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**Hand Delivered**

December 10, 1998

Mr. Gerald Delavan, P.G.
Solid Waste Division
Arkansas Department of Pollution Control and Ecology
8001 National Drive
Little Rock, AR 72209

RECEIVED
DEC 10 1998

Re: Work Plan for In-Situ Bioremediation
At the El Dorado Chemical Company Plant
El Dorado, Arkansas
WC File 98B319 – 1

Dear Mr. Delavan:

Attached is one copy of the referenced report. We are looking forward to working with the Department on this important project.

If you have questions or comments, I can be reached at (225) 756-1431.

Sincerely,

Cheryl C Warren
for Dennis E. Reece
Vice President

William Beal, P.G., P.E.

cc: Mr. John Carver, LSB Industries
Mr. Byron Smith, EDC

F I N A L   R E P O R T



# WORK PLAN

# IN-SITU BIOREMEDIATION

## RESPONSE TO PARAGRAPH 4(B) OF CONSENT ADMINISTRATIVE ORDER LIS 98-119

## EL DORADO CHEMICAL COMPANY
## EL DORADO, ARKANSAS

*Prepared for*
El Dorado Chemical Company
El Dorado, Arkansas

December 1998

**Woodward-Clyde**

2822 O'Neal Lane
Baton Rouge, LA 70816
(504) 751-1873
WC File 98B319

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## APPENDICES

El Dorado Chemical Corporation (EDCC) entered into Consent Administrative Order (CAO) LIS 98-119 with the Arkansas Department of Pollution Control and Ecology (ADPC&E) which became effective in October, 1998. The CAO requires EDCC to implement several actions. One of the provisions of the CAO (Paragraph 4, pages 15 and 16) requires an Interim Measure consisting of in-situ bioremediation of the existing groundwater monitoring wells which have exhibited nitrate concentrations in excess of 10 mg/L. The CAO requires EDCC to submit to the ADPC&E a work plan for in-situ bioremediation. This work plan is submitted in fulfillment of this requirement.

The CAO requires that this work plan describe the activities and present a schedule of significant dates for initiation of bioremediation, sampling the groundwater, submission of the sample analysis results to the ADPC&E, and preparation of annual reports evaluating the effectiveness of this Interim Measure. Section 2.0 of this Work Plan presents relevant background information for the facility. Section 3.0 describes the planned activities for the in-situ bioremediation and Section 4.0 presents the proposed implementation schedule. Section 5.0 describes the planned reporting of results. Section 6.0 lists references.

## 2.1 GENERAL FACILITY INFORMATION

The EDCC facility is located at 4500 North West Avenue in the city of El Dorado, Union County, Arkansas. The EDCC property consists of approximately 1,340 acres, of which about 150 acres are utilized for plant operations.

EDCC is a manufacturer of basic agricultural chemicals, including sulfuric acid, nitric acid, ammonium nitrate fertilizers and industrial grade ammonium nitrate. The facility is currently owned by El Dorado Chemical Company, a wholly owned subsidiary of LSB Industries of Oklahoma City, Oklahoma. EDCC purchased the plant in July 1983 from Monsanto Chemical Company, which had occupied the site since 1955. Previous site occupants included Lion Chemical Corporation (1943-1949) and Lion Oil Company (1949-1955). Based on information provided by EDCC, the plant property was undeveloped prior to 1943. Since 1943, site operations have generally been limited to production of ammonia-related products, sulfuric acid, and nitric acid.

EDCC is currently implementing procedures for pollutant source control, wastewater minimization and enhanced wastewater treatment/disposal measures. These measures are expected to reduce nitrate concentrations in the shallow groundwater.

## 2.2 REGIONAL GEOLOGIC AND HYDROGEOLOGIC SETTING

The EDCC facility lies within the Gulf Coastal Plain Province in southern Arkansas. This province is basically comprised of a relatively undissected low-lying plain underlain by complex interbedded sands, silts, and clays which thicken progressively toward the coast and toward the Mississippi River. Sediments within the sequence are, for the most part, unconsolidated or non-lithified. The sediments range in age from Quaternary (youngest) to Triassic.

Structurally, depositional dip was basinward in a general southern to southeasterly direction. Growth fault development at depth enhances the basinward dip of the sediment accumulations across the region. A graben structure (a down-thrown faulted block of sediments) is located approximately seven miles south of the facility. The fault planes which form the graben strike northwest-southeast.

Table 2-1 shows the age relationships of the various formations found in the subsurface of the region. Also shown are the approximate thickness of each formation and a description of the hydrogeologic character of the sediments.

## 2.3 SITE SPECIFIC HYDROGEOLOGY

EDCC investigated the site hydrogeology with Phase I and Phase II groundwater investigations. The Phase I groundwater investigation drilled soil borings and installed temporary well points at thirty-five locations throughout the facility. The Phase I data were used to select locations for installation of monitor wells during the Phase II groundwater investigation. The Phase II groundwater investigation drilled 18 soil borings in which monitor wells were installed. The monitor wells were installed approximately 10 feet into the uppermost saturated unit with well depths ranging from 17 to 34.7 feet. Figure 2-1 shows the locations of the Phase II monitor wells. Reports dated January 1995 and January 1997 for the Phase I and II investigations, respectively, were prepared by Woodward-Clyde and submitted to the ADPC&E.

The soil borings indicate that the shallow soils at the site consist primarily of silty clays and clayey silts with occasional thin occurrences of silts or silty sands. Groundwater occurs within these deposits under conditions that range from semi-confined to unconfined.

Groundwater elevations were measured in the temporary well points during the Phase I groundwater investigation and in the monitor wells during the Phase II groundwater investigation and during a subsequent sampling event in October 1997. The results indicate the direction of shallow groundwater flow at the site is generally to the east-south-east, with the exception of areas locally influenced by ground surface topography and surface water. Figure 2-2 presents a groundwater elevation map for the most recent measurements (October 1997).

During 1997, Woodward-Clyde completed slug tests in monitor wells MW-EDC-4, MW-EDC-13, and MW-EDC-18 to calculate hydraulic conductivity. The hydraulic conductivity values ranged from 0.0004 to 0.000826 cm/sec. The arithmetic average hydraulic ~~specific~~ ~~conductance~~ for these three wells was 0.000661 cm/sec (1.87 ft/day).

## 2.4 GROUNDWATER SAMPLING AND ANALYSIS RESULTS

Groundwater was sampled from the temporary well points during the Phase I groundwater investigation and analyzed for nitrate, sulfate, lead and chromium. The Phase II monitor wells and four monitor wells installed previously at the EDCC landfill area were sampled during the Phase II groundwater investigation and analyzed for nitrate, sulfate, pH, specific conductance, temperature, turbidity, chromium and lead. Eight monitor wells were also sampled during October 1997. All sampling results have been previously reported to the ADPC&E.

Groundwater from 10 of the monitor wells have exhibited nitrate concentrations in excess of 10 mg/L. These monitor wells are MW-EDC-6, 7, 8, 9, 10, 11, 14, 15, 16, and 17. As specified in the CAO, these 10 monitor wells are the wells which will be included in the in-situ bioremediation program. Soil boring logs and monitor well construction diagrams are presented in Appendix A. Table 2.2 lists the analytical results for nitrate, sulfate, pH, and specific conductance for these 10 monitor wells.

Risk-based target monitoring levels for nitrate in groundwater at the site were developed and submitted to the ADPC&E in a report prepared by Woodward-Clyde in February, 1997. Groundwater modeling and risk assessment procedures were utilized in this work. The findings indicate that the existing nitrate concentrations in shallow groundwater on the site do not present unacceptable risks to human health.

## 2.5 REQUIREMENTS OF THE CAO

As discussed in Section 1.0, the CAO requires an Interim Measure which includes in-situ bioremediation in the existing groundwater monitoring wells which have exhibited nitrate concentrations in excess of 10 mg/L. Specifically the CAO requires:

- Submission of a work plan describing activities and including a schedule of significant dates for initiation of bioremediation, sampling the groundwater and submission of the sample analysis results to the ADPC&E, and preparation of annual reports evaluating the effectiveness of the Interim Measure.

- Upon receiving the ADPC&E's written approval of the work plan, implementation of the in-situ bioremediation.

- Continuation of the in-situ bioremediation activities until nitrate concentration become less than 10 mg/L or for 12 months after completion of the wastewater improvements required by Paragraph 2 of the CAO, whichever comes first.

- At the completion of the Interim Measure, prepare and submit to the ADPC&E an Interim Measures Report. If nitrate concentration exceeds 10 mg/L for any well at that time, the report is to include a recommendation of a Final Remedy and supporting documentation including an evaluation of the potential risks to human health and the environment associated with the residual concentration of nitrates in the groundwater. A determination may be made that further remediation is not necessary or that additional action may be necessary.

Nitrate can be used as an electron acceptor in microbiologically mediated oxidation reduction reactions. In these denitrification reactions, nitrate is reduced to $NO_2^-$, $N_2O$, NO, $NH_4^+$, or $N_2$ and organic matter (which is utilized as the electron donor) is oxidized. Sufficient organic matter to allow significant biodegradation of the nitrate is not expected to be present in the groundwater at the site. Consequently, the approach for the in-situ bioremediation involves adding organic matter (organic supplement) to the monitor wells to enhance the biodegradation of the nitrate.

The in-situ bioremediation is planned to be implemented in three steps as follows:

- Initial sampling and testing. Data will be collected from the ten monitor wells to provide baseline data necessary to design the in-situ bioremediation. The 10 monitor wells will be sampled and the groundwater samples will be analyzed for parameters that identify geochemical conditions, parameters that are degradation products of microbiological mediated oxidation reduction reactions, microbiological parameters, and parameters that are alternate electron acceptors. In addition, slug tests to determine hydraulic conductivity will be completed in each monitor well. These tests will allow design of the quantity and type of organic supplement to be added to enhance in-situ bioremediation and will also provide baseline information which can be used to assess effectiveness of the bioremediation.

- Preliminary field testing. Based on the results from the initial sampling and testing, two of the monitor wells will be selected to represent the range of conditions present in the ten wells. These selected monitor wells will then be used in short term field tests of the addition of organic supplement. These field tests will be used to verify the amount and mechanism for addition of the organic supplement. Following completion of the field tests, the procedures will be finalized for implementation of the in-situ bioremediation in all 10 monitor wells.

- Implementation of in-situ bioremediation. The enhanced in-situ bioremediation will be implemented in all 10 monitor wells. This will include periodic addition to each well of the organic supplement, periodic sampling and analysis of groundwater from each well, and reporting to the ADPC&E

results of the analysis. As specified by the CAO, this will continue until nitrate concentrations are less than 10 mg/L in the monitor wells or for 12 months after completion of the wastewater improvements required by Paragraph 2 of the CAO, whichever occurs first. EDCC will then prepare and submit to the ADPC&E an Interim Measures Report, as specified by the CAO.

The above activities are discussed in more detail in Sections 3.1 through 3.3. Section 4.0 discusses the overall schedule for these activities. Section 5.0 discusses reporting throughout the implementation of this plan.

## 3.1 INITIAL SAMPLING AND TESTING

The 10 monitor wells will be sampled and analyzed one time for the following chemical and microbiological parameters:

- ***pH.*** Biological activity can be inhibited by extremely low or high pH values. Current pH values will be considered in selecting the organic supplement for enhancing bioremediation. Denitrification is a hydrogen consuming reaction. The groundwater pH is likely to change (become more basic) as denitrification proceeds. Denitrification rates may be low at high pH.

- ***Specific Conductance.*** Specific conductance provides a general indication of the amount of dissolved solids present and changes in specific conductance during bioremediation may be used in assessing progress.

- ***Oxidation-Reduction Potential (ORP).*** ORP is a general indicator of the oxidizing or reducing conditions present in the groundwater and can be useful in evaluating reactions that compete with denitrification and in designing the organic supplement.

- ***Temperature.*** Groundwater temperature affects microbiological activity. Biodegradation rates are generally accelerated at temperatures above 20 degrees C.

- ***Chloride.*** At high concentrations chloride can inhibit microbiological activity.

- ***Alkalinity.*** Carbon dioxide released by microbiological activity reacts with carbonate minerals to form bicarbonate, which increases alkalinity. Increases in alkalinity can indicate increased biodegradation.

- ***Methane.*** Methane is a degradation product of anaerobic biodegradation of many organics and can be a measure of progress of bioremediation.

- ***Dissolved Oxygen (DO).*** DO is an electron acceptor which competes with nitrate in oxidation reduction reactions. Nitrate will generally not be degraded until DO has been depleted.

- ***Carbon Dioxide.*** Carbon dioxide can be a degradation product of many organics and is a potential indicator of degradation activity.

- ***Nitrate.*** The amount of nitrate present is a key factor in designing the addition of organic supplement to enhance in-situ bioremediation.

- ***Nitrite.*** Nitrite is a potential degradation intermediate of nitrate biodegradation.

- ***Ammonia and Total Kjeldahl Nitrogen (TKN).*** Ammonia and organic nitrogen, as measured by TKN, can affect microbiological activity. Ammonia and organic nitrogen could also possibly be intermediate degradation products during bioremediation of nitrate.

- ***Ferrous Iron.*** Ferrous iron is a product of utilization of ferric iron from the soil as an electron acceptor in microbiological mediated oxidation reduction reactions. However, when present in sufficient concentration, nitrate will generally out compete ferric iron as an electron acceptor in microbiological mediated oxidation reduction reactions. Ferrous iron may be produced during autotrophic denitrification which can often occur with heterotrophic denitrification. Analysis of ferrous iron may be useful as a process control for denitrification.

### *8:5.1 Autotrophic bacteria*

**Autotrophic bacteria** obtain their nutritive carbon from carbon dioxide, but it is the processes by which they obtain energy that make them beneficial to humans. Specific groups of autotrophic bacteria can oxidize ammonia, nitrites, sulfur, iron, manganese, hydrogen, and carbon monoxide (which also can be reduced by a different bacterium). The oxidation transforms mineral forms, which are often less useful to plants (nitrites, sulfides) to useful forms (nitrates, sulfates). Other oxidations eliminate toxic forms of carbon and manganese.

Probably the most important groups of autotrophic soil bacteria are those that oxidize ammonia to nitrites (a toxic form of nitrogen that is short lived) and then to nitrates (see Sec. 6: 3.3). These *nitrifying* organisms achieve maximum growth under the following conditions:

1 The presence of proteins to release ammonia as they decompose, or the presence of ammonia salts, such as ammonium sulfate.

2 Adequate aeration.

3 A moist but not wet soil.

4 A large amount of calcium (not strongly acidic).

5 Optimum temperature at 99°F (37°C) with a minimum of 41°F (5°C) and a maximum of 131°F (55°C).

The bacterial nitrification process is shown diagrammatically as follows:

$$NH_4^+ \xrightarrow{\text{Bacteria}} NO_2^- \xrightarrow{\text{Bacteria}} NO_3^-$$

| | | |
|---|---|---|
| ammonium (utilized by plants) | nitrite (temporary) (apparently toxic) | nitrate (utilized by plants) |

Nitrification is of great concern to the quality of our environment because the conversion of stable $NH_4^+$ into $NO_3^-$ may mean that the nitrates will move to contaminate groundwaters. Although a high nitrogen (protein) content is usually desirable, nitrates in high concentrations are toxic to humans and animals; in lesser concentrations, nitrates in streams and lakes can promote the growth of algae (**eutrophication**), which, when dead and decomposing, consume water oxygen needed by aquatic faunae.

Several groups of autotrophic bacteria can either oxidize or reduce carbon monoxide to carbon dioxide or methane, all of which are gases.[7] These bacteria are literally life giving. The world's population adds 220 million tons (200 million mt) of carbon monoxide to the atmosphere each year. With no conversion to carbon dioxide or methane, the atmosphere would become lethal to animal life within a few years. The bacterial conversion is always anaerobic (the absence of free oxygen), but in the absence of hydrogen, carbon monoxide (CO) is oxidized to carbon dioxide ($CO_2$); in the presence of hydrogen, CO is reduced to methane ($CH_4$). The CO oxidizing and reducing bacteria are present

[7] Robert E. Inman, Royal B. Ingersoll, and Elaine A. Levy, "Soil: A Natural Sink for Carbon Monoxide," *Science*, 172 (18 June 1971), 1229–31.

in most soils but not in those under asphalted surfaces or in congested central cities. This is one more argument for establishing and maintaining green belts to enhance the environment near large concentrations of people.

**Denitrification**, the reduction of nitrates ($NO_3^-$) to inert nitrogen gas ($N_2$), is another autotrophic bacterial reaction that is anaerobic (see Sec. 6: 3.5). *Thiobacillus denitrificans* is one of the more common bacteria of this type. The presence of elemental sulfur hastens denitrification.

### *8:5.2 Heterotrophic bacteria*

**Heterotrophic bacteria** are those that depend upon organic matter for their nutrition; in this group are most of the soil bacteria. Heterotrophic bacteria include both nitrogen-fixing and non-nitrogen-fixing kinds; the nitrogen-fixing bacteria groups are subdivided into symbiotic and nonsymbiotic. The symbiotic bacteria are most commonly associated with leguminous plants, but some non-leguminous plants also have symbiotic nitrogen-fixing bacteria.

Heterotrophic bacteria, which do not fix nitrogen, are the most prevalent type of these common soil bacteria. The non-nitrogen-fixing bacteria are the bacteria most responsible for the decomposition of organic matter. Some members of this group include (1) the *thermophilic* bacteria that continue decomposition even when released energy heats and occasionally burns hay when it is baled too wet, and (2) certain of the genus *Bacillus*, some of which produce antibiotics.

### *8:5.3 Symbiotic bacteria*

The word **symbiotic** comes from the Greek and means "living together." It is used to describe the heterotrophic bacteria that fix atmospheric nitrogen in plant root nodules because it illustrates the dependence of the process on *both* the bacteria and the host plants, the majority of which are legumes.

In the days of ancient Greece, it was known that **legumes** (pod-bearing plants such as peas, beans, alfalfa, and clovers) had a beneficial effect upon whatever crop was next planted in the same soil. It was not until 1838 that Boussingault demonstrated that the beneficial effect was due to the fixation of atmospheric nitrogen in the legume **root nodules**. In 1879, Frank proved that artificial inoculation with specific bacteria resulted in legume root nodule formation and that the bacteria in these nodules fixed atmospheric nitrogen.

Symbiotic bacteria attack the root hairs of the host plant, and the resulting injury induces the root cells to grow around the bacteria, thus forming root bulges called nodules. The bacteria live within these nodules that are produced. The plant roots supply essential minerals and organic matter to the bacteria and eventually benefit from the atmospheric nitrogen that the bacteria have fixed and used to build body protein.

- ***Total Iron.*** Total iron may be a source of autocatalytic denitrification. Suspended solids present in the well water may provide a source of nonferrous iron.

- ***Manganese.*** Manganese is a potential electron acceptor which may compete with nitrate in microbiological mediated oxidation reduction reactions.

- ***Sulfate.*** Sulfate is a potential electron acceptor. However, nitrate, when present in sufficient concentration, will generally out compete sulfate as an electron acceptor in microbiological mediated oxidation reduction reactions.

- ***Total Organic Carbon (TOC).*** TOC is a general indicator of the amount of organic matter present and is useful in determining the amount of organic supplement that will be required to enhance the bioremediation. Determination of current TOC concentrations can allow monitoring of TOC during bioremediation as a surrogate analyte for the organic supplement.

- ***Total Phosphate.*** Phosphate is an essential nutrient and, if not naturally present in sufficient concentrations, will need to be present in the organic supplement.

- ***Microbiological Testing.*** For denitrification, denitrifying bacteria can be determined. Denitrifying bacteria are a heterogeneous group of organisms that mediate the conversion of nitrate to elemental nitrogen. Testing for denitrifying bacteria can be useful in determining if the appropriate microbial population of microorganisms are being enhanced and if the injection of nutrients is stimulating microbial activity.

### 3.1.1 Sampling Procedures

The monitor wells will be purged and sampled using a redi-flow submersible pump. The general procedure will be as follows:

The well caps will be removed and the static water level and the total depth of the well will be measured using an electronic water level sensor. Depth to water will be referenced to the survey point (generally the top of the PVC well casing).

Wells will be purged until a volume equaling at least three times the calculated standing water in the well has been removed. This is calculated as follows:

Volume of water in the casing (gallons) = 3.14 x $r^2$ x (H-h) x 7.48

where:

Depth to water (feet) = h
Depth of well (feet) = H
Radius of well (feet) = r

The specific conductance, pH, temperature, DO, and turbidity will be measured prior to and during purging. If the specific conductance (within 10%), pH (within 0.1 standard units), temperature (within 0.5 degree C), DO ( within 10%) or turbidity within (10% or less than 5 NTU) of the water has not stabilized when three well volumes have been purged, then purging will continue until these parameters have stabilized or to a maximum of five well volumes. If a well is purged to dryness, the well will be allowed to recover prior to collecting samples.

When the well has been purged the samples will be collected with the redi-flow pump. The sampling pump will be decontaminated between each use. New discharge tubing will be used at each well. Discharge rate of the pump will be reduced to approximately 100 ml/min for sampling for dissolved gases. Samples for analysis for ferrous iron will be filtered with a 0.45 micron filter placed in-line on the discharge line from the pump. All other samples will be unfiltered. Flow-through cells will be used for field measurements of samples for pH, specific conductance, DO, ORP, and temperature.

### 3.1.2 Analysis of Samples

The analytical methods, containers, and preservatives for each analyte are listed in Table 3.3.1. Samples will be handled under chain-of-custody procedures and will be transported to a commercial laboratory for analysis.

### 3.1.3 Hydraulic Conductivity Tests

Slug tests to determine hydraulic conductivity will be completed for each of the ten monitor wells. The following procedures will be used:

- The static water level will be measured using an electronic water level sensor which will be decontaminated between wells.

- A pressure transducer will be lowered into the well to measure water level changes and proper functioning of the transducer and recording data logger will be checked.

- A slug (suspended weight of known volume) will be lowered into (slug-in test) the water in the well. The slug will be introduced as rapidly as possible without causing undue splashing or turbulence, so as to produce an instantaneous head increase. The magnitude of the slug will be such that the slug will not cause water to overflow the well casing. The slug will be decontaminated prior to use in each well.

- The data logger will record the water levels continuously (millisecond intervals). Measurements will continue until the water level stabilizes.

- Water level measurements will be checked for credibility before proceeding to the next testing stage (slug-out test).

- When checking of the data has been completed and the data determined to be acceptable, the slug will be removed from the well as rapidly as possible, so as to produce an instantaneous head reduction. Water levels will be measured and recorded continuously, the same as in the slug-in stage of the testing. Measurements will be terminated when the water level stabilizes.

- Water levels will be checked for credibility before proceeding to the next well. Any test or test stage will be repeated if the field review of the recorded data indicates questionable validity.

- The data from the slug test will be reduced to evaluate time versus change in water level using the methods of Cooper et. al. (1967) or Bouwer and Rice (1976).

## 3.2 PRELIMINARY FIELD TESTING

The data collected during the initial sampling and testing will be used to design the preliminary field tests. This will involve selection of two or three monitor wells for the tests, selection of the appropriate organic supplement, and selection of procedures for supplement addition and for monitoring. These activities are discussed in Sections 3.2.1, 3.2.2, and 3.2.3, respectively.

### 3.2.1 Selection of Monitor Wells

Monitor wells will be selected to provide tests representative of the range of conditions present in the 10 monitor wells. Key factors in the selection are expected to be concentrations of the various nitrogen species (nitrate, ammonia, and TKN), pH, and microbiological parameters.

Final determination of the wells will be made after the initial sampling and testing has been completed. It is anticipated that two pilot wells will be used to evaluate denitrification potential. Two ranges of nitrate concentrations will be evaluated: 10 – 400 mg/L and above 400 mg/L. Denitrification in the low concentration range is less likely to be complicated by clogging of the permeable zone due to biomass growth and the production of intermediates such as nitrite. However, areas of high nitrate concentration are more likely to develop denitrifying microbial populations. The optimum pH range for denitrification is 7 – 8 (Bengtsson 1995); however, since denitrification is a hydrogen consuming reaction, denitrification may be preferred at low pHs.

### 3.2.2 Selection of Organic Supplement and Application Method

There are numerous methods that are utilized in the denitrification of groundwater. For in-situ denitrification, two common practices are:

1. Direct injection of a carbon source into selected wells. The most direct and straightforward method of promoting denitrification is to inject wells with a

carbon substrate. Carbon limitation is often the cause of nitrate accumulation in groundwater (Bradley 1992). A variety of common substrates may be utilized, such as ethanol, methanol, sucrose, molasses, cellulose, acetate, and urea. The carbon sources that are most readily utilized by indigenous microorganisms in the groundwater are natural carbon sources, such as cellulose and acetate; however, positive results have been achieved with a variety of carbon sources. Molasses, methanol, cellulose, and acetate will be evaluated following completion of the initial sampling and testing. One or two of these supplements will be selected for use in the field tests.

The most significant drawback to substrate injection is aquifer fouling due to the production of biomass (Hiscock et.al.1991 and Dahab 1993). In some cases, significant denitrification can lead to gas production (nitrous oxide or nitrogen) that can also promote aquifer clogging. To limit the potential for aquifer clogging, the substrate may be pulse injected. Initially, the concentration of substrate will be limited to reduce the potential for over production of biomass.

2. Utilization of Hydrogen Releasing Compound®. Hydrogen Releasing Compound (HRC) is produced by Regenesis to promote reductive dechlorination of chlorinated solvents. The HRC, upon hydration, slowly releases lactic acid into the groundwater. The lactic acid can be fermented to produce hydrogen gas which drives reductive dechlorination. In the presence of other electron acceptors, such as nitrate and sulfate, HRC is utilized by denitrifying and sulfate reducing bacteria. The principal advantage of HRC is reduced potential for aquifer clogging versus direct injection. HRC may be evaluated for wells where aquifer clogging due to biomass production is observed.

Direct injection of molasses, methanol, cellulose, or acetate is anticipated to be the preferred remedial method. HRC may be evaluated if aquifer clogging is observed. Additional nutrient needs (i.e. ammonia and/or phosphate) will be evaluated during the preliminary field testing.

### 3.2.3 Procedures for the Tests

Procedures for the tests will be finalized after completion of the initial sampling and testing. However, these tests are expected to be conducted for an approximately eight week period. The organic supplement will be periodically added to each of the selected wells during the test period. The frequency and amount of addition is dependent on findings from the initial sampling and testing. Prior to each addition of supplement and at the end of the test, each well will be sampled and analyzed for certain parameters. On a preliminary basis these parameters are expected to be the following:

| | Week | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Parameter** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| pH | X | X | X | X | X | X | X | X | X |
| Specific Conductance | X | | | | X | | | | X |
| DO | X | X | X | | X | | | | X |
| ORP | X | | X | | X | | | | X |
| Nitrate | X | X | X | X | X | X | X | X | X |
| Ammonia | X | | X | | X | | X | | X |
| TKN | X | | | | X | | | | X |
| TOC | X | | X | | X | | X | | X |
| Alkalinity | X | | | | X | | | | X |
| Temperature | X | X | X | X | X | X | X | X | X |
| Carbon Dioxide | X | | X | | X | | X | | X |
| Nitrite | X | | X | | X | | X | | X |
| Chloride | X | | | | X | | | | X |
| Phosphate | X | | X | | X | | X | | X |
| Manganese | X | | | | X | | | | X |
| Denitrifying Bacteria | X | | X | | X | | | | X |
| Ferrous Iron | X | | | | X | | | | X |
| Total Iron | X | | | | X | | | | X |

Many of these analytes can be analyzed in the field to provide immediate data for evaluating supplement addition rates.

## 3.3 IMPLEMENTATION OF IN-SITU BIOREMEDIATION

The specifics of the bioremediation will be developed following completion of the preliminary field tests. This information will be transmitted to the ADPC&E prior to implementing the in-situ bioremediation.

Specifications for the mix, frequency, and method of addition of organic supplement will be provided for each of the 10 monitor wells. Each monitor well will be inspected each time supplement is added.

A monitoring program will be specified as part of the implementation. Specifics will be presented in the aforementioned transmittal to the ADPC&E. Semiannual monitoring of the 10 monitor wells for a specific set of analytes is anticipated. Analysis for additional parameters may be specified on an annual basis, as necessary. Analytical results from each sampling will be reported to the ADPC&E within 45 days of receipt by EDCC. Results will be discussed in the annual report to the ADPC&E and in the Interim Measures Report.

Figure 4-1 presents the proposed overall schedule. Milestones include the following:

- December 10, 1998 - Submittal of work plan to ADPC&E
- January 29, 1999 - Anticipated receipt of ADPC&E approval of work plan
- ≈ March 29, 1999 - Submittal of results of initial sampling and testing and of plans for preliminary field tests
- ≈ August 29, 1999 - Submittal of results of preliminary field tests and of plans for implementation
- ≈ September 29, 1999 up to August 1, 2002 - Operation of in-situ bioremediation
- November 1, 2002 - Submittal of Interim Measures Report

The above milestones are based on an assumed date of the ADPC&E approval of the Work Plan and the schedule may vary according to the actual date of approval. Also, the assumed period of operation of the in-situ bioremediation and of submittal of the Interim Measures Report may be accelerated if the nitrate concentrations are reduced before the latest date for completion of operation (August 1, 2002) is reached.

The following reports are planned:

- The results of the initial sampling and testing and the plans for the preliminary field tests will be transmitted as a letter report. All analytical results will be appended. Relevant findings will be discussed.

- The results of the preliminary field tests and the plans for the implementation of the in-situ bioremediation will be transmitted to the ADPC&E as a letter report. All analytical results will be appended. The planned supplement mix and the frequency and amount of addition for each well will be identified. The monitoring and reporting program will be specified.

- During implementation of the in-situ bioremediation, monitoring results will be submitted to the ADPC&E within 45 days of receipt of laboratory results. Monitoring is expected to be on a semiannual basis.

- Annual reports for a calendar year will be submitted by March 31 of the subsequent year. The reports will include all analytical results for the reporting period. Concentration changes over time will be discussed. Changes in the remediation will be discussed, if any changes were necessary. A groundwater elevation map will be included and any significant changes in direction of hydraulic gradient will be discussed.

- An Interim Measures Report will be submitted to the ADPC&E following completion of the Interim Measures. The report will document the Interim Measures. If nitrate concentration in any monitor well exceeds 10 mg/L, an evaluation of risks to human health and the environment associated with the residual concentrations of nitrate will be included. The risk evaluation will utilize the factors identified in the ADPC&E Regulation 22 at Section 22.1207(c)(1) through 22.1207(d)(8). The report will either include a determination that further action is not necessary or it will include a recommendation and supporting documentation for a Final Remedy.

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Woodward-Clyde, 1997. Phase II Groundwater Assessment Report, El Dorado Chemical Company, El Dorado, Arkansas. January 1997.

Woodward-Clyde, 1997. Development of Risk Based Target Monitoring Levels, Revision 1, El Dorado Chemical Company, El Dorado, Arkansas. December 1997.

TABLES

# TABLE 2-1

## DESCRIPTION OF REGIONAL HYDROGEOLOGIC UNITS IN THE EL DORADO, ARKANSAS AREA
## EL DORADO CHEMICAL COMPANY
## EL DORADO, ARKANSAS

| System | Series | Group | Formation | Hydrogeologic Unit | Hydrogeologic Properties |
|---|---|---|---|---|---|
| Quaternary | Holocene and Pleistocene | | Alluvial and terrace deposits | | Clay, silt, sand, and gravel. Present only in bottomlands of most streams. Generally not used. As much as 100 feet thick. |
| Tertiary | Eocene | Claiborne | Cockfield Formation | Cockfield aquifer | Lignitic sand with interbedded clay. Principal aquifer for rural domestic supply. Approximately 200 feet thick where present. |
| | | | Cook Mountain Formation | Cook Mountain confining unit | Clay with interbedded fine sand. Not an aquifer. Thickness ranges from 50 to 200 feet. |
| | | | Sparta Sand | Greensand aquifer | Thinly bedded fine glauconitic sand with interbedded clay. Source of municipal and industrial water supply principally in southeast part of county. Water withdrawals approximately 0.5 million gallons per day. Approximately 200 feet thick. |
| | | | | Middle confining bed | Clay and silt. Not an aquifer. Thickness ranges from 40 to 160 feet. |
| | | | | El Dorado aquifer | Thickly bedded medium to coarse sand. Source of municipal and industrial water supply throughout the county. Water withdrawals approximately 14 million gallons per day. Approximately 300 feet thick. |
| | | | Cane River Formation | Cane River confining unit | Clay and silty clay. Not an aquifer. Approximately 300 feet thick. |

**From Leidy and Taylor, 1992**

TABLE 2-2

ANALYTICAL RESULTS
MONITOR WELLS THAT HAVE EXHIBITED NITRATE CONCENTRATIONS EXCEEDING 10 MG/L
EL DORADO CHEMICAL COMPANY
EL DORADO, ARKANSAS

| Well No. | Nitrate (mg/l) March-April 1996 | Nitrate (mg/l) October 1997 | Sulfate (mg/l) March-April 1996 | Sulfate (mg/l) October 1997 | pH (S.U.) March-April 1996 | pH (S.U.) October 1997 | Specific Conductance (umhos/cm) March-April 1996 | Specific Conductance (umhos/cm) October 1997 |
|---|---|---|---|---|---|---|---|---|
| MW-EDC-6 | 51.1 | NS | 24 | NS | 7.7 | NS | 700 | NS |
| MW-EDC-7 | 282 | NS | 380 | NS | 8.1 | NS | 700 | NS |
| MW-EDC-8 | 1010 | 773 | 68.3 | 95.9 | 7.9 | 4.3 | 710 | 735 |
| MW-EDC-9 | 37.3 | NS | 621 | NS | 9 | NS | 320 | NS |
| MW-EDC-10 | 257 | NS | 89 | NS | 7.7 | NS | 410 | NS |
| MW-EDC-11 | 22.1 | NS | 578 | NS | 11.1 | NS | 130 | NS |
| MW-EDC-14 | 11.9 | NS | 139 | NS | 4.6 | NS | 650 | NS |
| MW-EDC-15 | 34.5 | NS | 4.4 | NS | 6.4 | NS | 266 | NS |
| MW-EDC-16 | 137 | NS | 4.6 | NS | 5.7 | NS | 890 | NS |
| MW-EDC-17 | 45 | 109 | 145 | 74.5 | 4.9 | 4.2 | 730 | 1230 |

NS = NOT SAMPLED

# TABLE 3-1

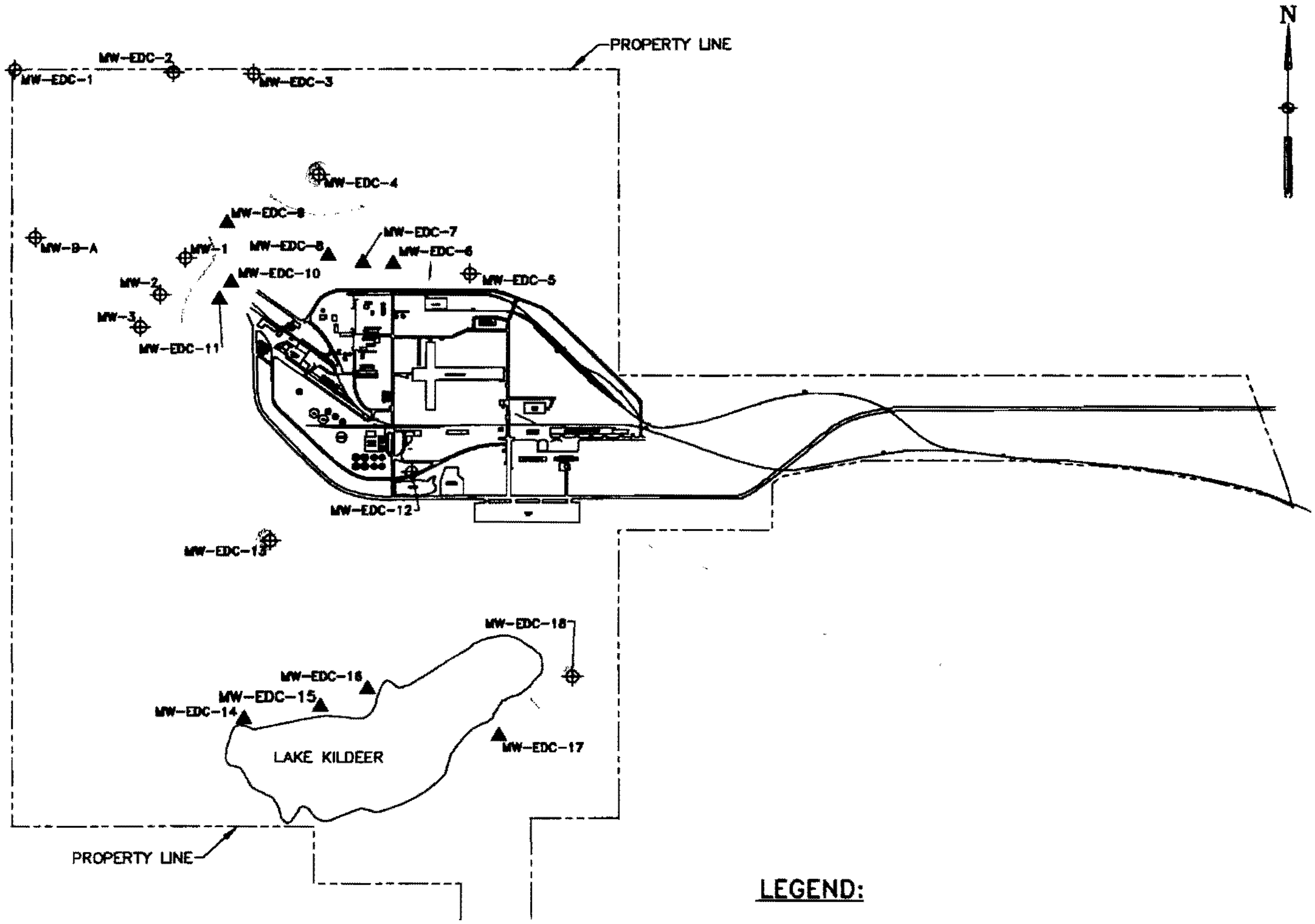
## SAMPLE CONTAINERS, PRESERVATION METHODS AND ANALYTICAL METHODS
## EL DORADO CHEMICAL COMPANY
## EL DORADO, ARKANSAS

| Parameter | Analytical Method/Instrument | Field or Laboratory Analysis | Container | Preservation [1] | Field Filtered | Hold Time [2] | Special Consideration |
|---|---|---|---|---|---|---|---|
| Dissolved Oxygen | Multi-Parameter Probe with Flow-Through Cell | Field | NA | None | No | NA | Two-point calibration between wells; record parameters when readings stable. |
| Oxidation-Reduction Potential (ORP) | Multi-Parameter Probe with Flow-Through Cell | Field | NA | None | No | NA | Record parameters when readings stable. |
| Specfic Conductance | Multi-Parameter Probe with Flow-Through Cell | Field | NA | None | No | NA | Record parameters when readings stable. |
| Temperature | Multi-Parameter Probe with Flow-Through Cell | Field | NA | None | No | NA | Record parameters when readings stable. |
| pH | Multi-Parameter Probe with Flow-Through Cell | Field | NA | None | No | NA | Record parameters when readings stable. |
| Ferrous Iron | HACH Test Kit-8146 | Field | 1 x 100 mL (G,P) | Ice (4°C) | Yes | ASAP | Minimize introduction of oxygen. |
| Carbon dioxide | HACH Test Kit 26193-07 | Field | 1 x 100 mL (G) | None | No | ASAP | |
| Total Iron | EPA Method 3010, 6010 | Laboratory | 1 x 250 mL (G,P) | Cool 4°C, HCl to pH<2 | No | 6 Months | |
| Manganese | EPA Method 3010, 6010 | Laboratory | 1 x 250 mL (G,P) | Cool 4°C, HCl to pH<2 | No | 6 Months | |
| Major Anions ($Cl^-$, $NO_3^-$, $NO_2^-$, $SO_4^{-2}$) | EPA Method 300, 353.2 | Laboratory | 1 x 1,000 mL (G,P) | Ice (4°C) | No | 48 Hours | |
| Alkalinity | EPA Method 310.1 | Laboratory | 1 x 250 mL (G,P) | Ice (4°C) | No | 14 Days | |
| Methane | Method AM-19 or RSK-175 | Laboratory | 3 x 40 mL VOA | Ice (4°C) | No | ASAP | Method by Microseeps, Inc. or Robert S. Kerr Laboratory |
| Ammonia | EPA Method 350.3 | Laboratory | 1 x 1,000 mL (G,P) | Cool 4°C, $H_2SO_4$ to pH<2 | No | 28 Days | |
| Total Kjeldahl Nitrogen | EPA Method 351.3 | Laboratory | 1 x 1,000 mL (P) | Cool 4°C, $H_2SO_4$ to pH<2 | No | 28 Days | |
| Total Phosphate | SW846 9060 | Laboratory | 1 x 500 mL (P) | Cool 4°C, $H_2SO_4$ to pH<2 | No | 48 Hours | |
| Total Organic Carbon | SW846 9060 | Laboratory | 2 x 125 mL (A,G) | Cool 4°C, $H_2SO_4$ to pH<3 | No | 28 Days | |
| Denitrifying Bacteria | HACH Test Kit 1436-01 | Field | 50 mgL (G) | None | No | ASAP | |

NOTE:
Wells to be purged and sampled as per USEPA Region IV and DNR Protocols.

Key:
NA = Not Applicable.
G,P = Glass or Polyethylene container.
A = Amber container.
SW846 = Test Methods for Evaluating Solid Waste, dated 4/92.
EPA = "Methods for Chemical Analysis of Water and Waste", 1979, Revision 3/83.
[1] Sample preservation is performed by sampler immediately upon sample collection if not already done so by the laboratory.
[2] Hold time based upon day of sample collection not verified time of sample receipt.

FIGURES




## LEGEND:

MW-1 ⊕ MONITOR WELL WITH NITRATE < 10 mg/l

▲ MONITOR WELL WITH NITRATE > 10 mg/l

SCALE: 1 INCH=1600 FEET

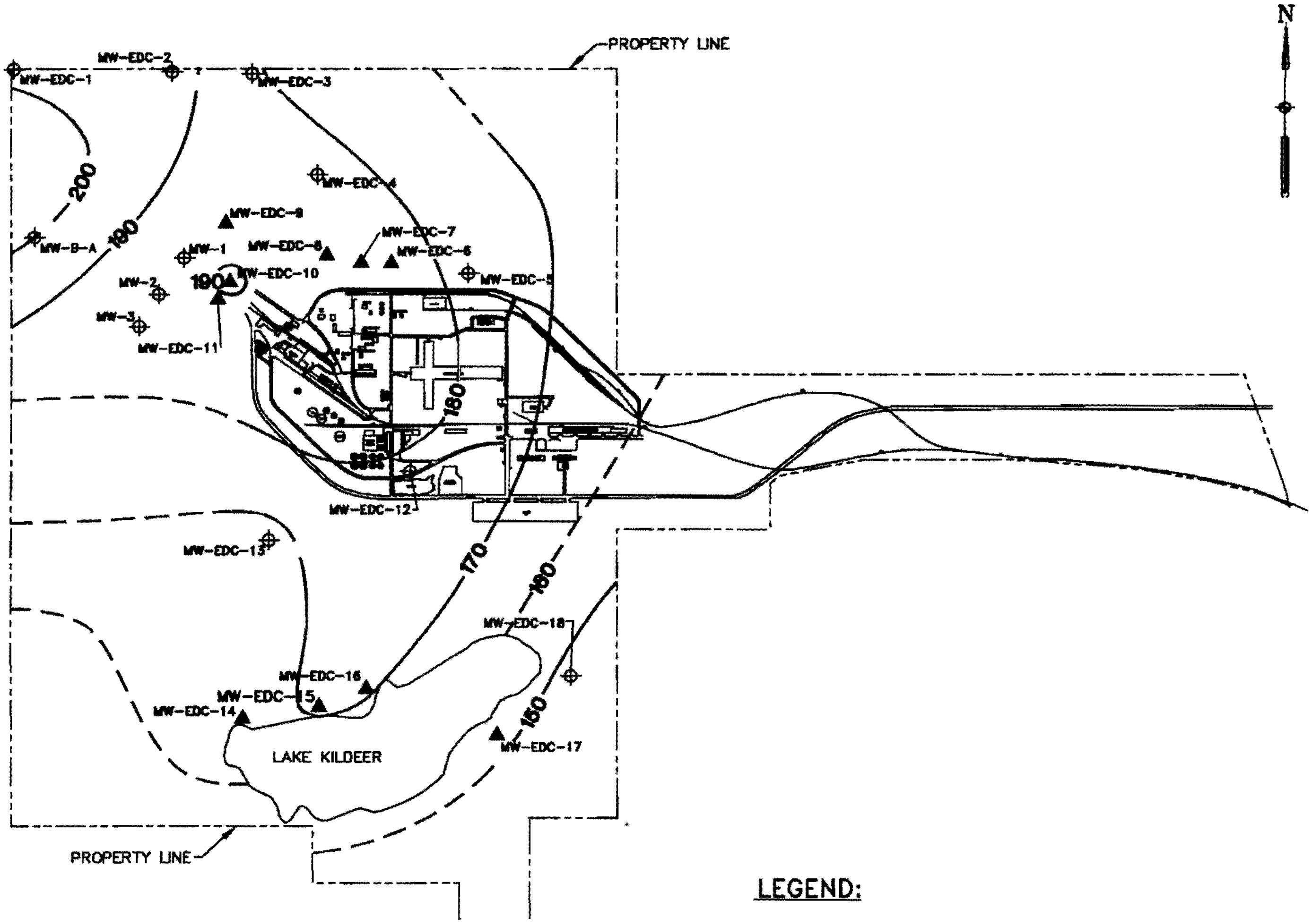
1600' 0 1600'

NOTE: THE BASE FOR THIS DRAWING WAS CREATED USING THE FOLLOWING REFERENCES

1. EL DORADO CHEMICAL CO. PLOT PLAN, DWG. NO. 7045-1.
2. SMITH-ROBERTS AND ASSOCIATES TRACT LOCATION MAP (QUAD), SC31,663C DWG. NO. SHT.4.
3. BALL AND PAULUS SURVEYORS, INC. JOB NO. 181F-95, MONITORING WELLS.

| | | | | | | |
|---|---|---|---|---|---|---|
| EL DORADO CHEMICAL COMPANY | URS Greiner Woodward Clyde<br>2822 O'Neal Lane<br>Baton Rouge, Louisiana 70816<br>225/751-1873 | | | | WORK PLAN<br>IN-SITU BIOREMEDIATION<br><br>SITE MAP | FILE NO.<br>98B319<br>FIG. NO.<br>2-1 |
| | SCALE: AS SHOWN | DRAWN BY: | PCG | DATE: 12/3/98 | | |
| | | CHKD. BY: | DR | DATE: 12/3/98 | | |

K:\ELDORADO\ELDORADO\98B319\98b319B.DWG Thu Dec 03 10:59:53 1998




## LEGEND:

- MW-1 ⊕ MONITOR WELL WITH NITRATE < 10 mg/l
- ▲ MONITOR WELL WITH NITRATE > 10 mg/l
- 200 EQUIPOTENTIAL CONTOUR LINE
- INFERRED EQUIPOTENTIAL CONTOUR LINE

SCALE: 1 INCH=1600 FEET

1600' 0 1600'

NOTE: THE BASE FOR THIS DRAWING WAS CREATED USING THE FOLLOWING REFERENCES

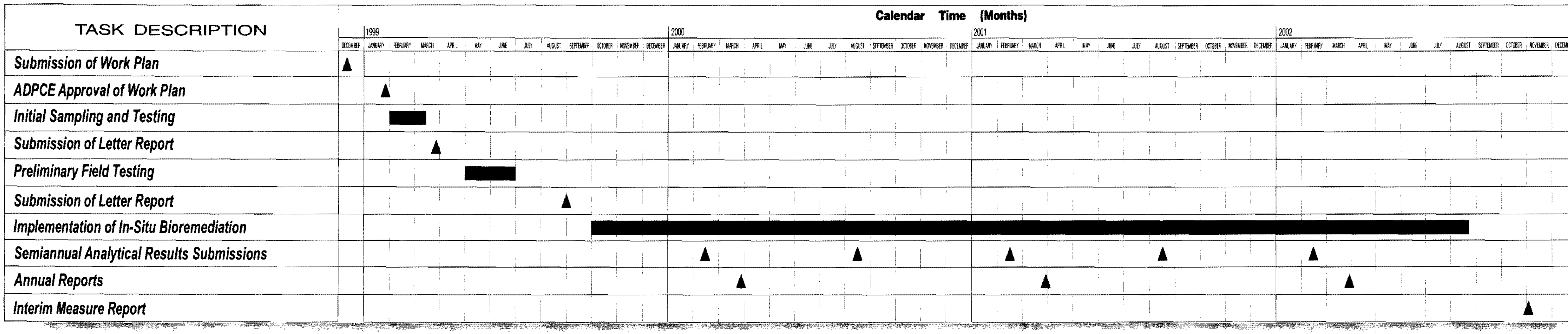
1. EL DORADO CHEMICAL CO. PLOT PLAN, DWG. NO. 7045-1.
2. SMITH-ROBERTS AND ASSOCIATES TRACT LOCATION MAP (QUAD), SC31,663C DWG. NO. SHT.4.
3. BALL AND PAULUS SURVEYORS, INC. JOB NO. 181F-95, MONITORING WELLS.

| | | | | |
|---|---|---|---|---|
| EL DORADO CHEMICAL COMPANY | **URS Greiner Woodward Clyde**<br>2822 O'Neal Lane<br>Baton Rouge, Louisiana 70816<br>225/751-1873 | | WORK PLAN<br>IN-SITU BIOREMEDIATION<br><br>GROUNDWATER ELEVATIONS, OCTOBER, 1997 | FILE NO. 98B319 |
| | SCALE: AS SHOWN | DRAWN BY: PCG DATE: 12/3/98<br>CHKD. BY: DR DATE: 12/3/98 | | FIG. NO. 2-2 |

K:\ELDORADO\ELDORADO\98B319\98b319C.DWG Thu Dec 03 11:04:00 1998

**FIGURE 4-1.** PROPOSED SCHEDULE IN-SITU BIOREMEDIATION FROM EL DORADO CHEMICAL COMPANY EL DORADO, ARKANSAS

EL DORADO
CHEMICAL COMPANY




URSGWC FILE: R:\DPOLSON\ELDORADO\SHEDULE Dec98.CDR

# APPENDIX A

# SOIL BORING LOGS AND MONITOR WELL CONSTRUCTION DIAGRAMS FOR MONITOR WELLS TO BE USED IN THE IN-SITU BIOREMEDIATION

# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-06 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/21/96 |
| CLIENT: | El Dorado Chemical Company<br>El Dorado, Arkansas | GEOLOGIST: | EJF |
| | | APPROVED: | [signature] |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 18 | Light gray (5YR, 7/1) Clayey SILT; damp; dense. | (ML) |
| 9–14 | | | | 18 | Reddish gray (5YR, 5/2) Silty CLAY; dry to damp. | (CL) |
| 14–19 | | | | 18 | Wet reddish gray (5YR, 5/2) SILT and Silty SAND. | (ML/SM) |
| 19 | | | | | End of Boring at 19'. | |

SITE EL DORADO CHEMICAL CO.

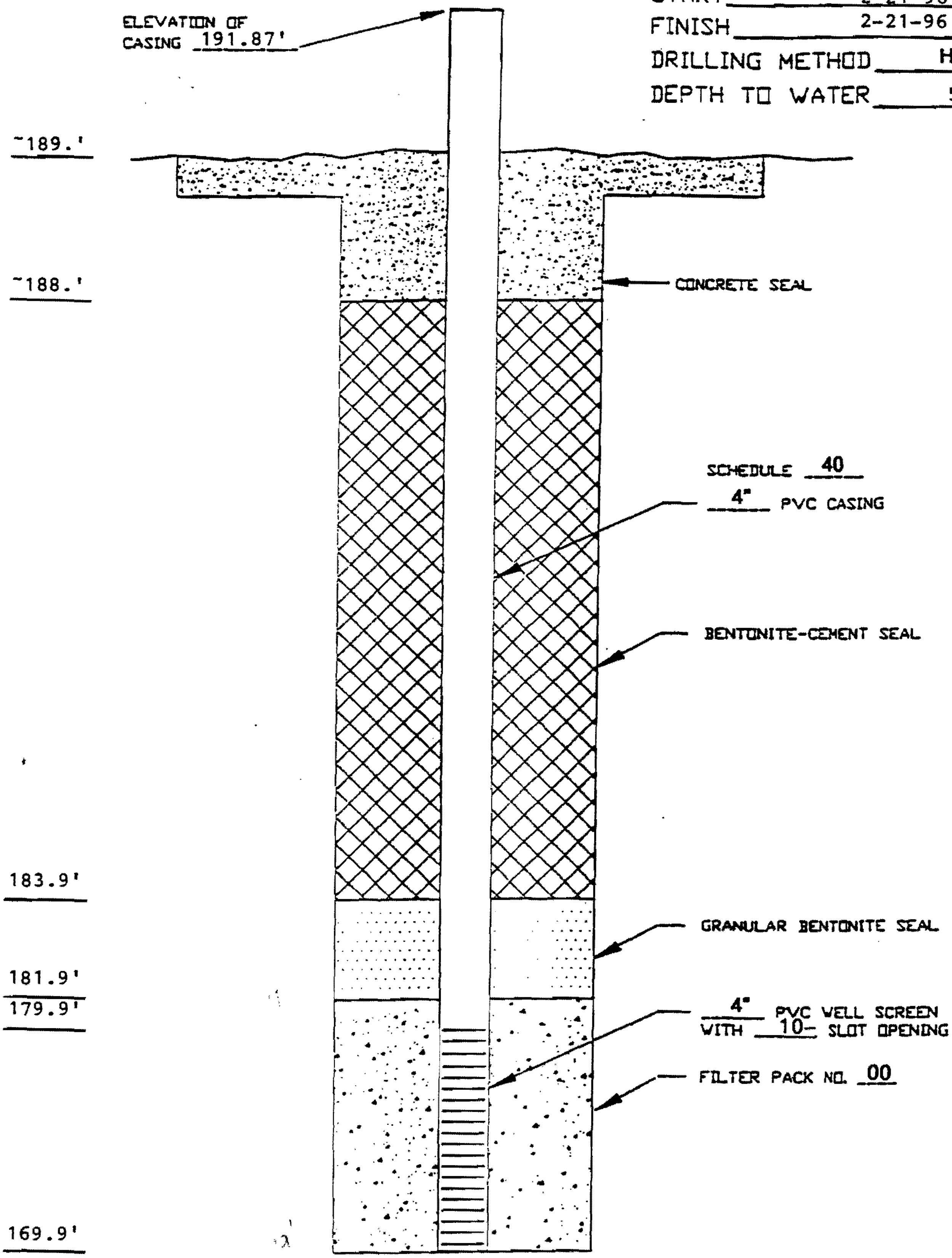
WELL NUMBER MW-EDC-6

START 2-21-96

FINISH 2-21-96

DRILLING METHOD HSA

DEPTH TO WATER 5.73'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO.<br>95B165 |
| | SCALE: DRAWN BY: DATE:<br>CHKD. BY: [illegible] DATE: 5/96 | | FIG. NO |

## LOG OF BORING

PROJECT: Monitor Well Installation
LOCATION: El Dorado, Arkansas

CLIENT: El Dorado Chemical Company
El Dorado, Arkansas
DRILLER: Anderson Engineering

BORING: MWEDC-07
FILE: 95B165
DATE: 2/20/96
GEOLOGIST: EJF
APPROVED:
PAGE: 1 of 1

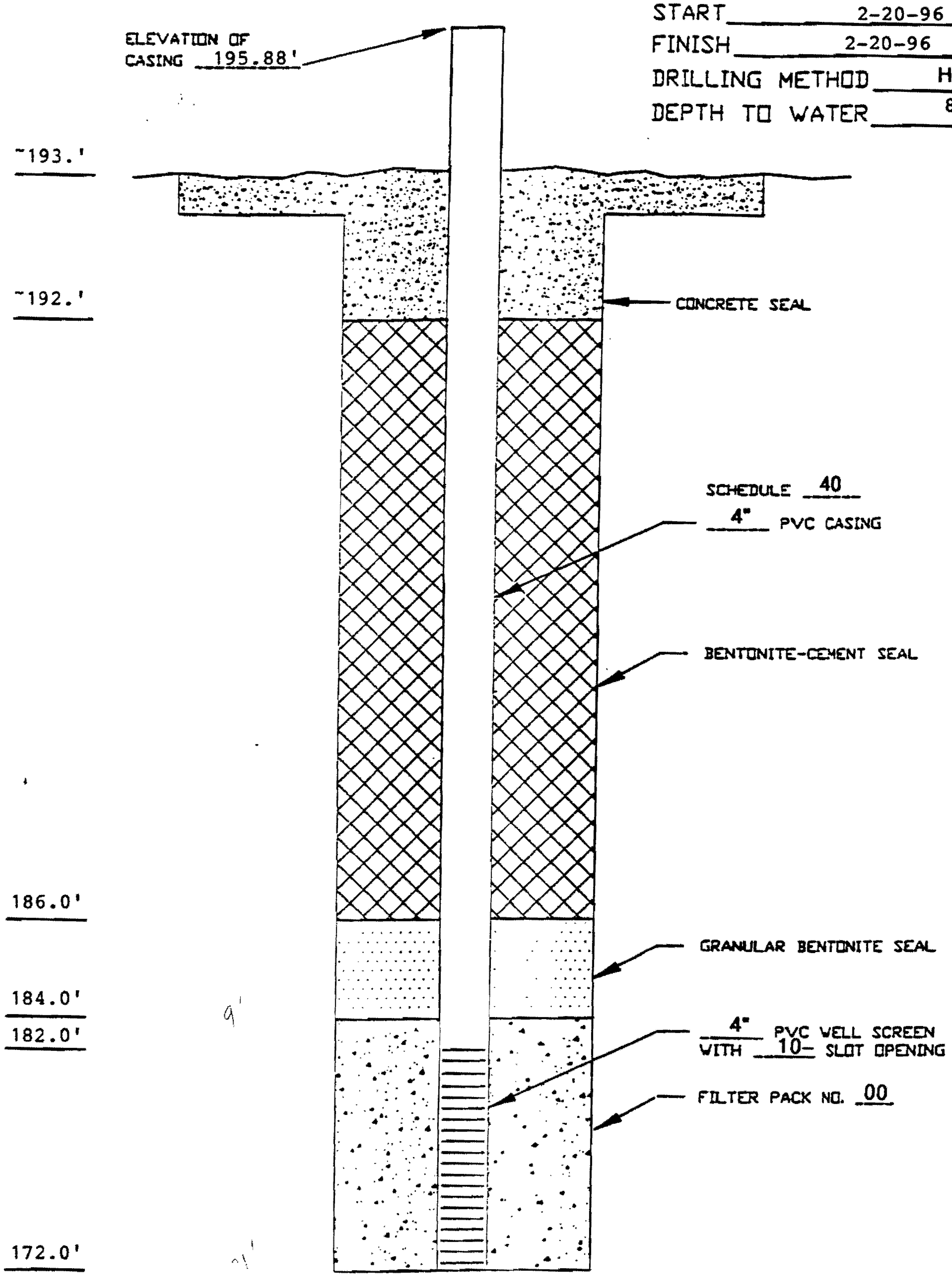
Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 18 | Reddish yellow (7.5YR, 6/6) Silty SAND with traces of light gray SILT; dry. | (SM) |
| 9–19 | | | | 18 | Stiff reddish gray (5YR, 5/2) CLAY. | (CL) |
| | | | | 18 | —very stiff dark gray (10YR, 4/1) CLAY. | (CL) |
| 19–22 | | | | 18 | Wet, loose light gray (5YR, 7/1) SILT and fine Silty SAND. | (ML/SM) |
| 22 | | | | | End of Boring at 22'. | |



Woodward-Clyde Consultants

SITE EL DORADO CHEMICAL CO.
WELL NUMBER MW-EDC-7
START 2-20-96
FINISH 2-20-96
DRILLING METHOD HSA
DEPTH TO WATER 8.45'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO. 95B165 |
| | SCALE: DRAWN BY: DATE: | | FIG. NO |
| | CHKD. BY: [illegible] DATE: 5/96 | | |

# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-08 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/20/96 |
| CLIENT: | El Dorado Chemical Company | GEOLOGIST: | EJF |
| | El Dorado, Arkansas | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|
| 0–9 | | 18 | Fill material consisting of dark brown (5YR, 7/1 + 10YR, 6/3) Sandy CLAY, yellow brown medium SAND, and light gray Silty SAND, loose. | (SC/SP) |
| 9 | | 18 | Light gray (5YR, 7/1) Silty CLAY; medium dense; damp. | (CH) |
| 14 | | 18 | Very stiff dark grayish brown (10YR, 4/1) CLAY. | |
| 20 | | 4 | Light gray (5YR, 7/1) CLAY and light brown fine SAND. | (CL/SM) |
| 24 | | | —wet, light gray (5YR, 7/1) fine Silty SAND. | (SM) |
| 27 | | | End of Boring at 27'. | |

SITE EL DORADO CHEMICAL CO.

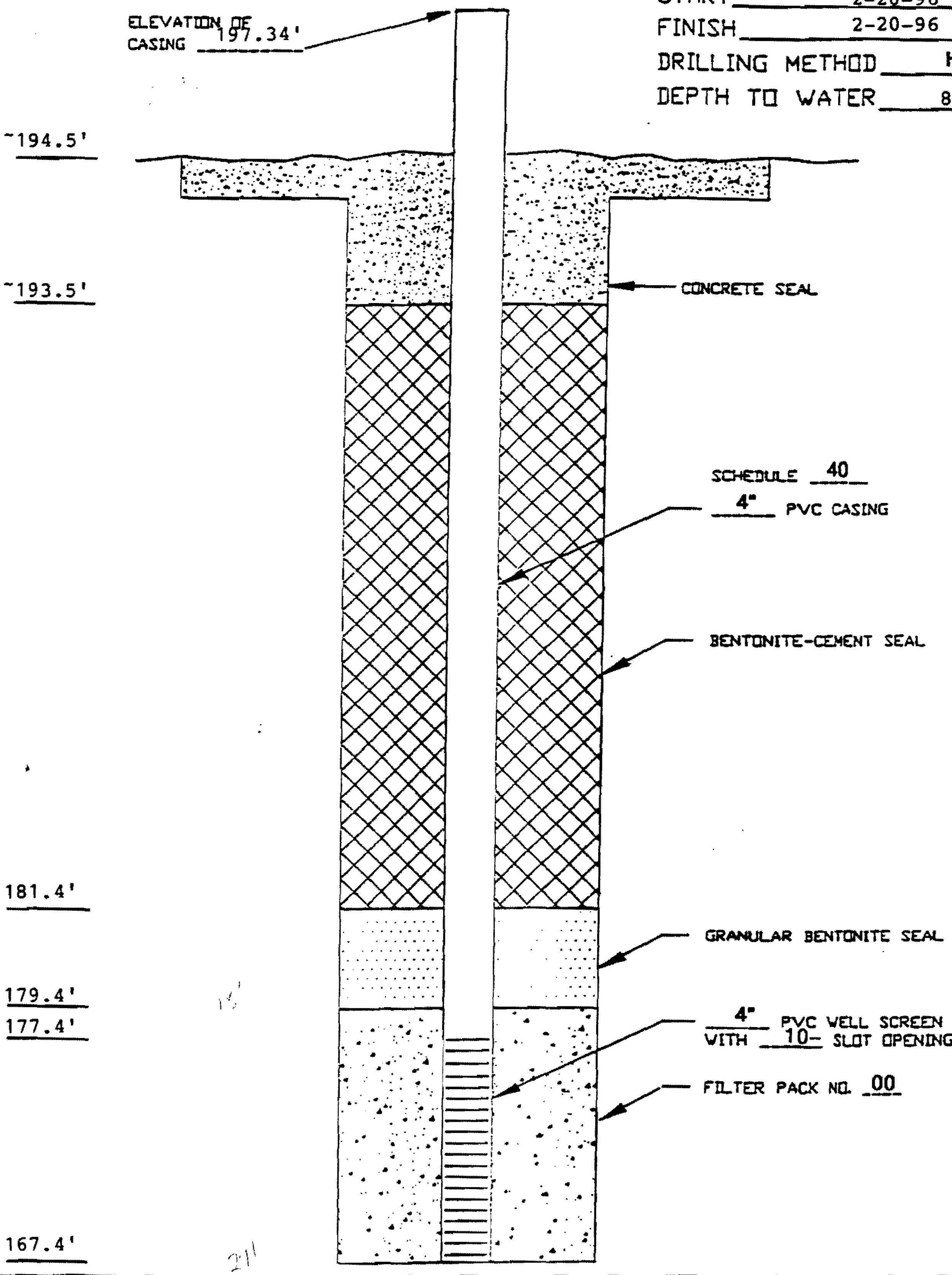
WELL NUMBER MW-EDC-8

START 2-20-96

FINISH 2-20-96

DRILLING METHOD HSA

DEPTH TO WATER 8.69'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | **Woodward-Clyde Consultants**<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO 95B165<br>FIG. NO |
| | SCALE: DRAWN BY: DATE:<br>CHKD. BY: EF DATE: 5/96 | | |

## LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-09 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/15/96 |
| CLIENT: | El Dorado Chemical Company | GEOLOGIST: | EJF |
| | El Dorado, Arkansas | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–10 | | | | 18 | White - light gray (5YR, 8/1-7/1) dense Silty CLAY; dry. | (CL) |
| 10 | | | | 18 | Light gray (5YR, 7/1) stiff CLAY; damp; with lenses. | (CL/ML) |
| 14 | | | | 18 | —stiff gray (5YR, 7/1) CLAY; moist | (CL) |
| 20 | | | | 18 | —dark gray (5YR, 7/1) stiff CLAY with white to light gray SILT; damp. | (CL) |
| 26 | | | | 18 | Wet gray (5YR, 7/1) SILT. | (ML) |
| 28 | | | | | End of Boring at 28'. | |



Woodward-Clyde Consultants

SITE EL DORADO CHEMICAL CO.

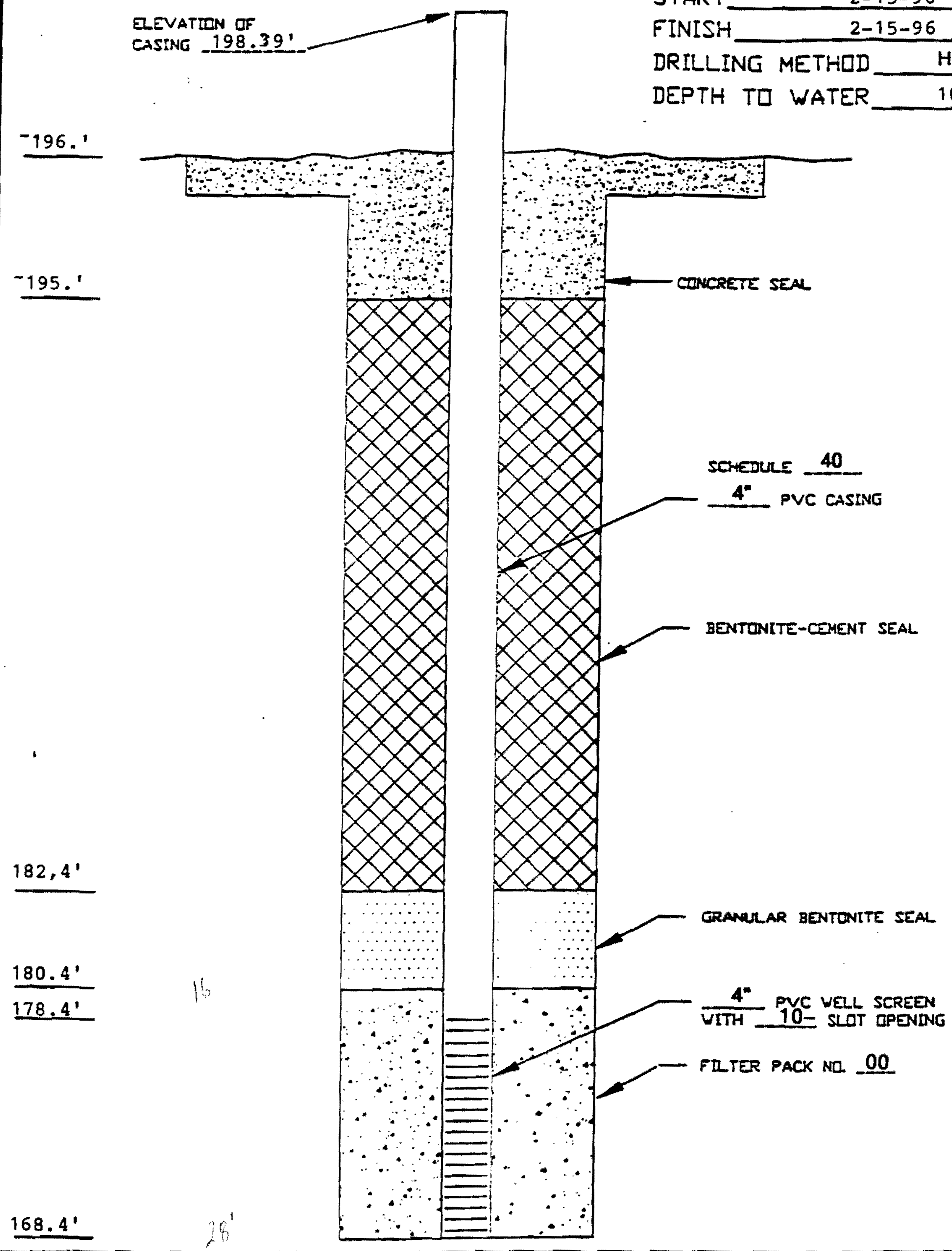
WELL NUMBER MW-EDC-9

START 2-15-96

FINISH 2-15-96

DRILLING METHOD HSA

DEPTH TO WATER 10.43'




| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL CONSTRUCTION DIAGRAM | FILE NO 95B165 |
|---|---|---|---|
| | SCALE: DRAWN BY: DATE: | | FIG. NO |
| | CHKD. BY: JEF DATE: 5/96 | | |

# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-10 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/19/96 |
| CLIENT: | El Dorado Chemical Company<br>El Dorado, Arkansas | GEOLOGIST: | EJF |
| | | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 16 | Stiff gray (5YR, 6/1) CLAY; dry. | (CL) |
| 9–14 | | | | 18 | Stiff reddish gray (5YR, 5/2) Silty CLAY with traces of yellow Silty SAND; dry to damp. | (CL) |
| 14–20 | | | | 18 | Reddish brown (5YR, 5/2 + 7/1) CLAY with intermittent light brown SILT and yellow fine sand lenses; wet. | (CL/SM) |
| 20 | | | | | End of Boring at 20'. | |

SITE EL DORADO CHEMICAL CO.

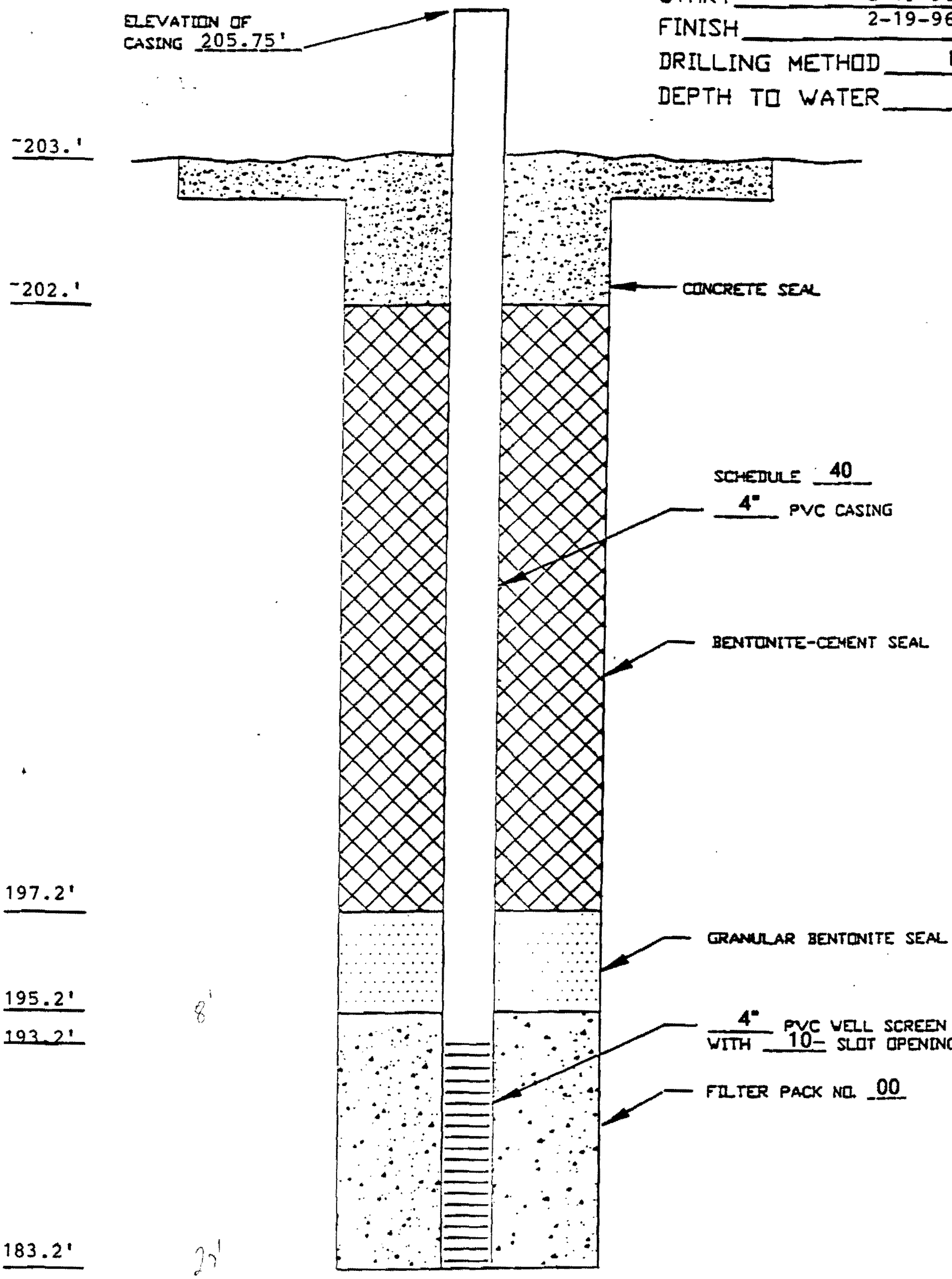
WELL NUMBER MW-EDC-10

START 2-19-96

FINISH 2-19-96

DRILLING METHOD HSA

DEPTH TO WATER 14.06'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO 95B165<br>FIG. NO |
| SCALE: | DRAWN BY: / CHKD. BY: E | DATE: / DATE: 5/96 | |

# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-11 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/19/96 |
| CLIENT: | El Dorado Chemical Company | GEOLOGIST: | EJF |
| | El Dorado, Arkansas | APPROVED: | ncl |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 18 | Loose, damp, light gray (5YR, 7/1) and tan Silty CLAY. | (CL) |
| 9–14 | | | | 18 | Stiff red-gray (5YR, 5/2) CLAY; with intermittent tan fine sand and light gray silt lenses; damp to moist. | (CL/ML) |
| 14–19 | | | | 18 | Light gray, tan and reddish brown (10YR, 6/6) fine-medium SAND; wet; with silty sand lenses. | (SM) |
| 19 | | | | | End of Boring at 19'. | |



Woodward-Clyde Consultants

SITE EL DORADO CHEMICAL CO.

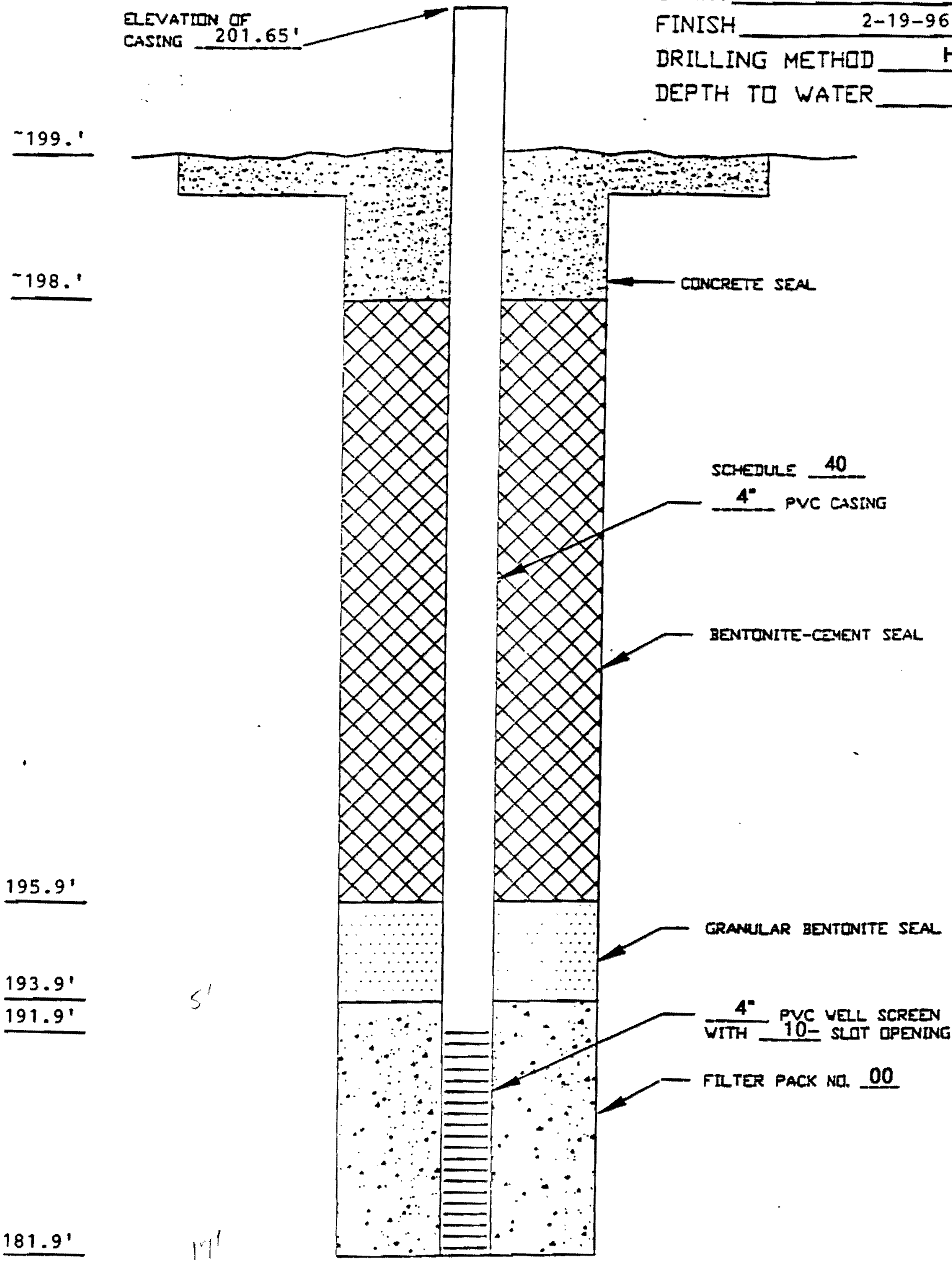
WELL NUMBER MW-EDC-11

START 2-19-96

FINISH 2-19-96

DRILLING METHOD HSA

DEPTH TO WATER 11.07'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO<br>95B165 |
| | SCALE: DRAWN BY: DATE: | | FIG. NO |
| | CHKD. BY: E F DATE: 5/96 | | |

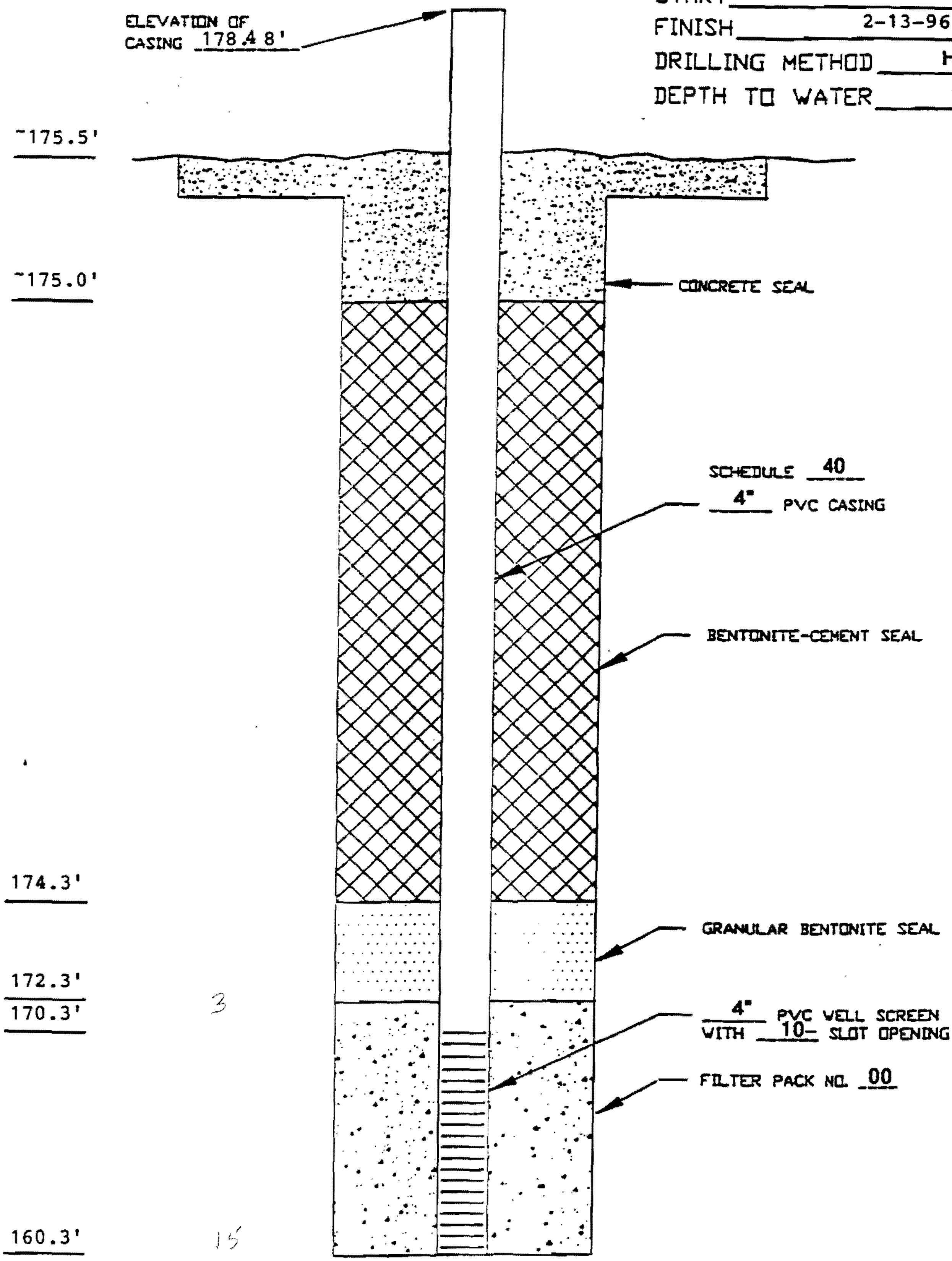
# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-14 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/13/96 |
| CLIENT: | El Dorado Chemical Company<br>El Dorado, Arkansas | GEOLOGIST: | EJF |
| | | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 17 | Fine Silty SAND; light gray and tan in color (7.5YR, 7/0). | (SM) |
| 9–13 | | | | 18 | Silty CLAY with traces of silt and fine sand; light to dark gray in color (7.5YR, 5/0); damp. | (CL) |
| 13–17 | | | | 18 | Wet fine SAND, primarily gray with traces of tan and light brown (7.5YR, 6/0-7/0) fine sand. | (ML) |
| 17 | | | | | End of Boring at 17'. | |

SITE: EL DORADO CHEMICAL CO.
WELL NUMBER: MW-EDC-14
START: 2-13-96
FINISH: 2-13-96
DRILLING METHOD: HSA
DEPTH TO WATER: 9.86'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO<br>95B165 |
| | SCALE: DRAWN BY: DATE: CHKD. BY: [illegible] DATE: 5/96 | | FIG. NO |

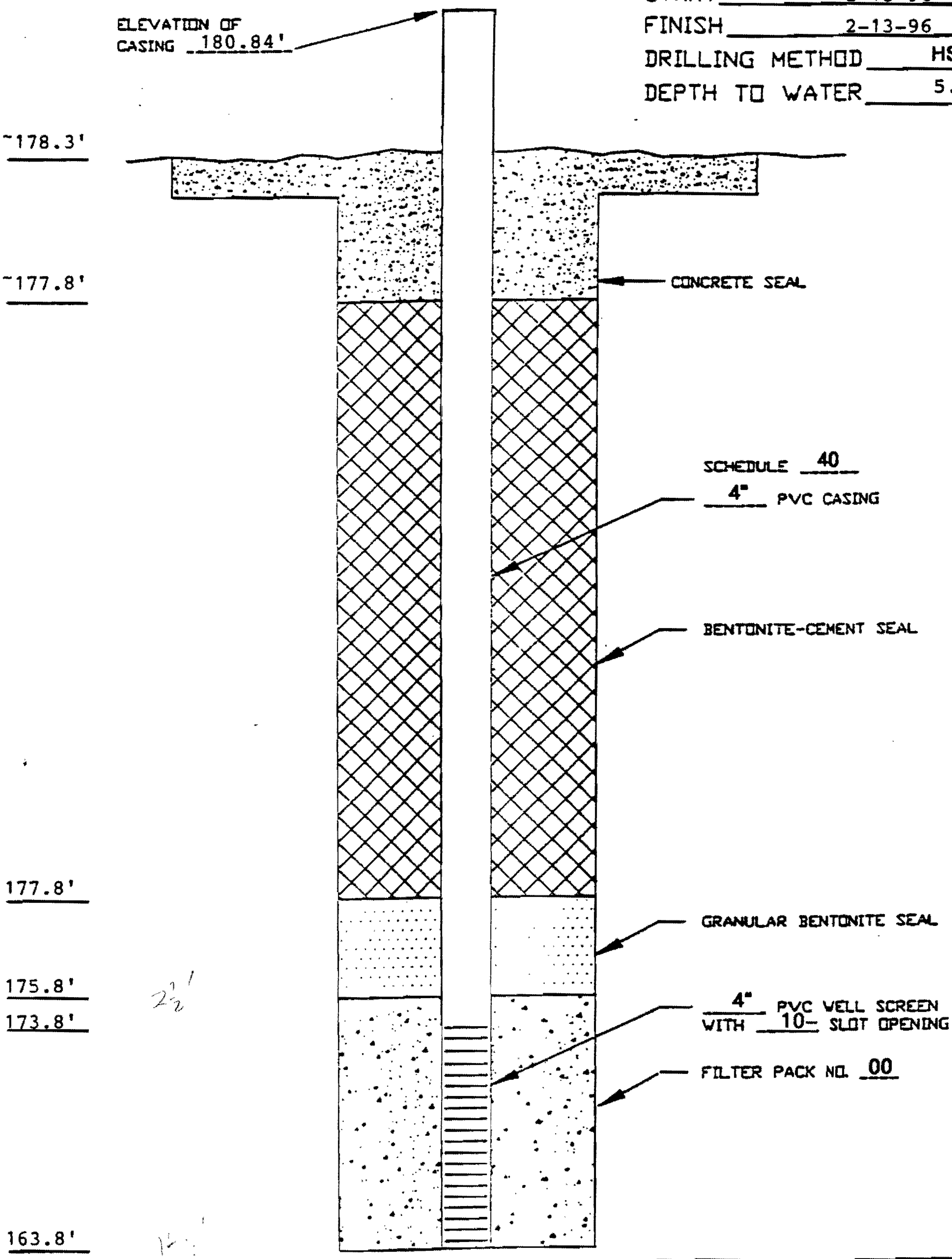
# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-15 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/13/96 |
| CLIENT: | El Dorado Chemical Company<br>El Dorado, Arkansas | GEOLOGIST: | EJF |
| | | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 18 | Fine Silty SAND; damp; gray (7.5YR, 7/0); traces of red and gray clay. | (SM) |
| 9–15 | | | | 18 | Light gray to dark gray (7.5YR, 7/0) Clayey SILT, with traces of light brown silty sand; wet; dense. | (ML) |
| | | | | 18 | ---Clayey SILT with lenses of coarse sand and gravel; wet; dense; gray with dark brown (7.5YR, 7/0). | (ML/GM) |
| 15 | | | | | End of Boring at 15'. | |

SITE EL DORADO CHEMICAL CO.
WELL NUMBER MW-EDC-15
START 2-13-96
FINISH 2-13-96
DRILLING METHOD HSA
DEPTH TO WATER 5.81'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO. 95B165 |
| | SCALE: / DRAWN BY: / DATE: / CHKD. BY: / DATE: | | FIG. NO. |

LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-16 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/12/96 |
| CLIENT: | El Dorado Chemical Company | GEOLOGIST: | EJE |
| | El Dorado, Arkansas | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| DEPTH (FEET) | SYMBOL | SAMPLE | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|---|---|
| 0–9 | | | | 15 | Moist fine SAND and Silty SAND; tan - white in color (7.5YR, 7/7). | (SM) |
| 9–14 | | | | 12 | Wet Sandy and Silty CLAY; gray in color (7.5YR, 7/0-7/6). | (CL) |
| 14–17 | | | | 20 | Wet fine SAND and SILT, stiff; gray in color (7.5YR, 6/0). | (SM) |
| 17 | | | | | End of Boring at 17'. | |

SITE EL DORADO CHEMICAL CO.

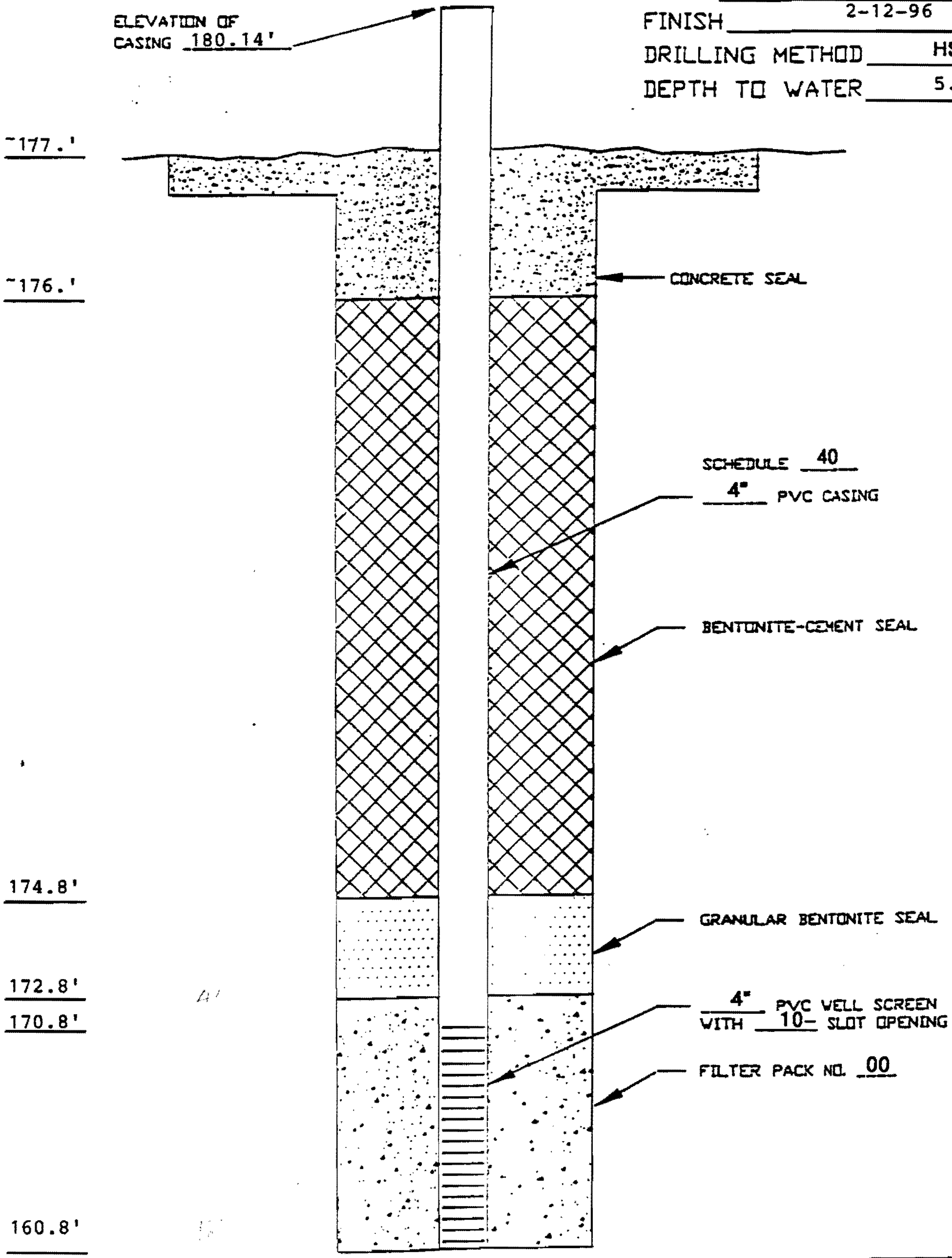
WELL NUMBER MW-EDC-16

START 2-12-96

FINISH 2-12-96

DRILLING METHOD HSA

DEPTH TO WATER 5.80'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO 95B165<br>FIG. NO |
| | SCALE: DRAWN BY: DATE: | | |
| | CHKD. BY: CF DATE: 3/96 | | |

# LOG OF BORING

| | | | |
|---|---|---|---|
| PROJECT: | Monitor Well Installation | BORING: | MWEDC-17 |
| LOCATION: | El Dorado, Arkansas | FILE: | 95B165 |
| | | DATE: | 2/13/96 |
| CLIENT: | El Dorado Chemical Company | GEOLOGIST: | EJF |
| | El Dorado, Arkansas | APPROVED: | |
| DRILLER: | Anderson Engineering | PAGE: | 1 of 1 |

Hollow-stem Augered:

| Depth (feet) | S.P.T.(b/ft) or P.Pen.(tsf) | Recovery (inch) | Description of Stratum | |
|---|---|---|---|---|
| 0–10 | | 2 | Red (10YR,4/6) Sandy CLAY. | (SC) |
| 10 | | 18 | Pinkish gray (5YR, 6/2) fine Silty SAND with trace of gray clay. | (SM) |
| 16 | | 12 | —light gray (5YR, 6/2) fine Silty SAND; dry; with a trace of tan SAND. | |
| 20 | | 18 | —light gray (5YR, 7/1) fine SAND and Silty SAND, with traces of yellow fine sand and dark gray clay. | |
| 26 | | 18 | —light gray (5YR-7.5YR, 7/0) fine SAND; damp. | |
| 30 | | 18 | —light gray (7.5YR, 7/0) fine SAND and silt; wet. | |
| 34 | | | End of Boring at 34'. | |

SITE EL DORADO CHEMICAL CO.

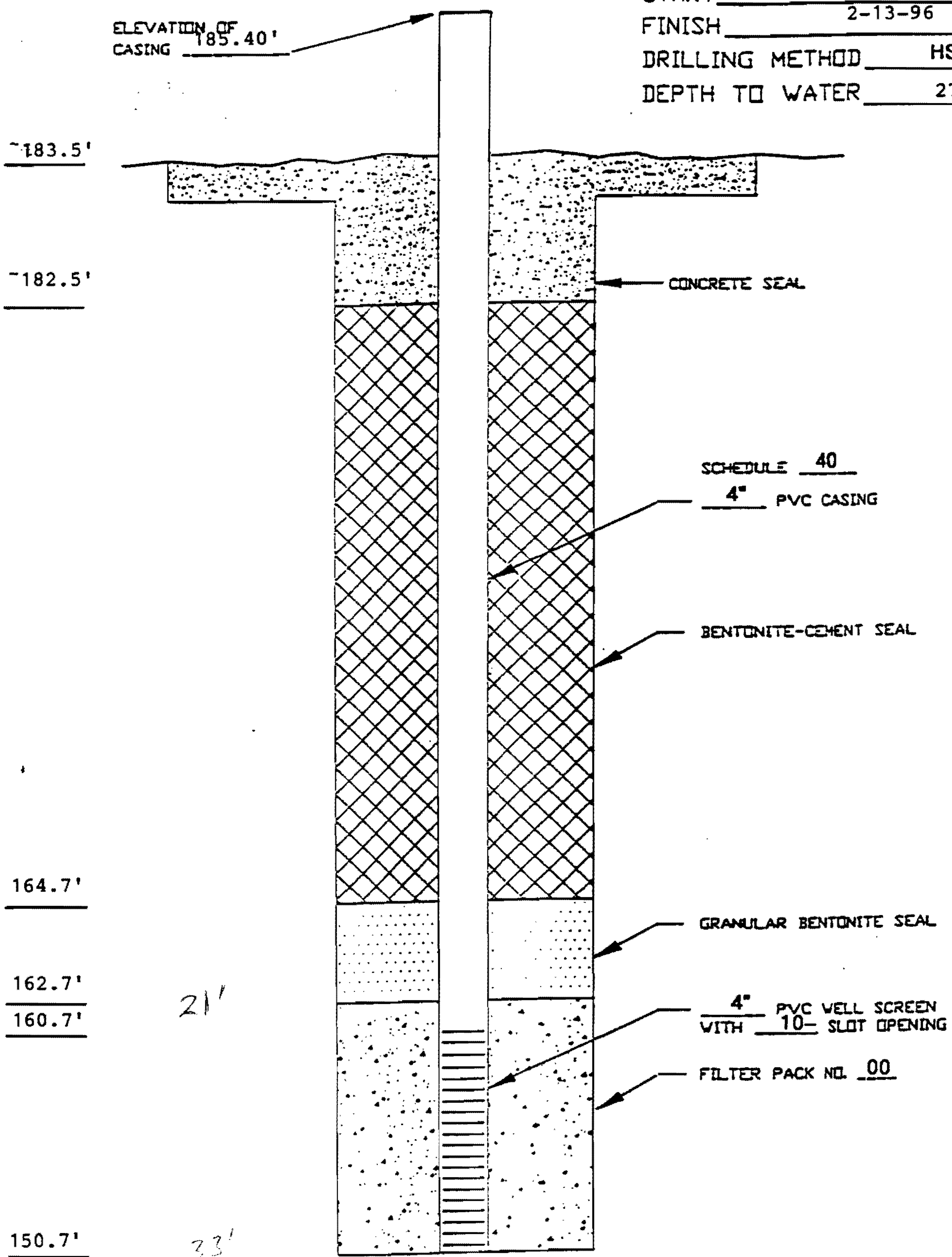
WELL NUMBER MW-EDC-17

START 2-13-96

FINISH 2-13-96

DRILLING METHOD HSA

DEPTH TO WATER 27.64'




| | | | |
|---|---|---|---|
| EL DORADO CHEMICAL COMPANY<br>EL DORADO, ARKANSAS | Woodward-Clyde Consultants<br>Consulting Engineers, Geologists and Environmental Scientists<br>Little Rock, Arkansas | MONITORING WELL<br>CONSTRUCTION DIAGRAM | FILE NO<br>95B165 |
| | SCALE: DRAWN BY: DATE:<br>CHKD. BY: FT DATE: 5/96 | | FIG. NO |