second window is the same as the previously active window.

1. Select **Normal Probability** from the **View** menu to plot values of residuals (errors) plotted on normal probability axes in the new window. This view option is only available after you have performed automatic curve matching.
2. After you have inspected the normal probability plot, close the window.

Diagnostic test for normal distribution of residuals

If the residuals are normally distributed, they will fall on a straight line when plotted on normal probability axes. Deviations from a normal distribution may indicate that the chosen analytical solution is inadequate for the analysis.

Save Data Set

Choose **Save** from the **File** menu to save your work in the TOUR1.AQT data set.

Analyzing a Slug Test

The second sample in the guided tour illustrates the analysis of a slug test in a confined aquifer using a type-curve solution by Cooper, Bredehoeft and Papadopulos and a straight-line solution by Bouwer and Rice. The step-by-step instructions in this example lead you through the use of visual and automatic curve matching to estimate aquifer properties from slug test data.

Open a New Data Set

Open a new data set by choosing **New** from the **File** menu. In the **New Data Set** dialog box, choose **Guided Tour** from the list box to initialize the new data set with default values. AQTESOLV for Windows opens a new window with an Error Log view that reports any errors identified in the data set.

Enter Data for Slug Test

Units

Choose **Units...** from the **Edit** menu to open the **Units** dialog box for selecting units of measurement for the data set.

1. Select **m** (meters) for **Length**, **min** (minutes) for **Time**, and **cm/sec** (centimeters-per-second) for **Hyd. Conductivity**.
2. Click the **OK** button to close the **Units** dialog box.

Title

Choose **Title...** from the **Edit** menu to open a dialog box for editing the data set title.

1. Enter **Confined Slug Test** for the **Title**.
2. Click the **OK** button to close the dialog box.

Slug test data

Choose **Slug Test Well...** from the **Edit** menu to open a dialog box for entering slug test data.

1. Enter **0.56** for **Initial Displacement.**
2. Enter **0.076** for **Casing Radius.**
3. Enter **0.076** for **Wellbore Radius.**
4. Enter **100.0** for **Screen Length.**
5. Enter **100.0** for **Water Column Height.**
6. Enter **100.0** for **Saturated Thickness.**
7. Click the **Edit** button to open the **Observation Data** dialog box for entering observation data from the keyboard. Enter the following 21 measurements into the edit controls for **Time** and **Displacement** (set all weights equal to 1.0):

Time	Displacement
[illegible]	[illegible]
6	0.392
[illegible]	[illegible]
12	0.308
[illegible]	[illegible]
18	0.252
[illegible]	[illegible]
24	0.205
[illegible]	[illegible]
30	0.168
[illegible]	[illegible]
36	0.14
[illegible]	[illegible]
42	0.112
[illegible]	[illegible]
48	0.093
[illegible]	[illegible]
54	0.082
[illegible]	[illegible]
60	0.071
[illegible]	[illegible]

8. Click the **<<Add** button to transfer values from the edit controls to the list box.
9. When you have finished entering the observations, click the **OK** button to close the **Observation Data** dialog box.
10. Click the **OK** button to close the **Slug Test Data** dialog box.

After you have completed the previous data entry steps, the **Error Log** displayed in the active window should show that the data set contains no errors. Now you are ready to display the data, choose a solution and estimate aquifer properties.

Save Data Set

Choose **Save As...** from the **File** menu to open a dialog box for saving the data you have entered into the current data set.

1. Enter **TOUR2.AQT** for the file name.
2. Click the **OK** button to close the dialog box and save the data set.

Display Report in Window

Choose **Report** from the **View** menu to display a complete report of the data set in the active window.

Complete report

The complete report displays in report format all of the data contained in the active data set. The report also shows parameters estimated by visual or automatic curve matching. The report includes diagnostic statistics if you have performed automatic estimation.

Display Plot in Window

Choose **Displacement-Time** from the **View** menu to display a plot of displacement vs. time in the active window. The window displays the data plotted on semi-logarithmic axes.

Choose Cooper Et Al. Solution

Choose **Confined...** from the **Solution** menu to open a dialog box with solutions for analyzing slug tests in a confined aquifer.

1. Choose the **Cooper-Bredehoeft-Papadopulos (1967)** solution.
2. Click the **OK** button to close the dialog box.

For details concerning the Cooper-Bredehoeft-Papadopulos slug test solution, see "Cooper-Bredehoeft-Papadopulos (1967) Solution for a Slug Test in a Confined Aquifer" on page 61.

Perform Automatic Matching with Cooper Et Al.

Choose **Automatic...** from the **Match** menu to open a dialog box for automatically matching the Cooper-Bredehoeft-Papadopulos type curve solution to the slug test data.

1. Click the **Start** button to begin the automatic estimation procedure.
2. As th- automatic estimation procedure completes iterations, the dialog box displays the changes in the residual sum of squares (RSS) criterion and the values of the aquifer properties. After the automatic estimation procedure finishes, AQTESOLV for Windows displays a message box containing residual summary statistics. Click the **OK** button to close the message box.
3. Click the **Close** button when the automatic estimation procedure has finished.

Display Diagnostic Report in Window

Choose **Diagnostics** from the **View** menu to display a report containing diagnostic statistics for the estimated aquifer properties in the active window.

Diagnostic report

In the diagnostic report, the standard errors indicate the precision of the estimated parameters. Ideally, the standard errors should be small compared to the estimates. The correlation matrix shows correlations between the estimated parameters and may indicate estimation difficulties when strong correlations exist. The diagnostic report also displays summary statistics for the model residuals.

Display Plot in Window

Choose **Displacement-Time** from the **View** menu to display a plot of displacement vs. time in the active window.

Choose Bouwer-Rice Solution

Change the solution by choosing **Confined...** from the **Solution** menu.

1. Choose the **Bouwer-Rice (1976)** solution.
2. Click the **OK** button to close the dialog box.

After you have selected the Bouwer-Rice straight-line solution for a slug test in a confined aquifer, AQTESOLV for Windows updates the window by plotting the data on semi-logarithmic axes and superimposing a straight line predicted by the Bouwer-Rice solution on the plot.

For details on the Bouwer-Rice slug test solution, see "Bouwer-Rice (1976) Solution for a Slug Test in an Unconfined Aquifer" on page 82.

Perform Visual Matching with Bouwer-Rice

Choose **Visual** from the **Match** menu to perform visual curve matching of the Bouwer-Rice solution to the slug test data.

1. To begin interactively matching the Bouwer-Rice solution to the data, click the left mouse button and hold it down to anchor a point along the new straight line you wish to match to the data.
2. As you move the mouse, AQTESOLV for Windows drags a straight line between the anchor point and the mouse cursor.
3. When you have finished matching the Bouwer-Rice solution to the observation well data, release the left mouse button. AQTESOLV for Windows computes new estimates of hydraulic conductivity (K) and y-axis intercept (y0) and updates the straight line displayed on the plot.

Estimation tip

For most slug tests, one should use visual matching to obtain the most meaningful estimate of K with the Bouwer-Rice solution because visual matching gives you greater control over the range of data that you want to match with the straight line. If you choose to attempt automatic matching with the Bouwer-Rice solution, you should assign weights of zero to the measurements not within the range of data that you want to match.

Save Data Set

Choose **Save** from the **File** menu to save your work in the **TOUR2.AQT** data set.

Additional Tutorials

The on-line version of this User's Guide contains additional tutorials for pumping test and slug test solutions found in AQTESOLV for Windows. To access these tutorials, choose **Index** from the **Help** menu to access the **Table of Contents** for the on-line help manual.

Pumping Test Tutorials

Theis (1935) solution for a confined aquifer

Cooper-Jacob (1946) solution for a confined aquifer

Papadopulos-Cooper (1967) large-diameter well solution for a confined aquifer

Theis (1935) solution for a recovery test in a confined aquifer

Theis (1935) solution for a step drawdown test in a confined aquifer

Hantush (1962) solution for a wedge-shaped aquifer

Theis (1935) solution for an unconfined aquifer

Cooper-Jacob (1946) solution for an unconfined aquifer

Neuman (1974) and Quick Neuman solutions for an unconfined aquifer

Streltsova (1974) solution for an unconfined aquifer

Moench (1997) large-diameter well solution for an unconfined aquifer

Hantush-Jacob (1955) solution for a leaky aquifer

Hantush (1960) solution for a leaky aquifer

Moench (1985) large-diameter well solution for a leaky aquifer

Moench (1984) solution for a double-porosity fractured aquifer (slab-shaped blocks)

Moench (1984) solution for a double-porosity fractured aquifer (spherical blocks)

Slug Test Tutorials

Cooper-Bredehoeft-Papadopulos (1967) solution for a confined aquifer

Bouwer-Rice (1979) solution for an unconfined aquifer

Hvorslev (1951) solution for an unconfined aquifer

Working With Data Sets

What is an AQTESOLV for Windows Data Set?

An AQTESOLV for Windows data set is a file created by AQTESOLV for Windows that records your work during an aquifer test analysis session. It contains data from an aquifer test (e.g., aquifer geometry data, test well data, pumping data, and time-displacement data) and information concerning the solution method used to analyze the test data (e.g., solution method and aquifer properties). A data set also contains data that you enter to format plots and reports. In other words, an AQTESOLV for Windows data set contains a complete record of your aquifer test analysis at the time you save it.

Managing Data Set Files

Creating a New Data Set

Click 🗋 on the toolbar to open a new data set

Select **New** from the **File** menu to create a new AQTESOLV for Windows data set.

From the **New Data Set** dialog box, choose a template or wizard from the list box to create a new data set.

Default

The **Default** template creates a new data set with default values. Choose options from the **Edit** menu to modify the default values (see "Editing Data Sets" on page 18).

Guided Tour

The **Guided Tour** template creates a new data set containing default values for a "Guided Tour" example contained in this manual.

Import AQTESOLV for DOS Wizard

The **AQTESOLV for DOS Wizard** helps you import a data set created with a DOS version of AQTESOLV.

Pumping Test Wizard

The **Pumping Test Wizard** helps you create a new data set for a typical pumping test. This wizard allows you to import time-displacement data from a pressure transducer file.

Slug Test Wizard

The **Slug Test Wizard** helps you create a new data set for a typical slug test. This wizard allows you to import time-displacement data from a pressure transducer file.

Template Wizard

The **Template Wizard** helps you create a new data set using an existing AQTESOLV for Windows data set as a custom template.

Tutorial

The **Tutorial** template creates a new data set containing default values for a tutorial contained in this manual.

When you create a new data set, AQTESOLV for Windows automatically opens an **Error Log** window that indicates data items that you need to enter for a complete data set. The **Error Log** view displays deficiencies in the data set. After completing data entry, view the data by choosing an option from the **View** menu (see "Viewing Data and Results" on page 29).

Saving a Data Set

You have two options for saving an AQTESOLV for Windows data set.

Click on the toolbar to save the active data set

To save data set using the current file name

Choose **Save** from the **File** menu to save an AQTESOLV for Windows data set on disk using the current file name.

To save data set with a new file name

1. Select **Save As...** from the **File** menu to specify a file name before you save the data set.
2. Enter a name for the data set you want to save in the dialog box.
3. Click the **OK** button to save the data set.

Opening a Data Set

Click on the toolbar to open an existing data set

Choose **Open...** from the **File** menu to open an existing data set created with AQTESOLV for Windows.

1. Enter the name of the data set you want to open in the dialog box.
2. Click the **OK** button to retrieve the data set.

Closing a Data Set

Choose **Close** from the **File** menu to close the active data set. If you have changed any data, AQTESOLV for Windows prompts you to save the modified data set.

Importing an AQTESOLV for DOS Data Set

You have two options for importing a data set created with a DOS version of AQTESOLV.

To import an AQTESOLV for DOS data set into a new AQTESOLV for Windows data set

1. Select **New** from the **File** menu to open the **New Data Set** dialog box.
2. Choose **Import AQTESOLV for DOS Wizard** from the listbox to import an AQTESOLV for DOS data set.

To import an AQTESOLV for DOS data set into an active AQTESOLV for Windows data set

1. Select **Import...** from the **File** menu to open the **Import** dialog box.
2. Choose **Import AQTESOLV for DOS data set** from the listbox and follow the steps in the **Import AQTESOLV for DOS Data Set** Wizard.

Importing Observations

You have two options for importing a file containing time-displacement measurements from a pumping test or slug test.

To import observation data from the File Menu

1. Select **Import...** from the **File** menu to open the **Import** dialog box.
2. Choose **Observation Well Measurements** from the listbox and follow the steps in the **Observation Data Import** Wizard.

To import pumping period data from the Edit Menu

1. For a pumping test, choose **Obs. Well/Edit...** from the **Edit** menu to open the **Observation Well Data** dialog box. For a slug test, choose **Slug Test Well...** from the **Edit** menu to open the **Slug Test Data** dialog box.
2. Click the **Import** button and follow the steps in the **Observation Data Import** Wizard.

Importing Pumping Rates

You have two options for importing a file containing pumping rate data from a pumping test.

To import pumping period data from the File Menu

1. Select **Import...** from the **File** menu to open the **Import** dialog box.
2. Choose **Pumping Rate Measurements** from the listbox and follow the steps in the **Pumping Period Data Import** Wizard.

To import pumping period data from the Edit Menu

1. Choose **Pumping Well/Edit...** from the **Edit** menu to open the **Pumping Well Data** dialog box.
2. Click the **Import** button and follow the steps in the **Pumping Period Data Import** Wizard.

Editing Data Sets

The **Edit** menu provides options for entering or modifying data in the active data set. Selecting any of the options will open dialog boxes which prompt you for information stored in AQTESOLV data sets.

Units

Choose **Units...** from the **Edit** menu to open a dialog box which prompts you for units of measurement for time, length, pumping rate and hydraulic conductivity.

Dimensionally consistent units

Unless otherwise specified, AQTESOLV for Windows assumes that pumping rates and hydraulic conductivity/transmissivity units are dimensionally consistent with the units specified for length and time. For example, if the units of length and time were feet and minutes, respectively, the dimensionally consistent units would be ft^3/min cubic feet per minute for pumping rate and ft^2/day square feet per day for transmissivity.

Optional units for pumping rate and hydraulic conductivity

For those not wishing to use dimensionally "consistent" units, AQTESOLV for Windows provides options for pumping rate units including gallons and liters (e.g., gpm and L/sec). For units of hydraulic conductivity/transmissivity, you also can select units containing gallons (e.g., gpm/ft^2 gal/min/sq. ft).

Title

Select **Title...** from the **Edit** menu to open a dialog box that allows you to enter a 40 character title for the data set.

Project Info

Choose **Project Info...** from the **Edit** menu to open a dialog box prompting you to enter information for any of the following items into the active data set (each item may contain up to 30 characters):

- client name
- project number
- location of test
- test well name
- observation well name
- date of test

Aquifer Data

Select **Aquifer Data...** from the **Edit** menu to enter aquifer geometry and special hydraulic property data into the active data set.

Aquifer data

- saturated thickness of the aquifer [L]
- ratio of vertical to horizontal hydraulic conductivity (for partial penetration) [dimensionless]
- thickness of slab-shaped matrix blocks (fractured aquifers) [L]
- diameter of spherical matrix blocks (fractured aquifers) [L]
- slope orientation (wedge-shaped aquifers) [degrees]

Saturated thickness

1. Enter the saturated thickness of the aquifer measured from the top of the aquifer (or the water table) to the bottom of the aquifer.
2. In an unconfined aquifer, the maximum displacement should not exceed the saturated thickness.

Hydraulic conductivity ratio

1. Enter the ratio of vertical to horizontal hydraulic conductivity (K_z/K_r Kz/Kr) for pumping test solutions applying the Hantush (1961a,b) corrections for partially penetrating wells.
2. The Neuman (1974) solution for pumping tests in unconfined aquifers, which estimates the value of K_z/K_r Kz/Kr in the value of the β beta parameter, does not use the hydraulic conductivity ratio value entered in the aquifer data.

Fractured aquifer data

1. Enter the thickness of slab-shaped matrix blocks for the Moench (1984) solution for a double-porosity fractured aquifer with slab-shaped blocks.
2. Enter the diameter of spherical blocks for the Moench (1984) solution for a double-porosity fractured aquifer with spherical blocks.

Wedge-shaped aquifer data

1. Enter the orientation of the slope on the base of the aquifer as the angle measured in a counterclockwise direction from the positive x-coordinate axis to the vector oriented in the updip direction of the slope.
2. Enter the slope orientation angle in degrees.

Pumping Well

Choose the **Pumping Well** option from the **Edit** menu. Select **Edit...**, **Add...** or **Delete...** from the popup menu to edit, add or delete a pumping well. If you are editing or adding a pumping well, the **Pumping Well Data** dialog box allows you to enter data for the pumping well.

Pumping well data

- pumping well name
- x-coordinate location [L]
- y-coordinate location [L]
- casing radius [L]
- wellbore radius [L]
- full or partial penetration data

Well coordinates

1. AQTESOLV for Windows uses an x-y coordinate system to compute distances between pumping wells and observation wells.
2. For a simple pumping test involving only one pumping well and one observation well, locate the pumping well at x=0.0 and y=0.0. Locate the observation well at x=r and y=0.0 where r is the radial distance between the pumping and observation wells.

Large-diameter well data

1. To analyze pumping tests using large-diameter well solutions, enter values for the casing radius and wellbore radius of the pumping well.
2. If the value for either of these two variables is 0.0, AQTESOLV for Windows assumes the pumping well has an infinitesimal radius.

Well penetration data

1. A well is fully penetrating if its screen or perforated interval extends over the full saturated thickness of the aquifer.
2. The screen of a partially penetrating well only extends over a portion of an aquifer's saturated thickness. For a partially penetrating well, enter depths from the top of the aquifer (or water table) to the top and bottom of the well screen.
3. The bottom of well screen depth must be greater than the top of well screen depth. The minimum depth for the top of the well screen is 0.0; the maximum depth for the bottom of the well screen is the saturated thickness of the aquifer.

Entering or Importing rates

1. Click the **Edit** button to open the **Pumping Period Data** dialog box for entering rate data from the keyboard (see "Entering Pumping Rates from the Keyboard" on page 20).
2. Click the **Import** button to open the **Import Wizard** for importing rate data from a delimited text file (see "Importing Pumping Rates from a File" on page 22).

Entering Pumping Rates from the Keyboard

To enter pumping period data for a pumping well, open the **Pumping Period Data** dialog box.

To enter pumping period data

1. Choose **Pumping Well/Edit...** from the **Edit** menu to open the **Pumping Well Data** dialog box for a pumping well.
2. Click the **Edit** button to enter pumping period data for the well.

To add new pumping period data to the list box

1. Enter the values of time and pumping rate in the edit controls.

   TIPS
   Enter rates for a variable-rate test by entering a sequence of pumping periods. Define pumping periods by entering the starting time and pumping rate for the period. The first pumping period should have a time = 0.0. For recovery, enter the time when the pump was shut off and a pumping rate = 0.0.

2. Click the **<< Add** button to transfer data from the edit controls to the list box.

To edit the data for a specific pumping period in the list box

1. Select the pumping period that you want to edit by clicking the left mouse button on the data in the list box.
2. Click the **Edit >>** button to copy the selected time and pumping rate from the list box to the edit controls.
3. Modify the data in the edit controls
4. Click the **<< Add** button to transfer data from the edit controls to the list box.

To delete pumping period data from the list box

1. Select the pumping period(s) that you want to delete by clicking the left mouse button on the data in the list box. To select a range of pumping periods, press the **SHIFT** key when you click the mouse on the first and last pumping period in the range. To select several individual pumping periods, press the **CTRL** key when you click the mouse on the individual pumping periods.
2. Click the **Delete >>** button to delete the selected time and pumping rate data from the list box. Before deleting the data, AQTESOLV for Windows prompts to confirm your action.

To search for a specific time or pumping rate in the list box

1. Click the **Search** button to open a dialog box for the search.
2. Enter the data vector, time or pumping rate, that you wish to search and the specific value.
3. Click the **OK** button to search for the value.

To transform pumping period data in the list box

1. Select the pumping period(s) that you want to transform by clicking the left mouse button on the data in the list box. To select a range of pumping periods, press the **SHIFT** key when you click the mouse on the first and last pumping period in the range.

To select several individual pumping periods, press the **CTRL** key when you click the mouse on the individual pumping periods.

2. Click the **Math** button to open a dialog box for the operation.
3. Enter the data vector, time or pumping rate, that you wish to transform.
4. Select a transformation operation (add, subtract, multiply, divide or replace).
5. Click the **OK** button to perform the transformation. Before transforming the data, AQTESOLV for Windows prompts to confirm your action.

To filter pumping period data in the list box

1. Click the **Filters** button to open a dialog box for the filtering operations.
2. Select filter operations for discarding or retaining pumping periods.

   TIPS
   Use filters to reduce the number of pumping periods. Retain rate values exceeding a minimum threshold (AQTESOLV for Windows time-averages intermediate values not retained).

3. Click the **OK** button to filter the observations. Before filtering the data, AQTESOLV for Windows prompts to confirm your action.

Importing Pumping Rates from a File

Create a delimited text file to import measurements recorded by a pressure transducer.

Import pumping period starting time and pumping rate data for a pumping well with the **Pumping Period Import Wizard**. The delimited text import file may contain one or more columns of data separated by comma, blank or tab delimiters.

The **Import Wizard** supports delimited text files created by many different types of pressure transducers. The wizard automatically searches for the row containing the first pumping period, or you can specify the starting row in the file. Transformation and filter operations also allow you to modify and reduce the data during the import process.

To import rates for a pumping test

1. Choose **Pumping Well/Edit...** from the **Edit** menu to open the **Pumping Well Data** dialog box for a pumping well.
2. Click the **Import** button to start the **Import Wizard**.

Step 1. Open an import file containing pumping period data

1. Enter a path and filename for a text file containing pumping period data. Click the **Browse...** button to search for a file.
2. To view a specified file, click the **View Import File...** button.
3. To append data from the import file to pumping period data in the data set, check the **Append pumping periods from import file to data set** box.

4. Click the **Next >** button to proceed to Step 2 of the Import Wizard.

Step 2. Specify the file structure

1. Enter the **No. of Columns** contained in the file. The total number of columns contained in the file may be greater than the number of columns that you wish to import.

2. Enter a number for the **Starting Row** containing the first pumping period that you wish to import from the file.

   TIPS
   Click the **Select Starting Row...** button to view the import file. You can select the first row in the file that you want to import by double-clicking it.

3. Specify the **Data to Import** from the file. Enter a column number for each data item (starting time of the pumping period and pumping rate) that you are importing from the file. Enter a column number of 0 (zero) for any item not contained in the file.

4. Click the **Next >** button to proceed to Step 3 of the Import Wizard.

Step 3. Specify transformation and filter operations

1. Select **Pre-Filter Operations** for transforming time and pumping rate data contained in the file. Enter constants for subtraction and multiplication operations.

2. Click the **Filters...** button to select options for filtering the data imported from the file.

   TIPS
   Use filters to reduce the number of pumping periods. Retain rate values exceeding a minimum threshold (AQTESOLV for Windows time-averages intermediate values not retained).

3. Click the **Finish** button to import data from the file.

Observation Well

Choose the **Obs. Well** option from the **Edit** menu. Select **Edit...**, **Add...** or **Delete...** from the popup menu to edit, add or delete an observation well. If you are editing or adding an observation well, the **Observation Well Data** dialog box allows you to enter data for the observation well.

Observation well data

- observation well name
- x-coordinate location [L]
- y-coordinate location [L]
- full or partial penetration data
- observation well data

Well coordinates

1. AQTESOLV for Windows uses an x-y coordinate system to compute distances between pumping wells and observation wells.
2. For a simple pumping test involving only one pumping well and one observation well, locate the pumping well at x=0.0 and y=0.0. Locate the observation well at x=r and y=0.0 where r is the radial distance between the pumping and observation wells.

Well penetration data

1. A well is fully penetrating if its screen or perforated interval extends over the full saturated thickness of the aquifer.
2. The screen of a partially penetrating well only extends over a portion of an aquifer's saturated thickness. For a partially penetrating well, enter depths from the top of the aquifer (or water table) to the top and bottom of the well screen.
3. The bottom of well screen depth must be greater than the top of well screen depth. The minimum depth for the top of the well screen is 0.0; the maximum depth for the bottom of the well screen is the saturated thickness of the aquifer.
4. A piezometer (in contrast to an observation well) is an open-ended pipe installed in an aquifer to measure hydraulic head at a specific depth. The piezometer depth is distance from the top of the aquifer (or water table) to the piezometer opening.

Entering or importing observation well measurements

1. Click the **Edit** button to open the **Observation Data** dialog box for entering observation data from the keyboard (see "Entering Observations from the Keyboard" on page 24).
2. Click the **Import** button to open the **Import Wizard** for importing observation data from a delimited text file (see "Importing Observations from a File" on page 26).

Entering Observations from the Keyboard

To enter time, displacement and measurement weight data for an observation well or slug test well, open the **Observation Data** dialog box.

To enter observations for a pumping test

1. Choose **Obs. Well/Edit...** from the **Edit** menu to open the **Observation Well Data** dialog box for an observation well.
2. Click the **Edit** button to enter measurements for the well.

To enter observations for a slug test

1. Choose **Slug Test Well...** from the **Edit** menu to open the **Slug Test Data** dialog box.
2. Click the **Edit** button to enter measurements for the test well.

To add new observation data to the list box

1. Enter values of time, displacement and weight in the edit controls.

TIPS

- Assign weights to indicate the relative weight of each measurement during automatic curve matching. Assign a weight of zero for measurements you wish automatic curve matching to ignore.

2. Click the << **Add** button to transfer data from the edit controls to the list box.

To edit the data for a specific observation in the list box

1. Select the observation that you want to edit by clicking the left mouse button on the data in the list box.
2. Click the **Edit** >> button to copy the selected time, displacement and weight from the list box to the edit controls.
3. Modify the data in the edit controls
4. Click the << **Add** button to transfer data from the edit controls to the list box.

To delete observation data from the list box

1. Select the observation that you want to delete by clicking the left mouse button on the data in the list box. To select a range of observations, press the **SHIFT** key when you click the mouse on the first and last observation in the range. To select several individual observations, press the **CTRL** key when you click the mouse on the individual observations.
2. Click the **Delete** >> button to delete the selected time, displacement and weight data from the list box. Before deleting the data, AQTESOLV for Windows prompts to confirm your action.

To search for a specific time, displacement or weight in the list box

1. Click the **Search** button to open a dialog box for the search.
2. Enter the data vector, time, displacement or weight, that you wish to search and the specific value.
3. Click the **OK** button to search for the value.

To transform observation data in the list box

1. Select the observation that you want to transform by clicking the left mouse button on the data in the list box. To select a range of observations, press the **SHIFT** key when you click the mouse on the first and last observation in the range. To select several individual observations, press the **CTRL** key when you click the mouse on the individual observations.
2. Click the **Math** button to open a dialog box for the transformation operation.
3. Enter the data vector, time, displacement or weight, that you wish to transform.
4. Select a transformation operation (add, subtract, multiply, divide or replace).

5. Click the **OK** button to perform the transformation. Before transforming the data, AQTESOLV for Windows prompts to confirm your action.

To filter observation data in the list box

1. Click the **Filters** button to open a dialog box for the filtering operations.
2. Select filter operations for discarding or retaining observations.

   TIPS
   Use filters to reduce the number of observations. Retain time values having a uniform logarithmic spacing or displacement values exceeding a minimum threshold.

3. Click the **OK** button to filter the observations. Before filtering the data, AQTESOLV for Windows prompts to confirm your action.

Importing Observations from a File

Create a delimited text file to import measurements recorded by a pressure transducer.

Import time, displacement and measurement weight data for an observation or slug test well with the **Observation Data Import Wizard**. The delimited text import file may contain one or more columns of data separated by comma, blank or tab delimiters.

The **Import Wizard** supports delimited text files created by many different types of pressure transducers. The wizard automatically searches for the row containing the first observation, or you can specify the starting row in the file. Transformation and filter operations also allow you to modify and reduce the data during the import process.

To import observations for a pumping test

1. Choose **Obs. Well/Edit...** from the **Edit** menu to open the **Observation Well Data** dialog box for an observation well.
2. Click the **Import** button to start the **Import Wizard**.

To import observations for a slug test

1. Choose **Slug Test Well...** from the **Edit** menu to open the **Slug Test Data** dialog box.
2. Click the **Import** button to start the **Import Wizard**.

Step 1. Open an import file containing observation data

1. Enter a path and filename for a text file containing observation data. Click the **Browse...** button to search for a file.
2. To view a specified file, click the **View Import File...** button.
3. To append data from the import file to observation data in the data set, check the **Append observations from import file to data set** box.
4. Click the **Next >** button to proceed to Step 2 of the Import Wizard.

Step 2. Specify the file structure

1. Enter the **No. of Columns** contained in the file. The total number of columns contained in the file may be greater than the number of columns that you wish to import.
2. Enter a number for the **Starting Row** containing the first observation that you wish to import from the file.

   TIPS
   Click the **Select Starting Row...** button to view the import file. You can select the first row in the file that you want to import by double-clicking it.
3. Specify the **Data to Import** from the file. Enter a column number for each data item (elapsed time, displacement and measurement weight) that you are importing from the file. Enter a column number of 0 (zero) for any item not contained in the file.
4. Click the **Next >** button to proceed to Step 3 of the Import Wizard.

Step 3. Specify transformation and filter operations

1. Select **Pre-Filter Operations** for transforming time and displacement data contained in the file. Enter constants for subtraction and multiplication operations.

   TIPS
   Subtract the static water level from each value of displacement contained in the file to transform depth to water values to displacement values. To transform negative displacements to positive displacements, multiply each displacement value by -1.
2. Click the **Filters...** button to select options for filtering the data imported from the file.

   TIPS
   Use filters to reduce the number of observations contained in the import file. Retain time values having a uniform logarithmic spacing or displacement values exceeding a minimum threshold.
3. Click the **Finish** button to import data from the file.

Slug Test Well

Choose **Slug Test Well...** from the **Edit** menu to open the **Slug Test Data** dialog box for entering slug test data.

Slug test data

- initial displacement in well [L]
- casing radius [L]
- wellbore radius [L]
- saturated thickness of aquifer [L]
- screen length [L]

- static height of water in well [L]
- porosity of gravel pack [dimensionless]
- ratio of vertical to horizontal hydraulic conductivity (for partially penetrating wells in an anisotropic aquifer) [dimensionless]

Entering or importing slug test well measurements

1. Click the **Edit** button to open the **Observation Data** dialog box for entering observation data from the keyboard (see "Entering Observations from the Keyboard" on page 24).
2. Click the **Import** button to open the **Import Wizard** for importing observation data from a delimited text file (see "Importing Observations from a File" on page 26).

Test Type

Choose **Test Type...** from the **Edit** menu to select the type of test (pumping test or slug test) contained in an AQTESOLV for Windows data set.

Setting the test type in a new data set

1. When you open a new AQTESOLV for Windows data set, the test type is defined automatically when you enter pumping test or slug test data.
2. If you enter data for a pumping well or observation well, AQTESOLV for Windows defines the test type as Pumping Test.
3. If you enter data for a slug test well, AQTESOLV for Windows defines the test type as Slug Test.

Changing the test type in a data set

1. The **Edit** menu only enables options for the type of test contained in a data set.
2. Choose **Edit/Test Type...** to change the test type.

Viewing Data and Results

Overview

View Menu

The **View** menu provides options for viewing data, solutions and estimation results. Two general types of views, plots and reports, are available for viewing data and solutions, and evaluating estimation results. Other options in the **View** menu allow you to customize the appearance of your plot.

Format Menu

The **Format** menu provides options for formatting plots and reports. For plots, choose options for specifying axes parameters, colors, fonts and symbols. For reports, select fonts and colors.

Window Menu

AQTESOLV for Windows allows more than one view (window) for a data set. The **Window** menu provides you with options for opening new windows, positioning windows and activating windows.

Choosing a View

Plot Views

Select different plot views from the View menu or the toolbar list box

Graphical formats for viewing aquifer test (displacement) data and matching analytical solutions include **displacement vs. time**, **composite** and **derivative vs. time** plots. AQTESOLV for Windows also provides **discharge vs. time** plots to view discharge rates from variable rate pumping tests.

Perform automatic estimation to view residual plots

Graphical formats for examining residuals (errors) from the matching of analytical solutions to aquifer test data include **residual vs. time**, **residual vs. simulated displacement** and **normal probability** plots.

Displacement Vs. Time Plot

Choose the **Displacement-Time** option from the **View** menu to plot values of displacement as a function of time in the active window.

- The **Displacement-Time** view option allows you to analyze displacement data from one or more observation wells contained in the active data set.
- For pumping test solutions containing only two parameters, **Displacement-Time** plots display a single type curve regardless of the number of observation wells shown on the plot. For solutions involving three or more parameters, **Displacement-Time** plots show one type curve for each observation well.

Composite Plot

Select **Composite** from the **View** menu to plot values of displacement as a functions of time divided by the square of radial distance (t/r^2).

- The **Composite** view option allows you to analyze displacement data from one or more observation wells contained in the active data set.
- For pumping test solutions containing only two parameters, **Composite** plots display a single type curve regardless of the number of observation wells shown on the plot. For solutions involving three or more parameters, **Composite** plots show one type curve for each observation well.
- **Composite** plots are only enabled for data sets containing pumping test data.

Residual Vs. Time Plot

After performing automatic estimation of aquifer properties for a given analytical solution, plot residual values as a function of time by choosing **Residual-Time** from the **View** menu.

- Ideally, the residual values should not exhibit correlation with time.
- When **Residual-Time** data are plotted linear axes, AQTESOLV for Windows fits a straight line to the data to indicate the degree to which the residuals are biased with respect to time.

Residual Vs. Simulated Plot

After performing automatic estimation of aquifer properties for a given analytical solution, plot residual values as a function of simulated displacement by choosing **Residual-Simulated** from the **View** menu.

- Ideally, the residual values should not exhibit correlation with the values of simulated displacement.
- When **Residual-Simulated** data are plotted on linear axes, AQTESOLV for Windows fits a straight line to the data to indicate the degree to which the residuals are biased with respect to simulated displacement.

Normal Probability Plot

After performing automatic estimation of aquifer properties for a given analytical solution, plot residual values on normal probability axes by choosing **Normal Probability** from the **View** menu.

- A **Normal Probability** plot displays the standard normal deviates of the ranked residuals (residuals sorted from smallest to largest) as a function of the residual values.
- If the residuals are normally distributed, they will fall on a straight line when plotted on normal probability axes. AQTESOLV for Windows fits a straight line to residuals shown on the **Normal Probability** plot to measure the degree to which the residuals fit the normality assumption.
- Deviations from a normal distribution may indicate inadequacy in the fit of the aquifer model to the data.
- After sorting the residual values for all observation wells, AQTESOLV for Windows plots the standard normal deviates using the plot symbol for the first observation well.

Discharge Vs. Time Plot

To view pumping well discharge rates from a variable rate pumping test, choose **Discharge-Time** from the **View** menu.

- The **Discharge-Time** view option allows you to view constant or variable pumping rates for one or more pumping wells.
- **Discharge-Time** plots are only enabled for data sets containing pumping test data.

Derivative Vs. Time Plot

Choose **Derivative-Time** from the **View** menu to display the first derivative of displacement data as a function of time. If you have chosen a solution, AQTESOLV for Windows also plots the first derivative of the solution.

- The **Derivative-Time** view option allows you to view the first derivative of displacement measurements from one or more observation wells.
- **Derivative-Time** plots provide a useful diagnostic tool for detecting deviations in the rate of displacement change. For example, interpretation of a **Derivative-Time** plot can indicate the presence of aquifer boundaries, leakage and delayed gravity response.
- AQTESOLV for Windows computes derivatives for displacement using either **nearest neighbor** or **smoothing** techniques. Choose **Options...** from the **View** menu to select the method used to calculate derivatives from displacement data.

Linear Axes

Choose **Linear Axes** from the **View** menu to display a plot with linear x and y axes.

Semi-Log Axes

Choose **Semi-Log Axes** from the **View** menu to display a plot with a logarithmic x axis and a linear y axis.

Log Axes

Choose **Log Axes** from the **View** menu to display a plot with logarithmic x and y axes.

Depending on the active view type and solution, not all axis types may be enabled in the **View** menu. For example, if the active window displays a plot of displacement vs. time with the Cooper-Jacob (1946) solution for confined aquifers, the **Linear Axes** and **Log Axes** options will be disabled because the Cooper-Jacob solution only plots as a straight line on semi-logarithmic axes.

Show Data

Choose **Show Data** from the **View** menu to enable/disable the display of observation well or residual data on plots.

Show Legend

Choose **Show Legend** from the **View** menu to enable/disable the display of a legend on plots. The plot legend displays symbols for observation wells, aquifer type, solution method and parameter values.

Show Type Curve

Choose **Show Type Curve** from the **View** menu to enable/disable the display of a type curve for the active solution on displacement vs. time and composite plots.

Show Type Curve Family

Choose **Show Family** from the **View** menu to enable/disable the display of a family of type curves for the active solution on displacement vs. time and composite plots. This option is only enabled if the active solution has two or more parameters.

If you enable the **Show Family** option, AQTESOLV for Windows will display two additional type curves, one above and one below the curve matched to your data. By default, AQTESOLV for Windows multiplies the current value of the type curve family parameter (e.g., r/B) by 0.5 to plot the upper curve and 2.0 to plot the lower curve. To edit the multipliers used for the upper and lower curves, choose **Options...** from the **View** menu.

Show Theis Curve

Choose **Show Theis** from the **View** menu to enable/disable the display of bounding Theis type curves for the active solution on displacement vs. time and composite plots. This option is only enabled if for pumping solutions having two or more parameters.

For example, two bounding Theis type curves are displayed for the Neuman solution for unconfined aquifers using the values of T and S for the first curve and T and Sy for the second curve.

Show Valid Time

Choose **Show Valid Time** from the **View** menu to enable/disable the display of the time after which a straight-line approximation solution becomes valid on displacement vs. time and composite plots. This option is only enabled if the active solution is the Cooper-Jacob (1946) solution for a confined or unconfined aquifer.

To set a **critical value of u** used to compute the valid time, select **Options...** from the **View** menu.

Zoom

Choose **Zoom...** from the **View** menu to change the size of the plot within the active window.

1. Enter a **Zoom Factor** ranging from **0.5** to **5**.
2. Use this option to scale the size of a plot within the active window. To scale the length of plot axes within all windows attached to the active data set, see "Axes" on page 35.

Options

Choose **Options...** from the **View** menu to open a dialog box for entering parameters controlling the display of valid times and type curve families.

Critical Value of U

1. Set the critical value of u used to compute the valid time displayed for the Cooper-Jacob (1946) solution when you enable the **Show Valid Time** option in the **View** menu.
2. A conservative critical value of u is **0.01**.

Type Curve Families

1. Enter multipliers for the upper and lower type curves displayed when you enable the **Show Family** option in the **View** menu.
2. The upper curve, displayed above the active type curve, has a multiplier less than 1; the lower curve, displayed below the active type curve, has a multiplier greater than 1.

Derivative Calculation

1. Choose a method for calculating derivatives from time-displacement data (**nearest neighbor** or **smoothing**).
2. The **nearest neighbor** option provides the least amount of smoothing for "noisy" data and works well for displacement data that show ideal response.
3. The **smoothing** option allows you to choose a "smoothing factor" for the calculation of derivatives from "noisy" data. Enter the smallest smoothing factor to discern the derivative pattern from the data.

Report Views

Select Report Views from the View menu or the toolbar list box

The View menu provides you with a **Diagnostic** report and a **Complete** report that display textual summaries of your data set and the results of your aquifer test analysis. An **Error Log** report identifies any errors that your active data set may contain.

Diagnostic Report

Perform automatic estimation to view diagnostic report

Choose **Diagnostics** from the **View** menu to display a report containing estimation statistics for parameters (hydraulic properties) and residuals. The diagnostics report contains standard errors for estimated parameters, correlations between estimated parameters, and residual summary statistics.

Complete Report

Choose **Report** from the **View** menu to display a complete report summarizing the contents of the active data set and estimation results in a textual format.

Error Log

Choose **Error Log** from the **View** menu to display a report identifying any errors contained in the active data set. Choose this report option if you are entering data into a new data set.

Viewing Options

Refresh

Click on the toolbar to refresh display

Choose **Refresh** from the **View** menu to refresh (redraw) the plot or report in the active window.

Toolbar

Choose **Toolbar** from the **View** menu to enable/disable the AQTESOLV for Windows toolbar.

Status Bar

Choose **Status Bar** from the **View** menu to enable/disable the AQTESOLV for Windows status bar. The AQTESOLV for Windows status bar contains four panes which indicate messages and status information.

Message Pane

The first pane in the status bar supplies descriptive messages for menu options.

Check Errors Indicator

The second pane in the status bar displays the message **Check Errors** if AQTESOLV for Windows detects errors in active data set. To view the errors, choose **Error Log** from the **View** menu.

Test Type Indicator

The third pane in the status bar displays either **Pumping Test** or **Slug Test** to indicate the type of test contained in the active data set.

Solution Indicator

The fourth pane in the status bar displays the current solution for the active data set. AQTESOLV for Windows will prompt you to choose a solution if the data set contains sufficient data to perform a forward solution.

Formatting a View

Plot Formats

Choose **Plot** from the **Format** menu to select options for formatting axes, symbols, legends and colors.

Axes

Choose **Plot/Axes...** from the **Format** menu to open a dialog box for editing plot axes.

X and Y Axis Parameters

1. Edit parameters controlling axis ranges, tickmarks and labels. Choose minimum and maximum values, major and minor tickmarks, and tickmark label spacing for each axis.
2. Select the axis **Label** boxes to choose x- and y-axis labels. Choose one of the predefined axis labels or enter a new label.
3. Select the **Units** boxes to choose a format for appending units to the x- and y-axis labels.

Options

1. Check the **Upper Left Origin** box to place the origin of the plot axes in the upper left corner of the plot.
2. Check the **Show Graph Paper** box to display horizontal and vertical lines at the major tickmarks of the graph.
3. Enter a value between 0.5 and 1.5 for the **Axis Length Scale Factor** to adjust the length of the axes displayed on the screen.
4. Click the **Font...** button to change the font used to display axis labels.
5. Click the **Color...** button to change the color used for drawing the axis labels.

Symbols

Choose **Plot/Symbols...** from the **Format** menu to open a dialog box for editing plot symbols.

Symbol

Select a symbol type (e.g., square, circle, etc.) from **Symbol** box.

Size

Select a symbol size from **Size** box.

Color

Click the **Color...** button to change the color used for drawing plot symbols.

Legend

Choose **Plot/Legend...** from the **Format** menu to open a dialog box for editing plot legends.

Font

Click the **Font...** button to change the font used to display text.

Color

Click the **Color...** button to change the color used for text.

Printer Options

From the options provided, check the data to appear in the legend of printed plots.

Curves

Choose **Plot/Curves...** from the **Format** menu to open a dialog box for editing colors used for plotting curves.

Report Formats

Choose **Report...** from the **Format** menu to open a dialog box for formatting reports.

Header Text

Enter text for a report header.

Footer Text

Enter text for a report footer.

Printer Options

Choose options for including blocks of text in a report.

Font

Click the **Font...** button to choose a font for the report.

Color

Click the **Color...** button to choose a color for the report.

Formatting Options

Choose **Options...** from the **Format** menu to enter formatting options for plots and reports.

Step Test Prediction Time

1. Enter a time for predicting drawdown in a pumping well including linear and nonlinear well losses based on the Jacob-Rorabaugh equation (see "Theis (1935) Solution for a Step Drawdown Test in a Confined Aquifer" on page 56).
2. AQTESOLV for Windows uses the prediction time to print the Jacob-Rorabaugh well-loss equation in plots and reports.
3. The prediction time is **not** required for estimation of aquifer properties.

Working with Multiple Views

AQTESOLV for Windows allows you to have more than one view (window) for a data set. The **Window** menu provides you with options for opening new windows, positioning windows and activating windows.

Opening a New Window

Choose **New Window** from the **Window** menu to open a new window for the active data set. The new window will have the same view (plot or report) as the previously active window. To change the view, select a view option from the **View** menu.

Cascading Windows

Choose **Cascade** from the **Window** menu to cascade windows from the upper left corner of the AQTESOLV for Windows client area.

Tiling Windows

Choose **Tile Horizontal** or **Tile Vertical** from the **Window** menu to tile windows horizontally or vertically, respectively.

Kruseman, G.P. and N.A. DeRidder, 1990. Analysis and Evaluation of Pumping Test Data (2nd ed.), Publication 47, Intern. Inst. for Land Reclamation and Improvement, Wageningen, The Netherlands, 370p.

Tutorial

Perform the tutorial for the Cooper-Jacob (1946) solution for a pumping test in a confined aquifer (see "Tutorial" on page 47) to learn how to use this solution.

Neuman (1974) Solution for a Pumping Test in an Unconfined Aquifer

Neuman (1974) derived an analytical solution for unsteady flow to a partially penetrating well in an unconfined aquifer with delayed gravity response:

$$s = \frac{Q}{4\pi T}\int_0^\infty 4yJ_0(y\sqrt{\beta})\left[u_0(y) + \sum_{n=1}^{\infty} u_n(y)\right]dy$$

$$\beta = \frac{r^2 K_z}{b^2 K_r}$$

$$\sigma = \frac{S}{S_y}$$

For a partially penetrating pumping well, the drawdown in a piezometer is found using the following equations:

$$u_0(y) = \frac{\{1-\exp[-t_s\beta(y^2-\gamma_0^2)]\}\cosh(\gamma_0 z_D)}{\{y^2+(1+\sigma)\gamma_0^2-(y^2-\gamma_0^2)^2/\sigma\}\cosh(\gamma_0)} \cdot \frac{\sinh[\gamma_0(1-d_D)]-\sinh[\gamma_0(1-l_D)]}{(l_D-d_D)\sin(\gamma_0)}$$

$$u_n(y) = \frac{\{1-\exp[-t_s\beta(y^2+\gamma_n^2)]\}\cos(\gamma_n z_D)}{\{y^2-(1+\sigma)\gamma_n^2-(y^2+\gamma_n^2)^2/\sigma\}\cos(\gamma_n)} \cdot \frac{\sin[\gamma_n(1-d_D)]-\sin[\gamma_n(1-l_D)]}{(l_D-d_D)\sin(\gamma_n)}$$

For a partially penetrating pumping well, the drawdown in a partially penetrating observation well is found using the following equations:

$$u_0(y) = \frac{\{1-\exp[-t_s\beta(y^2-\gamma_0^2)]\}\{\sinh(\gamma_0 z_{2D})-\sinh(\gamma_0 z_{1D})\}}{\{y^2+(1+\sigma)\gamma_0^2-(y^2-\gamma_0^2)^2/\sigma\}\cosh(\gamma_0)} \cdot \frac{\sinh[\gamma_0(1-d_D)-\sinh[\gamma_0(1-l_D)]}{(z_{2D}-z_{1D})\gamma_0(l_D-d_D)\sin(\gamma_0)}$$

$$u_n(y) = \frac{\{1-\exp[-t_s\beta(y^2+\gamma_n^2)]\}\{\sin(\gamma_n z_{2D}) - \sin(\gamma_n z_{1D})\}}{\{y^2-(1+\sigma)\gamma_n^2-(y^2+\gamma_n^2)^2/\sigma\}\cos(\gamma_n)} \cdot \frac{\sin[\gamma_n(1-d_D)]-\sin[\gamma_n(1-l_D)]}{(z_{2D}-z_{1D})\gamma_n(l_D-d_D)\sin(\gamma_n)}$$

The gamma terms are the roots of the following equations:

$$\sigma\gamma_0\sinh(\gamma_0)-(y^2-\gamma_0^2)\cosh(\gamma_0)=0,\ \gamma_0^2<y^2$$

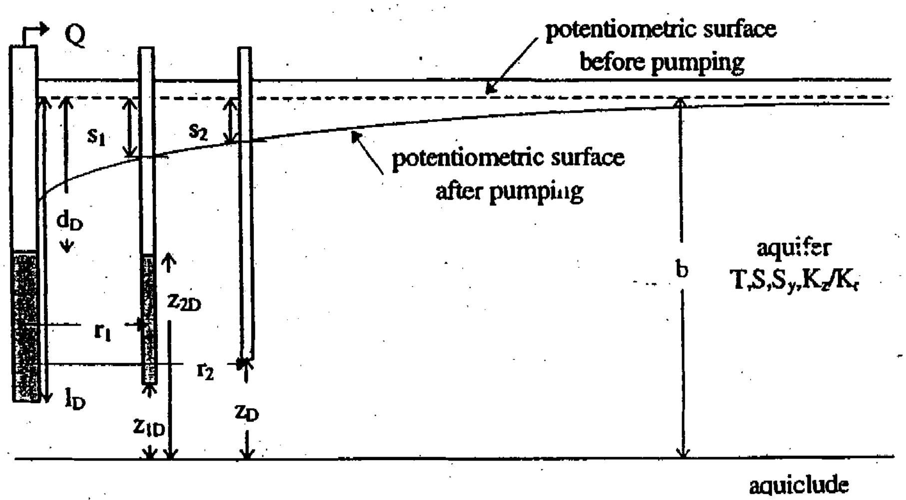
and

$$\sigma\gamma_n\sin(\gamma_n)+(y^2+\gamma_n^2)\cos(\gamma_n)=0,\ (2n-1)/(\pi/2)<\gamma_n<n\pi,\ n\geq 1$$

Refer to the "List of Symbols" on page 109 for a description of the parameters and variables contained in the equations.

AQTESOLV for Windows allows you to analyze both constant- and variable-rate pumping tests using the Neuman solution. For tests with a variable discharge rate, the program uses the principle of superposition to compute drawdown in the aquifer. For more information concerning the application of the principle of superposition in variable-rate pumping tests, refer to the "Theis (1935) Solution for a Pumping Test in a Confined Aquifer" on page 40.

The Neuman solution supports observation wells and piezometers. Use this solution to estimate values of transmissivity, elastic storage coefficient, specific yield and βbeta (or K_z/K_rKz/Kr for a data set containing more than one pair of pumping and observation wells) in an unconfined aquifer.



Entering partial penetration data for observation wells or piezometers

The equations of Neuman (1974) for a partially penetrating observation well or a piezometer use elevations measured from the base of the unconfined aquifer (z_{1D}, z_{2D}, z_D); however, when entering partial penetration data for observation wells and piezometers into AQTESOLV for Windows, input depths measured from the potentiometric surface before pumping (static water table).

Assumptions

- aquifer has infinite areal extent

- aquifer is homogeneous and has uniform thickness
- aquifer potentiometric surface is initially horizontal
- aquifer is unconfined
- flow is unsteady
- diameter of pumping well is very small so that storage in the well can be neglected

Data Requirements

- pumping and observation well locations
- pumping rate(s)
- observation well measurements (time and displacement)
- aquifer saturated thickness
- partial penetration depths (optional)

Solution Options

- variable pumping rates
- multiple pumping wells
- multiple observation wells
- partially penetrating wells

Visual Curve Matching

In practice, one uses two sets of type curves to analyze a pumping test in an unconfined aquifer with the Neuman solution. Type A curves match early time data and Type B curves match late time data:

$$s_A = \frac{Q}{4\pi T} w(u_A, \beta)$$

$$s_B = \frac{Q}{4\pi T} w(u_B, \beta)$$

To analyze a pumping test using the Neuman type curve method, one plots drawdown as a function of time on double logarithmic axes. By matching two families of type curves drawn by plotting $w(u_A,\beta)$ as a function of $1/u_A$ and $w(u_B,\beta)$ as a function of $1/u_B$, one can estimate the values of transmissivity, storage coefficient, specific yield and βbeta by visual analysis.

Procedure for Visual Curve Matching

1. Match **Type A** curves to early drawdown data to estimate T, S and βbeta.
2. Match **Type B** curves to late drawdown data to estimate T, S_Yy and βbeta.
3. From the **View** menu, choose **Type A** or **Type B** to display the type curve for the active value of βbeta and initiate visual curve matching.

4. Choose **Increase beta** or **Decrease beta** from the **View** menu to change the value of βbeta used for visual curve matching.
5. Click and hold the left mouse button down to drag the Neuman type curves to a new position on the screen. Release the left mouse button when you have finished moving the curves.

Partial Penetration Type Curves

AQTESOLV for Windows stores Type A and Type B curves for fully penetrating wells. If your data set contains partially penetrating wells, however, you must compute new Type A and Type B curves for the partial penetration depths of the pumping and observation wells. AQTESOLV for Windows automatically prompts you when new partial penetration type curves are required for your data set.

Computing Curves

Choose **Calculate** in the **Partial Penetration Curves** dialog box to compute partial penetration curves using partial penetration data for the pumping and observation wells. AQTESOLV for Windows will save the partial penetration curves with the data set.

Retrieving Curves From Disk

Choose **Retrieve from disk** from the **Partial Penetration Curves** dialog box to open a disk file containing partial penetration type curves. The format of the file is compatible with DOS versions of AQTESOLV.

Saving Curves on Disk

After computing partial penetration type curves, AQTESOLV for Windows prompts you to save the type curve data on disk. The format of the file created by AQTESOLV for Windows is compatible with DOS versions of AQTESOLV.

References

Neuman, S.P., 1974. Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response, Water Resources Research, vol. 10, no. 2, pp. 303-312.

Moench, A.F., 1993. Computation of type curves for flow to partially penetrating wells in water-table aquifers, Ground Water, vol. 31, no. 6, pp. 966-971.

Moench, A.F., 1996. Flow to a well in a water-table aquifer: an improved Laplace transform solution, Ground Water, vol. 34, no. 4, pp. 593-596.

Tutorial

Access the tutorial for this solution from the on-line User's Guide in AQTESOLV for Windows.

In this tutorial, you will use the Neuman and Quick Neuman type curve solutions to analyze a constant rate pumping test in an unconfined aquifer. This tutorial shows you how to use visual and automatic curve matching to match Neuman type curves to drawdown data measured during the test.

Open a New Data Set

Open a new data set by choosing **New** from the **File** menu. In the **New Data Set** dialog box, choose **Tutorial** in the list box and click **OK** to initialize the new data set with default values. AQTESOLV for Windows opens a new window with an Error Log view that reports any errors identified in the data set.

Enter Data for Pumping Test

Choose **Units...** from the **Edit** menu to open the **Units** dialog box for selecting units of measurement for the data set.

1. Select **ft** (feet) for **Length**, **min** (minutes) for **Time**, **gal/min** (gallons-per-minute) for **Pumping Rate** and **ft/min** (feet/minute) for **Hyd. Conductivity**.
2. Click the **OK** button to close the **Units** dialog box.

Choose **Title...** from the **Edit** menu to open a dialog box for editing the data set title.

1. Enter **Fairborn, Ohio** for the **Title**.
2. Click the **OK** button to close the dialog box.

Choose **Aquifer Data...** from the **Edit** menu to open a dialog box for editing aquifer data.

1. Enter **78.0** for the value of **Saturated Thickness**.
2. Click the **OK** button to close the dialog box.

Choose **Pumping Well/Edit...** from the **Edit** menu to open the **Pumping Well Data** dialog box for editing pumping well data.

1. Click the **Edit** button to open the **Pumping Period Data** dialog box for entering pumping rates.
2. In the **Time** and **Rate** edit controls, enter values of **0.0** and **1080.0** for time and rate, respectively, where time is in minutes and rate is in gallons-per-minute.
3. Click the **<<Add** button to transfer the values you entered to the list box.
4. Click **OK** to close the **Pumping Period Data** dialog box.
5. Click **OK** to close the **Pumping Well Data** dialog box.

Choose **Obs. Well/Edit...** from the **Edit** menu to open the **Observation Well Data** dialog box and edit data for the observation well.

1. Enter a value of **73.0** for the **X-Coordinate** location of the well.
2. Click the **Import** button to import observation well measurements from a delimited text file using the **Observation Data Import Wizard**. In Step 1 of the **Import Wizard**, enter **FAIRBORN.DAT** for the name of the import file. The file FAIRBORN.DAT contains time and displacement data arranged in two columns separated by a tab delimiter. Click the **Next** button to proceed to the next step.
3. In Step 2 of the **Import Wizard**, enter data describing the structure of the import file. The **Import Wizard** automatically determines that the import file contains 2 columns of data. Enter **1** for the **Elapsed**

Time column and 2 for the **Displacement** column. Click the **Next** button to proceed to the next step.

4. In Step 3 of the **Import Wizard**, choose transformation and filter options for the data contained in the import file. Retain the default settings, and click the **Finish** button to import data from the file.
5. After AQTESOLV for Windows has finished importing the data, a message box displays the number of observations imported from the file. Click the **OK** button to close the message box.
6. Click the **OK** button to close the **Observation Well Data** dialog box.

After you have completed the previous data entry steps, the **Error Log** displayed in the active window should show that the data set contains no errors. Now you are ready to display the data, choose a solution and estimate aquifer properties.

Save Data Set

Choose **Save As...** from the **File** menu to open a dialog box for saving the data you have entered into the current data set.

1. Enter **NEUMAN1.AQT** for the file name.
2. Click the **OK** button to close the dialog box and save the data set.

Change View in Window

Choose **Displacement-Time** from the **View** menu to display a plot of displacement vs. time in the active window. The window displays a plot of the observation well data on semi-log axes.

Choose Quick Neuman Solution

Change the aquifer model and solution by choosing **Unconfined...** from the **Solution** menu to open a dialog box with solutions for analyzing pumping tests in an unconfined aquifer.

1. Choose the **Quick Neuman** solution.
2. Click the **OK** button to close the dialog box.

After you have selected the Quick Neuman solution for a pumping test in an unconfined aquifer, AQTESOLV for Windows updates the window by plotting the data on double logarithmic axes, superimposing a Neuman type curve on the plot, and displaying values of transmissivity (T), storage coefficient (S), specific yield (Sy) and beta in the legend.

The Quick Neuman implementation of the Neuman solution, rather than the full Neuman solution, is ideal for most situations. Computations with Quick Neuman are much faster than Neuman with virtually no loss in accuracy. Therefore, you should use Quick Neuman for initial estimation followed by Neuman to refine the estimates obtained with Quick Neuman.

Perform Visual Matching with Quick Neuman

Visually match the Quick Neuman solution to the data as follows:

1. Choose **Type A** from the **Match** menu to match Type A curves to the early data.
2. Choose **Increase beta** or **Decrease beta** from the **Match** menu to display a Type A curve using one of the 19 preset values of beta.

3. To begin interactively moving the Type A curve, move the mouse cursor over the plot, click the left mouse button, and hold it down.
4. As you move the mouse, the type curve also moves. AQTESOLV for Windows updates the values of T and S in the legend as you move the Type A curve.
5. When you have finished matching the Type A curve to the early data, release the left mouse button to end visual curve matching and redraw the complete type curve.
6. Choose **Type B** from the **Match** menu to match Type B curves to the late data.
7. Follow the procedure for Type A curve matching to fit a Type B curve to the late data. As you move the Type B curve, AQTESOLV for Windows updates the values of T and Sy in the legend.

You should obtain a match using a value of 0.06 for beta. If necessary, repeat the preceding steps to finish matching the Type A and B curves.

Perform Automatic Matching with Quick Neuman

Choose **Automatic...** from the **Match** menu to open a dialog box for performing automatic matching of the Neuman type curve solution to the observation well data.

1. Click the **Start** button to begin the automatic estimation procedure.
2. As the automatic estimation procedure completes iterations, the dialog box displays the changes in the residual sum of squares (RSS) criterion and the values of the aquifer properties. After the automatic estimation procedure finishes, AQTESOLV for Windows displays a message box containing residual summary statistics. Click the **OK** button to close the message box.
3. Click the **Close** button when the automatic estimation procedure has finished.

The plot shown in the active window displays the values of transmissivity (T=24.04), storage coefficient (S=0.0.002111), specific yield (Sy=0.1061) and beta (=0.4458) determined by automatic estimation.

Choose Neuman Solution

Change the aquifer model and solution by choosing **Unconfined...** from the **Solution** menu to open a dialog box with solutions for analyzing pumping tests in an unconfined aquifer.

1. Choose the **Neuman (1974)** solution.
2. Click the **OK** button to close the dialog box.

Compared to the Quick Neuman implementation of the Neuman solution, the full Neuman implementation is computationally more intensive and therefore requires greater time to plot the type curve. In all other respects, working with the Neuman solution for visual and automatic curve matching is identical to Quick Neuman.

Save Data Set

Choose **Save** from the **File** menu to save your work in the NEUMAN1.AQT data set.

Quick Neuman Solution for a Pumping Test in an Unconfined Aquifer

The Quick Neuman solution option provided by AQTESOLV for Windows computes Neuman type curves using a two-stage interpolation technique. QuickNeuman yields essentially the same results as the Neuman solution option, only much more quickly. Therefore, Quick Neuman is a viable alternative for performing automatic curve matching prior to using Neuman (see "Neuman (1974) Solution for a Pumping Test in an Unconfined Aquifer" on page 66).

Assumptions

- aquifer has infinite areal extent
- aquifer is homogeneous and has uniform thickness
- aquifer potentiometric surface is initially horizontal
- aquifer is unconfined
- flow is unsteady
- diameter of pumping well is very small so that storage in the well can be neglected

Data Requirements

- pumping and observation well locations
- pumping rate(s)
- observation well measurements (time and displacement)
- aquifer saturated thickness
- partial penetration depths (optional)

Solution Options

- variable pumping rates
- multiple pumping wells
- multiple observation wells
- partially penetrating wells

Reference

Neuman, S.P., 1974. Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response, Water Resources Research, vol. 10, no. 2, pp. 303-312.

Tutorial

To learn how to use the Quick Neuman solution, perform the tutorial for the Neuman (1974) Solution for a Pumping Test in an Unconfined Aquifer.

List of Symbols

a = constant defining variation in thickness of wedge-shaped aquifer [L^{-1}]
b = thickness of aquifer [L]
b_0 = thickness of aquifer at pumping well [L]
b_s = thickness of fracture skin [L]
b' = thickness of aquitard overlying aquifer in leaky system or one-half thickness of blocks in fissured system [L]
b'' = thickness of aquitard underlying aquifer [L]
B = leakage factor [L^{-1}]
$B(r_e,t)$ = linear head-loss coefficient [T/L^2]
$B_1(r_w,t)$ = linear aquifer-loss coefficient [T/L^2]
B_2 = linear well-loss coefficient [T/L^2]
C = nonlinear well-loss coefficient [T^2/L^5]
d_D = vertical distance between top of perforations in pumping well and initial position of water table divided by initial saturated thickness of aquifer [L]
H = static height of water in well measured from base of well to static water level [L]
H_0 = initial displacement in well due to slug injection or extraction [L]
J_0 = Bessel function of first kind, zero order
J_1 = Bessel function of first kind, first order
K = hydraulic conductivity of fractures in fissured system [L/T]
K_0 = modified Bessel function of second kind, zero order
K_1 = modified Bessel function of second kind, first order
K_r = radial (horizontal) hydraulic conductivity of aquifer [L/T]
K_s = hydraulic conductivity of fracture skin [L/T]
K_z = vertical hydraulic conductivity of aquifer [L/T]
K' = hydraulic conductivity of aquitard overlying aquifer in leaky system or block system in fissured system [L/T]
K'' = hydraulic conductivity of aquitard underlying aquifer [L/T]
l_D = vertical distance between bottom of perforations in pumping well and initial position of water table divided by initial saturated thickness of aquifer [L]
L = length of well screen [L]
p = Laplace transform variable
P = order of nonlinear well-losses [dimensionless]
Q = pumping rate [L^3/T]
r = radial distance [L]
r_c = well casing radius [L]
r_e = equivalent radius over which head loss occurs [L]
r_w = well radius [L]

s = displacement [L]
s_t = displacement at time t [L]
s_0 = initial displacement in well [L]
S = coefficient of storage of aquifer [dimensionless]
S_f = fracture skin [dimensionless]
S_s = specific storage of aquifer or fractures in fissured system [L^{-1}]
S_s' = specific storage of aquitard in leaky system or blocks in fissured system [L^{-1}]
S_w = wellbore skin [dimensionless]
S_y = specific yield of aquifer [dimensionless]
S' = coefficient of storage of aquitard overlying aquifer [dimensionless]
S'' = coefficient of storage of aquitard underlying aquifer [dimensionless]
t = time since pumping began [T]
t_s = dimensionless time with respect to S_s equal to Tt / Sr^2 [T]
t_y = dimensionless time with respect to S_y equal to $Tt / S_y r^2$ [T]
T = transmissivity [L^2 / T]
x_0 = x-coordinate location of pumping well [L]
y = variable of integration
y_0 = y-coordinate location of pumping well [L]
Y_0 = Bessel function of second kind, zero order
Y_1 = Bessel function of the second kind, first order
z_D = vertical distance above bottom of aquifer divided by initial saturated thickness of aquifer [L]
z_{1D} = vertical distance from bottom of aquifer to bottom of observation well perforations divided by initial saturated thicknessof aquifer [L]
z_{2D} = vertical distance from bottom of aquifer to top of observation well perforations divided by initial saturated thickness of aquifer [L]

Estimating Aquifer Coefficients

Overview

The **Match** menu provides two methods for estimating the hydraulic properties of aquifers from pumping tests and slug tests. Each method matches analytical solutions to data measured during an aquifer test.

- The first method, visual matching, is analogous to traditional graphical methods which rely on manually fitting type curves or straight lines to determine hydraulic parameters.
- The second method uses a nonlinear least-squares parameter estimation technique to automatically fit analytical solutions to aquifer test data.

Whichever method you choose, AQTESOLV for Windows allows you to visualize the results of your analysis by plotting the solution and data. In addition, the automatic curve matching technique provides statistical measures of the "fit" of the solution to the data.

Editing Parameters and Estimation Options

Setting Parameters

Choose **Parameters...** from the **Match** menu to open a dialog box for editing values of the hydraulic parameters in an aquifer model, setting parameter bounds, and enabling/disabling parameters for automatic estimation.

Setting Parameter Values

Choose **Parameters...** from the **Match** menu to open a dialog box for editing values of the hydraulic parameters in an aquifer model. Enter new values in the **Estimate** boxes for each parameter.

For example, if you are matching the Theis (1935) solution to your data, use the **Estimate** boxes to assign values for the transmissivity (T) and storage coefficient (S) parameters.

Automatically Setting Parameter Values

1. Click **Automatic...** to set parameter estimates to values determined most recently from automatic curve matching.
2. Click **Visual...** to set parameter values to their visual curve matching estimates.
3. Click **Current...** to reset the parameters to their current values.

Assigning Parameter Bounds

Choose **Parameters...** from the **Match** menu to assign feasibility constraints for each of the parameters in a solution during automatic curve matching. Enter constraints in the **Minimum** and **Maximum** boxes for each parameter.

For example, if you are estimating transmissivity (T) in the Theis solution, you can constrain the range of T between a minimum value of 10 and a maximum value of 100. During automatic curve matching, AQTESOLV for Windows will constrain the estimated value of T to lie between 10 and 100.

Activating/Deactivating Parameters

Choose **Parameters...** from the **Match** menu to activate or deactivate the estimation of certain parameters during automatic curve matching. The **Active?** check boxes indicate the active or inactive status of each parameter.

For example, to estimate transmissivity (T) and hold storage coefficient (S) constant in the Theis solution, deactivate (turn off) estimation by removing the check in the **Active?** field for S.

Controlling Automatic Estimation

Choose **Iterations..** from the **Match** menu to edit parameters which control the automatic curve matching procedure.

Automatic curve matching changes the values of parameters using an iterative procedure to match a type curve or straight line as closely as possible to your data. In each iteration, the automatic curve matching algorithm seeks parameter adjustments that reduce the residual sum of squares (RSS). When additional iterations fail to lower the RSS, AQTESOLV for Windows automatically terminates the iterations.

Convergence Criteria

If you wish to control the iteration procedure yourself, you can edit the following three criteria which control the termination of the automatic curve matching algorithm:

- maximum number of iterations
- residual sum of squares tolerance
- parameter change tolerance

During automatic curve matching, AQTESOLV for Windows checks each of the criteria at the end of each iteration. If the iterations reach the maximum number of iterations criterion *or* the RSS reaches the RSS tolerance *or* the maximum change in any of the estimated parameters reaches the parameter change tolerance, the iterations terminate.

Tips

Generally, you should maintain the tolerances for RSS and parameter change at small values (e.g., 1×10^{-10}1.0E-10); however, for certain solutions, changing the maximum number of iterations may be valuable. For example, if the automatic curve matching feature is converging slowly, you may wish to increase the maximum number of-iterations.

Setting Match Options

Choose **Options..** from the **Match** menu to enable/disable the following solution options:

- partial penetration
- multiple wells

if your data set includes partially penetrating wells or more than one pumping well. This feature allows you to examine effects of enabling/disabling partial penetration or image well data.

Automatic Curve Matching

Click on the toolbar to invoke automatic curve matching

Choose **Automatic...** from the **Match** menu to use automatic curve matching to estimate the values of hydraulic parameters. This procedure automatically adjusts the values of hydraulic properties to achieve the best statistical match between the solution (i.e., type curve) and the test data.

The automatic curve matching feature provided by AQTESOLV for Windows uses a nonlinear least squares estimation procedure to match a type curve or straight-line solution to your data. The procedure iteratively minimizes the "residuals" or errors between the computed and the observed drawdown or displacement.

Starting Estimation

Click the **Start** button to begin the procedure of automatically matching a solution to your data. During automatic estimation, the dialog box displays a residual sum of squares (RSS) convergence criterion and the values of the estimated parameters which indicates the progress of the automatic curve matching.

Aborting Estimation

*Click the **Abort** button to terminate automatic estimation at any time.*

To halt estimation before any of the termination criteria are met, click the **Abort** button. Viewing residual plots and diagnostic statistics requires that you allow the automatic estimation procedure to terminate normally; if you halt estimation prematurely, you will not be able to view residual plots or diagnostic statistics.

Tips

In general, automatic curve matching performs more efficiently with good starting guesses for the hydraulic properties in an aquifer model. One way to ensure good initial guesses is to perform visual curve matching prior to initiating automatic estimation. For solutions involving three or more parameters, it a good idea to perform visual estimation prior to automatic curve matching.

If you wish to perform automatic curve matching with the Neuman (1974) solution, the following procedure is strongly recommended:

1. Perform visual curve matching with Quick Neuman to determine initial estimates of hydraulic properties.
2. Perform automatic curve matching with Quick Neuman to refine the parameter estimates.
3. In most cases, the parameter estimates determined using Quick Neuman are sufficiently accurate; however, if desired, you can further refine the parameter estimates by changing the solution method to Neuman (1974) and performing automatic estimation.

How Automatic Curve Matching Works

AQTESOLV for Windows performs nonlinear weighted least-squares parameter estimation (automatic curve matching) using the Gauss-Newton linearization method. To improve the convergence of the method from poor initial guesses for the unknown parameters, AQTESOLV for Windows includes the Marquardt correction factor (Marquardt, 1963).

In the Gauss-Newton method of parameter estimation, the parameter corrections necessary to minimize the difference between observed and estimated values of the response variable can be expressed as a Taylor series expanded about the current estimated value as follows:

$$y_i = \hat{y} + \frac{\partial y}{\partial b}\Delta b + \frac{\partial^2 y}{2!\partial^2 b}(\Delta b)^2 + \frac{\partial^3 y}{3!\partial^3 b}(\Delta b)^3 \ldots$$

where:

y_i = ith observed value of response variable
$\hat{y}_i$ = estmate of the ith value of response variable
Δb = parameter correction, $\hat{b}^1 - \hat{b}^0$
$\hat{b}^1$ = updated estimate of the unknown parameter
$\hat{b}^0$ = current estimate of the unknown parameter

The previous equation can be linearized by truncating the Taylor series after the first derivative as follows:

$$y_i \approx \hat{y}_i + \frac{\partial y}{\partial b}\Delta b$$

Thus, for p unknown parameters, the general linearized equation for computing parameter corrections is written as follows:

$$y_i \approx \hat{y}_i + \sum_{k=1}^{p}\frac{\partial y_i}{\partial b_k}\Delta b_k$$

The previous equation is written for each observed value of the response variable. The partial derivatives of the response variable with respect to the unknown parameters are known as sensitivity coefficients. The resulting system of linearized equations is solved iteratively until convergence is obtained. The objective function for this minimization problem is the sum of the squared residuals given by the following expression:

$$RSS = \sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

where n is the total number of observed values of the response variable. In matrix form, the Gauss-Newton method computes parameter correction as follows:

$$\Delta B = (X^T X)^{-1} X^T \Delta Y$$

where:

$$\begin{aligned}
\Delta B &= p \times 1 \text{ vector of parameter corrections} \\
X &= n \times p \text{ matrix of sensitivity coefficients} \\
X^T &= p \times n \text{ transpose of } X \\
X^T X &= p \times p \text{ variance-covariance matrix} \\
\Delta Y &= n \times 1 \text{ vector of residuals } (y_i - \hat{y}_i)
\end{aligned}$$

To improve the conditioning of the variance-covariance matrix, AQTESOLV for Windows adds the Marquardt correction factor to the previous equation:

$$\Delta B = (X^T X + \lambda \cdot I)^{-1} X^T \Delta Y$$

where:

$$\begin{aligned}
\lambda &= \text{Marquardt correction factor} \\
I &= \text{identity matrix}
\end{aligned}$$

The Marquardt correction factor is added when parameter corrections computed by the Gauss-Newton method fail to reduce the residual sum of squares (RSS). Iterations performed with the Marquardt correction factor start with a sufficiently small value of λlambda; larger values of λlambda are added until the RSS is reduced. The parameter estimation algorithm terminates when the RSS is minimized.

Weighted least-squares estimation is accomplished as follows:

$$\Delta B = (X^T W X)^{-1} X^T W \Delta Y$$

where:

$$\begin{aligned}
W &= n \times n \text{ nonsingular symmetric matrix obtained from } \omega^T \omega \\
\omega &= n \times n \text{ diagonal matrix of weights}
\end{aligned}$$

Thus, in this implementation of the weighted least-squares algorithm, a larger weight assigned to a measurement results in greater influence by that measurement in the parameter estimation procedure.

Visual Curve Matching

Click on the toolbar to initiate visual curve matching

Choose **Visual** from the **Match** menu to invoke the visual curve matching feature provided by AQTESOLV for Windows. By selecting this option, you can interactively match a type curve or straight line to your data. The **Visual** option is only available if you are viewing a **displacement vs. time** or **composite** plot in the active window.

AQTESOLV for Windows lets you perform visual estimation of aquifer properties by using a mouse to move a type curve or straight line on the screen.

Matching Type Curves

1. After choosing the **Visual** option from the **Match** menu, click and hold the left mouse button down within the plot axes.
2. Move the mouse to match the type curve to your data. As you move the type curve, AQTESOLV for Windows automatically updates the plot legend to reflect changes in parameter values.
3. Release the left mouse button when you have finished matching the type curve.

Matching Straight Lines

1. After choosing the **Visual** option from the **Match** menu, move the mouse to a point located on the new straight line you wish to match to your data. Click and hold the left mouse button down to anchor the new straight line at this point.
2. Move the mouse to match a new straight line to your data. As you move the mouse, AQTESOLV for Windows drags a straight line between the anchor point and the position of the mouse.
3. Release the left mouse button when you have finished matching a new straight line. AQTESOLV for Windows automatically updates the plot legend to reflect changes in parameter values.

Sensitivity Analysis

Choose **Perturb...** from the **Match** menu to test the sensitivity of the fitted solution to discrete changes in the values of parameters in the aquifer model.

Performing Sensitivity Analysis

1. Select one or more parameters you wish to perturb in the list box.
2. Click a radio button to increase or decrease the selected parameters.
3. Enter a percentage for the perturbation applied to each selected parameter.
4. Click the **OK** button to proceed with the sensitivity analysis.

Options for Neuman Type Curve Matching

The **Match** menu and toolbar provide several options that are available only when performing visual curve matching with the Neuman and Quick Neuman solutions. See "Automatic Curve Matching" on page 113 for tips on using automatic curve matching with the Neuman solution.

Type A

Click A on the toolbar to use Type A curves

Choose **Type A** from the **Match** menu to invoke visual curve matching with the Neuman or Quick Neuman solution using Type A curves. Type A curves allow you to estimate values of transmissivity (T) and elastic storage coefficient (S).

Procedure

1. For a fixed value of βbeta, match Type A curves to early time-displacement data.
2. Click and hold the left mouse button in the plot area to drag the type curve to a new location.
3. Choose **Increase beta** or **Decrease beta** from the **Match** menu to change the value of βbeta used to draw the Type A curves.

Type B

Click B *on the toolbar to use Type B curves*

Choose **Type B** from the **Match** menu to invoke visual curve matching with the Neuman or Quick Neuman solution using Type B curves. Type B curves allow you to estimate values of transmissivity (T) and specific yield (Sy).

Procedure

1. For a fixed value of βbeta, match Type B curves to late time-displacement data.
2. Click and hold the left mouse button in the plot area to drag the type curve to a new location.
3. Choose **Increase beta** or **Decrease beta** from the **Match** menu to change the value of βbeta used to draw the Type B curves.

Decrease Beta

Click -β *on the toolbar to decrease beta*

Choose **Decrease beta** from the **Match** menu to decrease the value of βbeta used for visual curve matching with the Neuman and Quick Neuman solutions.

Increase Beta

Click +β *on the toolbar to increase beta*

Choose **Increase beta** from the **Match** menu to increase the value of βbeta used for visual curve matching with the Neuman and Quick Neuman solutions.

Obtaining Output

Overview

AQTESOLV for Windows has two options for obtaining output from the program. First, you can print plots and reports on output devices connected to your computer. Second, you can export data from the program to files for use by other software.

Printing Plots and Reports

The **File** menu provides options for obtaining printer output from AQTESOLV for Windows. The options allow you to print plots and reports, preview the printed appearance of plots and reports prior to printing, and configure a printer connected to your computer.

Printing

Click 🖨 on the toolbar to open the Print dialog box

Choose **Print...** from the **File** menu to open a dialog box for printing the plot or report in the active window. Click the **Setup...** button to select a specific printer.

Print Preview

Click on the toolbar for Print Preview

Choose **Print Preview** from the **File** menu to preview the appearance of a plot or report prior to printing. While previewing, click the **Print...** button to print the plot or report or click the **Close** button to end print preview without printing.

Print Setup

Choose **Print Setup...** from the **File** menu to open a dialog box for choosing the specific printer connected to your computer, selecting paper size and orientation, and setting printer options.

Page Setup

Choose **Page Setup...** from the **File** menu to open a dialog box for configuring the printing of report headers and footers.

Margins

Enter values (in inches) for the margins of printed pages of reports and plots.

Headers and Footers

Select these options to show headers and footers displayed on the printed pages of reports.

Font Rotation

Select this option to display the y-axis plot labels with a rotated font. This option is disabled if the current default printer connected to your system does not support font rotation.

Troubleshooting

Y-Axis Label Printed Horizontally

If you encounter difficulties printing the y-axis label of a plot, perform each of the following steps in succession to remedy the problem.

1. Check the settings in the **Print Setup...** menu. Make sure you are using the correct driver for your printer.
2. If available, select the option to **print graphics in raster mode** in the **Print Setup...** menu.
3. If available, select the option to **print True Type fonts as graphics** in the **Print Setup...** menu.
4. Override font rotation for the y-axis label in the **Page Setup...** menu.

Plot Legend Exceeds Page Size

If the legend beneath a plot exceeds the page size, choose **Plot/Legend...** from the **Format** menu and perform one or more of the following remedies to decrease the size of the legend.

1. Click the **Font...** button to select a smaller font size.
2. In the group of **Printer Options**, deactivate one or more of the text blocks displayed in the legend (e.g., **title, project info, aquifer data** or **well data**).

Plot or Report Output Is Compressed

If the output for a plot or report appears compressed on the output device, attempt the following remedies.

1. If available, select the option to **print graphics in raster mode** in the **Print Setup...** menu.
2. If available, select the option to **print True Type fonts as graphics** in the **Print Setup...** menu.

Exporting Data and Type Curves

To Save Data in a File

Choose **Export/Data...** from the **File** menu to export data from AQTESOLV for Windows to a file. A dialog box prompts you for the name of a file for the exported data.

To Save Type Curves in a File

Choose **Export/Type Curve...** from the **File** menu to export type curves from AQTESOLV for Windows to a file. A dialog box prompts you for the name of a file for the exported data.

Format of Exported Files

When you export data or type curves, AQTESOLV for Windows creates a text (ASCII) file consisting of two columns with a tab separator. The first column contains data plotted on the x-axis and the second column contains data plotted on the y-axis of an AQTESOLV for Windows plot.

The following table lists the variables exported for each type of plot displayed by AQTESOLV for Windows.

TYPE OF PLOT	X	Y
Displacement vs. Time	time	displacement
Composite	time/radius^2	displacement
Residual vs. Time	time	residual
Residual vs. Simulated	displacement	residual
Normal Probability	residual	standard normal deviate
Derivative vs. Time	time	derivative
Discharge vs. Time	time	discharge rate

References

Bouwer, H., 1989. The Bouwer and Rice slug test--an update, Ground Water, vol. 27, no. 3, pp. 304-309.

Bouwer, H. and R.C. Rice, 1976. A slug test method for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells, Water Resources Research, vol. 12, no. 3, pp. 423-428.

Birsoy, Y.K. and W.K. Summers, 1980. Determination of aquifer parameters from step tests and intermittent pumping data, Ground Water, vol. 18, pp. 137-146.

Cooper, H.H. and C.E. Jacob, 1946. A generalized graphical method for evaluating formation constants and summarizing well field history, Am. Geophys. Union Trans., vol. 27, pp. 526-534.

Cooper, H.H., J.D. Bredehoeft and S.S. Papadopulos, 1967. Response of a finite-diameter well to an instantaneous charge of water, Water Resources Research, vol. 3, no. 1, pp. 263-269.

Hantush, M.S., 1960. Modification of the theory of leaky aquifers, Jour. of Geophys. Res., vol. 65, no. 11, pp. 3713-3725.

Hantush, M.S., 1961a. Drawdown around a partially penetrating well, Jour. of the Hyd. Div., Proc. of the Am. Soc. of Civil Eng., vol. 87, no. HY4, pp. 83-98.

Hantush, M.S., 1961b. Aquifer tests on partially penetrating wells, Jour. of the Hyd. Div., Proc. of the Am. Soc. of Civil Eng., vol. 87, no. HY5, pp. 171-194.

Hantush, M.S., 1962. Flow of ground water in sands of nonuniform thickness; 3. Flow to wells, Jour. Geophys. Res., vol. 67, no. 4, pp. 1527-1534.

Hantush, M.S. and C.E. Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer, Am. Geophys. Union Trans., vol. 36, pp. 95-100.

Hvorslev, M.J., 1951. Time Lag and Soil Permeability in Ground-Water Observations, Bull. No. 36, Waterways Exper. Sta. Corps of Engrs, U.S. Army, Vicksburg, Mississippi, pp. 1-50.

Jacob, C.E., 1947. Drawdown test to determine effective radius of artesian well, Trans. Amer. Soc. of Civil Engrs., vol. 112, paper 2321, pp. 1047-1064.

Kruseman, G.P. and N.A. DeRidder, 1990. Analysis and Evaluation of Pumping Test Data (2nd ed.), Publication 47, Intern. Inst. for Land Reclamation and Improvement, Wageningen, The Netherlands, 370p.

Marquardt, D.W., 1963. An algorithm for least-squares estimation of nonlinear parameters, Journ. Soc. Indust. Appl. Math., vol. 11, no. 2, pp. 431-441.

Moench, A.F., 1984. Double-porosity models for a fissured groundwater reservoir with fracture skin, Water Resources Research, vol. 20, no. 7, pp. 831-846.

Moench, A.F., 1985. Transient flow to a large-diameter well in an aquifer with storative semiconfining layers, Water Resources Research, vol. 21, no. 8, pp. 1121-1131.

Moench, A.F., 1993. Computation of type curves for flow to partially penetrating wells in water-table aquifers, Ground Water, vol. 31, no. 6, pp. 966-971.

Moench, A.F., 1996. Flow to a well in a water-table aquifer: an improved Laplace transform solution, Ground Water, vol. 34, no. 4, pp. 593-596.

Moench, A.F., 1997. Flow to a well of finite diameter in a homogeneous, anisotropic water table aquifer, Water Resources Research, vol. 33, no. 6, pp. 1397-1407.

Neuman, S.P., 1974. Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response, Water Resources Research, vol. 10, no. 2, pp. 303-312.

Papadopulos, I.S. and H.H. Cooper, 1973. Drawdown in a well of large diameter, Water Resources Research, vol. 3, pp. 241-244.

Ramey, H.J., 1982. Well-loss function and the skin effect: A review. In: Narasimhan, T.N. (ed.) Recent trends in hydrogeology, Geol. Soc. Am., special paper 189, pp. 265-271.

Rorabaugh, M.J., 1953. Graphical and theoretical analysis of step-drawdown test of artesian well, Proc. Amer. Soc. Civil Engrs., vol. 79, separate no. 362, 23 pp.

Spane, F.A., Jr., and S.K. Wurstner, 1993. DERIV: A computer program for calculating pressure derivatives for use in hydraulic test analysis, Ground Water, vol. 31, no. 5, pp. 814-822.

Streltsova, T.D., 1974. Drawdown in compressible unconfined aquifer, Jour. of the Hyd. Div., Proc. of the Am. Soc. of Civil Eng., vol. 100, no. HY11, pp. 1601-1616.

Streltsova, T.D., 1988. Well Testing in Heterogeneous Formations, John Wiley & Sons, New York, 413p.

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans., vol. 16, pp. 519-524.

Zlotnik, V., 1994. Interpretation of slug and packer tests in anisotropic aquifers, Ground Water, vol. 32, no. 5, pp. 761-766.

Glossary of Terms

Aquiclude

A saturated geologic unit that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients.

Aquifer

A saturated permeable geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients.

Aquitard

A saturated geologic unit that transmits water in quantities insufficient for economic use.

Casing Radius

Radius of unperforated portion of well casing.

Client Name

A user-supplied character string (up to 30 characters) storing the name of the client which sponsored the aquifer test. Used for reports and plots.

Coefficient of Permeability

See Hydraulic Conductivity.

Company Name

A user-supplied character string (up to 30 characters) storing the name of the company which conducted the aquifer test. Used for reports and plots.

Confined Aquifer

An aquifer with upper and lower boundaries consisting of aquicludes.

Date of Test

A user-supplied character string (up to 30 characters) storing the date of an aquifer test. Used for reports and plots.

Displacement

Change in water level relative to static condition.

Double-Porosity Fractured Aquifer

An aquifer represented by a double porosity system consisting of low-permeability, primary porosity blocks and high-permeability, secondary porosity fissures.

Fracture Skin

A thin, low-permeability material coating the surface of fractures (e.g., mineral deposit) that restricts flow of water.

Fractured Aquifer

See Double-Porosity Fractured Aquifer

Hydraulic Conductivity

The volume of water moving through a unit area of aquifer perpendicular to the direction of flow in unit time under a unit hydraulic gradient.

Leaky Aquifer

An aquifer with upper and lower boundaries of one aquitard and one aquiclude or two aquitards.

Location of Test

A user-supplied character string (up to 30 characters) storing the location of the aquifer test. Used for reports and plots.

Measurement Weight

Use weights to assign the relative weight of each measurement for use during automatic curve matching. In typical cases, assign weights of 1.0 or 0.0 to include or exclude measurements during automatic curve matching.

Observation Well Name

A user-supplied character string (up to 30 characters) storing the name of the observation well used in the aquifer test. Used for reports and plots.

Permeability

See Hydraulic Conductivity.

Piezometer

An open-ended pipe installed in an aquifer to measure hydraulic head at a specific depth.

Porosity

The ratio of void volume to total volume in an unconsolidated material.

Project Number

A user-supplied character string (up to 30 characters) storing the company's number or ID of the aquifer test project. Used for reports and plots.

Residual

The difference between simulated and observed displacement.

Residual Displacement

Water-level displacement measured from static condition in an observation well after pumping has stopped during the recovery phase of a pumping test.

Saturated Thickness

Vertical distance measured from the top of an aquifer (confining layer or water table) to the base of the aquifer.

Semiconfined Aquifer

See Leaky Aquifer.

Specific Storage

The volume of water released from storage by a unit volume of confined aquifer per unit decline in hydraulic head.

Specific Yield

The volume of water released from storage per unit surface area of an unconfined aquifer per unit decline of the water table.

Storage Coefficient

See Storativity.

APPENDIX D

JOURNAL ARTICLES

Velocity Plots and Capture Zones of Pumping Centers for Ground-Water Investigations[a]

by Joseph F. Keely[b] and Chin Fu Tsang[c]

ABSTRACT

Nonpumping monitoring wells are commonly installed and sampled to delineate the extent of a contaminant plume and its chemical character. Samples from municipal and private pumping wells are frequently collected during ground-water contamination investigations as well. Pumping wells are also employed for remedial actions.

To properly interpret sampling data from monitoring and pumping wells and to estimate their potential effectiveness in remedial actions, it is important to clearly define the geometry of that portion of the aquifer contributing water to the well (the capture zone). Velocity distribution plots by manual and computerized methods are illustrated and shown to be simple and of reasonable accuracy.

INTRODUCTION

Oftentimes in the course of ground-water investigations, water-supply wells are sampled to obtain first-order approximations of the quality of water being delivered to consumers. The most common response to showings of unacceptable levels of contaminants is the installation of low-cost, small-diameter nonpumping monitoring wells for the express purpose of estimation of the magnitude and extent of the problem. The differences in construction, operation, and sampling of supply (pumping) wells as opposed to monitoring (nonpumping) wells may result in combined data sets which are confusing to the investigator. The primary exception, of course, is the case where the contaminant of concern has spread ubiquitously throughout the aquifer—a rare occurrence indeed.

Since very limited areal and vertical extent of contaminant plumes is the norm, combining data from wells of different construction and operation to produce contours of contaminant concentrations for source location or remedial action could potentially result in poor decisions, wasted funds, and so on. Unfortunately, such a predicament is all too often encountered. Several recent articles address these points in greater detail (Gibb and others, 1981; Keely, 1982; Keely and Wolf, 1983; Keith and others, 1983; Nacht, 1983; Schuller and others, 1981; and Schmidt, 1977 and 1982). In the present paper, it shall be assumed that data have been appropriately corrected to account for the different sources of data variability. Based on this, several easily mastered methods for rapid estimation of the impact of pumping centers on nearby contaminant plumes are described and illustrated by examples.

MANUAL PLOTS OF VELOCITY DISTRIBUTIONS

The velocity of flow through an aquifer can be simplistically represented by rearranging and slightly modifying Darcy's law, which is:

$$Q = KIA,$$

where

Q is the volumetric flow rate in gallons per day (cubic meters/day),

[a]Although this article was produced in part or wholly by an employee of the United States Environmental Protection Agency, it has not been subject to Agency review and therefore does not necessarily reflect the views of the Agency; no official endorsement should be inferred.

[b]Ground Water Research Branch, R. S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, P.O. Box 1198, Ada, Oklahoma 74820.

[c]Senior Staff Scientist, Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, California 94700.

Received June 1983, accepted July 1983.
Discussion open until May 1, 1984.

K is the hydraulic conductivity in gallons per day per square foot (meters/day),

I is the hydraulic gradient (dimensionless),

A is the cross-sectional area through which flow occurs in square feet (square meters).

By rearrangement alone, "Darcy velocity" (V_D) expressions are obtained:

$$\frac{Q}{A} = KI = V_D$$

But, since the flow actually occurs only through the pores, rather than through the entire cross-sectional area (A), a slight modification is needed. Division of the Darcy velocity by the effective porosity (ϕ_e) yields the true pore velocity (v).

$$\frac{Q}{A\phi_e} = \frac{KI}{\phi_e} = \frac{V_D}{\phi_e} = v$$

Generally one finds the left-hand term of the preceding relationship to be most useful for computing the velocity towards a pumping well because Q is usually known for the well, and A is readily estimated. Assuming uniformly radial flow towards the well is possible, the cross-sectional area (A) through which flow must pass to reach the well is equal to the area of the curved face of an imaginary cylinder of radius r. That radius is chosen by the investigator as the distance from the well where the velocity effect is of interest to him or her, and is entirely arbitrary. The area of the curved face of the imaginary cylinder at that radial distance is given by $A = 2\pi rh$ where h is the height of the imaginary cylinder (the effective saturated thickness of the aquifer zone yielding water to the well). Naturally this implies that there is a *distribution* of velocities surrounding the pumping well, which increases in magnitude as one gets closer and closer to the well. By substitution of $A = 2\pi rh$ into the velocity equation $Q \div A\phi_e = v$, one arrives at the operative formula needed:

$$Q \div 2\pi rh\phi_e = v_{pumping}$$

The right-hand term of the pore velocity form of Darcy's law is generally employed for estimation of the natural flow velocity, $KI \div \phi_e = v_{natural}$. This is because the average hydraulic conductivity (K) and hydraulic gradient (I) are usually known or fairly well estimated for an aquifer, whereas the average bulk flow (Q) and cross-sectional area (A) of the aquifer are not usually known or estimated accurately. One must estimate the effective porosity (ϕ_e) regardless of the approach adopted.

These simple formulae for $v_{pumping}$ and $v_{natural}$ are quite often all that can be justifiably employed because detailed information on variations in hydraulic conductivity, flow, hydraulic gradient, and so forth are unavailable to the investigator—at least in the initial stages of a contaminant investigation.

Manual plots of the velocity distribution surrounding a pumping well, in the presence of a real natural flow rate and direction, can be readily constructed with the equations just described. The data in Table 1 result from such an approach; also incorporated in Table 1 is a column listing the theoretical drawdown, calculated by use of a hand-held programmable calculator version of the Theis equation (Warner and Yow, 1979). The important features of the data in Table 1 are that velocities from natural flow and pumpage are added together to yield net velocities at distances upgradient of the well, whereas their differences must be obtained to yield net velocities downgradient of the well. This is quite sensible since the natural flow system is moving waters toward the well on the upgradient side of the well, but is trying to move waters away from the well on its downgradient side. Figure 1 is a graphical presentation of the data in Table 1, to facilitate conceptual appreciation of this discussion.

As can be seen in Figure 1 and Table 1, at some distance downgradient the pull of waters back toward the well by pumping is exactly countered by the flow away from the well due to the natural flow velocity. Todd (1980) refers to this as the "stagnation point"; the American Petroleum Institute (1972) refers to it as a "velocity divide." Note that the stagnation point/velocity divide occurs well within the cone of depression caused by pumping. This may seem counterintuitive initially, but calculation of net water surface elevations (by subtraction of drawdown values from prepumping elevations) will confirm that the situation depicted is quite real. This relationship is such that the greater the pumping stress, the farther downgradient the velocity divide occurs (for a given natural flow velocity). Conversely, the greater the natural flow velocity, the closer the divide comes to the pumping well (for a given pumping stress).

It is much more efficient to solve directly for the distance to the stagnation point than it is to construct plots like Figure 1. One abides by the definition of the stagnation point and sets the expression for $v_{pumping}$ equal to the value of $v_{natural}$:

Table 1. Drawdowns and Velocities Toward a Well Constantly Discharging 500 Gallons Per Minute (114 m^3/hr) for 1000 Minutes

Observation radius (ft)	*Theoretical drawdown (ft)*	*Velocity due to pumping (ft/day)*	*Net velocity upgradient (ft/day)*	*Net velocity downgradient (ft/day)*
25	1.19	20.44	23.33	17.55
50	1.04	10.22	13.11	7.33
75	0.94	6.81	9.70	3.92
100	0.88	5.11	8.00	2.22
125	0.83	4.09	6.98	1.20
150	0.78	3.14	6.03	0.25
175	0.75	2.92	5.81	0.03
200	0.72	2.55	5.44	−0.34
225	0.69	2.27	5.16	−0.62
250	0.67	2.04	4.93	−0.85
275	0.65	1.86	4.75	−1.03
300	0.62	1.70	4.59	−1.19
325	0.61	1.57	4.46	−1.32
350	0.59	1.46	4.35	−1.43
375	0.57	1.36	4.25	−1.53
400	0.56	1.28	4.17	−1.61
425	0.55	1.20	4.09	−1.69
450	0.53	1.14	4.03	−1.75
475	0.52	1.08	3.97	−1.81
500	0.51	1.02	3.91	−1.87
⋮	⋮	⋮	⋮	⋮
750	0.42	0.68	3.57	−2.21
⋮	⋮	⋮	⋮	⋮
1000	0.35	0.51	3.40	−2.38

Notes: T is transmissivity (= 5×10^5 gallons/day/ft), S is the storage coefficient (= 0.005), h is the saturated aquifer thickness (= 100 ft), ϕ_e is the effective porosity (= 0.30), and I is the natural gradient (= 0.0013, or 13 ft/10,000 ft; a water-level elevation change of roughly 7 ft/mile). Positive velocity values indicate flow toward the well. Negative velocities indicate flow away from the well. Also note: m = ft × 0.31, m^3 = gallons × 0.21, and km = miles × 1.62.

$$v_{pumping} = v_{natural} \quad \text{(definition of stagnation)}$$

$$Q \div 2\pi r h \phi_e = v_{natural} \quad \text{(substitution)}$$

and then one rearranges this to solve directly for r:

$$r = Q \div 2\pi h \phi_e v_{natural}.$$

Using the data from Table 1 (for the graphical comparison, see Figure 1),

$r = 9.63 \times 10^4$ ft^3/day ÷

$2\pi(100\text{ ft})(0.30)(2.895\text{ ft/day}) = 176.5\text{ ft }(53.8\text{ m}).$

Todd (1980) notes that the maximum width of the upgradient inflow zone is equal to 2π times the stagnation distance immediately downgradient. Hence, contaminated waters lying just beyond π times the stagnation distance [$\pi \times 176.5$ ft = 554 ft (169 m) for the preceding example] to either side of the well are *not* drawn into the well. Again, this occurs despite the fact that significant drawdowns are felt there [0.5 ft (15 cm) in Table 1]. These boundaries define the areal limits of what will be referred to as the "capture zone" of the well. Only for the extremely rare case of zero natural flow velocity are the areal boundaries of the capture zone and the cone of depression everywhere identical.

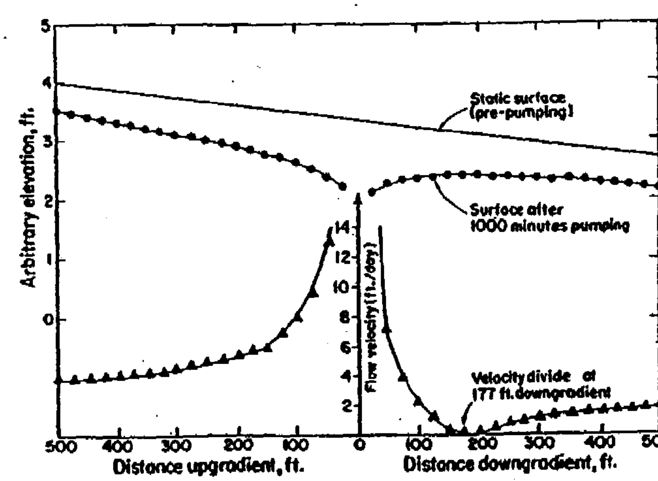


Fig. 1. Drawdown and velocity distribution plot for data presented in Table 1.

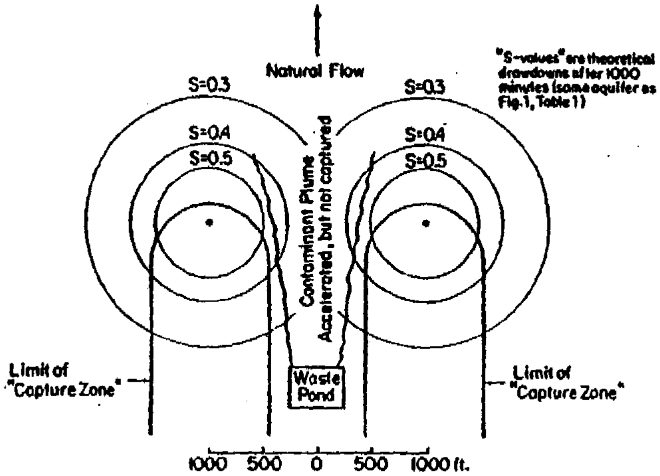


Fig. 2. Two wells accelerating a plume without capturing it.

The importance of performing these calculations can hardly be overemphasized for ground-water contamination investigations. Using such calculations it is no great task to show that a line of wells designed to stop the advance of a contaminant plume due to a fairly large natural flow velocity may fail miserably, despite the fact that their adjacent cones of depression overlap (an almost sacred benchmark for field practitioners). Figure 2 illustrates such a situation, using selected data from Table 1.

It is also important to note that this is not an earth-shattering discovery. Virtually all contaminant transport codes are based on the calculation of a velocity field, so that use of such codes need not be viewed with suspicion from that standpoint. However, it is the authors' contention that because the vast majority of ground-water contamination investigations are initiated, performed, and concluded without the use of numerical transport models and qualitative decision benchmarks such as "overlapping cones of depression" are heavily employed, it is imperative that velocity plots now be emphasized.

RADIAL FLOW TIME-SERIES MODEL (RT)

Major impediments to the widespread use of sophisticated contaminant transport models include their general reliance on advanced mathematics, the need for large computing systems and programming skills, and the tedious selection and construction of appropriate grids. In order to circumvent the most undesirable of these characteristics, two nondispersive transport codes are presented here which rely on the simple velocity expression discussed in the preceding section. The examples employed here to illustrate these codes were produced with very short FORTRAN programs, which are currently available from the authors. The full program descriptions, expanded theory, and users guides will be released shortly as part of a report by Lawrence Berkeley Laboratory (Javandel and others, 1983a). Also of great interest to field personnel may be the planned subsequent release of handheld programmable calculator and microcomputer versions of these same codes (Javandel and others, 1983b).

The radial flow time-series model, RT, is particularly useful for estimation of impacts to a pumping well from nearby contaminant sources. Since this code ignores regional flow, it is not as detailed as might be required for many complete analyses, but its simplicity and brevity makes it attractive for rapid estimation purposes (RESSQ, the other code to be described below, incorporates regional flow). One may use RT with confidence for such situations as the combination of a large pumping well and a low regional (natural) flow velocity. Caution must be exercised when using RT for field problems where low pumping stresses are combined with fairly rapid natural flows because substantial errors may result. RT is capable of providing several useful plots: (1) time-concentration data, (2) radial distance-concentration data, (3) specified point (x, y)-concentration data, and (4) selected concentration contours.

The primary situation examined here by RT is one where a pumping well is surrounded by several observation wells, some of which are being impacted by a spreading contaminant plume. Of great interest are the changes in levels of contaminants at the observation wells and the pumping well as pumping progresses; these concentration-time patterns will yield substantial clues as to the spatial distribution of the contaminants. This technique of correlating time-series data to spatial distributions has been developed from the techniques described by Keely (1982).

Because of the radial flow situation addressed by RT, it is useful to slightly modify the expression for $v_{pumping}$ given earlier. In radial coordinates, it is:

$$v_{pumping} = v_{radial} + v_{theta} = v_r + v_\theta,$$

where v_r and v_θ are the radial and angular components of velocity in the radial coordinate system (r, θ), analogous to the x and y velocity components of the Cartesian system (x, y). Substitution of the expression for $v_{pumping}$ then gives:

$$v_{pumping} = \frac{Q}{2\pi r h \phi_e} = v_r + v_\theta$$

For a pumping well at the origin (0, 0) of the plot to be constructed, $v_\theta = 0$ by symmetry, so $v_{pumping} = v_r$. Hence, the expression for v_r at some radial distance (r) from the pumping well in radial coordinates is the same as $v_{pumping}$ calculated previously by considering the distance to the edge of an imaginary cylinder around the well:

$$v_r = \frac{Q}{2\pi r h \phi_e}.$$

Recognizing that the velocity on some radial (v_r) is the result of the change in distance being divided by the change in time (dr/dt), a substitution can be made

$$v_r = \frac{dr}{dt} = \frac{Q}{2\pi r h \phi_e}$$

which will lead directly to the equations most useful for estimating the position of the contaminant front. Solution of the differential expression $dr/dt = Q \div 2\pi r h \phi_e$ requires only the most straightforward rules of integration: (1) that constants in the equation are unaffected, (2) that open integrals imply simple subtraction of the maximum and minimum values (in this case, the time of interest minus some arbitrary starting time of pumping, or $t - t_0$), and (3) that a variable (here, radial distance) is raised to the next power and divided by a value equal to that power (e.g., r becomes $r^2 \div 2$). Hence, integration of the radial velocity expression gives:

$$\frac{r^2/2 - r_0^2/2}{(t - t_0)} = \frac{Q}{2\pi h \phi_e}.$$

This can be readily rearranged to solve for the distance traveled during a specific time ($= t - t_0$),

$$r = \left[r_0^2 + \frac{Q(t - t_0)}{\pi h \phi_e}\right]^{1/2}.$$

Likewise, it can be rearranged to solve for the time required to travel a specific distance ($= r - r_0$),

$$t = t_0 + \frac{(r^2 - r_0^2)\,\pi h \phi_e}{Q}$$

These two equations form the basis for calculations performed by RT.

For example, if an observation well is located at a distance r_1 from the pumping well, then a time series of contaminant concentration measurements at that well taken at $t_1, t_2, t_3, \ldots, t_n$, will yield the corresponding locations of $r_2, r_3, \ldots, r_{n+1}$ for those concentrations at any given time. Hence, assuming that the concentration distribution of a given solute in an aquifer is not uniform, the time-series data from a given well can be mapped out into the aquifer to produce a "snapshot" of the spatial contaminant concentration distribution, along the radius between the observation well and the production well at various times. By using observation wells in several directions from the pumping well, an areal picture of the contaminant concentration in the aquifer at various times can be determined.

To illustrate this situation, RT was used to create the sequence of plots shown in Figure 3, which run from prepumping to a little more than one day's pumping. Each of the scatter points is brought closer to the origin (0, 0) by the pumping well located there. Alternatively, RT can be used to generate contours of relative concentration, such as shown in Figure 4.

Perhaps the most powerful outputs generated by RT, however, are the individual relative concentration-time plots for any of the six monitoring/observation wells or the pumping well (Figure 5). It should come as no surprise that these patterns of contaminant arrival look like the breakthrough curves generated during tracer experiments; the fundamental laws and the field design are the same. The noticeable difference is that the low level leading edge is absent from the early time portions of the plots because dispersive effects are not accounted for by RT.

An invaluable variation on this presentation of relative concentration-time plots is also output by RT (Figure 6). Relative concentrations are plotted versus distance for a select number of times of interest, generating a family of curves. Thus one can examine the relative concentration along a selected radial and readily observe the manner in which this relationship changes with time. In the example shown in Figure 6, it can be seen that the farther from the pumping well, the less the disturbance of the contaminant plume. As one gets closer to the pumping well, the greater the disturbance, so that the overall relative concentrations are lowered rapidly and the length of the plume expands considerably. This kind of graphical presentation underscores the need to plot velocity distributions to estimate the impact of pumping centers on plume movement. Plume travel times based solely on a single average velocity will be much greater than they ought to be, giving planners a false sense of security or lack of urgency.

Because of retardation/attenuation or degradation of some contaminants by physical, chemical, or biological interactions, the velocity at

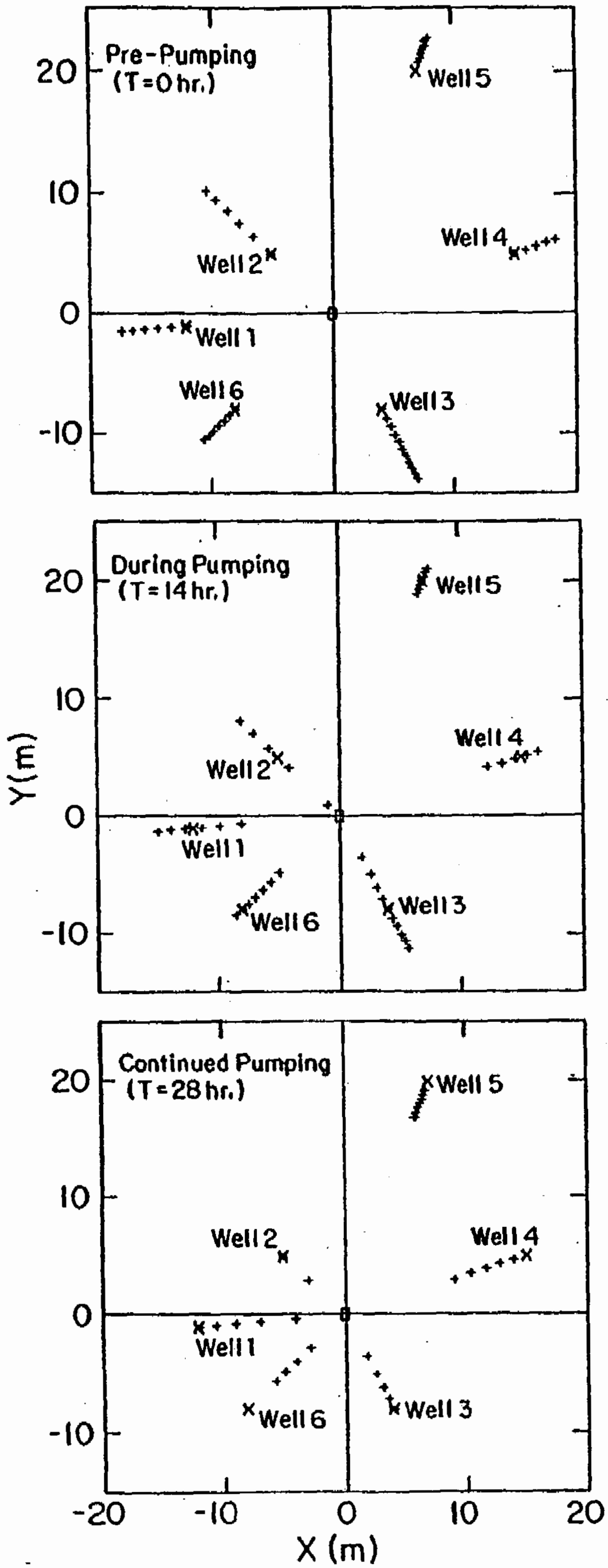


Fig. 3. Scatter maps produced by radial draw-time series model.

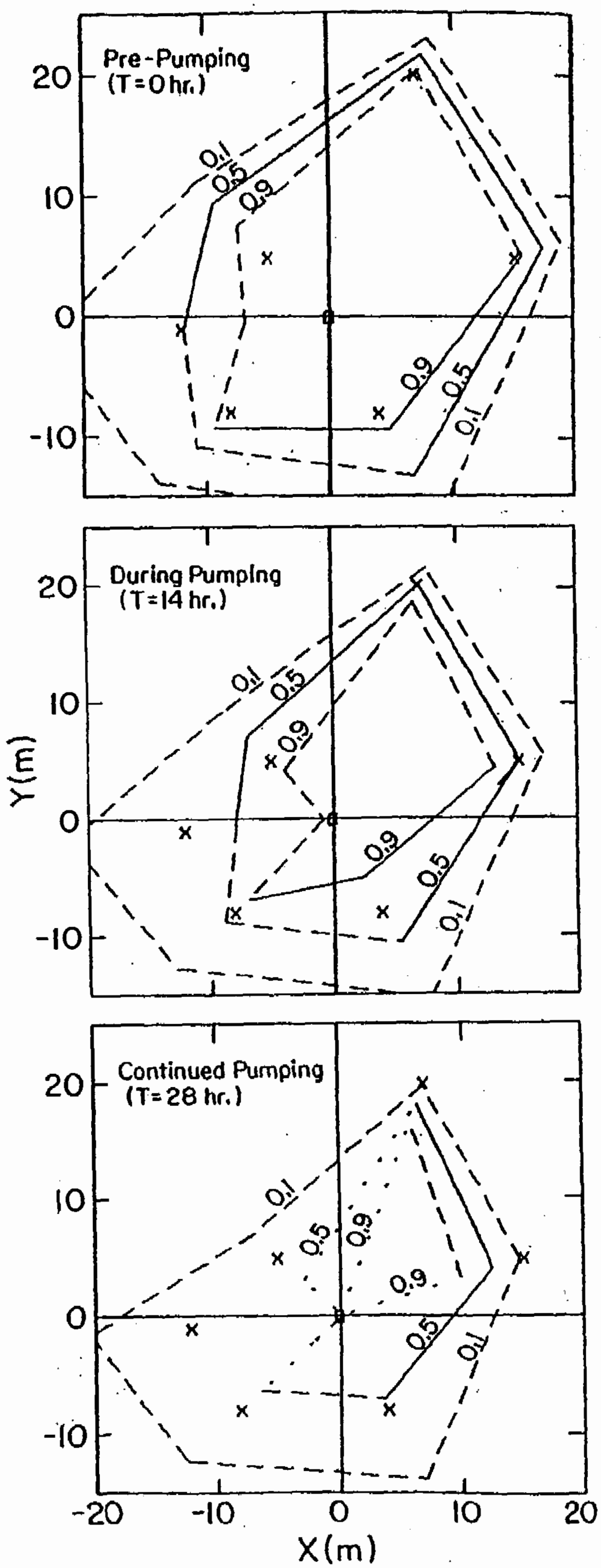


Fig. 4. Contour maps produced by radial draw-time series model.

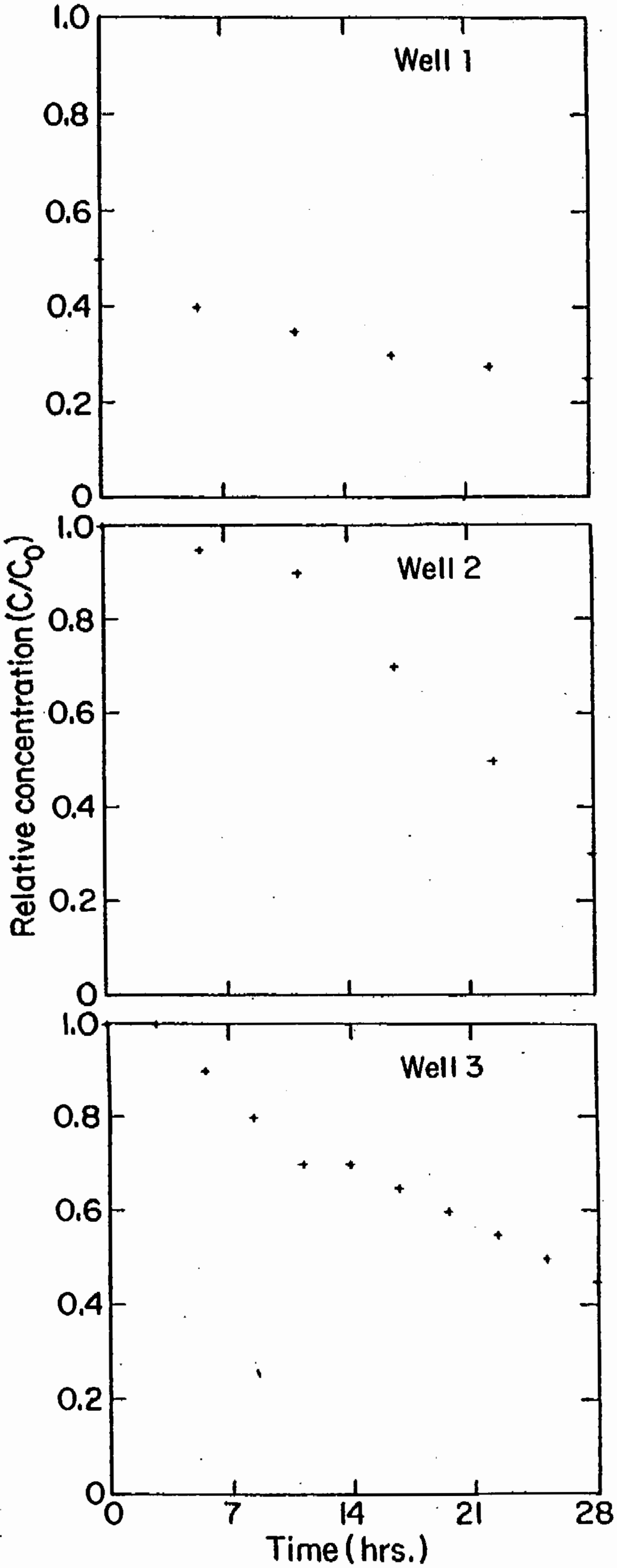


Fig. 5. Relative concentrations versus time of pumpage plots produced by radial draw-time series model.

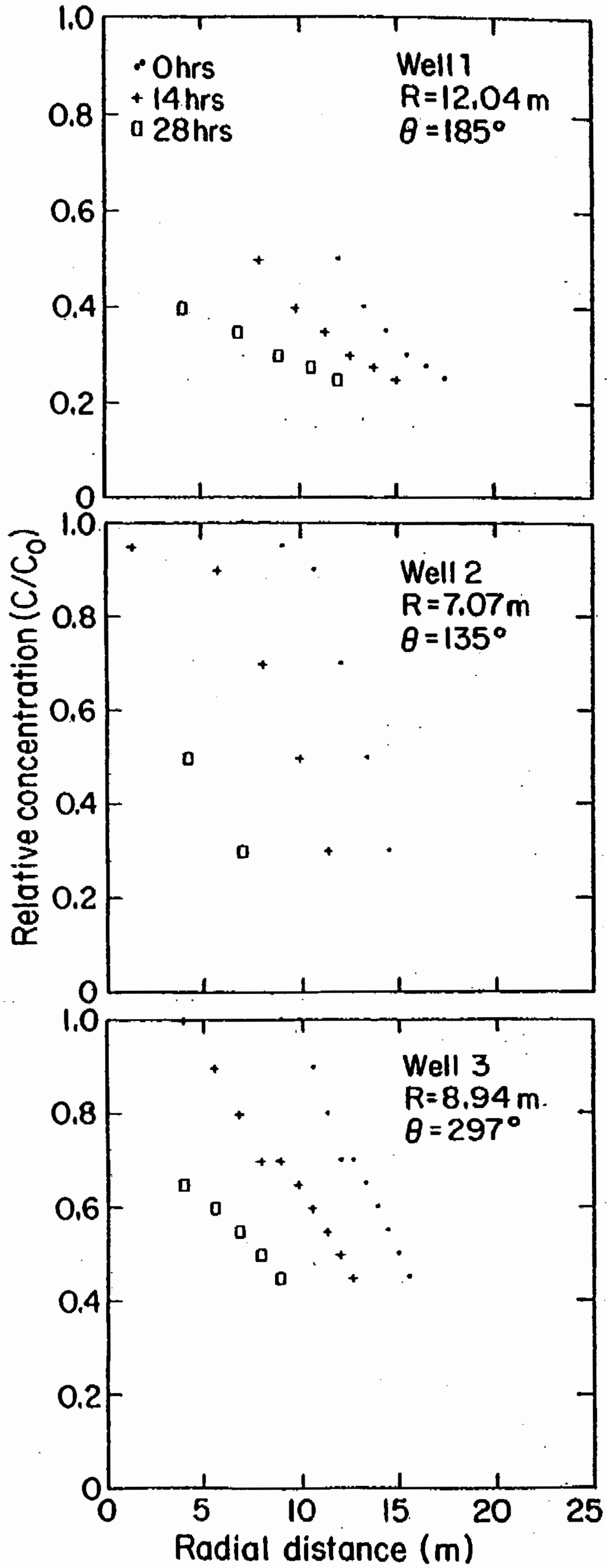


Fig. 6. Relative concentrations along selected radials without attenuation (R = 1.0).

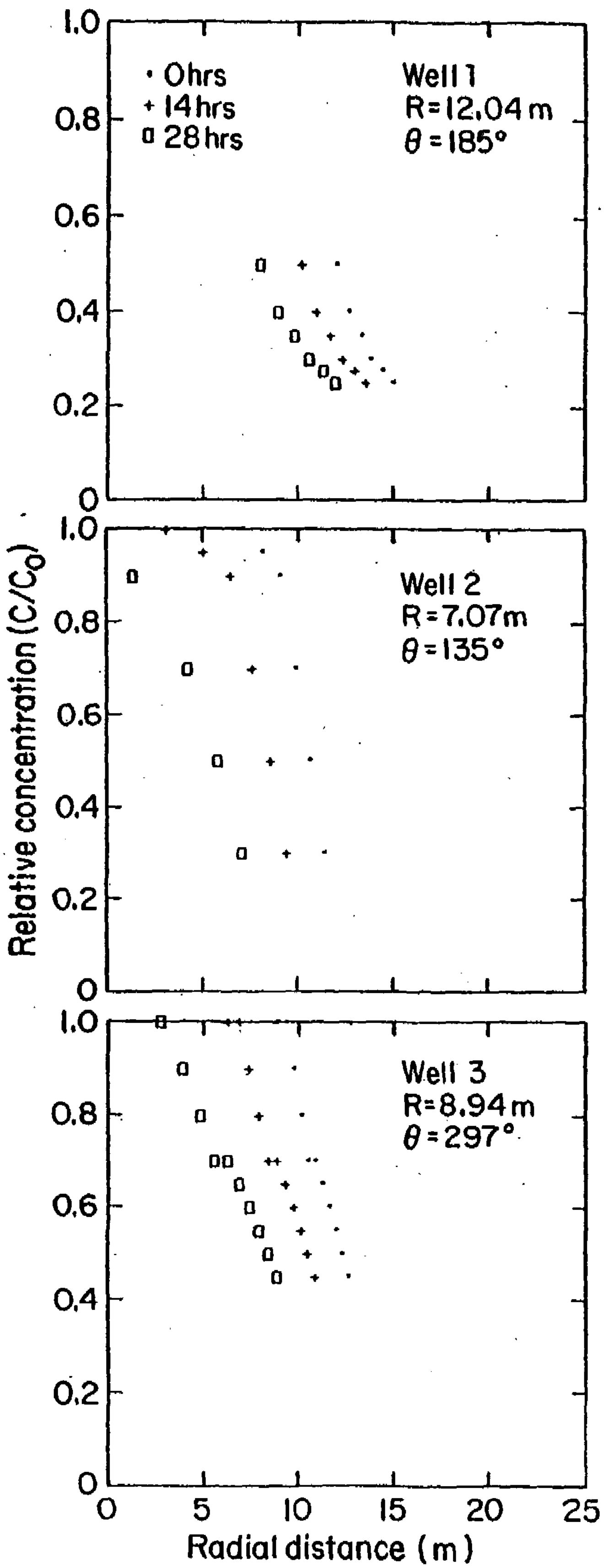


Fig. 7. Relative concentrations along selected radials with attenuation (R = 1.5).

which a contaminant species is transported through the subsurface may be substantially less than the average pore-water velocity. Since the magnitude of these effects can rarely be assessed in detail, use of an empirical weighting factor is often justified. A simplified retardation factor (R) can be incorporated into velocity calculations of the water front movement (v_r) to give the velocity of the contaminant (v_c):

$$v_c = v_r/R$$

where one notes that R is equal to the ratio of the average pore-water velocity to the contaminant velocity ($R = v_r/v_c$). Use of a large retardation factor ($R \gg 1$) then implies considerable attenuation of the contaminant relative to the water front. Figure 7 is a replotting of the example in Figure 6, but with R = 1.5.

RESSQ MODEL

While the brevity and simplicity of RT make it a useful tool for rapid assessment of simplified situations, it does lack the ability to deal with the effect on contaminant levels at pumping and observation wells which is due to the regional/natural flow velocity. As was shown in the earlier section of this paper which described manual plotting techniques for velocity distributions, the effect of a moderate natural flow velocity can be quite important.

RESSQ is an expanded version of RT, capable of incorporating the natural flow velocity and also capable of simulating more complex situations where several pumping wells and contaminant sources need to be evaluated simultaneously. As such, it has been constructed so that all inputs and outputs are geared to a Cartesian (x, y) coordinate system (see Figure 8). The expression for velocity due to a pumping well was given previously as

$$v_r = \frac{Q}{2\pi r h \phi_e}$$

where r was the distance from the origin (0, 0) to the edge of an imaginary cylinder surrounding the well (radial flow assumption). It is useful to create a more generalized expression in terms of actual x- and y-coordinates. The easiest approach is to use the origin (0, 0) as a reference point and employ the Pythagorean theorem of geometry for right triangles,

$$r^2 = x^2 + y^2 .$$

Here, the right triangle has its short sides parallel to the x- and y-axes, and its hypotenuse (of length r) defining the line connecting the origin (0, 0) to the point of interest (x, y). For a pumping well located at (x_0, y_0), the pumping velocity at the point of interest (x, y) has x- and y-components given by:

$$v_x = \frac{Q}{2\pi h \phi_e} \frac{x - x_0}{(x - x_0)^2 + (y - y_0)^2},$$

and

$$v_y = \frac{Q}{2\pi h \phi_e} \frac{y - y_0}{(x - x_0)^2 + (y - y_0)^2}.$$

The x and y components of the natural flow velocity v_0, which has a direction at an angle α from the x-axis, are: $v_x = v_0 \cos \alpha$, and $v_y = v_0 \sin \alpha$. If one considers a waste-water injection well (with $Q = 50\ m^3/hr$ or 220 gpm) located at point A in Figure 9 which is suspected of potentially contaminating a water-supply well (also with $Q = 50\ m^3/hr$ or 220 gpm) located 848.5 m (2784 ft) away at point B, the prime questions to be answered are:

1. What do the flow patterns of the system look like?

2. Where will the injected waste-water front be after certain time periods (e.g., 0.5, 2, and 4 years)?

3. How long does it take for the injected waste water to reach the water-supply well?

4. How does the contaminant concentration vary at the water-supply well?

Based on local geology, it has been estimated that the effective porosity (ϕ_e) of the aquifer is 25 percent.

As a first cut, analogous to the simple approach in RT, the regional/natural flow velocity will be neglected. Using RESSQ, Tables 2 and 3 are generated. Table 2 lists the arrival times at the pumping well of the injected waste waters flowing along streamlines between the two wells, depicted graphically by RESSQ in Figure 10. Note that nine

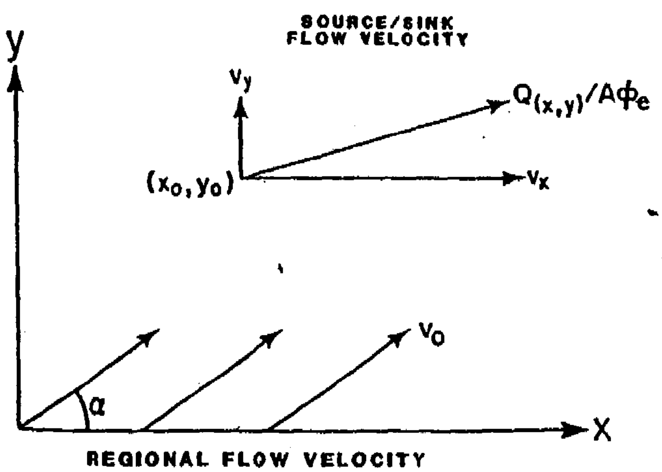


Fig. 8. Cartesian system showing x- and y-components of pumping flow velocity and showing regional flow velocity with angle α to x-axis.

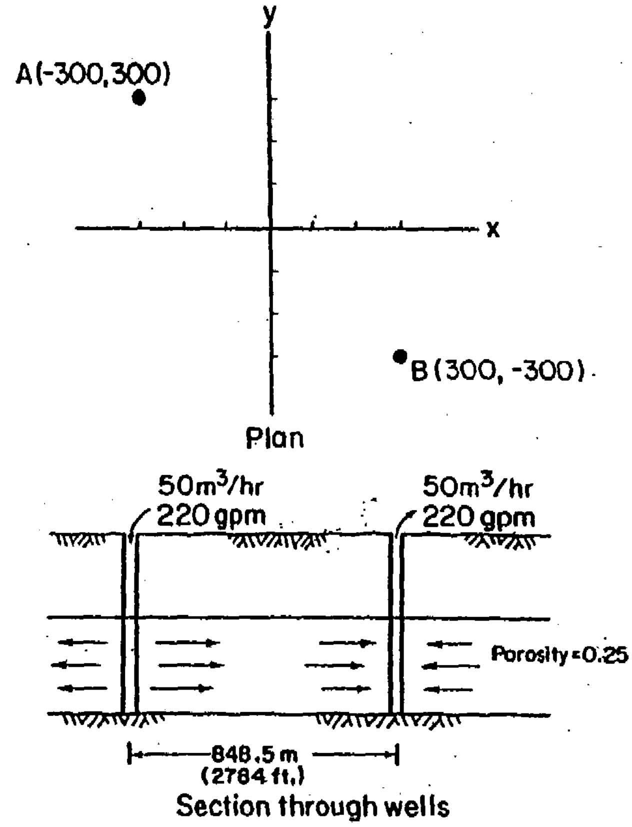


Fig. 9. Plan view and cross section for RESSQ model examples (discussed in text).

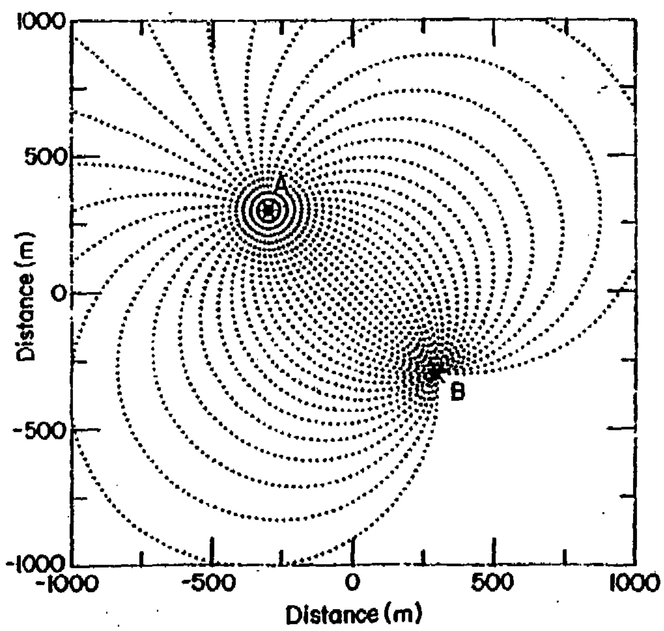


Fig. 10. Streamlines for RESSQ model example without regional flow considered.

Table 2. Streamlines Departing from Injection Well at Point A

Number of the line	*Well reached*	*Time of arrival*	*Minimum step in cm*	*Angle beta in degrees*
1st	Prod. one	5.6 yrs	42.4264E+01	0.
2nd	Prod. one	6.2 yrs	42.4264E+01	8.0
3rd	Prod. one	7.0 yrs	42.4264E+01	16.0
4th	Prod. one	8.1 yrs	42.4264E+01	24.0
5th	Prod. one	9.5 yrs	84.8528E+01	32.0
6th	Prod. one	11.6 yrs	42.4264E+01	40.0
7th	Prod. one	14.4 yrs	42.4264E+01	48.0
8th	Prod. one	18.5 yrs	42.4264E+01	56.0
9th	Prod. one	24.6 yrs	42.4264E+01	64.0
10th	Prod. one	34.3 yrs	42.4264E+01	72.0
11th	Prod. one	50.4 yrs	42.4264E+01	80.0
12th	Prod. one	79.3 yrs	42.4264E+01	88.0
13th	Prod. one	137.0 yrs	42.4264E+01	96.0
14th	++++none+	200.1 yrs	84.8528E+01	104.0
15th	++++none+	200.8 yrs	84.8528E+01	112.0
16th	++++none+	201.3 yrs	84.8528E+01	120.0
17th	++++none+	200.8 yrs	84.8528E+01	128.0
18th	++++none+	201.7 yrs	84.8528E+01	136.0
19th	++++none+	201.5 yrs	84.8528E+01	144.0
20th	++++none+	201.4 yrs	84.8528E+01	152.0
21st	++++none+	200.1 yrs	84.8528E+01	160.0
22nd	++++none+	200.0 yrs	84.8528E+01	168.0
23rd	Prod. one	118.3 yrs	42.4264E+01	176.0
24th	Prod. one	70.3 yrs	42.4264E+01	184.0
25th	Prod. one	45.5 yrs	42.4264E+01	192.0
26th	Prod. one	31.4 yrs	42.4264E+01	200.0
27th	Prod. one	22.8 yrs	42.4264E+01	208.0
28th	Prod. one	17.3 yrs	42.4264E+01	216.0
29th	Prod. one	13.6 yrs	42.4264E+01	224.0
30th	Prod. one	11.0 yrs	42.4264E+01	232.0
31st	Prod. one	9.1 yrs	42.4264E+01	240.0
32nd	Prod. one	7.8 yrs	42.4264E+01	248.0
33rd	Prod. one	6.8 yrs	42.4264E+01	256.0
34th	Prod. one	6.0 yrs	84.8528E+01	264.0
35th	Prod. one	5.4 yrs	42.4264E+01	272.0
36th	Prod. one	5.0 yrs	42.4264E+01	280.0
37th	Prod. one	4.7 yrs	84.8528E+01	288.0
38th	Prod. one	4.5 yrs	84.8528E+01	296.0
39th	Prod. one	4.4 yrs	84.8528E+01	304.0
40th	Prod. one	4.3 yrs	42.4264E+01	312.0
41st	Prod. one	4.3 yrs	42.4264E+01	320.0
42nd	Prod. one	4.4 yrs	84.8528E+01	328.0
43rd	Prod. one	4.5 yrs	42.4264E+01	336.0
44th	Prod. one	4.8 yrs	42.4264E+01	344.0
45th	Prod. one	5.1 yrs	42.4264E+01	352.0

of the streamlines carrying the contaminants have not reached the water-supply well during the specified period of study which was arbitrarily chosen to be 200 years. The angle (β) at which each streamline leaves the injection well (relative to the x-axis) is also shown in Table 2. Note that streamlines 40 and 41 leave the injection well at angles of 312 and 320 degrees, respectively, and are the first to arrive at the water-supply well—which agrees with one's intuitive expectations. The time of arrival of these two streamlines is 4.3 years; the water-supply well is affected rather quickly in terms of a normal operational lifetime for the injection well (10-20 years).

Table 3 presents the time variation of concentration at the water-supply well. Note that the total number of streamlines emanating from the injection well was again set at 45. Each of these

On Capture Width and Capture Zone Gaps in Multiple-Well Systems

by John B. Erdmann[a]

bstract

A barrier well line's capture width along its alignment is shown to depend only on total system flow rate Q_T and aquifer back-ound flow rate per unit width Q_o (prepumping gradient times transmissivity) under idealized horizontal flow: Irrespective of umber of wells, the capture width is $Q_T/2Q_o$, as for a hypothetical single well with flow rate Q_T. This result applies even to bar-er lines with irregular well spacings and flow rates—and, in fact, to the capture width through the center of any pumping con-guration that is symmetrical respecting a line perpendicular to uniform background flow. A flow-perpendicular line of regularly aced, equal wells ("regular barrier line") has the same capture width along its alignment as an identical well line parallel to back-ound flow has through its center. In the general symmetrical case, the center capture width remains $Q_T/2Q_o$ whether transverse ell spacings are large (allowing contaminated ground water to escape through capture zone gaps), critical (with incipient ps), or safely small. For design reference, critical spacings derived for regular barrier lines of N wells with N through 100 and $\to\infty$ vary from $Q/\pi Q_o$ (N = 2, previously known) to $Q/2Q_o$ ($N \to \infty$), where Q is each well's flow rate. Incipient gaps at critical spac-g occur always between the two center wells, or the center well and two adjacent wells. Spacings substantially smaller than crit-al are recommended for contaminant capture. Designs are illustrated that preclude capture zone gaps.

...uction

...en a pumping well system is used to capture contaminated ...water, the system's capture zone—aquifer region ultimately ...buting water to its wells—must span the contaminant plume ...dth without gaps. Although broadly applicable techniques now ...ist for delineating multiple-well capture zones, including their evo-...tion over time (Strack et al. 1994; Bakker and Strack 1996), the ...rature offers remarkably little general guidance on multiple-well ...stem design for contaminant capture. Moreover, some recom-...ended designs are unnecessarily risky in light of the findings pre-...nted herein.

The analytical solution for a single well's steady-state capture ...ne in uniform flow has long been known (e.g., Jacob 1950, ...ges 344-345; De Wiest 1965, pages 252-255; Keely and Tsang ...83) and is frequently invoked in single-well system design. ...cording to this solution, if the well's flow rate is Q $[L^3 T^{-1}]$ and ...e uniform flow rate per unit aquifer width (prepumping hydraulic ...adient times transmissivity) is Q_o $[L^2 T^{-1}]$, then the well's capture ...ne has width $b = Q/Q_o$ infinitely far upgradient, width $c = Q/2Q_o$ ...the well, and extent downgradient from the well $d = Q/2\pi Q_o$ ...igure 1). With the well at the xy-plane origin and uniform flow ...the positive x-direction, the equation for the complete capture zone ...undary is $x = y \cot(y/d)$.

Ground water levels from a transect of wells across a capture ...ne boundary, no matter how closely spaced, cannot in general dis-...guish the boundary. Because of this observational difficulty,

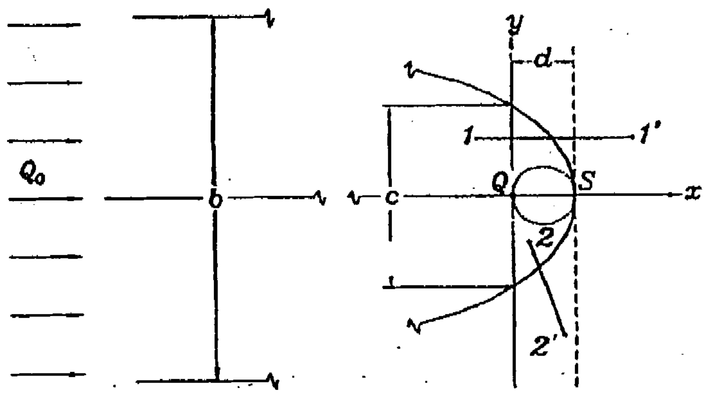


Figure 1. Capture zone boundary (solid), and curves on which $\partial\phi/\partial x = 0$ (dotted) and $\partial\phi/\partial r = 0$ (dashed), for well at origin with uniform flow in positive x-direction.

capture zone calculations based on ground water flow models are essential. To illustrate the difficulty, the well-in-uniform-flow analytical solution is posed here in terms of the discharge potential Φ defined by Strack (1989, page 49) as follows:

$$\Phi = \begin{cases} kH\phi - \frac{1}{2} kH^2, \text{ if confined} & \text{(1a)} \\ \frac{1}{2} k\phi^2 \quad\quad\quad, \text{ if unconfined} & \text{(1b)} \end{cases}$$

where k $[L\,T^{-1}]$ is hydraulic conductivity, H is confined-aquifer thickness, and ϕ [L] is hydraulic head referenced to the aquifer base. Then with the discharge vector (Q_x, Q_y) $[L^2 T^{-1}]$ defined as the product of the saturated thickness and the specific discharge vector, and treating k and (as applicable) H as constants, it follows that $Q_x = -\partial\Phi/\partial x$ and $Q_y = -\partial\Phi/\partial y$ whether the flow is confined or unconfined. If the discharge vector's radial and tangential components are

---

[a]Wenck Associates Inc., 1800 Pioneer Creek Center, P.O. Box 249, ...aple Plain, MN 55359-0249; (612) 479-4203, fax (612) 479-4242, ...dmann@wenck.com

Received June 1999, accepted December 1999.

Q_r and Q_θ, the relations $Q_r = -\partial\Phi/\partial r$ and $Q_\theta = -\partial\Phi/(r\,\partial\theta)$, where r and θ are the usual polar coordinates, are also valid. Arbitrary additive constants in the definition of Φ are chosen to guarantee continuity even at transitions between confined ($\phi \geq H$) and unconfined ($\phi < H$) flow. For a well in uniform flow as in Figure 1, Φ is (Strack 1989, page 228)

$$\Phi = -Q_o x + \frac{Q}{2\pi} \ln \frac{(x^2 + y^2)^{1/2}}{r_o} + \Phi_o \tag{2a}$$

or in polar coordinates

$$\Phi = -Q_o r \cos\theta + \frac{Q}{2\pi} \ln \frac{r}{r_o} + \Phi_o \tag{2b}$$

where Φ_o is the value of Φ at sidegradient points $(0, r_o)$ and $(0, -r_o)$. Equation 2a implies $Q_x = Q_o - xQ/[2\pi(x^2 + y^2)] = Q_o[1 - xd/(x^2 + y^2)]$ where $d = Q/2\pi Q_o$ as before. The locus of points where $Q_x = 0$, and hence also $\partial\phi/\partial x = 0$, is the circle $(x - d/2)^2 + y^2 = (d/2)^2$ excluding the well location (Figure 1). Also, $\partial\phi/\partial x$ is positive ($Q_x < 0$) inside the circle and negative outside it. Along any line segment parallel to the x-axis and outside the circle, such as 1-1′ in Figure 1, from inside to outside the capture zone, ϕ strictly decreases. But at the same time, Equation 2b implies $Q_r = Q_o \cos\theta - Q/2\pi r = Q_o(x - d)/r$, hence Q_r vanishes (and so also $\partial\phi/\partial r = 0$) on the line $x = d$; and $\partial\phi/\partial r$ is positive upgradient and negative downgradient from the line. Along any line segment on a radius from the well and upgradient from the line $x = d$, such as 2-2′ in Figure 1, from inside to outside the capture zone, ϕ strictly increases. Therefore, water levels from monitoring wells along 1-1′ and 2-2′ cannot distinguish the capture zone boundary and even exhibit opposite trends from inside to outside the capture zone.

In the antecedent literature, generalizations concerning multiple-well capture zones focus on lines of regularly spaced, equal wells aligned perpendicular to background flow ("regular barrier lines"). Keely (1984) observes that a regular barrier line of N wells with flow rate Q per well has ultimate capture width $b = NQ/Q_o$, as for a hypothetical single well with flow rate NQ, the system's total flow rate. Generally in multiple-well systems, if transverse well spacings are too large, the system's capture zone has gaps between wells through which contaminated ground water may escape. Whenever the capture zone has no gaps but any small increase in transverse spacing would cause gaps, the spacing is termed "critical." In analyzing critical spacings for regular barrier lines with N = 2, 3, and 4, Javandel and Tsang (1986) conclude that the capture width c along the well alignment also is the same as for a single well with the system's total flow rate, $c = NQ/2Q_o$, when the spacing is critical. These authors recommend the critical spacing as "optimum" for regular barrier lines—a recommendation, however, that is shown herein to be ill-founded.

The assumptions forming the basis for the present analysis, the analyses of Keely (1984) and of Javandel and Tsang (1986), and the single-well solution noted previously are the following: (1) flow is horizontal and steady; (2) the aquifer is homogeneous, isotropic, and infinite in horizontal extent; and (3) uniform background flow represents far-field recharge, local recharge being neglected. The horizontal flow idealization rests on the Dupuit-Forchheimer assumption: resistance to flow in the vertical direction is regarded as negligible (Strack 1989, page 36). Transverse dispersion is neglected insofar as contaminant capture is identified with hydraulic capture. Although models based on less restrictive assumptions are available, simple analytical models are often useful as a means of preliminary analysis or as an approximate check on other models. In discussing the use of hydrogeologic models in performance assessment, Konikow and Ewing (1999) remark that "[c]omplex [performance assessment] models should be complemented by more transparent simplified analyses." In situations where boundary conditions are uncomplicated, simple analytical models also remain widely useful for remedial design.

The present analysis demonstrates that the capture width result of Javandel and Tsang (1986) actually generalizes to all gradientwise-symmetric systems—i.e., systems in which well locations and flow rates are symmetrical respecting a line perpendicular to background flow. Gradientwise-symmetric systems consist of "symmetric elements," each element being either a well on the symmetry line, or a pair of equal wells located symmetrically up- and downgradient from the line. Barrier lines (i.e., lines of wells perpendicular to background flow) are composed strictly of the first kind of element: The well alignment itself is the flow-perpendicular symmetry line. Any barrier line, even with irregular well spacings and flow rates, is gradientwise-symmetric. Some examples of other gradientwise-symmetric systems are lines of regularly spaced, equal wells that are parallel to the background flow, and equal wells placed at the vertices of regular polygons, appropriately oriented. The generalized capture width c for a gradientwise-symmetric well system is measured on the symmetry line and termed the "center" capture width.

The center capture width result derived herein has counter-intuitive implications, as discussed subsequently. A practical application, determining whether certain systems have capture zone gaps, is demonstrated. Transverse well spacings substantially smaller than critical are recommended in systems used for contaminant capture. For design reference, critical spacings are derived for regular barrier lines with N through 100 and N→∞. The critical spacings reported here for N = 3 and 4 differ slightly (though not significantly for practical purposes) from those of Javandel and Tsang (1986). For existing well lines that have capture zone gaps, flow rate modifications that preclude gaps are discussed.

Capture Width in Multiple-Well Systems

Derivation of Capture Width

Figure 2 illustrates capture width analyses for two multiple-well systems in uniform flow of magnitude Q_o in the positive x-direction. The arbitrarily configured system in Figure 2a consists of two wells with flow rates Q_1 and Q_2. The gradientwise-symmetric system in Figure 2b consists of two symmetric elements, a well on the y-axis (gradientwise symmetry line) with flow rate Q_1, and two equal wells symmetrically straddling the y-axis with combined flow rate Q_2. Pairs of dividing streamlines delineate capture zone boundaries. Stagnation points on a boundary (for example, the points labeled S_1 and S_2 in Figure 2) are locations of zero discharge where dividing streamlines meet and diverge, with one divergent streamline running to the well (said to be "associated" with the stagnation point) inside the capture zone and one running outside. When one well's capture zone is nested inside another's, as in Figure 2, the dividing streamline that diverges outside the nested well's capture zone runs to the nesting well.

Before deriving the center capture width for gradientwise-symmetric systems, the ultimate capture width b for arbitrary sys-

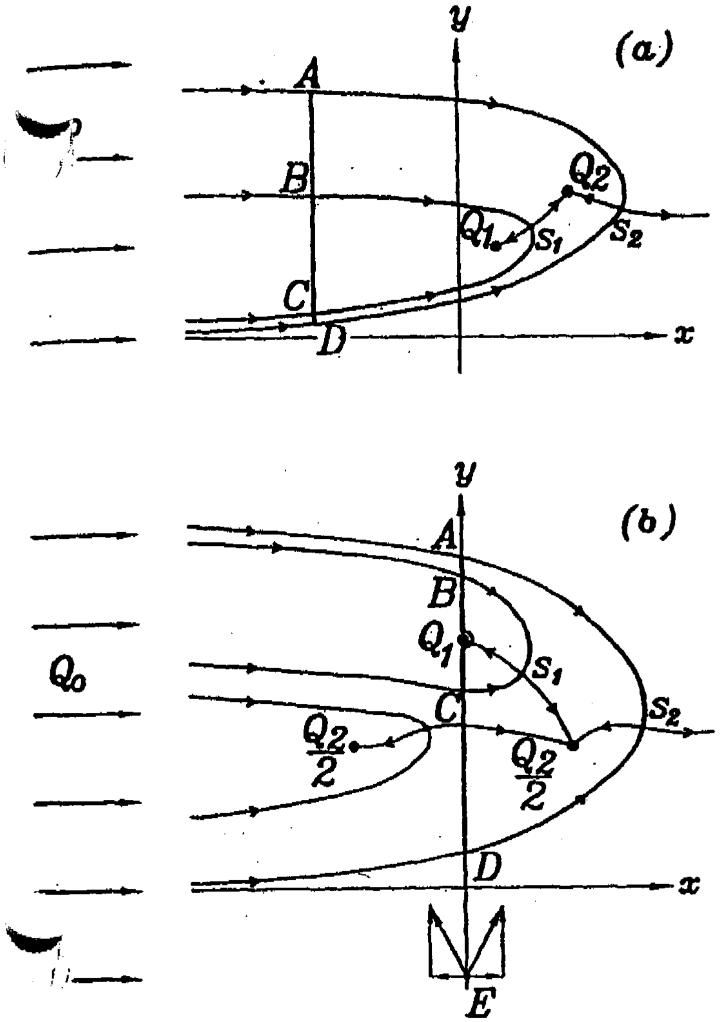


Figure 2. Dividing streamlines indicating capture zones for individual wells in (a) arbitrary and (b) gradientwise-symmetric multiple-well systems.

tems will be analyzed by way of introduction. In Figure 2a, since inflow to closed figure AS_2D occurs only across AD, representing the system's capture width at arbitrary x-coordinate, the line integral of Q_x on AD equals Q_T, the system's total flow rate. In the limit as $x \rightarrow -\infty$, the system's influence on the flow field vanishes, thus $Q_x \rightarrow Q_o$ and the flow balance $Q_o\,b = Q_T$ results. Similarly, the ultimate capture width b_1 for the well with flow rate Q_1 (i.e., length of BC as $x \rightarrow -\infty$) satisfies $Q_o\,b_1 = Q_1$, and, despite the capture zone nesting, the second well's ultimate capture width b_2 satisfies $Q_o\,b_2 = Q_2$. Therefore, an arbitrary well system's ultimate capture width equals that of a hypothetical single well with the system's total flow rate, $b = Q_T/Q_o$; and the ultimate capture width b_n for any individual well with flow rate Q_n is the same as though that well operated alone, $b_n = Q_n/Q_o$.

Now for gradientwise-symmetric systems, the center capture width result follows from this observation: At every point on the symmetry line except well locations, the discharge vector component parallel to background flow is unaffected by the system and thus equals Q_o. In Figure 2b, for example, the well on the y-axis has no effect on Q_x anywhere else on the y-axis since it induces purely radial flow, and the symmetric well pair's contributions to Q_x everywhere on the y-axis cancel one another (see point E); therefore, every point on the y-axis but the well location has $Q_x = Q_o$. In Figure 2b, the "line segment" BC measures the single well's center capture width c_1. (Actually, BC circumvents the well via a small semicircle which may be regarded as infinitesimal.) Inflow across BC to closed figure BS_1C equals Q_oc_1, and outflow (through the small semicircle) equals $Q_1/2$, so the flow balance implies $Q_oc_1 = Q_1/2$. For the symmetric well pair's center capture width c_2, inflow across AB and CD to closed figure AS_2DCS_1B equals Q_oc_2 and balances the flow rate of the enclosed well, hence $Q_oc_2 = Q_2/2$. All elements of a gradientwise-symmetric system can be treated in one or the other of these ways, so the system's overall center capture width c and total flow rate Q_T also satisfy $Q_oc = Q_T/2$.

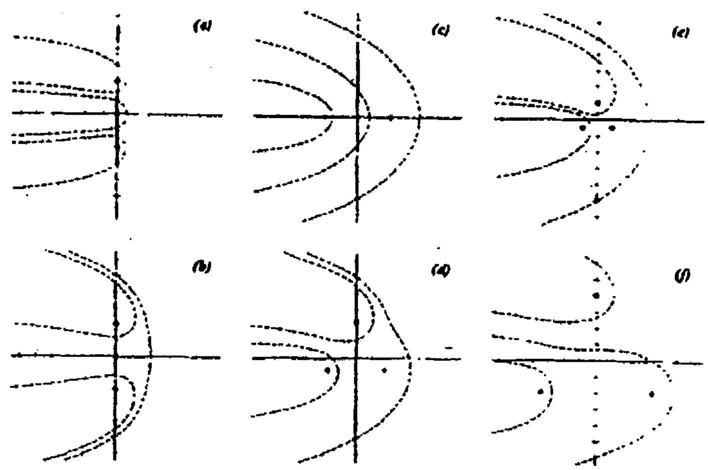


Figure 3. Capture zones for gradientwise-symmetric systems of three equal wells with (a) $Q_T = 200$ m^3 d^{-1} and (b) through (f) $Q_T = 400$ m^3 d^{-1}. Aquifer has $Q_o = 2$ m^2 d^{-1} with flow left to right. Axes marked on 10 m intervals. (Capture zones traced by SLAEM, based on stagnation points computed externally.)

Therefore, a gradientwise-symmetric well system's center capture width c is the same as for a hypothetical single well with flow rate Q_T, $c = Q_T/2Q_o$; and the center capture width c_m for any symmetric element with flow rate Q_m is the same as for a well with flow rate Q_m operating alone, $c_m = Q_m/2Q_o$. This result applies even if the system's capture zone has gaps. When gaps occur, if wells inside one disjoint capture zone part have flow rate subtotal Q_T', then that part's center capture width c′ is also $c' = Q_T'/2Q_o$.

Some Counter-Intuitive Implications

To ground water remediation practitioners, it seems an annoyingly perverse quirk of nature that a well's capture width is only half at the well what it is infinitely far upgradient. And contrary to intuition, distributing the flow among multiple wells yields no relief from this harsh limitation. For example, Figures 3a and 3b show two regular barrier lines with N = 3 and $Q_T = 200$ and 400 m^3 d^{-1}, respectively, in an aquifer wherein $Q_o = 2$ m^2 d^{-1} (e.g., an aquifer with k = 50 m d^{-1}, prepumping saturated thickness 8 m —hence transmissivity 400 m^2 d^{-1}—and prepumping hydraulic gradient 0.005). The smaller flow rate equals the background flow through a width of 100 m. However, the well line with that flow rate actually captures only 50 m along its alignment; to capture 100 m, Q_T must be double the background flow through that width, as in Figure 3b. No matter how finely divided the flow and closely spaced the wells, the capture width along a barrier line remains $Q_T/2Q_o$.

Throughout Figures 3 through 5, dividing streamlines traced with the SLAEM model (Strack 1989, pages 311-316) delineate capture zones. External to SLAEM, stagnation point coordinates were found algebraically (Figures 3 and 4) or through numerical search

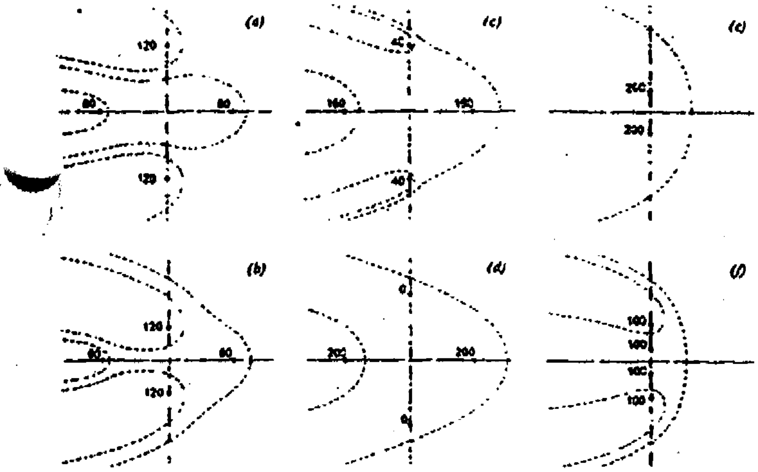


Figure 4. Capture zones for well systems that are both gradientwise- and laterally symmetric, with Q_T = 400 m^3 d^{-1} and individual flow rates (m^3 d^{-1}) as indicated. Other data as in Figure 3. (Capture zones traced by SLAEM, based on stagnation points computed externally.)

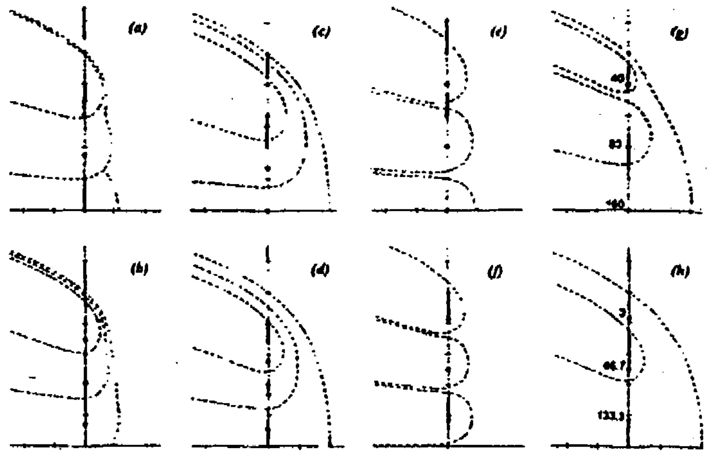


Figure 5. Capture zones (upper half-plane only) for five and six-well (a) through (f) regular barrier lines with (a) through (b) $LQ_o/Q = (LQ_o/Q)_c$, (c) through (d) LQ_o/Q = 0.33, and (e) through (f) LQ_o/Q = ½, and (g) through (h) barrier lines with L as in (e) through (f) and individual flow rates (m^3 d^{-1}) as indicated; all with QT = 400 m^3 d^{-1} and other data as in Figure 3. (Capture zones traced by SLAEM, based on stagnation points computed externally.)

(Figure 5). Nearby points on the convergent dividing streamlines were located by matching stream function values, and SLAEM was then used to trace the convergent streamlines backward, starting from these points. The stagnation points and capture zones could also be determined using the public domain model CZAEM (Bakker and Strack 1996; Strack et al. 1994). Throughout Figures 3 through 5, the aquifer has the same background flow, and (except in Figure 3a) the well systems have the same total flow rate (400 m^3 d^{-1}) and center capture width (100 m).

In addition to being independent of the number of wells, a gradientwise-symmetric system's center capture width is independent of the particular well configuration, so long as gradientwise symmetry is maintained. For example, a regular barrier line has the same center capture width as it would have if rotated parallel to the background flow—or, for that matter, if rearranged in the form of a regular polygon with appropriate orientation (Figures 3b through 3d). Most important, neglecting possible flow rate limitation by mutual well interference, a gradientwise-symmetric system's center capture width is independent of the distance between wells. If transverse well spacings are too large, the system's capture zone has gaps, but the aggregate center capture width remains unaltered; conversely, merely decreasing transverse spacings does not decrease the system's center capture width (Figures 3d through 3f).

Determining the Occurrence of Capture Zone Gaps

The center capture width result enables one to determine whether capture zone gaps occur in certain well systems. For example, in Figure 3f, with the system's center capture width known to be 100 m, a capture zone gap between the two symmetric elements (well and symmetric well pair) is certain if the distance between their centers is 50 m or more because their capture zones are skewed away from one another. (The discharge vectors induced by the elements partially annul one-another at locations between them while reinforcing each other outside them.) The transverse spacing in Figure 3f is actually 60 m, so a gap is easily foreseeable.

A reasonable prescription for preventing capture zone gaps is ot obvious in cases such as the one just presented, but systems that ssess both lateral and gradientwise symmetry are more tractable. he system in Figure 4a is doubly symmetric, consisting of a symmetric well pair up- and downgradient from the system's center, with a center capture width of 40 m, and two laterally symmetric outer wells with center capture widths of 30 m each. Since the outer wells' capture zones skew outward, gaps are certain if the outer wells are 15 m or less from the target width's edge. They are actually only 10 m from the edge, so gaps are once again predictable. An obvious modification that would prevent gaps is to place the outer wells 20 m from the system's center, thereby guaranteeing that the central well pair's capture zone nests those of the outer wells (Figure 4b). Alternatively, with the original placement, this rationale can be applied to flow rates. If the central well pair's combined flow rate can be increased from 160 to 320 m^3 d^{-1}, resulting in a center capture width for them of 80 m, then this would ensure nesting with the original placement, even while maintaining the original Q_T by reducing the outer-well flow rates (Figure 4c). Carrying this idea further, splitting Q_T entirely between the central wells would leave a two-well system aligned with the background flow (Figure 4d). For comparison, Figures 4e and 4f show examples of regular barrier lines with two and four wells.

Capture Zone Gaps in Regular Barrier Lines

Especially important because of their wide usage for contaminant capture, regular barrier lines are both gradientwise- and laterally symmetric. The occurrence of capture zone gaps through regular barrier lines depends on the number of wells N and the "relative spacing" LQ_o/Q, where L is the well spacing, Q_o the background flow per unit width, and Q each well's flow rate. The relative spacing equals the ratio of L to the ultimate capture width of one well. The "critical relative spacing" $(LQ_o/Q)_c$ for a given N corresponds to the condition of incipient gaps—i.e., $(LQ_o/Q)_c$ is the largest relative spacing that yields no capture zone gaps. For systems designed with critical spacing, any underestimate in Q_o or decrease in Q results in one or more capture zone gaps. A regular barrier line at critical spacing can also have capture zone gaps as a result solely of being slightly off-perpendicular to the background flow when N is odd.

Fallacy of 'Optimum' Spacing

For regular barrier lines used for contaminant capture, others have recommended critical spacings as "optimum" (Javandel and 'sang 1986; also summarized in Gorelick et al. 1993, pages 123-3^ The notion that capture width increases as well spacing ...es is intuitive but erroneous. It has not been recognized ...re, apparently, that capture width along a barrier line is inde-...t of spacing. Figures 5a and 5b illustrate critical-spacing capture zones for regular barrier lines with $N = 5$ and 6, respectively. Figure 5 shows portions of the upper half-plane only.) With smaller pacings but the same flow rates (Figures 5c and 5d), the well apture zones are safely nested, and there is no decrease in center apture width. Designing for critical spacing is risky because of ...ncertainties in aquifer characteristics and possible fluctuations in ystem flow rate. To avoid risking capture zone gaps, well spacings hould be substantially smaller than critical in regular barrier lines ...sed for contaminant capture.

Critical Relative Spacings

Although designing for critical spacing is not recommended, ritical spacings remain important as reference points for design. The well-known case $N = 2$ has the smallest critical relative spacing, $(LQ_o/Q)_c = 1/\pi$, which is derivable algebraically (e.g., Javandel and Tsang 1986; Strack 1989, pages 236-240). Dimensionally, the two-well critical spacing is $Q/\pi Q_o$, considerably smaller than each well's center capture width, $Q/2Q_o$. The outward skew of the wells' apture zones is the reason such small spacing is required. At the ther extreme, however, with infinitely many wells, every well's capture zone is identical and laterally symmetric, hence the critical spac-...g exactly equals one well's center capture width. Explicit analy-... infinite regular barrier lines affirms that $(LQ_o/Q)_c \rightarrow ½$ as ... Erdmann 1995, 1997). One can also derive this limiting value ... considering a regular barrier line with variable N, Q, and L, but ixed total flow rate $Q_T = NQ$, total length $L_T = NL$, and "strength" $Q/L = Q_T/L_T$. In the limit as $N \rightarrow \infty$, the result is a line-sink (formally, line integral of wells). At every point along a line-sink, the line-sink-induced discharge vector component that is perpendicular to he line-sink on either side is equal to half the strength, or $Q/2L$ Strack 1989, pages 283–287). With uniform flow in the positive -direction, a line-sink on the y-axis then has $Q_x = Q_o + Q/2L$ on s upgradient side, and $Q_x = Q_o - Q/2L$ on its downgradient side. Ground water flow on the downgradient side will be reversed so long s $Q/L > 2Q_o$, but there will be some flow through the line-sink (i.e., will "leak") whenever $Q/L < 2Q_o$. At equality the condition is critical, thus $(LQ_o/Q)_c = ½$.

Antecedent literature gives a few critical spacings for $N > 2$. Javandel and Tsang (1986) report $(LQ_o/Q)_c = 2^{1/3}/\pi$ for $N = 3$ and he approximation $(LQ_o/Q)_c \approx 1.2/\pi$ for $N = 4$. However, for $N =$. Erdmann (1995, 1997) provides the complete algebraic solution or stagnation points as functions of relative spacing, and on this asis derives $(LQ_o/Q)_c = 0.4025455$ (about 0.4% larger than $2^{1/3}/\pi$). Erdmann (1995, 1997) also calculates $(LQ_o/Q)_c$ numerically for $N = 4$ through 40. A general technique for determining critical spacings of regular barrier lines is outlined in Appendix A and detailed lsewhere (Erdmann 1997). Determining critical spacings amounts ...ding "critical stagnation points" on the system's capture zone ...ary. Situated at junctures between the abutting capture zones ...rent wells, critical stagnation points mark locations of incipient capture zone gaps.

Table 1 lists critical relative spacings for $N = 2$ through 100, erived numerically by the method in Appendix A. Considering even nd odd N separately, $(LQ_o/Q)_c$ increases smoothly with N, but the increase is more rapid for odd N, which results in a small even-odd oscillation in the values. The largest even and odd critical spacings in Table 1 are 0.49200 for $N = 100$ and 0.49349 for $N = 99$. Appendix B presents an algebraic analysis for $N = 4$. The result agrees closely (within at least 0.001%) with the value in Table 1 and reasonably (within about 1%) with the approximation of Javandel and Tsang (1986).

Location of Critical Stagnation Points

In all cases analyzed, critical stagnation points occur between the two center wells when N is even, or the center and two adjacent wells when N is odd. At critical spacing, capture zone gaps are incipient where contaminant concentrations are usually maximum. Table 1 includes the dimensionless critical stagnation point coordinates.

Suggested Maximum Relative Spacings

When regular barrier lines are used for contaminant capture, well spacings substantially smaller than critical are recommended to ensure against capture zone gaps. Spacings not exceeding 80% of critical are suggested as a prudent minimum precaution. The following relative spacings for four ranges of N correspond to 70% to 80% of critical in all cases:

Range of N	Suggested Maximum LQ_o/Q
$N = 2$	0.25
$N = 3, 4$	0.30
$N = 5, \ldots 14$	0.33
$N = 15, \ldots \infty$	0.37

Figures 3b, 4e, 4f, 5c, and 5d illustrate these suggested maximum spacings for $N = 2$, 3, 4, 5, and 6. Uncertainties in hydraulic conductivity and other factors should be carefully considered in selecting well spacings. Depending on specific conditions, more stringent limitations than these may often be warranted.

Modifying Flow Rates to Eliminate Gaps

Capture zone gaps in existing regular barrier lines that have $LQ_o/Q = ½$, as in Figures 5e and 5f, can be eliminated by modifying flow rates, if aquifer conditions allow. For $N = 2$, the flow rate must be doubled to meet the suggested maximum relative spacing; a doubling of capture width also necessarily results. For all greater N, however, a flow rate redistribution suffices that maintains the original Q_T and center capture width. For odd N, doubling the center well's flow rate, while halving each end well's flow rate, precludes capture zone gaps. This results in a center capture width of 2L for the center well and ensures nesting of the entire system inside the center well's capture zone. For even $N \geq 4$, doubling the flow rate for both center wells, while shutting down both end wells, prevents capture zone gaps. This redistribution is more drastic than for odd N; however, with only a 50% increase at the two center wells and a halving at the two end wells, a gap is almost incipient at the center when $N = 4$. A safe approach when N is even is to regard the two center wells as though they operated alone, and it is on this basis that doubling their flow rate is recommended. The even-N flow rate redistribution put forward here also ensures that the two center wells' capture zones nest the entire system. Figures 5g and 5h illustrate the described schemes for $N = 5$ and 6.

Table 1
Critical Relative Spacings and Dimensionless Critical Stagnation Point Coordinates for Regular Barrier Lines

N	$\left(\frac{LQ_o}{Q}\right)_c$	$\frac{x_u}{L/2}$	N	$\left(\frac{LQ_o}{Q}\right)_c$	$\frac{x_c}{L/2}$	$\frac{y_c}{L/2}$
2	0.31831	1.0000	3	0.40255	0.5765	1.5040
4	0.38629	1.1857	5	0.43171	0.7468	1.4699
6	0.41609	1.3056	7	0.44643	0.8563	1.4570
8	0.43297	1.3936	9	0.45552	0.9376	1.4503
10	0.44392	1.4630	11	0.46175	1.0022	1.4463
12	0.45162	1.5201	13	0.46633	1.0559	1.4435
14	0.45735	1.5687	15	0.46985	1.1019	1.4416
16	0.46180	1.6109	17	0.47265	1.1420	1.4401
18	0.46536	1.6482	19	0.47493	1.1776	1.4390
20	0.46827	1.6816	21	0.47683	1.2097	1.4381
22	0.47070	1.7119	23	0.47845	1.2388	1.4374
24	0.47277	1.7395	25	0.47983	1.2655	1.4368
26	0.47454	1.7650	27	0.48104	1.2901	1.4362
28	0.47609	1.7886	29	0.48209	1.3129	1.4358
30	0.47744	1.8105	31	0.48303	1.3343	1.4354
32	0.47865	1.8311	33	0.48386	1.3542	1.4351
34	0.47972	1.8504	35	0.48462	1.3731	1.4348
36	0.48068	1.8686	37	0.48529	1.3908	1.4345
38	0.48155	1.8858	39	0.48591	1.4076	1.4343
40	0.48234	1.9021	41	0.48648	1.4236	1.4341
42	0.48307	1.9177	43	0.48699	1.4388	1.4339
44	0.48373	1.9325	45	0.48747	1.4533	1.4338
46	0.48434	1.9467	47	0.48791	1.4672	1.4336
48	0.48490	1.9602	49	0.48831	1.4805	1.4335
50	0.48542	1.9732	51	0.48869	1.4933	1.4333
52	0.48590	1.9857	53	0.48905	1.5056	1.4332
54	0.48635	1.9978	55	0.48938	1.5174	1.4331
56	0.48677	2.0094	57	0.48968	1.5287	1.4330
58	0.48717	2.0205	59	0.48997	1.5398	1.4329
60	0.48754	2.0313	61	0.49025	1.5504	1.4328
62	0.48789	2.0418	63	0.49051	1.5607	1.4327
64	0.48822	2.0519	65	0.49075	1.5707	1.4326
66	0.48852	2.0617	67	0.49098	1.5804	1.4326
68	0.48882	2.0712	69	0.49120	1.5897	1.4325
70	0.48909	2.0805	71	0.49140	1.5989	1.4324
72	0.48936	2.0895	73	0.49160	1.6077	1.4324
74	0.48961	2.0982	75	0.49179	1.6163	1.4323
76	0.48985	2.1067	77	0.49197	1.6247	1.4323
78	0.49007	2.1150	79	0.49214	1.6329	1.4322
80	0.49029	2.1230	81	0.49230	1.6409	1.4322
82	0.49049	2.1309	83	0.49246	1.6487	1.4321
84	0.49069	2.1386	85	0.49261	1.6563	1.4321
86	0.49088	2.1461	87	0.49275	1.6637	1.4320
88	0.49106	2.1534	89	0.49288	1.6709	1.4320
90	0.49123	2.1606	91	0.49302	1.6780	1.4320
92	0.49140	2.1676	93	0.49314	1.6849	1.4319
94	0.49156	2.1744	95	0.49326	1.6917	1.4319
96	0.49171	2.1811	97	0.49338	1.6984	1.4318
98	0.49186	2.1877	99	0.49349	1.7049	1.4318
100	0.49200	2.1941				

Note: Well spacing is L, discharge per well Q, background flow per unit aquifer width Q_o.
Dimensional critical stagnation points are $(x_u, 0)$ for even N, and (x_c, y_c) and $(x_c, -y_c)$ for odd N.
Dimensionless coordinates are scaled by L/2 to be consistent with Appendices A and B.
Termination criterion for numerical searches was 0.5×10^{-6} or smaller.

Summary

Capture zone delineations are fundamental to designing and …ing the performance of well systems used to capture con…ted ground water. Localized ground water level observations …ctice cannot usually define a well system's capture zone, thus calculations based on ground water flow models are essential. Steady-state capture zones for multiple-well systems in uniform background flow are analyzed here in the context of the horizontal flow idealization.

The center capture width c of a gradientwise-symmetric well system with total flow rate Q_T equals that of a hypothetical single well with flow rate Q_T, thus $c = Q_T/2Q_o$ where Q_o is the background flow rate per unit aquifer width. Each of the system's symmetric elements (wells on the symmetry line or pairs of equal wells symmetrically up- and downgradient from the line) has the same center capture width as a well operating alone at the element's flow rate. All well lines perpendicular to background flow, even with irregular spacings and flow rates, are gradientwise-symmetric, as are many other configurations. Although only wells are considered here, the center capture width result also applies to systems that include line-sinks (Erdmann 1995).

A gradientwise-symmetric system's center capture width is independent of the number of wells and of their particular placement and spacing. The center capture width remains $Q_T/2Q_o$ whether transverse well spacings are large (allowing contaminated ground water to escape through capture zone gaps), critical (with incipient gaps), or safely small. Critical spacings are therefore not "optimum." F… regular barrier lines of N wells with flow rate Q per well, the …l spacing varies from $Q/\pi Q_o$ (N = 2, previously known) to …$)_o$ (N→∞). At critical spacing, capture zone gaps are incipient …ween the two center wells, or the center well and two adjacent wells, where contaminant concentrations are usually maximum. Spacings substantially smaller than critical are recommended in regular barrier lines used for contaminant capture.

The center capture width result enables one to determine the occurrence of capture zone gaps and to design for their prevention in a variety of well configurations.

Appendix A—Determination of Critical Spacing for Regular Barrier Lines

With uniform background flow of magnitude Q_o in the positive x-direction, a regular barrier line of N wells with spacing L and flow rate Q per well is aligned on the y-axis, centered at the origin. Identifying each point (x, y) with the complex number $z = x + iy$, and with the discharge stream function Ψ (meaningful if recharge and leakage to or from the aquifer can be regarded as negligible) being the harmonic conjugate of Φ (discharge potential, Equation 1), the complex potential $\Omega = \Phi + i\Psi$ (Strack 1989, pages 278–279) is

$$\Omega = -Q_o z + \frac{Q}{2\pi}\sum_{n=1}^{N} \ln(z - iv_n L/2) + C \qquad \text{(A.1)}$$

…re well locations are $iv_n L/2$ with v_n including the odd integers …I is even) or the even integers (if N is odd) from $-(N-1)$ to …$-1)$; and C is a real constant determined by specifying Φ at a reference point. Defining dimensionless $Z = X + iY$ and $\hat\Omega = \hat\Phi + i\hat\Psi$ by $z = ZL/2$ and $\Omega = \hat\Omega L Q_o/2$ gives $\hat\Omega = -Z + D\sum \ln(Z - iv_n) + \hat C$, where $D = Q/\pi L Q_o$ is a "strength parameter" inversely proportional to relative well spacing, and $\hat C$ is a dimensionless real constant: hence, $\hat\Phi = -X + D\sum \ln|Z - iv_n| + \hat C$ and $\hat\Psi = -Y + D\sum \arg(Z - iv_n)$. (All summations are for n = 1, …, N.) Curves on which $\hat\Psi$ is constant are streamlines. The condition $\hat\Psi = 0$ holds on the positive X-axis and, hence, on the capture zone boundaries of (1) the center well when N is odd; (2) the two center wells when N is even and there is no capture zone gap between them; and (3) the entire well line when there are no capture zone gaps anywhere (whether N is even or odd). Critical stagnation points then also have $\hat\Psi = 0$. On the Y-axis, except for discontinuities at wells, $\hat\Psi$ is a decreasing function of Y. Thus, at least one well on the positive Y-axis has $\hat\Psi < 0$ on its capture zone boundary if the system's capture zone has any gaps. Whenever $\hat\Psi \geq 0$ at all upper half-plane stagnation points, there are no capture zone gaps.

The dimensionless discharge function $\hat W = \hat Q_x - i\hat Q_y = -d\hat\Omega/dZ$ has the form $\hat W = 1 - D\sum 1/(Z - iv_n)$, hence $\hat Q_x = 1 - DX\sum 1/|Z - iv_n|^2$, and $\hat Q_y = -D\sum (Y - v_n)/|Z - iv_n|^2$. For every point in the right half-plane, there is a positive D giving $\hat Q_x = 0$. The condition $\hat Q_y = 0$ is independent of D and holds (1) on the X-axis, except the origin when N is odd; (2) on the centerward side of each noncenter well, on an ovate curve that passes through, but excludes, the well; and (3) when N is even, on an ovate curve that passes through the points X_μ and $-X_\mu$ (see next paragraph) and through, but excluding, the two center wells. Points on (1) through (3) with X > 0 are the possible stagnation points.

When N is even, $\hat Q_x$ restricted to the X-axis has its minimum at location X_μ that is the positive root of $\partial\hat Q_x/\partial X = 0$ (with Y = 0), the root being independent of D. With the D that yields $\hat Q_x = 0$ at X_μ, X_μ is the lone X-axis stagnation point (double root of $\hat W = 0$). If all upper half-plane stagnation points then have $\hat\Psi \geq 0$, X_μ and this D are critical.

Whereas the X-axis has $\hat Q_y = 0$, lines parallel to the X-axis that pass through either a well or a midpoint between neighboring wells have nonzero $\hat Q_y$ directed toward the X-axis, except at well locations; some of the system's wells are symmetric with respect to each of these lines, and the remaining wells are in the opposite half-plane. Let well n be a noncenter well located at iv_n on the positive Y-axis ($v_n \geq 2$). Then $\hat Q_y < 0$ holds on the line $Y = v_n$ (except at the well) and the midpoint line $Y = v_n - 1$. The curve corresponding to $\hat Q_y = 0$ on which well n's stagnation point lies is constrained between these two lines, and well n's entire capture zone must be above the line $Y = v_n - 1$ since no streamline can run up to well n from any point on this line or below it. Points on the curve $\hat Q_y = 0$ can be found through numerical search, independent of D. The D that also gives $\hat Q_x = 0$ at a point on the curve with X > 0 can be found directly; and $\hat\Psi$ can then be directly evaluated at this stagnation point. As Y increases between the zero-$\hat Q_y$ curve's Y-intercept (say, η_n) and v_n, the corresponding stagnation-point values of both D and $\hat\Psi$ decrease. The limiting values are $D\to\infty$ and $\hat\Psi\to\infty$ as $Y\to\eta_n$, and $D\to 0$ and $\hat\Psi\to -v_n$ as $Y\to v_n$. Thus, a stagnation point associated with well n can be found through numerical search for any prescribed value of either D > 0 or $\hat\Psi > -v_n$.

Now let Z_s be well n's stagnation point, and assume that (1) $\hat\Psi = 0$ at Z_s, and (2) $\hat\Psi \geq 0$ at all upper half-plane stagnation points. The system's capture zone then has no gaps, hence $\hat\Psi = 0$ on its boundary. Well n's capture zone (with $\hat\Psi = 0$ on its boundary also) must either (a) share some common boundary with the system's capture zone—in which case Z_s and the corresponding D are critical—or else (b) nest inside the capture zone of another well—say, well m. But suppose (b) is true. Let iv_m be well m's location and $\hat\Psi_m$ its stagnation-point $\hat\Psi$ value. Well m must be below well n since well m's entire capture zone would be above the line $Y = v_m - 1$ if $v_m > v_n$. Let the upper Y-intercepts of the capture zone boundaries of well m and n be σ_m and σ_n, respectively, and note $\sigma_m > \sigma_n$ because of the nesting. If there is no well between $i\sigma_m$ and $i\sigma_n$, then $\hat{\Psi}_m < 0$ because $\hat{\Psi}$ is a decreasing function of Y on the Y-axis, except for discontinuities at wells. But even if there are wells between $i\sigma_m$ and $i\sigma_n$, their capture zones are nested inside well m's and are entirely above (though possibly abutting) well n's capture zone. Accordingly, the constraint $\hat{\Psi}_m < \hat{\Psi} \leq 0$ applies to $\hat{\Psi}$ on the capture zone boundary of any such well. So again it follows that $\hat{\Psi}_m < 0$. But this is impossible since well m must be either a center well, in which case $\hat{\Psi}_m = 0$, or a noncenter well on the positive Y-axis, in which case $\hat{\Psi}_m \geq 0$ by assumption; therefore, (b) cannot be true. Thus, a stagnation point Z_s associated with a noncenter well on the positive Y-axis, and the corresponding D, are critical whenever $\hat{\Psi} = 0$ at Z_s while $\hat{\Psi} \geq 0$ at all upper half-plane stagnation points.

Appendix B—Regular Barrier Line with N = 4

For a regular barrier line of four wells, the condition $\hat{W} = 0$ yields the quartic equation $Z^4 - 4DZ^3 + 10Z^2 - 20DZ + 9 = 0$, which has closed-form algebraic roots (e.g., see Abramowitz and Stegun 1965, pages 17-18). The roots are $Z_{sc} = (½)[-\beta_- \pm (\beta_-^2 - 4\gamma_-)^{½}]$ (center wells) and $Z_{so} = (½)[-\beta_+ \pm i(4\gamma_+ - \beta_+^2)^{½}]$ (outer wells), where $\beta_\pm = -2D \pm (4D^2 + u - 10)^{½}$ and $\gamma_\pm = u/2 \pm (u^2/4 - 9)^{½}$, where $u = \tau_+ + \tau_- + 10/3$, $\tau_\pm = (2/3)[4(117D^2 - 70 \pm 3\sqrt{3\rho})]^{½}$ and $\rho = 500D^6 - 793D^4 + 520D^2 - 144$. Requiring $\rho = 0$ (a cubic equation in D^2) results in $D = (\sqrt{15}/150)(793 + \upsilon_+ + \upsilon_-)^{½}$, in which $\upsilon_\pm = [\zeta \pm (\zeta^2 + \eta^3)^{½}]^{½}$, $\zeta = 56{,}867{,}257$, and $\eta = 151{,}151$; which gives $D = 0.824023996$. This value of D yields the double root condition $\beta_-^2 - 4\gamma_- = 0$, with stagnation points $Z_{sc} = 1.185732903$ and $Z_{so} = 0.462315088 \pm i\,2.487483346$. The upper stagnation point has $\hat{\Psi} \approx 0.28 > 0$, confirming D is critical, so $(LQ_o/Q)_c \approx 0.38629$. Alternatively, the positive real root of $X^6 + 5X^4 + 23X^2 - 45 = 0$, resulting from $\partial\hat{Q}_x/\partial X = 0$ with $Y = 0$, is $X_\mu = (\sqrt{3}/3)\{-5 + 2[(125 + 6\sqrt{471})^{1/3} + (125 - 6\sqrt{471})^{1/3}]\}^{½}$, and for $\hat{Q}_x = 0$ at X_μ, $D = (X_\mu^2 + 1)(X_\mu^2 + 9)/[4X_\mu(X_\mu^2 + 5)]$, which give $X_\mu = Z_{sc}$ and the same D as above.

Acknowledgments

This paper germinated in collaborations with Mark J. Simonett, Henry Y. He, and Barry F. Power. The writer appreciates helpful discussions with Paul Budde and Otto D.L. Strack, as well as review comments on this and an earlier version of the paper by C.-M. Zhang, Stephen R. Kraemer, and anonymous reviewers. The St. Anthony Falls Laboratory of the University of Minnesota and Wenck Associates Inc. both supported this work in part; the writer especially thanks his graduate advisor, Heinz G. Stefan, boss, Norman C. Wenck, and Lisa M. Haberman.

References

Abramowitz, M., and I.A. Stegun. 1965. *Handbook of Mathematical Functions*. New York: Dover.

Bakker, M., and O.D.L. Strack. 1996. Capture zone delineation in two-dimensional groundwater flow models. *Water Resources Research* 32, no. 5: 1309–1315.

De Wiest, R.J.M. 1965. *Geohydrology*. New York: Wiley.

Erdmann, J.B. 1995. Capture zone dimensions and leakage criteria for certain groundwater pumpout configurations. St. Anthony Falls Hydraulic Laboratory External Memorandum No. M-241. Minneapolis: University of Minnesota.

Erdmann, J.B. 1997. Capture zone widths and leakage criteria for groundwater barrier well systems. Section (5) in Modeling and analysis techniques for water quality management. Ph.D. diss., Dept. of Engineering, University of Minnesota, Minneapolis.

Gorelick, S.M., R.A. Freeze, D. Donahue, and J.F. Keely. 1993. *Groundwater Contamination: Optimal Capture and Containment*. Boca Raton, Florida: Lewis.

Jacob, C.E. 1950. Flow of ground water. In *Engineering Hydraulics*, ed. H. Rouse, 321–386. New York: John Wiley and Sons.

Javandel, I., and C.-F. Tsang. 1986. Capture-zone type curves: A tool for aquifer cleanup. *Ground Water* 24, no. 5: 616–625.

Keely, J.F. 1984. Optimizing pumping strategies for contaminant studies and remedial actions. *Ground Water Monitoring Review* 4, no. 2: 63–74.

Keely, J.F., and C.-F. Tsang. 1983. Velocity plots and capture zones of pumping centers for ground-water investigations. *Ground Water* 21, no. 6: 701–714.

Konikow, L.F., and R.C. Ewing. 1999. Is probabilistic performance assessment enough? *Ground Water* 37, no. 4: 481–482.

Strack, O.D.L. 1989. *Groundwater Mechanics*. Englewood Cliffs, New Jersey: Prentice Hall.

Strack, O.D.L., E.I. Anderson, M. Bakker, W.C. Olsen, J.C. Panda, R.W. Pennings, and D.R. Steward. 1994. CZAEM user's guide: Modeling of capture zones of ground-water wells using analytic elements. EPA/600/R-94/174.