# HYDROLOGIC AND GEOLOGIC INVESTIGATION

## TULSA REMEDIATION PROJECT

for

## Kaiser Aluminum Specialty Products

**Facility at**
**7311 East 41st Street**
**Tulsa, Oklahoma**

**July, 1999**

**Prepared by:**

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# EXECUTIVE SUMMARY

Kaiser Aluminum & Chemical Corporation (Kaiser) is conducting studies to be used in the development of a plan for remediation of its property at 7311 East 41st Street, Tulsa, Oklahoma, where activities were formerly conducted involving processing of material containing thorium until approximately 1970. The process of recovery of the magnesium resulted in the generation of dross/slag material containing limited amounts of thorium. This waste material was disposed onsite in impoundments (Retention Pond and Reserve Pond). As part of these studies, A&M Engineering and Environmental Services, Inc. (A&M Engineering) has been retained by Kaiser Aluminum & Chemical Corporation (Kaiser) to investigate the geology and hydrology relevant to the evaluation of remediation alternatives of dross/slag containing impoundments. This report provides the results of that investigation.

The investigation characterized (1) the site geology, including both shallow bedrock and overlying unconsolidated deposits; (2) the site hydrogeology, including the direction and velocity of groundwater flow; (3) surface water hydrology, including potential peak discharges; (4) the hydraulic interrelationships between the on-site surface water and groundwater water flow system; (5) potential radionuclide migration pathways in ground and surface water; (6) the geotechnical properties of subsurface materials; and (7) the basic ion chemistry of groundwater.

A&M Engineering achieved these objectives through a combination of the drilling of deep stratigraphic borings, the completion of monitoring wells and piezometers into bedrock and unconsolidated overburden materials, field and laboratory testing and analysis of selected surface and subsurface samples, slug testing of installed monitoring wells, chemical analysis of groundwater samples, monitoring of surface and groundwater levels, and analysis of peak discharge of surface water streams using Soil Conservation Service (SCS) rainfall runoff methods.

The Facility lies at the headwaters of Fulton Creek, which flows approximately two miles to Mingo Creek. The beneficial uses designated by the Oklahoma Water Resources Board (OWRB) for Mingo Creek do not include domestic or municipal drinking water use. According to the OWRB, there are no surface water withdrawals within nine miles of the Facility.

The dominant features of the Kaiser site hydrologic regime are the Fresh Water Pond and the Retention Pond at the Facility and the excavated Fulton Creek channel along the northern boundary of the Facility. Soil Conservation Service techniques for predicting flows in Fulton Creek were used to predict peak discharges in response to rainfall events for the 2, 5, 10, 25, 50, and 100 year storms. For some remediation alternatives it will be necessary to calculate peak stage heights and flow velocities based on the planned final configuration of Fulton

Creek. Analyses also indicate that closure of the Fresh Water Pond would have only a limited impact on storm water runoff.

The site geology is consistent with the regional geology defined in the literature. The Nowata Shale immediately underlies the Facility and extends to a depth of at least 200 feet. A buried bedrock valley, eroded in the Nowata Shale, trends in an east/west direction and underlies the Fresh Water and Retention Ponds. The unconsolidated materials overlying bedrock range in thickness from a few feet to as much as 28 feet. The naturally deposited materials are comprised of sand, silt, clay, peat and occasional gravel. A layer of more permeable, sandy deposits immediately overlying bedrock is overlain by less permeable silty clay deposits that generally underlie both the Fresh Water and Retention Ponds.

Bedrock formations in the vicinity of the Facility, including the Nowata Shale which immediately underlies the site, are considered water bearing but yield only very small amounts of fair to poor quality water. Wells completed in bedrock formations in this area typically do not produce sufficient quantities of groundwater to supply water for domestic use.
The higher permeability silty sands immediately overlying bedrock provide the most significant pathway for groundwater flow beneath the site. Deep groundwater flow through these deposits is from west to east along the axis of the bedrock valley. Shallow groundwater flow is more influenced by surface water bodies and topography than deeper groundwater flow. Shallow groundwater flow in the northeastern portion of the Facility, in the general area of the Reserve Pond, is similar to deep groundwater flow. Shallow groundwater flow along the northern berm of the Retention and Reserve Ponds, however, is expected to be northerly or northeasterly towards Fulton Creek. Along the southeastern boundary of the Retention Pond, shallow groundwater likely flows locally to the east and south due to the effects of groundwater mounding in the immediate vicinity of the Retention Pond.

The Fresh Water Pond exerts limited influence on water levels in the Retention Pond and underlying Unit 1 Sands. Water level in the Retention Pond, however, correlates well with water levels in the underlying shallow and deep overburden, indicating that these water levels are likely responding to the same influences. Moreover, a downward gradient is observed between the Retention Pond and the deep overburden, indicating potential recharge of the deep overburden by the Retention Pond. Adjacent to the northeast corner of the Retention Pond, these downward gradients all but disappear, potentially indicating a high degree of hydraulic interconnection between the Retention Pond and underlying deep overburden deposits in this area. Geochemical data and observed water level changes in the Retention Pond in response to extreme rain events also indicate that leakage from the Retention Pond is likely.

Geochemical data indicate only very limited thorium and radium migration in groundwater from the dross deposits. This is likely due to the high adsorption coefficients that have been measured for thorium and radium in the subsurface materials.

Potential pathways for the migration of radionuclides in groundwater include shallow groundwater flow through the berms on the northern, eastern, and southeastern sides of the Retention and Reserve Ponds. Groundwater flow through the northern berms likely discharges to Fulton Creek. Routine sampling and radioactivity measurements of surface water have indicated no significant impact on Fulton Creek. Another potential groundwater migration pathway is through the underlying Unit 2 silty clays into and through the deep overburden material and shallow, weathered bedrock. Discharges from the Facility through this pathway would largely be confined to the more permeable sands directly overlying the bedrock in the northeast corner of the Facility. The interstitial groundwater flow velocities through these more permeable, deep overburden deposits have been estimated to be 0.35 feet/day or 127.75 feet/year.

The Fresh Water and Retention Ponds are likely major sources of the groundwater outflow now observed along the eastern boundary of the Facility. If these surface water bodies are drained during remediation, surface water will no longer be a significant source of groundwater recharge, and the groundwater flow discharging from the site will be largely determined by groundwater inflows into the basin.

Geotechnical data obtained through split spoon sampling provide a qualitative measure of the strength of subsurface materials and indicate the relative density and consistency of the sampled soils. The unconsolidated overburden materials, particularly the deeper sandy materials, generally appear loose and have a relatively low density and a soft consistency, indicating poor bearing strength that would not be suitable for foundations without further consolidation.

# 1.0 INTRODUCTION

The Kaiser Aluminum Speciality Products facility (the Facility), located at 7311 East 41st Street in Tulsa, Oklahoma, is used for metal processing. On an intermittent basis between 1958 and 1970, scrap magnesium was processed at the Facility. The scrap magnesium contained up to four percent thorium. The process of recovery of the magnesium resulted in the formation of dross/slag material containing limited amounts of thorium. This waste material was disposed of on the property. Much of it was placed in surface impoundments located along the northern boundary of the facility. Due to the limited radioactivity of the waste material, areas of the Facility will likely require remediation. Kaiser Aluminum and Chemical Corporation (Kaiser) is currently conducting the studies necessary to develop a plan for remediation. As part of these studies, A&M Engineering and Environmental Services, Inc. has been retained by Kaiser to undertake an investigation to characterize the geology and hydrology of the general area of the impoundments previously used for disposal of the waste material.

## 1.1 INVESTIGATION OBJECTIVES

The objectives of the investigation were as follows:

- characterize the site geology, including both shallow bedrock and overlying unconsolidated deposits;
- characterize the site hydrogeology, including groundwater flow directions and velocity;
- characterize site surface water hydrology, including potential peak discharges for on-site stream;
- determine the hydraulic interrelationships between the on-site surface and ground water flow systems;
- identify potential radionuclide migration pathways in ground and surface water;
- evaluate the geotechnical properties of subsurface materials for purposes of an initial evaluation of potential remedial designs;
- determine basic ion chemistry of groundwater.

## 1.2 SCOPE OF INVESTIGATION

The scope of the investigation implemented to achieve the above objectives was as follows:

- completion of three deep stratigraphic borings (using coring followed by air rotary rigs) ranging between 50 and 200 feet in depth with geophysical logging and permeability testing of selected zones using inflatable packers;
- completion of continuously sampled borings (using hollow stem augers and split spoons) through unconsolidated overburden to weathered bedrock at eighteen locations;
- field and laboratory testing of selected soil samples for geotechnical parameters;
- installation of twenty-three monitoring wells and piezometers ranging in depth from 16 to 58 feet, including the installation of well clusters at 3 locations;
- slug testing of installed monitoring wells to determine hydraulic characteristics of subsurface materials;
- sampling of groundwater and analysis of major ions at selected monitoring wells;
- periodic monitoring of surface and groundwater levels;
- analysis of peak discharge of surface water stream using Soil Conservation Service (SCS) rainfall runoff methods.

## 1.3 ORGANIZATION OF THE REPORT

Following this introduction, background material for the site is presented in Section 2.0. A detailed description of the characterization activities conducted during this investigation is presented in Section 3.0. Section 4.0 provides a discussion of the physical setting of the site based, in part, on the results of characterization activities. Section 5.0 provides conclusions and recommendations from the study. Figures and tables for each section are included at the end of each section. Some of the Figures are printed on D-size paper (24"x36") and included as Appendix I.

# 2.0 BACKGROUND

## 2.1 FACILITY LOCATION AND DESCRIPTION

The Facility is located within the Corporate boundaries of the City of Tulsa at 7311 East 41st Street, approximately 7 miles southeast of downtown Tulsa Oklahoma. The location of the Facility is shown on Figure 2-1. The Facility consists of approximately 23 acres, with approximately 20.05 acres located on the north side of East 41st Street and approximately 2.95 acres located on the south side of East 41st Street.

The layout of the Facility is shown on Figure 2-2. As shown the 20.05-acre parcel located to the north of East 41st Street is divided into two parts by the Missouri Kansas & Texas (M.K.&T) Railroad easement. This active railroad traverses the Facility in a northwest-southeast orientation. Facility operations are located south of the railroad.

Two large ponds dominate the area north of the railroad. The western pond is referred to as the Fresh Water Pond and is thought to have been created as a supply of water for the railroad during the days of steam power. The Fresh Water Pond occupies approximately three acres and averages less than four feet in depth. An intermittent stream identified as Fulton Creek (also referred to by others as Unnamed Creek or No Name Creek) enters into the Fresh Water Pond under a railroad bridge at its southwest corner. The water level in the Fresh Water Pond is controlled by a broken weir in the northeast corner of the pond. Although somewhat variable depending on recent precipitation, the water level in the Fresh Water Pond is generally maintained at elevation of between 698.5 and 699.5 feet msl. Discharge from the Fresh Water Pond enters the man-made channel of Fulton Creek which runs along the northern boundary of the Facility. Fulton Creek discharges from the Facility through a weir located at the northeast corner of the Facility.

East of the Fresh Water Pond is the Retention Pond which occupies approximately five acres. The Retention Pond is surrounded by a well maintained berm. Water levels are variable in the Retention Pond depending on season and recent precipitation but are generally six feet or more below the water level of the nearby Fresh Water Pond. During the summer months, the Retention Pond may go dry. The Retention Pond currently receives discharge of stormwater runoff from a limited portion of the facility north of the railroad. Cooling waters from Facility operations are also discharged into the Retention Pond. There are no surface water discharges from the Retention Pond, and the Retention Pond is permitted by the Oklahoma Water Resources Board (OWRB). Northeast of the Retention Pond is a backfilled Reserve Pond. The Reserve Pond area is currently covered with grass. Dross was placed in both the Retention Pond and the Reserve Pond.

## 2.2 PROCESS DESCRIPTION

The Facility property is used for metal processing. Scrap magnesium from the manufacturing of aircraft components was processed at the Facility on an intermittent basis between 1958 and 1970. This scrap magnesium alloy contained up to four percent thorium. Magnesium-thorium scrap was initially processed at the Facility by Standard Magnesium Corporation, which received in March 1958 a license from the Atomic Energy Commission (AEC) to possess magnesium-thorium alloy. In 1964, Standard Magnesium became a wholly owned subsidiary of Kaiser and a part of Kasier's Industrial Chemical Division. In 1968, Kaiser's AEC Source Material License, STB-412, was amended to allow for possession of scrap containing up to 2% uranium but no evidence has been found indicating that uranium was ever received or processed at the site.

The scrap magnesium-thorium alloy was processed by placing the magnesium-thorium alloy at the bottom of a melting pot and other magnesium containing no thorium was also added. The magnesium-thorium fraction was approximately 5%. The mixture was heated to over 1000 degrees Fahrenheit. Magnesium was removed from the top of the melt and was converted into ingots or direct-contact anodes used for cathodic protection of underground tanks and pipelines. The impurities, including thorium, settled to the bottom. The thorium bearing dross/slag was removed and allowed to cool, and either recycled or disposed of on site. Starting in 1964, recycling of slag was discontinued. After cooling, the dross/slag was broken up and crushed. Ultimately, a fine powder-like waste material resulted from this process. This waste material was disposed of on site, much of it in surface impoundments located along the northern perimeter of the Facility, north of East 41st Street. These impoundments are currently identified as the Retention and Reserve Ponds.

In 1971, at Kaiser's request, the AEC license was terminated. In its request Kaiser indicated that no licensed material had been processed during the prior year (1970).

## 2.3 AERIAL PHOTOGRAPHY INTERPRETATION

Aerial photographs of the site have been obtained and studied in an effort to determine the original characteristics of the site prior to and during the construction of the Facility and deposition of dross. Aerial photographs of the Facility and surroundings have been obtained for the following years: 1943, 1945, 1950, 1958, 1964, 1965, 1967, 1972, 1979, 1980, and 1991. Analysis of these photographs is useful for identifying the original geomorphology of the site and for interpreting the geology and surface and ground water hydrology of the site. These photographs are also useful for identifying the pattern of dross deposition.

The aerial photographs indicate that the Fresh Water Pond (West Pond) was created prior to 1943. As shown in the marked-up 1943 and 1950 aerial photographs presented in Figures 2-3 and 2-4, the damming of Fulton Creek created a backwater area southwest of the railroad track. By this time, a series of small farm ponds was created in the current area of the Retention and Reserve Ponds Area. In the 1950 photograph, these ponds had apparently been joined into a single pond, hereafter referred to as the East Pond. The Fresh Water Pond was fed by upstream flow from the southwest and from an ephemeral channel in the northwest. A possible buried channel in the northeast may have been a minor contributor to groundwater flow. The Fresh Water Pond discharged via an apparent spillway or overflow at its southeast corner. Water flowed from the Fresh Water Pond into the East Pond. The East Pond was also fed by an intermittent stream from the north which deposited sediment as a delta, forcing Fulton Creek southward. These sediments were likely more permeable than those south of the delta. Discharge from the East Pond appears to have been through a spillway or overflow on the northeastern side of the Pond. Evidence of seepage or pond overflow is also apparent on the eastern side of the pond.

As shown in the 1958 aerial photograph presented in Figure 2-5, the Facility is in a stage of late construction and/or early operation by 1958. Some filling in the area adjacent to the Fresh Water Pond backwater is evident. A spillway between the Fresh Water Pond and East Pond is clearly evident.

As shown in the 1964 aerial photograph presented in Figure 2-6, the plant is in operation and using the area south of the East Pond for disposal of waste material. Based on the shading seen in the East Pond, it is apparently receiving dross or sediment. A trench/channel has been constructed on the north side of the East Pond to serve as a bypass for overflow water from the Fresh Water Pond. This appears to be the channel currently occupied by Fulton Creek. Weirs have been constructed at the bypass point on the Fresh Water Pond and at the off-site discharge point northeast of the East Pond. The old spillway on the south end of the embankment has been abandoned and partially filled. The area west of the Fresh Water Pond appears to be a fill area. This area eventually became a lumber yard. The backwater area southwest of the Fresh Water Pond has been encroached upon by building on fill in the Kaiser area.

As shown in the 1967 aerial photograph presented in Figure 2-7, the eastern boundary of the East Pond has been moved to the west. The debris shown in the 1964 photograph along the southern edge of the East Pond has either been removed or covered. A separate basin, now referred to as the Reserve Pond, has been constructed northeast of the East Pond. The East Pond has also been enlarged in the northwest portion of the pond, possibly by excavation and/or raising the water level in the Pond. The East Pond exhibits essentially the same configuration as the current Retention Pond. By this time, the backwater area of the Fresh Water Pond has also been filled and graded, and Fulton Creek has been channelized into a straight ditch.

Subsequent photographs show little change in the Retention Pond. By 1972, the Reserve Pond was covered with a soil cap. Over the following years, continued development in the area immediately surrounding the Kaiser Facility is readily apparent.

## 2.4 PREVIOUS AND CONCURRENT STUDIES

Since 1994, a series of studies and investigations have been conducted to characterize the Facility. These include field investigations to characterize radionuclide distribution and concentrations in both on-site and off-site areas. Studies have similarly been undertaken to provide background data regarding the physical setting of the site and to identify the role of Fulton Creek and the Fresh Water Pond in the City of Tulsa's stormwater control system. A series of field and laboratory investigations were also undertaken to study the geochemistry of thorium and radium at the Facility. These studies are identified and summarized below.

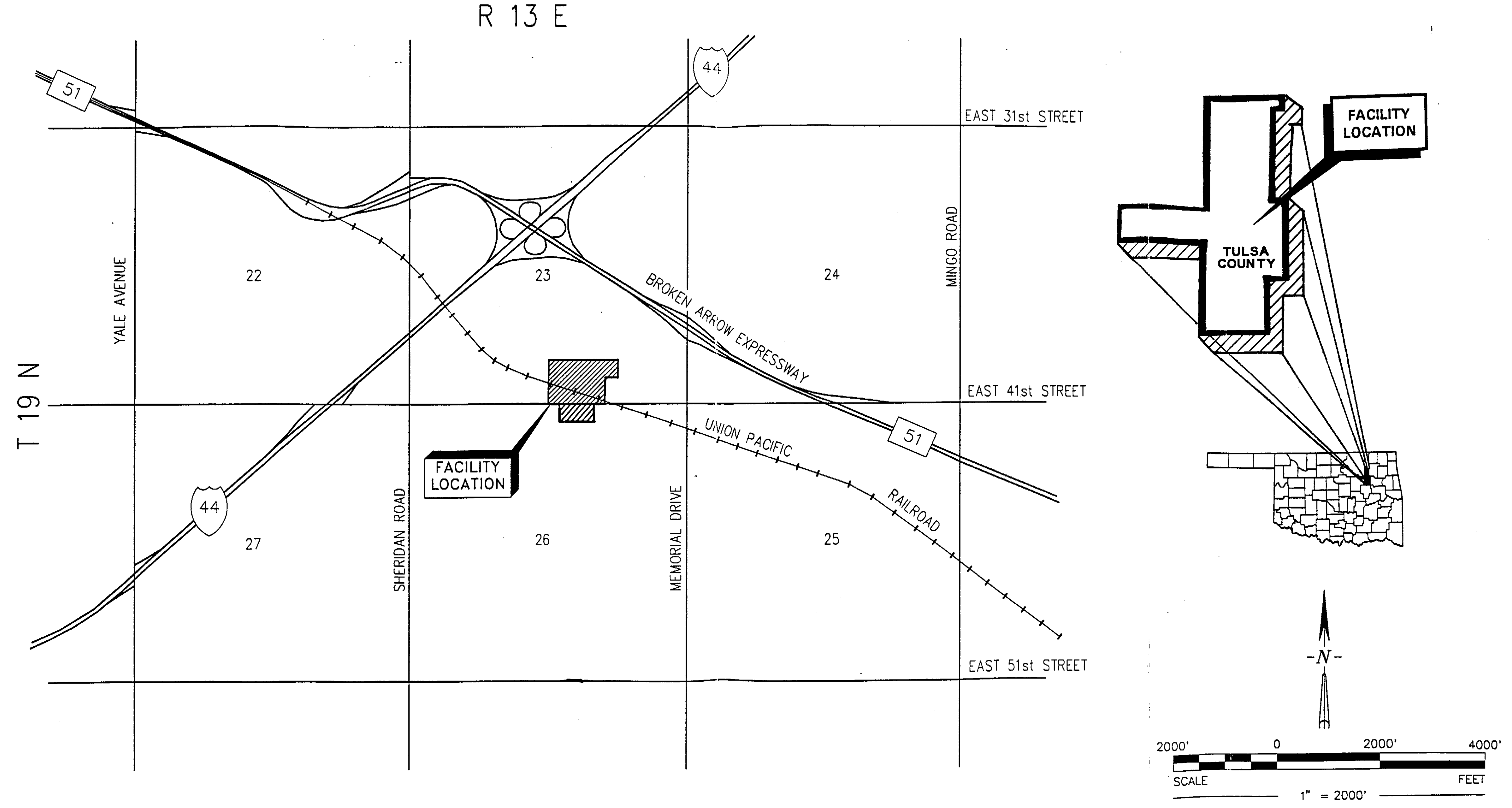
In 1994, a field study was performed by Advanced Recovery Systems (ARS), Inc. to sample and characterize the area of the Facility north of the railroad track and to estimate the volume of contaminated soil and pond sediments. The study area included the area between the railroad easement and the Retention Pond, the bermed areas west, north, south, and east of the Retention Pond, the Reserve Pond, and the Retention Pond. During the field study, two hundred and fifty samples were collected from ninety borehole locations in the study area. Fifty-five borings were made using a land-based drilling rig, and thirty-five borings were made using a pontoon mounted sampling rig. Continuous samples were taken in each boring, and a continuous zone of two to three feet of brown clay was used as the demarcation line between the dross and/or contaminated soil and uncontaminated soil. Each borehole location was uniquely identified, and its location surveyed. The study resulted in estimates of the volume of materials containing various concentrations of thorium. Further detail and discussion of the results of the study are presented in Advanced Recovery Systems (1995).

Characterization surveys have also been conducted in areas adjacent to the Facility. In 1994, a general walk-over of the areas surrounding the Facility was conducted by ADA Consultants (1994). Based on the results of the 1994 ADA survey, areas south and east of the Retention and Reserve Ponds were surveyed by B. Koh and Associates in 1998. This survey consisted of surface gamma scans, direct gamma measurements, collection of soil cores, exposure rate measurements, and collection of Fulton Creek sediment samples. An analysis of the soil cores was subsequently undertaken by ADA Consultants. A summary of 1998 off-site investigation activities and results is provided in the Adjacent Land Characterization Report which was submitted to the NRC by Kaiser in 1999. The Adjacent Land Characterization Report estimated the volume of contaminated soil in the off-site areas as 165,649 cubic feet.

In 1995, Roberts/Schornick & Associates (RSA) prepared a Local and Regional Environmental Data Report. The purpose of the Report was to provide Kaiser with a preliminary assessment of the physical setting of the Facility based solely on existing information that was readily available at its time of compilation. The report provides a basic description of the demography, climatology, surface water hydrology, geology, and groundwater hydrology in the Facility vicinity. No intrusive field investigations were conducted as part of this study.

In 1996, RSA undertook a study of the Fulton Creek drainage system. The purpose of the study was to determine the role of the Fresh Water Pond and Fulton Creek in the City of Tulsa's stormwater control system. Agencies or individuals responsible for or knowledgeable of the role of the Fresh Water Pond and Fulton Creek in the City of Tulsa's stormwater control system were identified and interviewed. Relevant design documents for the Fulton Creek drainage system were also identified and reviewed. The results of the study are documented in Roberts/Schornick & Associates (1996).

Since 1997, a series of field and laboratory investigations have been undertaken to study the geochemistry of thorium and radium at the Facility. These studies include chemical and mineralogic characterization of dross, chemical analyses of dross pore waters and selected ground waters, and measurements of thorium and radium concentrations in dross, dross pore waters and selected ground waters. In addition, thorium and radium concentrations were measured in dross and clays above and below the dross/clay interface and sorption coefficients were determined for thorium and radium in several soil samples from locations downgradient of the Retention and Reserve Ponds. The details and results of these studies are documented in Meijer (1999).



Client: KAISER ALUMINUM EXTRUDED PRODUCTS

Location: 7311 EAST 41ST STREET
TULSA, OKLAHOMA

Figure Title: FACILITY LOCATION MAP

Document Title: LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

REF: RSA, INC 1996

DATE: 11/1/95

SCALE: 1" = 2000'

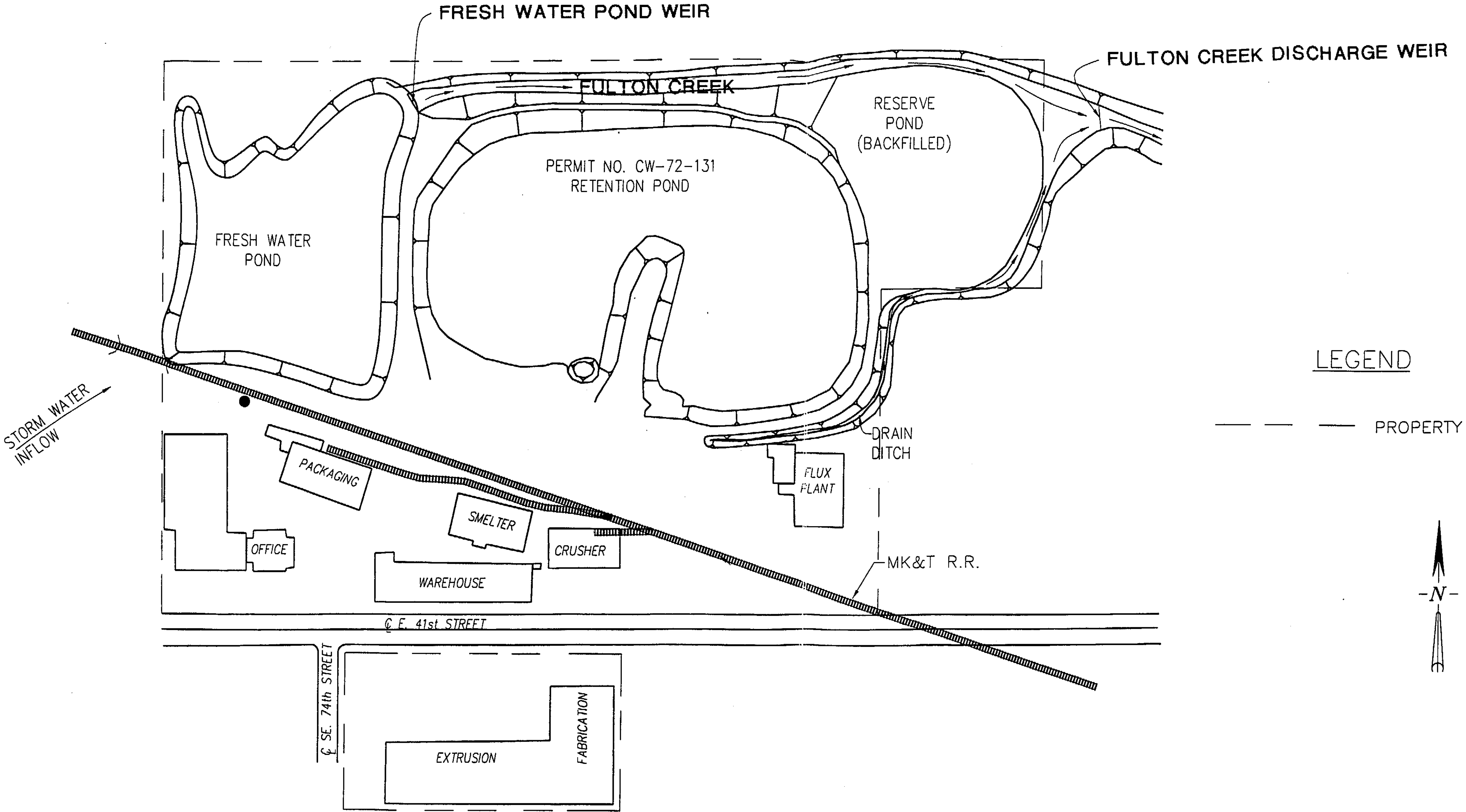
PROJECT NO: 9515901 F02

PREPARED BY: KE

CHECKED BY: KE

DRAFTED BY: GS

FIGURE NO.: 2-1



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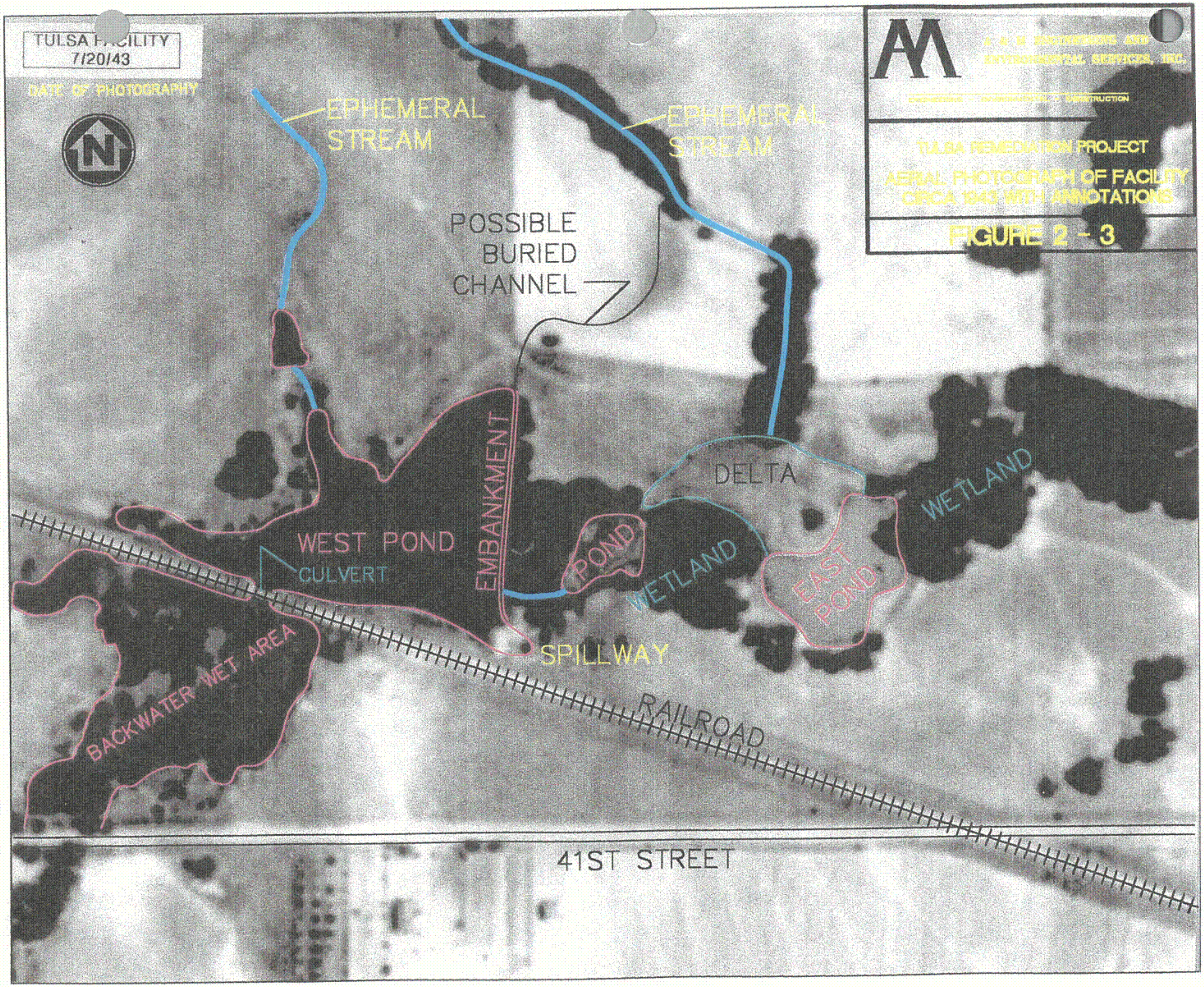
|---|---|---|---|
| Client: | KAISER ALUMINUM<br>EXTRUDED PRODUCTS | Figure Title: | FACILITY BASE MAP |
| Location: | 7311 EAST 41ST STREET<br>TULSA, OKLAHOMA | Document Title: | LOCAL AND REGIONAL<br>ENVIRONMENTAL DATA REPORT |
| REF: RSA, INC 1996 | | DATE: 11/1/95 | PREPARED BY: KE |
| | | | CHECKED BY: KE |
| | | SCALE: NOT TO SCALE | DRAFTED BY: GS |
| | | PROJECT NO: 9515901 F02 | FIGURE NO. 2-2 |

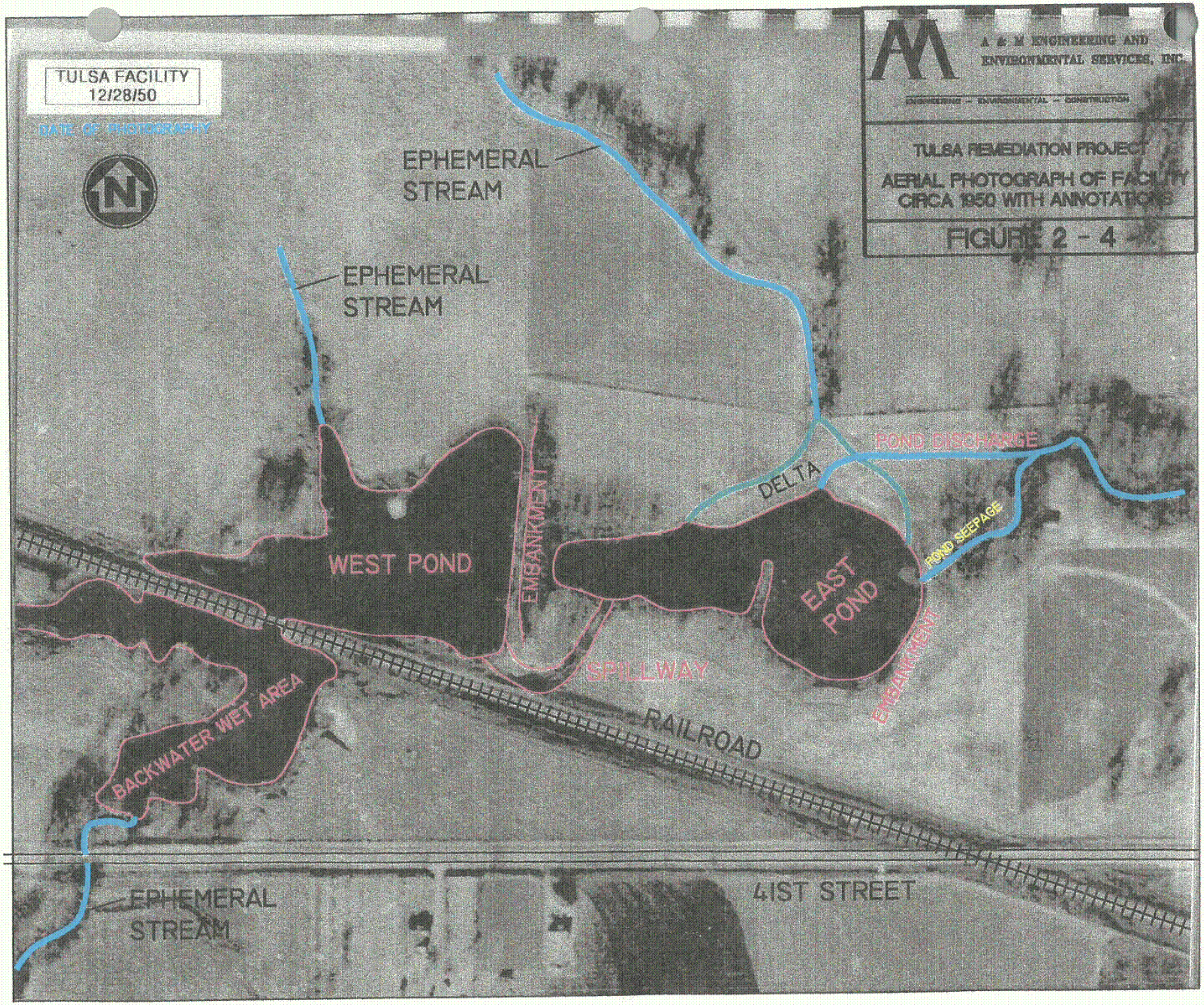


TULSA REMEDIATION PROJECT

AERIAL PHOTOGRAPH OF FACILITY CIRCA 1943 WITH ANNOTATIONS

FIGURE 2 - 3

1-7



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TULSA REMEDIATION PROJECT

AERIAL PHOTOGRAPH OF FACILITY CIRCA 1950 WITH ANNOTATIONS

FIGURE 2 - 4

TULSA FACILITY
12/28/50

DATE OF PHOTOGRAPHY

C2

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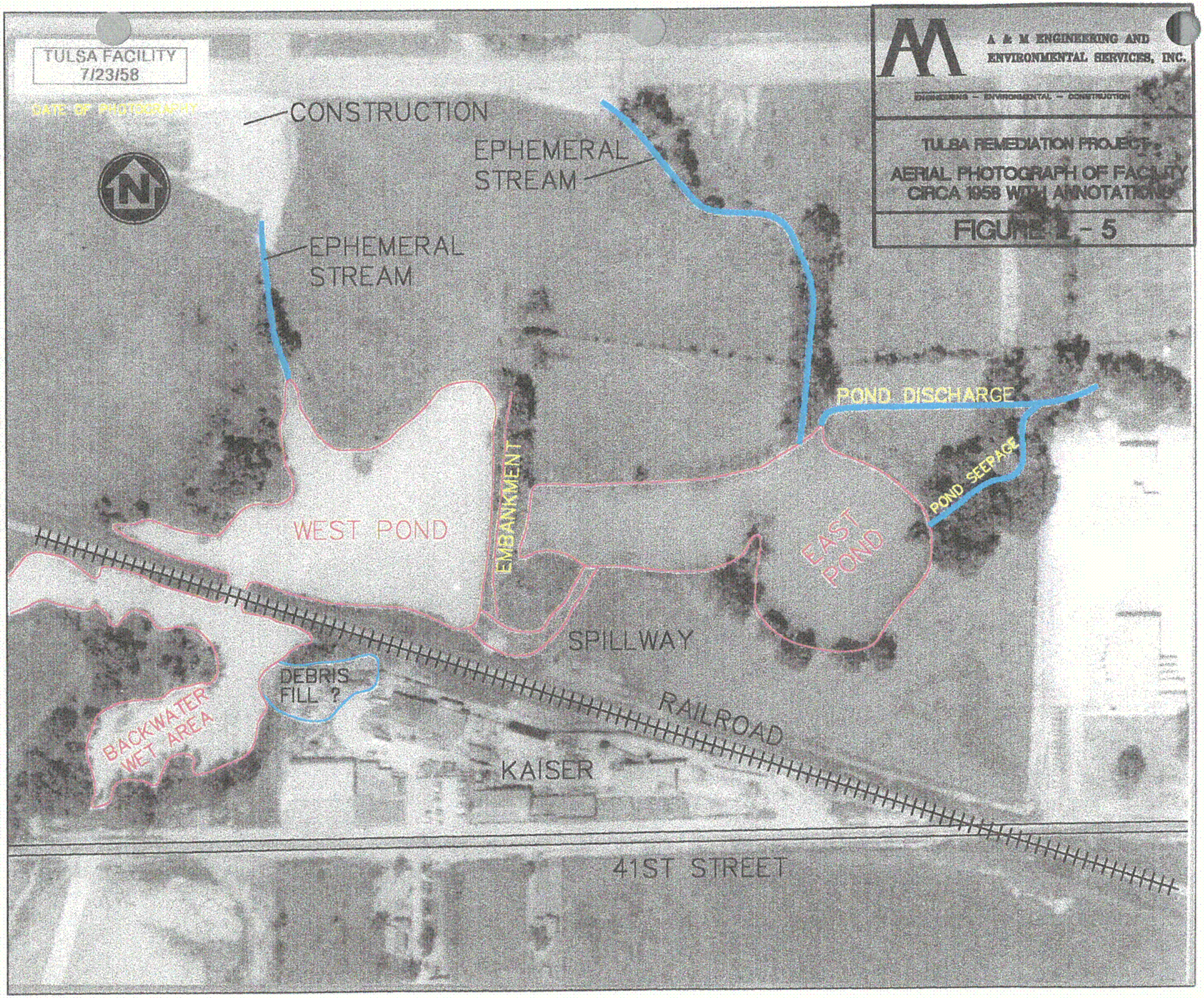
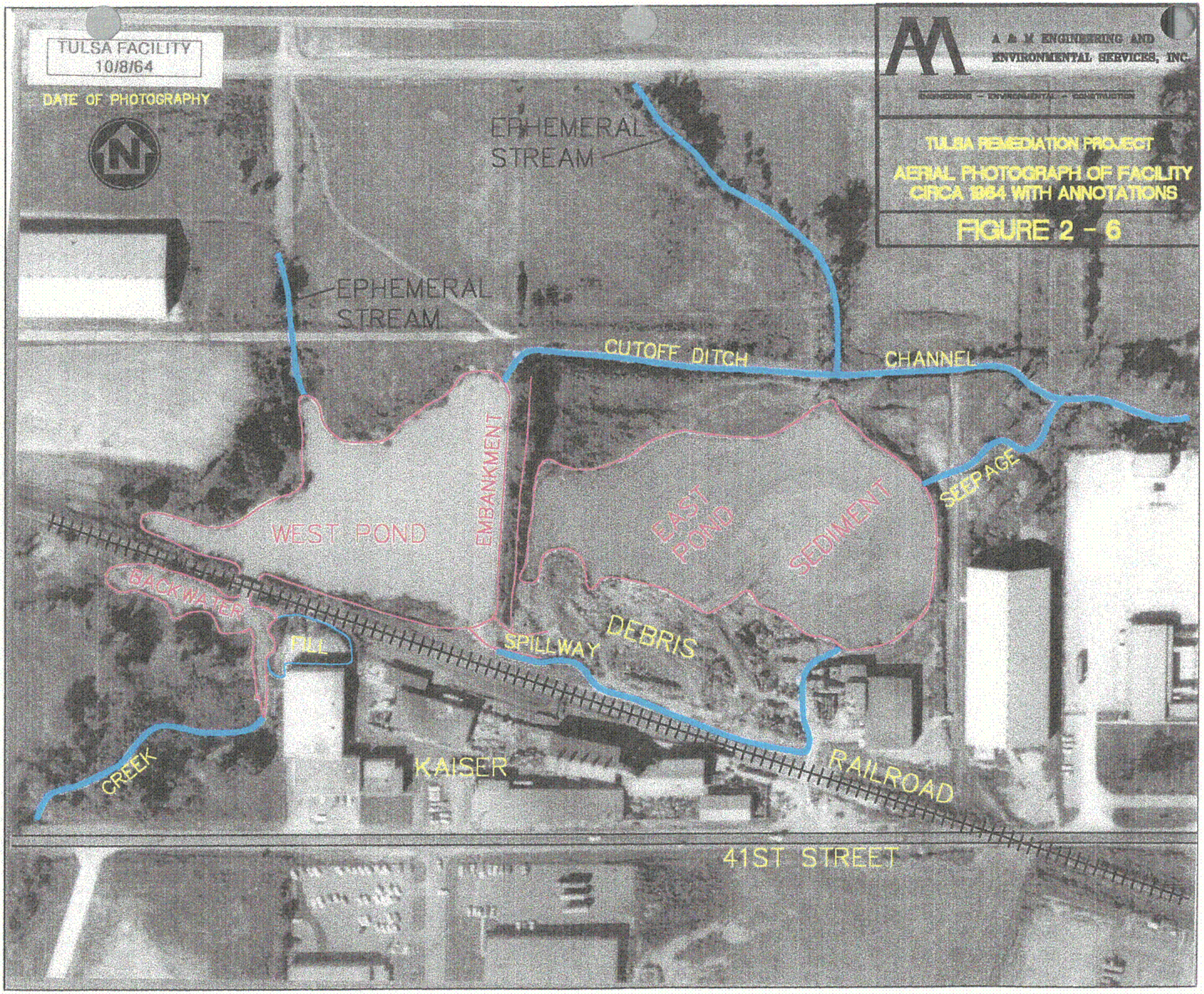
ENVIRONMENTAL SERVICES, INC.
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

TULSA REMEDIATION PROJECT
AERIAL PHOTOGRAPH OF FACILITY
CIRCA 1958 WITH ANNOTATIONS

FIGURE 2 - 5



C3



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TULSA REMEDIATION PROJECT

AERIAL PHOTOGRAPH OF FACILITY CIRCA 1964 WITH ANNOTATIONS

FIGURE 2 - 6

C4

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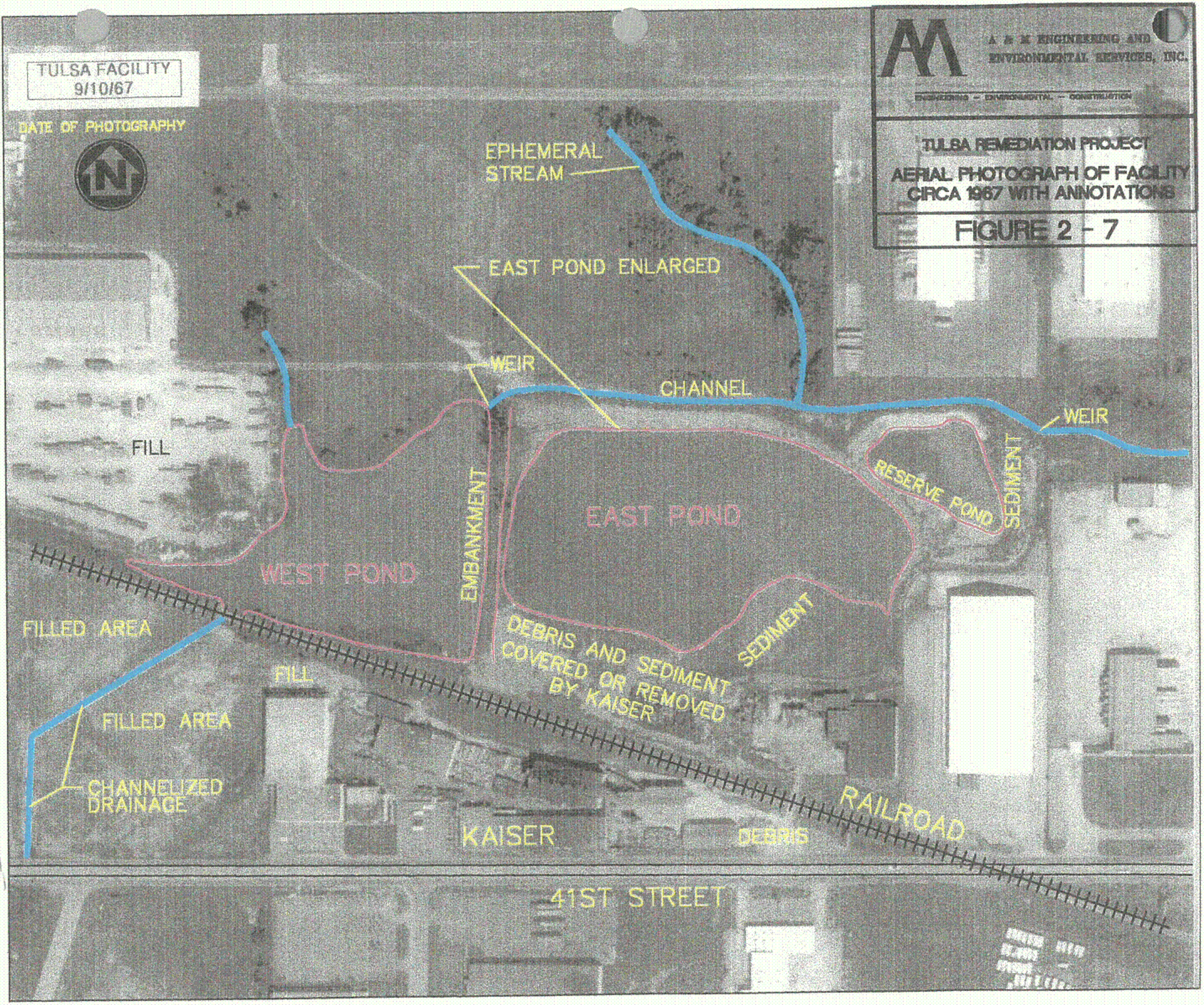
TULSA REMEDIATION PROJECT

AERIAL PHOTOGRAPH OF FACILITY CIRCA 1967 WITH ANNOTATIONS

FIGURE 2 - 7



C5

# 3.0 INVESTIGATION ACTIVITIES AND PROCEDURES

The investigation conducted at the Facility focused on drilling boreholes and sampling subsurface materials at eighteen different locations in the vicinity of the Fresh Water and Retention and Reserve Ponds and on the completion of twenty-three piezometers and monitoring wells at these locations. The monitoring well network included two locations at which wells were nested in both the bedrock and overburden deposits and three locations at which wells were nested at different depths in the overburden deposits. The locations of these borings, piezometers and monitoring wells are shown on Figure 3-1.

The borings drilled during the investigation included three stratigraphic borings (ST-1, ST-2, and ST-3) that were designed to penetrate and to characterize the uppermost shale at the site (Nowata Shale) and penetrate, if feasible, the first significant limestone (Oologah Limestone). Although 200 feet of shale was drilled, the Oologah Limestone was never penetrated. Monitoring wells were installed in the Nowata Shale at two of the three stratigraphic boring locations (ST-2 and ST-3).

The remainder of the borings were drilled in the overburden materials to sample these materials and to install wells and piezometers. These wells or piezometers were screened at the bedrock surface or in shallow overburden at the water table or first significant water-bearing zone. The boring and well locations were chosen primarily to define and monitor potential migration pathways from the retention and reserve pond areas and to further define the geology and hydrogeology beneath the northern part of the Facility, including the hydraulic influences of the Fresh Water Pond, the Retention Pond, and Fulton Creek on groundwater flow. Wells installed primarily to define hydraulic influences were identified as piezometers and given the prefix P (e.g., P-1, P-2, etc.). Wells installed to monitor potential radionuclide migration from the ponds were identified as monitoring wells and given the prefix MW (including upgradient well MWD-2). Monitoring wells completed at the top of bedrock were given a MWD prefix, while shallower wells were given a MWS prefix. The procedures used to drill these borings, obtain and characterize samples of subsurface materials, and to complete the piezometers and monitoring wells are described below.

During the field investigations, experienced geologists or geotechnicians were on site and supervised all drilling and sampling activities. Field observations were recorded in a project dedicated field notebook which is kept in a permanent project file. Work was conducted in accordance with the requirements of the Kaiser Health and Safety Plan.

In addition to the completion of geologic borings and the installation of monitoring wells, investigation activities included hydraulic conductivity testing, water level monitoring, and a limited program of groundwater sampling. An analysis to estimate potential peak flows in Fulton Creek was also undertaken. These activities are also further described below.

## 3.1 DRILLING METHODS AND GEOLOGIC SAMPLING PROCEDURES

Prior to entering the Facility, the drill rig and all tools were steam cleaned and inspected so that no visible mud or sediment remained. The pickup truck used by the crew in the controlled area was also cleaned. One pickup truck was left out of the controlled area for errands and general transportation to and from the site. The drilling rig and one truck remained in the containment area until drilling was completed. When drilling and well completions were finished, the equipment was steam cleaned and checked for radioactivity at earth contact points such as tires and drill pipes. Before being permitted on site, personnel were required to have received Health and Safety Training and to wear a radiation monitor badge.

### 3.1.1 Bedrock Boring

Bedrock borings were undertaken at three locations: ST-1, ST-2, and ST-3. At these locations, the unconsolidated overburden was initially drilled using 14" hollow stem augers. Split spoon samples of overburden and shallow, weathered bedrock were collected either from the boring, itself, or at a nearby monitoring well location. These samples were collected in accordance with the general procedure outlined in ASTM D 1586-92 (Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils). The procedures used to characterize these split spoon samples are the same as used in other unconsolidated overburden borings and are discussed in Section 3.2.1.

Core drilling procedures were used when the formation encountered was too hard to be sampled by soil sampling methods. In accordance with ASTM Method D 1586, a 1-inch or less penetration for 50 blows was used to indicate that soil sampling techniques were no longer applicable. Once bedrock was encountered and auger refusal occurred, augers were removed from the hole. Surface casing was installed and grouted in place. After the grout had cured for at least twenty-four hours, coring of bedrock materials was initiated using a 3.5-inch O.D. (3.0-inch I.D.) NX-core barrel. Coring was conducted in accordance with the general procedures outlined in ASTM D 2113-93 (Standard Practice for Diamond Core Drilling for Site Investigation). Clean water from a drinking water source at the Kaiser plant was used as the drilling fluid. No other extraneous materials were placed in the borehole. When a five-foot core was cut, the barrel was brought to the surface and opened for examination. The procedure for examining and describing rock cores are provided in Section 3.2.2. Bedrock cores were taken from 20 to 80 feet, 13 to 50 feet, and 20 to 64 feet at ST-1, ST-2, and ST-3, respectively.

After the desired interval was cored, the remainder of the boring was completed using air rotary drilling. Stratigraphic borings ST-1, ST-2, ST-3 were reamed and completed using air rotary drilling to total depths of 200, 58, and 64 feet, respectively. The total depth of ST-1 was based on an effort to identify the contact with the Oologah Limestone; the boring was terminated at 200 feet when the Oologah was not encountered. The total depths of ST-2 and ST-3 were based on an attempt to complete these borings well beneath zones of significant fracturing. The cuttings recovered from the holes and drilling performance parameters were used to characterize the bedrock material penetrated during air rotary drilling. Samples of cuttings derived from air drilling techniques are similar to samples taken during augering. The samples air lifted to the surface are representative of the interval drilled. The lag time, or time from the cutting of the sample to its recovery at the surface, is minimal. The samples obtained are suitable for qualitative stratigraphic descriptions. Air drilling is a valuable method for detecting isolated water zones in bedrock. The relative consistency of the rock, whether hard or soft, can readily be determined using air rotary drilling. Thin zones of shale, limestone, or siltstone can be identified by the character of the samples circulated to the surface as well as the color of the dust. Samples were placed in plastic bags and kept for stratigraphic reference. The boring logs for ST-1, ST-2, and ST-3 are included in Appendix A.

After drilling was complete, each of the three stratigraphic borings was logged using downhole geophysical logging techniques. Geophysical logging involves lowering sensing devices into a borehole and recording physical parameters that may be interpreted in terms of formation characteristics, groundwater quality, quantity and physical structure of the borehole. Each hole was logged by Century Geophysical Corporation. The suite of logs included SP (Spontaneous Potential), Gamma Ray, Caliper (Hole Diameter), Resistivity and Density. The interpreted geophysical log from each stratigraphic boring is provided in Appendix B.

Each of the stratigraphic borings also was tested to determine hydraulic conductivity of bedrock materials using inflatable packer tests on both permeable and non-permeable bedrock zones. A discussion of these tests is provided in Section 3.4.2.

After geophysical logging and packer testing were completed, boring ST-1 was grouted to the surface and abandoned. Stratigraphic borings ST-2 and ST-3 were backfilled with a bentonite seal to a depth of 48 feet. Both ST-2 and ST-3 were subsequently completed as monitoring wells. The details of monitoring well design and installation are provided in Section 3.3.1.

### 3.1.2 Unconsolidated Overburden Boring Procedures

After completion of the deep stratigraphic borings, hollow stem augers were generally employed to drill the remainder of the boreholes during the investigation. The hollow stem augers utilized had outside diameters of 6 inches and inside diameters of 4.25 inches. Continuous samples were taken using 2-inch split spoons in accordance with ASTM D 1586-92 (Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils). The split spoons were driven in 2-foot increments in front of the augers. The driving force for the split spoon sampler was a 140-pound hammer dropped from a height of 30 inches. Blow counts, or the number of times the hammer is dropped to advance the spoon through each of the four 6-inch intervals comprising a 2-foot spoon sample, were noted and recorded in the project dedicated field notebook. After driving the split spoon the required two feet, the spoon was removed from the hole and opened for examination and description. The procedure for describing split spoon samples is provided in Section 3.2.1.

After removing the split spoon from the borehole, the auger was used to ream the hole over the two-foot interval previously sampled by the split spoon. At this point, the split spoon was again lowered into the borehole and advanced in front of the auger to collect another soil sample. This process was repeated until the desired depth or refusal was achieved. Refusal refers to the point at which the auger is advanced to solid rock and the split spoon can be driven no further. At locations where a pair of borings was drilled (e.g., at monitoring well clusters), split spoons were generally only taken in the deep boring.

At selected locations, it was necessary to isolate the dross from deeper materials during drilling. At these locations, a surface casing was installed by using a large diameter (14-inch) auger to drill through the shallow materials. When the desired depth was reached, the auger was removed and an 8-inch surface casing was placed in the hole and grouted in place. After allowing 24 hours for the grout to harden, the hollow stem auger was then reinserted in the conductor casing. Split spooning and augering proceeded until the target depth was reached. The borings at which the surface casing was installed to isolate the dross were MWD-5 and MWD-11. After reaching the desired depths, monitoring wells were completed in these boreholes. The details of monitoring well design and installation are provided in Section 3.3.1.

Monitoring well MW-9 was drilled using the air rotary method, and soil samples were collected using a five-foot core barrel in a manner similar to that using split spoons. The core barrel was advanced in front of the air rotary bit. After the core barrel was removed from the hole, the air rotary bit was used to ream the five-foot section of the borehole sampled by the core barrel. After removing the air rotary bit from the borehole, the next five-foot interval was sampled using the core barrel.

## 3.2 SUBSURFACE SAMPLE DESCRIPTION AND TESTING

### 3.2.1 Unconsolidated Sample Description

Soil and weathered rock samples were collected using two-foot long, two-inch diameter split spoons or, in one case, using a five-foot long, 3-inch core barrels (see sections 3.1.1 and 3.1.2). After each split spoon was driven to the required depth, it was brought to the surface and opened for examination. Each sample was first scanned for radiation with a Ludlum Model 2224 scaler/rate meter and the count rate (cpm) measured was recorded in the project dedicated field log book. The samples were then examined by an experienced on-site geologist. The length of each split spoon sample was measured, the recovery noted, then described. The description included color, texture, fossils, discontinuities and apparent moisture. These data were recorded in a project dedicated field notebook. The field geologist used the Unified Soil Classification System in accordance with ASTM D 2488-93 (Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)) to describe the samples. A table outlining the Unified Soil Classification System based on field identification is provided in Table 3.1. The descriptions were recorded in the project dedicated field log book. Laboratory analyses were also conducted subsequently on a limited set of samples (see Section 3.2.3). The results of these analyses were also used to verify the field descriptions. The descriptions of the samples are provided in the boring logs contained in Appendix A.

### 3.2.2 Bedrock Core Description

Bedrock cores were obtained from Stratigraphic Boring ST-1 using a 3-inch NX-core barrel (see section 3.1.1). After each five-foot core was cut, the barrel was brought to the surface and opened for examination. Each core was first scanned for radiation with a Ludlum Model 2224 scaler/rate meter, and the count rate (cpm) measured was recorded in the project dedicated field log book. The cores were then examined and described by an experienced on-site geologist. These descriptions included rock type, color, texture, bedding, discontinuities and core recovery. A Rock Quality Designation (RQD) was also assigned to each core. RQD's are frequently used for describing the quality of rock (Deere, 1963) and is a quantitative description of the recovery and integrity of the core. The RQD is calculated by dividing the total length of a drill core run into the summation of the length of all recovered pieces in a core run that equals or exceeds twice the core diameter. These descriptions were recorded in the project dedicated field log book and are provided in Table 3.2.

### 3.2.3 Sample Storage

After the soil samples or rock cores were fully characterized, the cores were wrapped in plastic, labeled, and placed in waxed core boxes in depth sequence and the soil samples were placed in plastic bags. Cores and samples were marked with the depth below the surface from which the sample was taken, the boring number, and the field geologist's name. Cores and samples are stored in the flux building at the Facility (Flux Plant on Figure 2-2). This building is immediately adjacent the Retention Pond, and access to this building is controlled in order to secure custody of the samples.

### 3.2.4 Geotechnical Testing

Selected samples were tested in the soils laboratory for Atterberg Limits and grain size distribution. The Atterberg Limits define the characteristics of plasticity and soil liquidity. The grain size distribution provides a measurement of soil texture. The tests were performed in accordance with ASTM D 4318-87 (Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils) and ASTM D 421-85 (Standard Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants). Laboratory determinations of both the Atterberg Limits and grain size distributions are used to classify a soil in the Unified Soil Classification System in accordance with ASTM D 2487-93 (Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)). A table outlining the Unified Soil Classification System based on laboratory criteria is provided in Table 3.3. The results of the Atterberg Limits tests performed during the investigation and the resulting soil classifications are provided in Table 3.4. The graphs of the grain size distribution curves obtained from sieve analysis are provided in Appendix C, and a summary of results of the sieve analyses and the resulting soil classifications is provided in Table 3.5.

## 3.3 MONITORING WELL DESIGN AND INSTALLATION

### 3.3.1 Well Completion

Piezometers and monitoring wells were designed and installed in accordance with ASTM D 5092-90 (Design and Installation of Ground Water Monitoring Wells in Aquifers). Once drilling reached the target depth at a proposed piezometer or monitoring well location, the boring was reamed and cleaned of cuttings. Monitoring wells were constructed inside of hollow stem augers for borings that encountered sand or dross. Otherwise, at a boring that would stay open without the hollow stem augers in place, the augers were removed; and the well was constructed in the open borehole.

Two-inch diameter, Schedule 40 PVC casing and No. 10 screens were used to construct the wells. Depending on the thickness of the strata to be sampled, screen lengths were either 5 or 10 feet. Joints were flush threaded.

The assembled casing and screen was placed in the open hole or hollow stem auger and manually centered. With the exception of the deep stratigraphic borings, filter pack sand was poured into the annulus of the hole until the level of sand was no more than two feet above the top of the screen. Depth to the top of the sand was repeatedly measured using a weighted tape to ensure proper placement of the filter pack. The sand used was purchased from Colorado Silica Sand, Inc. and classified as 10-20 filter sand. After the sand level was measured, sodium bentonite pellets were poured into the hole until a two-foot dry thickness of bentonite was achieved. The bentonite was allowed to hydrate (expand) in the annulus due to the presence of moisture or water for 12 hours prior to grouting.

Portland cement grout was mixed in a trough using the mud pump from the rig. The grout mix was designed to have no more than six percent bentonite powder mixed with one 94-pound sack of Portland cement and about 7 to 8 gallons of water. This mix produces a grout weight of approximately 13 pounds per gallon. Because of the generally shallow depth of the borings, grout was poured into the well annulus at most wells rather than using a Tremie pipe. However, grout was placed in the deep stratigraphic wells using a Tremie pipe. Grout placement was supervised by the on-site geologist to assure proper mixture and complete placement. Twenty-four hours after initial grout emplacement, the holes were "topped off" with grout to about two feet below surface. Casing protectors were placed over the PVC pipe and concreted in the last two feet of the hole. Locking caps were installed on top of the casing protectors. The construction details of the wells and piezometers are provided in Table 3.6. Monitoring well and piezometer construction details are also depicted in the boring logs provided in Appendix A.

### 3.3.2 Well Development

Following completion of the wells, installation of casing protectors and well pads, each piezometer, monitor well and stratigraphic well was developed. Well development consisted of surging each well with a bailer, then pumping the well to dryness. If the well could not be pumped dry, pumping continued until clear water resulted. The wells pumped dry were allowed to recover then were repumped as many times as necessary to achieve clear water. To help ensure satisfactory development, pH and specific conductance measurements were also made on pumped water. When these parameters became constant and the water was clear, the well was considered developed.

### 3.3.3 Well Survey

Each well and test hole was located by land survey. The results of the survey were used to accurately locate each well on the Facility base map and to provide ground surface and top of casing (TOC) elevations above Mean Sea Level (MSL). Ground surface and top of casing elevations are provided in Table 3.6.

## 3.4 HYDRAULIC CONDUCTIVITY TESTING

### 3.4.1 Slug Testing

Slug testing was undertaken during the investigation to assist in determining the hydraulic conductivity of overburden materials at the site. Three series of tests were conducted. The first series, conducted in April 1997, was performed on a limited set of wells using a rising head slug test. During these tests a pump was used to remove a large volume of water, in some cases nearly evacuating the well totally. The water level recovery was then observed and recorded. The second series of tests, conducted in January 1998, was performed on the entire set of wells screened in the overburden (with the exception of MWD-7) using a falling head test. These tests were performed by inserting a slug into the well and observing and recording the recovery of the water level in the well. The third series of tests, conducted in May 1999, were performed on a limited number of wells using both falling head and rising head tests. The wells selected for this series were primarily wells screened at or near to water table and were selected to verify hydraulic conductivity measurements obtained during the previous falling head tests. These tests were performed by inserting a slug into the well, allowing the water level to equilibrate, and removing the slug. The recovery of the water level in the well was again observed and recorded.

During all three series of slug tests, the recovery of the water level was observed and recorded using a pressure transducer and data logger. All slug test data were evaluated using the method outlined by Hvorslev (1951). All data were analyzed using the widely used pump testing analysis program AquiferTest (Version 2.0) developed by Waterloo Hydrogeologic, Inc. The slug test data and analysis are provided in Appendix D. A summary of the hydraulic conductivity determinations is provided in Table 3.7.

### 3.4.2 Inflatable Packer Testing

Inflatable packer testing was conducted in the three deep stratigraphic borings to determine the hydraulic conductivity of the Nowata Shale underlying the site. Inflatable packer tests provide a means of assessing the permeability of earth materials included in a definite pre-selected test interval. The procedure used depends on the condition of the rock. A single or double packer arrangement can be used. The method used at the Facility was modified from that developed by the U.S. Bureau of Reclamation (Ahrens and Barlow, 1951). ASTM Procedure D 4630 - 91 (Standard Test Method for Determining Transmissivity and Storativity of Low-Permeability Rocks by In Situ Measurement Using the Constant Head Injection Test) was also referred to for guidance in conducting these tests.

Both single and double packer tests were conducted within the stratigraphic borings. In the double packer tests, two inflatable packers, separated by the desired interval, are mounted near the bottom of the pipe used for making the tests. The bottom of the pipe is sealed, and the section of the pipe between the packers is perforated. After setting the packers, water is pumped into the pipe at different pressures. The pressures and pumping rates are recorded. Upon completion of the test, the packer apparatus can be lowered or raised to test additional bedrock intervals. The single packer test is conducted in a similar manner except the interval tested includes the entire depth of the well below the packer. The intervals tested in each boring and the resulting hydraulic conductivity measurements are presented in Table 3.8. Test data and sample calculations are provided in Appendix E. Further description of the testing method and analysis of the data is also presented in Appendix E.

## 3.5 WATER LEVEL MONITORING

A program of periodic water level monitoring has been undertaken to help assess temporal trends in groundwater flow direction and velocity and to evaluate the hydraulic influences of the Fresh Water Pond, Retention Pond, and Fulton Creek on groundwater beneath the site. A temporary program of water level monitoring was conducted during the spring of 1997. A permanent, monthly program of water level monitoring was instituted in June 1998. Water levels have been measured in the wells, the Fresh Water Pond, the Retention Pond (beginning June 1998) and at the downstream Fulton Creek weir. Water levels in wells were determined by measuring the depth to top of the standing water in each well using an electronic water level probe from the survey point on the top of casing on each well. The water level measurements were made in accordance with the procedure specified for electrical measuring devices in ASTM Procedure D 4750 - 87 (Standard Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)). The water levels in the surface water body were determined by visually comparing water levels with the graduations on the surveyed staff gauges. The water level data collected are presented in Table 3.9.

## 3.6 GROUNDWATER SAMPLING

A limited program to determine major ion chemistry of groundwater was conducted as part of this investigation. The groundwater samples used for these analyses were collected using disposable bailers after evacuating three well volumes. In the case of low yielding wells, samples were collected using disposable bailers after removing the standing water in the well and allowing the water to recover sufficiently to obtain the required amount of water. These samples were filtered upon receipt by the laboratory. The detailed procedure used to collect these groundwater samples is provided in Appendix F. A summary of the results of this analysis is provided in Table 3.10. Completed Chain of Custody forms and Laboratory Reports are provided in Appendix G. Additional groundwater sampling, including analyses for radionuclides, has been undertaken as part of a concurrent geochemistry study. The results of this additional groundwater sampling are reported and discussed in Meijer (1999).

## 3.7 SURFACE WATER FLOW PREDICTIONS

Soil Conservation Service techniques for predicting flows were used to predict peak flow in Fulton Creek in response to rainfall events. Predictions for peak flows in Fulton Creek at the discharge weir at the northeastern corner of the Facility for the 2, 5, 10, 25, 50, and 100-year storms were developed. Equivalent stage heights at the weir were also computed for these discharges. The details of these analyses are presented in Appendix H. The results of these analyses are presented in Section 4.3 of this report.

## 3.8 SURFACE WATER SAMPLING

Kaiser undertakes a routine program of sampling surface water for radioactivity measurements. Samples are taken at the Fulton Creek inlet into the Kaiser property and at the Fulton Creek Discharge Weir. The results of the radioactivity measurements of these samples for the period of September 1997 through March 1999 are presented in Table 3-11. The difference of downstream minus upstream gross radioactivity concentration in Fulton is less than the NRC maximum radioactivity concentration limit in effluent water and was not high enough to trigger a specific radionuclide analysis according to the Kaiser surface water sampling plan.

## Table 3-1--Unified Soil Classification, Field Identification

| | | | | | | | | | | | UNIFIED SOIL CLASSES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| COARSE GRAINED SOILS | More than half of material (by weight) is of individual grains visible to the naked eye. | No. 200 sieve size is about the smallest particle visible to the naked eye. | GRAVEL AND GRAVELLY SOILS | More than half of Coarse Fraction (by weight) is larger than ¼ in. size. | For visual classification the ¼ in. size may be used as equivalent to the No. 4 sieve size. | CLEAN GRAVELS Will not leave a dirt stain on a wet palm. | Wide range in grain sizes and substantial amounts of all intermediate particle sizes. | | | | GW |
| | | | | | | | Predominantly one size or a range of sizes with some intermediate sizes missing. | | | | GP |
| | | | | | | DIRTY GRAVELS Will leave a dirt stain on a wet palm. | Nonplastic fines or fines with low plasticity (for identification of fines see characteristics of ML below). | | | | GM |
| | | | | | | | Plastic fines (for identification of fines see characteristics of CL below). | | | | GC |
| | | | SAND AND SANDY SOILS | More than half of Coarse Fraction (by weight) is smaller than ¼ in. size. | | CLEAN SANDS Will not leave a dirt stain on a wet palm. | Wide range in grain size and substantial amounts of all intermediate particle sizes. | | | | SW |
| | | | | | | | Predominantly one size or a range of sizes with some intermediate sizes missing. | | | | SP |
| | | | | | | DIRTY SANDS Will leave a dirt stain on a wet palm. | Nonplastic fines or fines with low plasticity (for identification of fines see characteristics of ML below). | | | | SM |
| | | | | | | | Plastic fines (for identification of fines see characteristics of CL below). | | | | SC |
| FINE GRAINED SOILS | More than half of material (by weight) is of individual grains not visible to the naked eye. | | | See Identification Procedures | ODOR | DRY CRUSHING STRENGTH | DILATANCY (SHAKE) REACTION | TOUGHNESS | RIBBON (NEAR THE P.L.) | SHINE (NEAR THE P.L.) | |
| | | | SILTS AND CLAYS (Low Plastic) | | | Slight | Rapid | Low to None | None | Dull | ML |
| | | | | | | High | Medium to None | Medium | Weak | Slight to Shiny | CL |
| | | | | | Pro-nounced | Medium | Slow to None | Low | None | Dull to Slight | OL |
| | | | SILTS AND CLAYS (Highly Plastic) | | | Medium | Very Slow to None | Medium | Weak | Slight | MH |
| | | | | | | Very High | None | High | Strong | Shiny | CH |
| | | | | | Pro-nounced | High | None | Low to Medium | Weak | Dull to Slight | OH |
| HIGHLY ORGANIC SOILS | | | | | | | Readily identified by color, odor, spongy feel and frequently by fibrous texture. | | | | Pt |

Source: U.S. Department of Agriculture Soil Conservation Service, SCS National Engineering Handbook, Section 8, 1968.

## Table 3-2
## ROCK QUALITY DETERMINATION (RQD)

| WELL | DEPTH | INCHES CORED | TOTAL INCHES RECOVERED | PERCENT RECOVERY (RQD) |
|---|---|---|---|---|
| ST-1 | 26-30 | 48 | 40.37 | 84.1 |
| | 30-40 | 120 | 111.50 | 92.9 |
| | 40-50 | 120 | 87.43 | 72.8<br>fracture |
| | 50-60 | 120 | 116.56 | 97.1 |
| | 60-70 | 120 | 115.81 | 96.5 |
| | 70-80 | 120 | 115.68 | 96.4 |
| | | | | |
| ST-2 | 13-20 | 84 | 58 | 69 |
| | 20-30 | 120 | 112.81 | 94.0 |
| | 30-40 | 120 | 111.68 | 93.0 |
| | 40-50 | 120 | 112.56 | 93.8 |
| | | | | |
| ST-3 | 1-10 (split spoon) | 108 | 103.68 | 96 |
| | 10-20 (split spoon) | 120 | 101.37 | 84.4 |
| | 20-30 (cored) | 120 | 102.31 | 85.2 |
| | 30-40 | 120 | 109.25 | 91.0 |
| | 40-50 | 120 | 86.62 | 72.1 |
| | 50-60 | 120 | 97.87 | 81.5 |
| | 60-64 | 48 | 48.5 | 100 |

# Table 3-3
## Unified Soil Classification System ASTM D 2488, Laboratory Criteria

| Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A] | | | | Group Symbol | Group Name[B] |
|---|---|---|---|---|---|
| COARSE-GRAINED SOILS More than 50 % retained on No. 200 sieve | Gravels More than 50 % of coarse fraction retained on No. 4 sieve | Clean Gravels Less than 5 % fines[C] | $Cu \geq 4$ and $1 \leq Cc \leq 3$[E] | GW | Well-graded gravel[F] |
| | | | $Cu < 4$ and/or $1 > Cc > 3$[E] | GP | Poorly graded gravel[F] |
| | | Gravels with Fines More than 12 % fines[C] | Fines classify as ML or MH | GM | Silty gravel[F,G,H] |
| | | | Fines classify as CL or CH | GC | Clayey gravel[F,G,H] |
| | Sands 50 % or more of coarse fraction passes No. 4 sieve | Clean Sands Less than 5 % fines[D] | $Cu \geq 6$ and $1 \leq Cc \leq 3$[E] | SW | Well-graded sand[I] |
| | | | $Cu < 6$ and/or $1 > Cc > 3$[E] | SP | Poorly graded sand[I] |
| | | Sands with Fines More than 12 % fines[D] | Fines classify as ML or MH | SM | Silty sand[G,H,I] |
| | | | Fines classify as CL or CH | SC | Clayey sand[G,H,I] |
| FINE-GRAINED SOILS 50 % or more passes the No. 200 sieve | Silts and Clays Liquid limit less than 50 | inorganic | PI > 7 and plots on or above "A" line[J] | CL | Lean clay[K,L,M] |
| | | | PI < 4 or plots below "A" line[J] | ML | Silt[K,L,M] |
| | | organic | $\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$ | OL | Organic clay[K,L,M,N]<br>Organic silt[K,L,M,O] |
| | Silts and Clays Liquid limit 50 or more | inorganic | PI plots on or above "A" line | CH | Fat clay[K,L,M] |
| | | | PI plots below "A" line | MH | Elastic silt[K,L,M] |
| | | organic | $\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$ | OH | Organic clay[K,L,M,P]<br>Organic silt[K,L,M,O] |
| HIGHLY ORGANIC SOILS | | Primarily organic matter, dark in color, and organic odor | | PT | Peat |

[A] Based on the material passing the 3-in. (75-mm) sieve.

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12 % fines require dual symbols:
GW-GM well-graded gravel with silt
GW-GC well-graded gravel with clay
GP-GM poorly graded gravel with silt
GP-GC poorly graded gravel with clay

[D] Sands with 5 to 12 % fines require dual symbols:
SW-SM well-graded sand with silt
SW-SC well-graded sand with clay
SP-SM poorly graded sand with silt
SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10}$ $\quad Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains ≥ 15 % sand, add "with sand" to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add "with organic fines" to group name.

[I] If soil contains ≥ 15 % gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29 % plus No. 200, add "with sand" or "with gravel," whichever is predominant.

[L] If soil contains ≥ 30 % plus No. 200, predominantly sand, add "sandy" to group name.

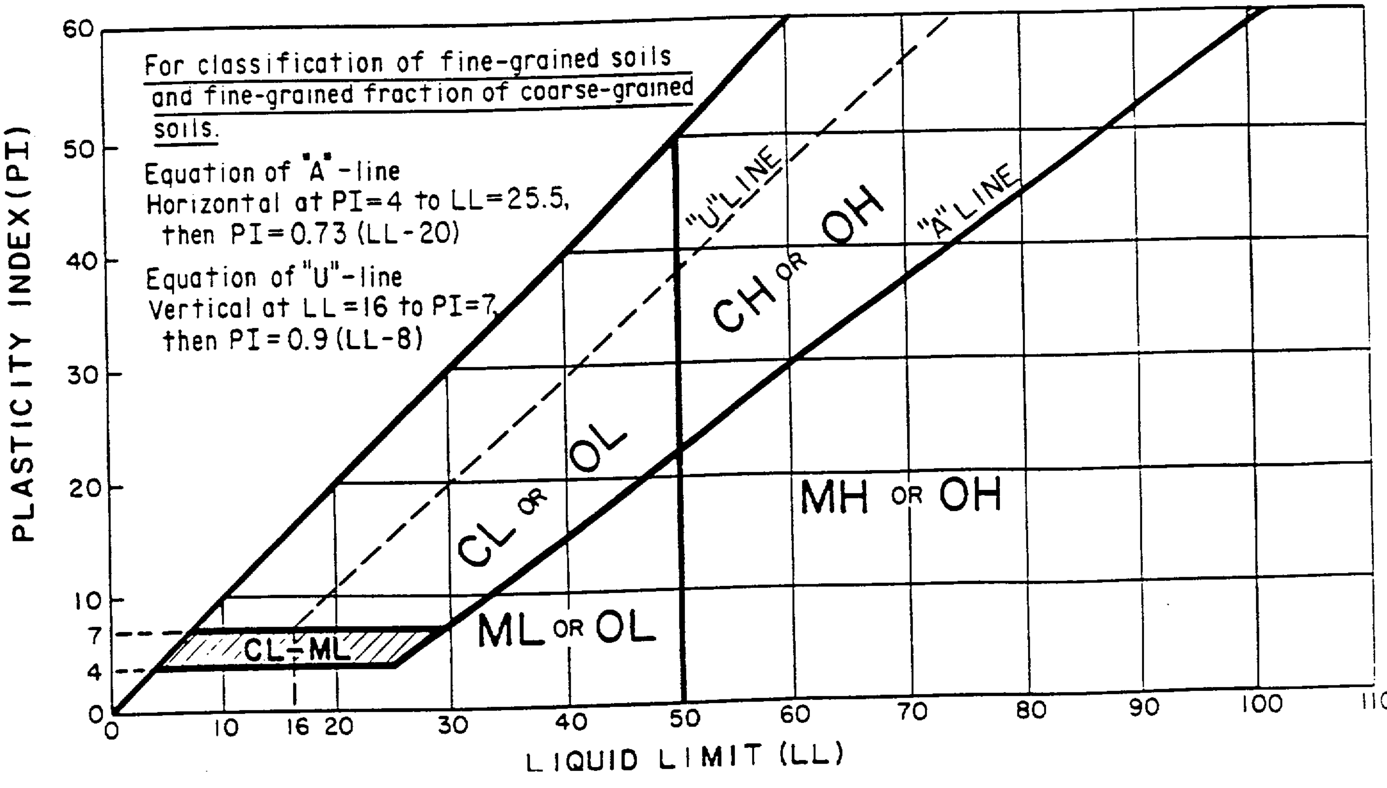
[M] If soil contains ≥ 30 % plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] PI ≥ 4 and plots on or above "A" line.

[O] PI < 4 or plots below "A" line.

[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.



Source: From ASTM, 1993, Annual Book of ASTM Standards - D 2488

## Table 3-4
## ATTERBERG LIMITS AND SOIL CHARACTERISTICS

| HOLE NO. | UNIT NO. | DEPTH FEET | LIQUID LIMIT % | PLASTIC INDEX % | CLASSIFICATION |
|---|---|---|---|---|---|
| P-8 | 1 | 18-26 | 35 | 15 | SC |
| P-7 | 1 | 18-22 | 26 | 8 | SP-SC |
| P-10 | 1 | 12-16 | 44 | 26 | SW-SC |
| P-5 | 1 | 13-18 | 31 | 14 | SW-SC |
| P-4 | 3 | 2-6 | 56 | 34 | CH |
| P-2 | 3 | 6-12 | 43 | 25 | CL |
| P-2 | 3 | 12-24 | 40 | 23 | CL |
| MWD-5 | 1 | 16-26 | 27 | 11 | SC |
| MWD-6 | 1 | 18-28 | 33 | 15 | SC |
| MWD-10 | 3 | 0-6 | 41 | 21 | CL |
| MWD-10 | 3 | 6-10 | 44 | 24 | CL |
| ST-1 | 3 | 1-3 | 50 | 27 | CL |
| ST-1 | 3 | 3-16 | 50 | 30 | CH |
| ST-3 | 3 | 0-1 | 39 | 18 | CL |
| ST-3 | 3 | 6-12 | 36 | 16 | CL |

*Source: Soil Conservation Service, 1968, Engineering Geology, Section 8 Chapter 1, Washington, D.C., p 1-34

SP-SC = Poorly graded sand with clay
SW-SC = Well graded sand with clay
CH = Inorganic clays of high plasticity
CL = Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays
SC = Clayey sand

## Table 3-5
## SIEVE ANALYSES OF ALLUVIAL MATERIALS DESCRIBED AS UNIT 1

| Point No. | Percent Gravel | Percent Sand | Percent Silt or Clay | USC* |
|---|---|---|---|---|
| MWD-5 | 15 | 31 | 54 | SC |
| MWD-6 | 22 | 34 | 44 | SC |
| P-5 | 8 | 84 | 8 | SW-SC |
| P-7 | 8 | 84 | 8 | SP-SC |
| P-8 | 6 | 72 | 22 | SC |
| P-10 | 4 | 89 | 7 | SW-SC |

* Unified Soil Classification System

SC is clayey sand
SW-SC is sand, well graded and clayey sand
SP-SC is sand, poorly graded with clayey sand

## TABLE 3-6

## WELL COMPLETION DATA

| Description | Ground Level | Elevations (MSL) | | | | | Water Levels In MSL |
|---|---|---|---|---|---|---|---|
| | | Top of Casing | Top of Screen | Bottom of Screen | Top of Filter Pack | Top of Bentonite | 4/29/97 |
| P-1 | 702.7 | 706.36 | 692.7 | 682.7 | 694.7 | 696.7 | 699.38 |
| P-2 | 704.5 | 708.6 | 686.5 | 676.5 | 689.5 | 691.5 | 698.67 |
| P-3 | 703.4 | 707.14 | 700.4 | 690.4 | 700.4 | 702.4 | 699.65 |
| P-4 | 698.2 | 701.27 | 688.2 | 678.2 | 690.2 | 692.2 | 695.93 |
| P-5 | 688.8 | 691.95 | 679.8 | 669.8 | 681.8 | 683.8 | 682.75 |
| P-7 | 702.4 | 706.35 | 690.4 | 680.4 | 692.4 | 694.4 | 694.29 |
| P-8 | 702.5 | 702.99 | 686 | 676 | 688.5 | 690.5 | 694.76 |
| P-10 | 702.6 | 706.19 | 690.6 | 680.6 | 692.6 | 694.2 | 697.03 |
| MWD-2 | 704.9 | 708.48 | 699.9 | 694.9 | 701.9 | 702.9 | 700.6 |
| MWD-4 | 696 | 700.24 | 686 | 676 | 688 | 690 | 692.59 |
| MWS-4 | 696 | 699.35 | 691 | 686 | 693 | 694.5 | 693.83 |
| MWD-5 | 696.1 | 699.76 | 680 | 670 | 682 | 684 | 688.76 |
| MWS-5 | 696 | 700.12 | 689 | 684 | 691 | 689 | 693.72 |
| MWD-6 | 695.7 | 699.62 | 676.2 | 666.2 | 678.2 | 680.2 | 690.59 |
| MWS-6 | 695.6 | 699.55 | 691.1 | 681.1 | 693.1 | 694.1 | 691.88 |
| MWD-7 | 686 | 689.83 | 676 | 666 | 678 | 680 | 679.22 |
| MWD-8 | 684.3 | 688.15 | 675.3 | 665.3 | 677.3 | 680.3 | 683.34 |
| MWD-9 | 690.6 | 692.86 | 680.1 | 670.1 | 681.1 | 683.1 | 681.51 |
| MWD-10 | 696.8 | 700.5 | 686.8 | 676.6 | 688.8 | 690.8 | 689.95 |
| MWS-11 | 693.8 | 697.53 | 688.8 | 683.8 | 690.8 | 692.8 | 685.33 |
| MWD-11 | 693.7 | 697.83 | 679.7 | 669.7 | 681.7 | 681.7 | 685.06 |
| ST-2 | 705 | 708.66 | 667 | 657 | 668 | 669 | 657.1 |
| ST-3 | 685.6 | 690.08 | 647.6 | 637.6 | 649 | 649 | 680.54 |

# TABLE 3-7
# A&M HYDRAULIC CONDUCTIVITY MEASUREMENTS (cm/sec)

| Well ID | Unit | Apr-97 Hvorslev | Jan-98 Hvorslev | May-99 Hvorslev | |
|---|---|---|---|---|---|
| | | Rising Head | Falling Head | Falling Head | Rising Head |
| P-1 | W. Shale | 6.86E-05 | 7.10E-05 | | |
| P-2 | 1 | 3.90E-04 | 3.54E-04 | | |
| P-3 | W. Shale | 4.17E-06 | 6.20E-06 | 1.60E-06 | (3) |
| P-4 | W. Shale | | (1) | 6.00E-06 | (3) |
| P-5 | 1 | 1.55E-03 | 1.02E-03 | | |
| P-7 | 1 | | 1.07E-04 | | |
| P-8 | 1 | 7.13E-04 | 1.05E-04 | | |
| P-10 | 1 | | 7.16E-05 | | |
| MWD-2 | W.Shale | 5.18E-04 | 5.55E-04 | 4.75E-04 | 4.29E-04 |
| MWS-4 | 5 | 3.06E-03 | 4.54E-04 | 1.37E-03 | 2.26E-03 |
| MWD-4 | 1 | | 2.84E-04 | | |
| MWS-5 | 5 | 4.16E-04 | 3.41E-04 | | |
| MWD-5 | 1 | 2.27E-03 | 9.11E-04 | | |
| MWS-6 | 3 | 3.69E-04 | 1.75E-04 | 4.72E-04 | 3.84E-04 |
| MWD-6 | 1 | | 5.36E-04 | | |
| MWD-7 | 1 | | | 4.63E-05 | 2.12E-05 |
| MWD-8 | 1 | | 3.38E-05 | 2.40E-03 | 5.67E-04 |
| MWD-9 | 2 | | 8.47E-05 | 2.85E-04 | 2.50E-04 |
| MWD-10 | 1 | 5.59E-04 | 1.15E-03 | | |
| MWS-11 | 5 | | (2) | | |
| MWD-11 | 1 | | 2.94E-03 | 3.32E-03 | 3.17E-03 |

NOTES:

(1) Test abandonded due to slow recovery
(2) Test performed, but due to lack of water, test deemed invalid
(3) Rising Head test not done due to slow recovery

Table 3-8

## SCOPE AND DESCRIPTION OF BEDROCK TESTING

| Borehole No. | Length of Interval Tested | Rock Description | Purpose for Testing Interval | Hyd./Cond. cm/sec |
|---|---|---|---|---|
| ST-1 | 43 feet (24-67) | Shale, gray, hard, siltstone at 52' | Fractures 38-39.6<br>Siltstone 51-52 | $< 10^{-7}$ |
| ST-1 | 17 feet (83-100) | Shale, gray siltstone | Siltstone 81-82 | $< 10^{-7}$ |
| ST-2 | 10 feet (50-58) | Shale, gray, hard | Non-fractured | 9.9x$10^{-7}$ |
| ST-2 | 25 feet (35-58) | Shale, gray, hard | Fracture at 38.8 | 3.7x$10^{-6}$ |
| ST-3 | 46 feet (20-64) | Shale, gray, siltstone | Siltstone at 35<br>Fracture fill at 40-42 | 2.6x$10^{-5}$ |
| ST-3 | 22 feet (34-64) | Shale, gray, siltstone | As above | 1.8x$10^{-4}$ |
| ST-3 | 16 feet (50-64) | Shale, gray, hard | Below fracture zone | 1.1x$10^{-4}$ |

# TABLE 3-9

## Water Level Measurements at Monitor Wells and Ponds

## April 1997 to March 1999

| Well ID. | 4/29/97 | 5/12/97 | 5/29/97 | 7/28/97 | 6/26/98 | 7/7/98 | 8/6/98 | 9/9/98 | 10/8/98 | 11/5/98 | 12/7/98 | 1/13/99 | 2/8/99 | 3/10/99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P-1 | 699.38 | 698.88 | 699.38 | 699.3 | 698.08 | 698.49 | 698.12 | 697.24 | 699.54 | 699.93 | 700.16 | 699.14 | 701.04 | 700.16 |
| P-2 | 698.67 | 698.58 | 698.67 | 698.96 | 699.15 | 699.48 | 699.37 | 697.68 | 700.3 | 699.62 | 699.5 | 699.5 | 699.57 | 699.43 |
| P-3 | 699.65 | 699.52 | 699.65 |  | 699.20 | 699.49 | 698.52 | 697.63 | 699.98 | 700.02 | 700.16 | 699.1 | 700.45 | 699.87 |
| P-4 | 695.93 | 695.48 | 695.93 | 695.09 | 693.89 | 694.17 | 692.85 | 691.65 | 692.83 | 693.69 | 694.98 | 694.75 | 697.37 | 696.21 |
| P-5 | 682.75 | 682.58 | 682.75 | 683.07 | 680.15 | 680.65 | 679.86 | 678.66 | 682 | 681.83 | 681.97 | 680.74 | 682.55 | 681.46 |
| P-7 | 694.29 | 694.02 | 694.29 | 693.09 | 692.08 | 692.38 | 691.88 | 689.34 | 693.15 | 693.41 | 693.54 | 692.91 | 694.14 | 693.23 |
| P-8 | 694.76 | 694.61 | 694.76 | 694.25 | 692.84 | 692.84 | 691.94 | 689.82 | 693.52 | 693.44 | 693.39 | 692.95 | 693.41 | 693.04 |
| P-10 | 697.03 | 696.69 | 697.03 | 696.82 | 697.14 | 697.34 | 697.32 | 695.51 | 697.74 | 697.75 | 698.03 | 697.3 | 697.92 | 697.48 |
| MWD-2 | 700.6 | 700.35 | 700.6 | 700.35 | 700.36 | 700.93 | 700.39 | 698.95 | 701.46 | 701.32 | 701.56 | 700.39 | 701.84 | 701.45 |
| MWS-4 | 693.83 | 694.6 | 693.83 | 694.6 | 690.93 | 691.59 | 690.70 | 688.26 | 692.80 | 692.79 | 692.8 | 692.51 | 692.95 | 692.29 |
| MWD-4 | 692.59 | 691.59 | 692.59 | 691.59 | 690.29 | 690.84 | 690.08 | 688.09 | 691.66 | 691.71 | 691.8 | 691.26 | 692.16 | 691.39 |
| MWS-5 | 693.72 | 693.67 | 692.59 | 693.67 | 690.50 | 691.35 | 689.59 | 688.96 | 692.17 | 692 | 692.06 | 691.26 | 692.54 | 691.35 |
| MWD-5 | 688.76 | 688.6 | 688.76 | 688.6 | 686.26 | 686.75 | 685.79 | 684.30 | 687.83 | 687.82 | 687.77 | 686.93 | 688.32 | 687.33 |
| MWS-6 | 691.88 | 691.75 | 691.88 | 691.75 | 684.87 | 685.19 | 684.30 | 683.03 | 689.46 | 688.17 | 687.24 | 685.63 | 688.51 | 685.93 |
| MWD-6 | 690.59 | 690.43 | 690.59 | 690.43 | 684.79 | 685.22 | 684.30 | 683.00 | 688.99 | 688.10 | 687.23 | 685.59 | 688.29 | 685.95 |
| MWD-7 | 679.22 | 678.72 | 679.22 | 679.23 | 677.45 | 677.72 | 677.82 | 676.68 | 679.46 | 679.2 | 680.77 | 678.18 | 681.22 | 680.64 |
| MWD-8 | 683.34 | 683.2 | 683.34 | 683.2 | 680.62 | 681.15 | 680.36 | 679.19 | 683.01 | 682.86 | 682.89 | 681.69 | 683.36 | 682.32 |
| MWD-9 | 681.51 | 681.36 | 681.51 | 681.36 | 680.86 | 680.99 | 680.94 | 680.35 | 681.56 | 681.61 | 681.86 | 681.34 | 682.25 | 681.88 |
| MWD-10 | 689.95 | 689.9 | 689.95 | 689.9 | 688.63 | 688.68 | 688.52 | 686.97 | 689.47 | 689.38 | 689.38 | 688.93 | 689.58 | 689.15 |
| MWS-11 | 685.33 | 685.09 | 685.33 | 685.09 | 683.66 | 683.66 |  | 683.53 | 685.04 | 684.75 | 684.41 | 684.23 | 684.97 | 683.68 |
| MWD-11 | 685.06 | 684.89 | 685.06 | 684.89 | 682.76 | 682.93 | 682.59 | 681.78 | 684.75 | 684.43 | 684.24 | 683.18 | 684.68 | 683.41 |
| ST-2 | 657.1 | 657.22 | 657.1 | 657.76 | 660.46 | 660.66 | 660.84 | 661.12 | 661.28 | 661.55 | 661.58 | 662.79 | 662.18 | 662.24 |
| ST-3 | 680.54 | 680.26 | 680.54 | 680.26 | 679.50 | 680.10 | 679.46 | 679.38 | 679.6 | 679.93 | 680.28 | 680.55 | 680.71 | 680.42 |
| FWP | 698.67 | 698.67 | 698.67 | 698.67 | 698.90 | 698.98 | 698.84 | 698.19 | 699.26 | 699.46 | 699.01 | 698.99 | 699.02 | 698.88 |
| RtP |  |  |  |  | 692.31 | 692.28 | 691.38 |  | 692.66 | 692.23 | 692.38 | 692.12 | 692.53 | 692.13 |
| East Weir | 679.75 | 679.74 | 680.15 | 680.1 |  | 679.73 | 680.19 |  | 679.77 | 679.79 | 679.86 | 679.75 | 679.92 | 679.85 |

Water level for freshwater pond has been inferred as constant during the period 4/29/97 -7/28/97

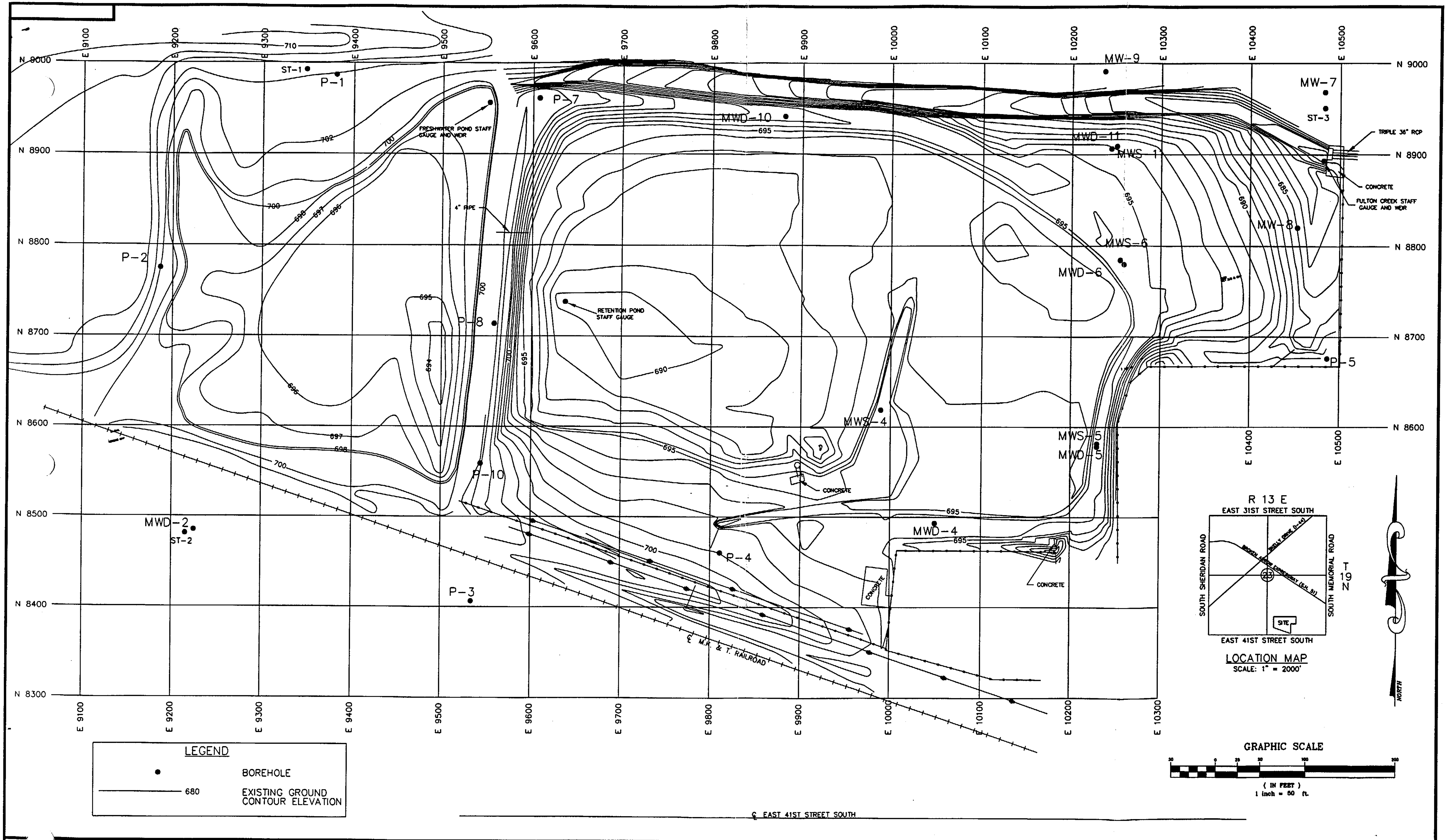
## Table 3-10

## CHEMICAL ANALYSIS OF WATER SAMPLES COLLECTED MAY 12, 1997
## TULSA REMEDIATION PROJECT

| Parameter mg/L | P-1 | P-2 | P-8 | MWD-5 | P-5 | MWD-8 | ST-3 | MWS-5 | Fresh Pond | Retention Pond |
|---|---|---|---|---|---|---|---|---|---|---|
| Calcium | 159 | 180 | 154 | 122 | 123 | 47.8 | 159 | 14.7 | 40.2 | 16.5 |
| Magnesium | 9.49 | 20 | 23.5 | 42.1 | 81.2 | 98.7 | 58.4 | 69.3 | 7.01 | 49.4 |
| Sodium | 19.4 | 32 | 23.8 | 48.7 | 60.6 | 25.3 | 1020 | 29.0 | 21.8 | 24.6 |
| Iron | 2.56 | 54.6 | 12.6 | 0.166 | ND | 1.87 | 0.384 | 0.8 | 1.18 | ND |
| Potassium | 1.57 | 8.2 | 2.04 | 232 | 357 | 194 | 10.4 | 11.6 | 2.74 | 10.3 |
| Alkalinity (Carb) | ND | ND | ND | 23.6 | ND | ND | ND | 20.5 | ND | 69.7 |
| Alkalinity (Bi-Carb) | 414 | 533 | 223 | 121 | 254 | 228 | 139 | 128 | 113 | 112 |
| Hardness $CaCO_3$ | 436 | 542 | 481 | 478 | 640 | 524 | 637 | 321 | 129 | 244 |
| Total Diss. Solids | 511 | 630 | 840 | 1150 | 1730 | 1130 | 13500 | 343 | 208 | 360 |
| Chloride | 20.6 | 24.6 | 268 | 636 | 981 | 517 | 6720 | 197 | 13.9 | 57.6 |
| Sulfate | 35.6 | 11.8 | 4.4 | 11.5 | 7.9 | 4.6 | 11.2 | 10 | 38.7 | 40.1 |
| Nitrate | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| pH S.U. | 7.07 | 7.2 | 7.24 | 9.15 | 7.37 | 7.91 | 7.72 | 9.84 | 8.13 | 9.53 |
| Spec. Cond. umho/cm | 866 | 990 | 1250 | 2240 | 3290 | 2160 | 6280 | 705 | 352 | 585 |
| Total Phosphate | ND | 0.21 | ND | ND | ND | ND | ND | ND | ND | ND |
| Total Sulfide | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Barium | 0.288 | 1.82 | 3.65 | 7.67 | 8.53 | 12.3 | 3.71 | 1.26 | 0.11 | 0.765 |

## Table 3-11
## Radioactivity Measured in Surface Water at Fulton Creek Inlet and Discharge Weir

| Radiation Measured | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date Sampled | Fulton Creek Inlet | | | | | | Fulton Creek Discharge Weir | | | | | | Net Increase | |
| | Gross Alpha | | | Gross Beta | | | Gross Alpha | | | Gross Beta | | | Gross Alpha | Gross Beta |
| | MDA pCi/L | Conc pCi/L | std dev pCi/L | MDA pCi/L | Conc pCi/L | std dev pCi/L | MDA pCi/L | Conc pCi/L | std dev pCi/L | MDA pCi/L | Conc pCi/L | std dev pCi/L | Conc pCi/L | Conc pCi/L |
| 09/02/97 | 9.5 | 12.2 | 11 | 22.5 | 0 | 19.5 | 8.4 | 6.2 | 8.9 | 22.2 | 1.9 | 20.6 | -6.0 | 1.9 |
| 10/28/97 | 3.1 | 0 | 2.6 | 5.1 | 3.3 | 4.8 | 3.2 | 0 | 2.6 | 5.1 | 18.2 | 5.4 | 0.0 | 14.9 |
| 12/17/97 | 4.2 | 3.5 | 4.5 | 6.3 | 2.2 | 6 | 3.6 | 0.4 | 3.4 | 6.3 | 24.6 | 7.2 | -3.1 | 22.4 |
| 01/21/98 | 2.8 | 1 | 2.7 | 4.6 | 1.8 | 4.3 | 3.2 | 1.1 | 3.1 | 5 | 25.3 | 5.2 | 0.1 | 23.5 |
| 02/24/98 | 3.7 | 6.1 | 4.4 | 4.6 | 5.5 | 4.5 | 4 | 1.3 | 3.9 | 4.6 | 24.6 | 5.3 | -4.8 | 19.1 |
| 03/25/98 | 3 | 3 | 3.3 | 5.9 | 0 | 5.1 | 1.9 | 0.6 | 1.8 | 5.8 | 11.3 | 5.8 | -2.4 | 11.3 |
| 04/30/98 | 3.3 | 0 | 2.7 | 5.1 | 0 | 4.7 | 2.5 | 0 | 2.2 | 5.1 | 6.9 | 5 | 0.0 | 6.9 |
| 05/12/98 | 6 | 2.8 | 6.2 | 14.6 | 0 | 13.1 | 6.5 | 0 | 5.7 | 14.7 | 25 | 15.1 | -2.8 | 25.0 |
| 06/11/98 | 1.6 | 0.6 | 1.6 | 3.5 | 2.7 | 3.3 | 1.8 | 0 | 1.6 | 4.1 | 4.3 | 4 | -0.6 | 1.6 |
| 07/03/98 | 1.7 | 1.1 | 1.8 | 2.9 | 2.2 | 2.8 | 1.5 | 1.0 | 1.5 | 2.8 | 9.5 | 3.0 | -0.1 | 7.3 |
| 08/07/98 | 4.7 | 0.3 | 4.4 | 6.7 | 0 | 6 | 4.2 | 0.0 | 3.8 | 6.8 | 1.8 | 6.3 | -0.3 | 1.8 |
| 09/10/98 | 7.4 | 3.7 | 7.8 | 19.6 | 0 | 17.2 | 8.3 | 1.0 | 7.9 | 19.2 | 0 | 16.9 | -2.7 | 0.0 |
| 10/13/98 | 6.3 | 7.9 | 7.6 | 20.3 | 0 | 18.2 | 10 | 1.3 | 9.6 | 18.7 | 0 | 17 | -6.6 | 0.0 |
| 10/30/98 | 3.1 | 0 | 2.7 | 12.3 | 17.5 | 12.3 | 3.1 | 4 | 3.6 | 12.3 | 26.2 | 12.7 | 4.0 | 8.7 |
| 12/19/98 | 4.1 | 0 | 3.7 | 6.7 | 19 | 6.9 | 4.5 | 1.9 | 4.4 | 6.7 | 42.7 | 7.7 | 1.9 | 23.7 |
| 01/29/99 | 4.7 | 0 | 4 | 7.5 | 6.7 | 7.3 | 4.1 | 0 | 3.2 | 7.4 | 15.3 | 7.4 | 0.0 | 8.6 |
| 03/07/99 | 1.8 | 0.3 | 1.7 | 3 | 1.8 | 2.8 | 2.5 | 0 | 2.3 | 3 | 7.3 | 3.1 | -0.3 | 5.5 |
| 03/27/99 | 5.2 | 0 | 4.6 | 4.6 | 1.6 | 4.3 | 3.7 | 0 | 3.2 | 4.5 | 1.7 | 4.2 | 0.0 | 0.1 |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| | | | | | | | | | |
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| | | | | | | | | | |

A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

# TULSA REMEDIATION PROJECT

## LOCATION OF BORINGS, PEZOMETERS AND MONITORING WELLS

| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV.: |
|---|---|---|---|---|---|---|---|---|
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 | DATE: | 1"=50' | 1556-003 | FIGURE 3-1 | |

# 4.0 SITE PHYSICAL CHARACTERISTICS

## 4.1 PHYSIOGRAPHY

### 4.1.1 Regional Physiography

Tulsa County is situated on the Northeastern Oklahoma Cherokee Platform. The present topography of Tulsa County is a result of the differential erosion of rock beds of unequal hardness. The geologic formations that are exposed in Tulsa County are predominantly soft shales with thinner yet more resistant beds of sandstone and limestone occurring less frequently. Over much of the County, erosion, principally by water, has worn away the softer shales, thus producing broad valleys and plains. Where the harder more resistant sandstone and limestone units are present, erosion is inhibited and ridges have formed.

The maximum relief in Tulsa County is about 450 feet. The Arkansas River enters Tulsa County at an elevation of about 650 feet msl, and exits Tulsa County at an elevation of about 550 feet msl. Notable high points in Tulsa County are: Turkey Mountain which is located on the west bank of the Arkansas River west of the City of Tulsa with an elevation of 900 feet msl and Turley Mountain which is located immediately northwest of the Town of Turley with an elevation of 950 feet msl.

### 4.1.2 Site Physiography

The Facility is located on the southern boundary of Section 23, T19N, R13E, Tulsa County, Oklahoma. At this location, the land surface is gently sloping and relatively stable. The highest elevation at the Facility is found in the southwest corner with an approximate elevation of 708 feet msl. The northeast corner of the Facility is the lowest with an approximate elevation of 690 feet msl. Relief across the Facility is approximately 18 feet.

The Kaiser Facility is in the intermittent stream portion of the Fulton Creek watershed. The watershed contains about 10 percent residential and 90 percent industrial land use. The northern portion of the Facility is dominated by the two ponds, previously identified as the Fresh Water and Retention Ponds. These ponds have been constructed in the former channel of Fulton Creek. In the general area of the Facility, the watershed divide (Fulton Creek) makes a directional change from northeast to due east. In the due east direction, the topography is almost flat for about one quarter mile. The flat area was an area of deposition of upland sediments and an area for swamp and low velocity flow conditions. The fall of the Fulton Creek watershed is about .007 ft/ft until it reaches the Facility. Within the Facility, the rate of fall decreases to .006 ft/ft, but the fall increases to about .009 ft/ft after Fulton Creek leaves the Facility. A topographic map of the northern half of the Facility is presented in Figure 4-1.

## 4.2 CLIMATOLOGY

The meteorological and climatological data for the Facility reported below were obtained from the Oklahoma Climatological Survey (OCS) and the National Climate Data Center.

The climate is essentially continental, characterized by rapid changes in temperature. Generally, the winter months are mild with temperatures occasionally below zero, but for short periods. Temperatures of 100 degrees Fahrenheit or higher are frequent from late July to early September, and are usually accompanied by low relative humidity and a good southerly breeze.

Rainfall is distributed throughout the year with spring the wettest season with rain in frontal showers and thunderstorms. April through June is the period of potential tornadoes and very strong thunderstorms. The steady rains of fall provide good recharge moisture. Snow in November to early March is usually light and remains on the ground for brief periods.

### 4.2.1 Wind

The frequency of the surface wind occurring over 12 months is shown on Figure 4-2. The predominant wind direction is from the south. The prevailing monthly wind speed varies from 9 to 12 knots. The highest 1-minute sustained wind speed of record was 52 miles per hour (mph). This occurred in April 1982. The highest peak gust was 70 mph, recorded in June 1992.

### 4.2.2 Temperature

The average annual temperature for the years 1948 through 1990 was 61° F. The average monthly temperatures for the years 1948 through 1990 are shown on Figure 4-3. The daily average temperature varies from 83°F in July to 36°F in January. Monthly extremes vary from -8°F in December to 112°F in July.

### 4.2.3 Precipitation

The average annual precipitation is 38.9 inches. The wettest year during the period 1948 through 1996 recorded 69.9 inches of rainfall, while the driest year received 23.2 inches. May is the wettest month with an average of 5.6 inches of precipitation, while January is the driest month with an average of 1.6 inches of precipitation. Average, maximum and minimum precipitation by month are provided on Figure 4-4. Weekly and monthly precipitation amounts for the period of August 1996 through March 1999 are shown on Figure 4-5 and listed in Table 4-1.

Storm events have an average duration of 9.21 hours. There is an average of 48 storm events per year. The average storm produces 0.00744 inch of rainfall at an intensity of 0.11 inch per hour. Annual snowfall averages 10 inches. Monthly snowfall exceeding 0.5 inches occurs in November, December, January, February and March. Trace amounts (less than 0.5 inch and greater than 0.05 inch) occur in both October and April. The remaining months are typically void of snowfall.

### 4.2.4 Relative Humidity

The average annual morning and afternoon relative humidities compiled from readings taken at 0600 hours and 1500 hours for the years 1948 through 1990 are 81% and 49% respectively. Monthly averages vary from 85% in May, June and September to 46% in April, August and October.

### 4.2.5 Lake Evaporation

The monthly lake evaporation rates calculated for two Corps of Engineers' (COE) Lakes (Lakes Skiatook and Keystone Lakes) within 25 miles of the Facility are presented in Table 4-2.

## 4.3 SURFACE WATER HYDROLOGY

### 4.3.1 Regional Surface Water Hydrology

The Facility is located within the Bird Creek sub-basin of the Verdigris River basin. The location of the Facility within the Bird Creek sub-basin, the other four sub-basins of the Verdigris River basin, and the overall Verdigris River basin are all shown on Figure 4-6.

The 351-mile long Verdigris River originates in the Flint Hills of southeastern Kansas at an elevation of 1,350 feet msl. The Verdigris River flows southward through northeastern Oklahoma joining the Arkansas River at a point 63.5 miles down the Arkansas River from Tulsa at an elevation of 450 feet msl. The Verdigris River has a drainage area of 8,303 square miles, 46 percent of which lies in Oklahoma. The Oklahoma area, which includes the Bird Creek and Caney River tributaries, covers Washington and Nowata Counties, most of Rogers and Osage Counties, and smaller portions of Tulsa, Craig and Wagoner Counties.

### 4.3.2 Local Surface Water Hydrology

The Facility lies at the headwaters of Fulton Creek. From the Facility, Fulton Creek flows north and east approximately two miles to Mingo Creek. From the Fulton Creek/Mingo Creek confluence, Mingo Creek flows north approximately nine (9) miles where it enters Bird Creek. Bird Creek flows to the east approximately 10 miles to the confluence with the Verdigris River. As previously discussed, the Verdigris River flows to the south in this region.

#### 4.3.2.1 Discharge Data

The nearest location to the Facility for which stream discharge data are available is the USGS gauging station on Mingo Creek located on E. 46th Street North, approximately eight (8) miles downstream from the Facility. Stream discharge data from USGS Water-Data Report OK-92-1 are summarized on Table 4-3.

#### 4.3.2.2 Local Surface Water Use

The OWRB has designated beneficial uses for Mingo Creek. These uses are listed as follows:

(1) Emergency Water Supply
(2) Fish & Wildlife Propagation - warm water aquatic community
(3) Agriculture
(4) Industrial & Municipal Process & Cooling Water
(5) Recreation - Primary Body Contact Recreation
(6) Aesthetics

There are flood control overflow impoundments located along Mingo Creek that function as diversion structures during periods of peak flow. Water that collects in the overflow impoundments can discharge to Mingo Creek as the water level in Mingo Creek falls.

According to the OWRB, surface water withdrawals occur on Bird Creek for irrigation purposes. The OWRB records indicate that the first permitted surface water withdrawal downstream of the Facility (Permit No. 63-190) allows for surface water withdrawals from Bird Creek in the Southeast 1/4 of Section 11, T20N, R14E. This permit was issued to Mr. Allen West to withdraw 320-acre feet per year (ac-ft/yr).

The first public water supply withdrawal downstream of the Facility occurs from the Verdigris River. The City of Broken Arrow, Oklahoma, constructed a water treatment plant that began providing water to the residents of Broken Arrow in January 1967. The plant treated approximately 1.0 million gallons per day (MGD) when it began. Broken Arrow ceased operating the plant in January 1982 when it was producing 5.0 MGD. Since 1992 the plant has operated on an emergency basis only. The last time the plant operated was in 1991.

#### 4.3.2.3 Flood Plain Data

The Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map (FIRM) for Mingo Creek and its tributaries in the vicinity of the Facility shows that the Facility is outside the 100-year and 500-year flood hazard boundaries. The FIRM Map for this area was last revised April 16, 1991 to reflect changes in the Base Flood Elevations resulting primarily from completion of major drainage improvement work on Mingo Creek (construction of stormwater retention basins.)

Figure 4-7 is a portion of a map prepared by the COE Tulsa District depicting the approximate boundary of areas which experienced significant flooding during the flood of record for Mingo Creek, which occurred on May 27, 1984. The Facility is not within the flood boundary shown on this figure. However, flash flooding can be expected on Fulton Creek in response to intense precipitation events. During the flood of record, widespread and severe flooding occurred along Mingo Creek and Bird Creek. As a result of this event, many properties (both residential and commercial) were acquired by the City of Tulsa along the Mingo Creek flood plain. These acquired properties and the existing Mingo Creek channel have been modified significantly since 1984 to prevent the recurrence of such flooding.

### 4.3.3 Site Surface Water Hydrology

#### 4.3.3.1 Local Watershed

The Facility occupies approximately 23 acres of a 297-acre watershed. This watershed forms the headwaters of an intermittent stream identified as Fulton Creek as shown on Figure 4-8. Fulton Creek has been referred to by others as *Unnamed Creek* and *No Name Creek*. Surface elevations within the watershed vary from approximately 680 to 780 feet msl.

Land use within the watershed is predominantly commercial and light industrial; much of the surface area in this part of the watershed is covered by concrete or asphalt paving. Storm water in roughly the southern two thirds of the watershed is routed by curb and gutter and underground storm sewers. The northern third of the watershed is traversed by the M K & T Railroad and contains mostly unpaved area. Drainage in this area is primarily overland flow and also routed by drainage ditches and culverts. The only water bodies within the watershed are the Fresh Water Pond and the Retention Pond, both of which are on the Facility.

#### 4.3.3.2 Facility Drainage

The dominating features of the Kaiser site hydrologic regime are the two ponds and the excavated Fulton Creek channel. These dominant hydrologic features as well as the general drainage patterns within the Facility are shown on Figure 4-9. A schematic diagram illustrating a conceptualized hydrologic system for the Facility is shown on Figure 4-10.

The western pond is referred to as the Fresh Water Pond and is thought to have been created as a supply of water for the railroad during the days of steam power. The Fresh Water Pond occupies approximately three acres and averages less than four feet in depth. Storm flow from the upstream watershed enters the Fresh Water Pond in the southwest corner under a railroad bridge. Runoff from off-site areas also enters this pond from the west over industrial property and from the north over a concrete paved storage area.

Discharge from the Fresh Water Pond exits in the northeast corner through a deteriorating (broken) concrete weir. A stage gauge has been installed adjacent to this weir, and water level measurements are taken routinely. However these measurements cannot be related directly to discharge through the weir as water goes around and beneath the broken weir.

Discharge from the Fresh Water Pond enters the man-made channel of Fulton Creek. In addition to the discharge from the Fresh Water Pond, Fulton Creek receives discharge from the north through the City of Tulsa storm water drain as well as runoff from overland flow from the mini-storage area to the north and from the closed and grassed Reserve Pond.

Fulton Creek discharges from the Facility through a weir at the northeast corner of the facility. This weir is a modified V-notch weir, through which the channel flow can be measured. The configuration of this weir and its stage-discharge relationship are shown in Figure 4-11. Random stage measurements were made at the Fulton Creek Weir during the spring and summer of 1997. Routine water level measurements at the Fulton Creek Weir have been made monthly from July 1998 through March 1999. These data are presented in Table 4-4. Based on these stage measurements and the stage discharge relationship presented in Figure 4-11, the discharge at the Fulton Creek Weir is also computed and presented in Table 4-4. The five-day preceding precipitation total is similarly presented.

These data are not sufficient to provide average, minimum, or maximum flow data or to determine storm runoff relationships since a recording stream gauge has not been used. However, they do provide an indication of the flow in the reach of Fulton Creek passing along the northern boundary of the Facility based on antecedent flow conditions. These data also indicate that only under drought conditions (September 1998) does the stream go dry. Otherwise, a minimal flow of approximately 0.045 cfs discharges through the Fulton Creek Weir.

The other dominating feature in the northern portion of the Facility is the Retention Pond. The Retention pond is approximately five acres and is permitted by the Oklahoma Water Resources Board (OWRB) as a non-discharging retention pond. The Retention Pond receives surface runoff from a small portion of the Facility (see below) as well as some industrial cooling water discharge.

General storm water drainage patterns within the Facility property are shown on Figure 4-9. Runoff from the concrete-covered area south of the railroad tracks flows north under the tracks at three (3) locations as indicated on Figure 4-9. Location 1 is a corrugated metal pipe which runs under the tracks to a ditch on the north side of the tracks. This ditch directs runoff to the running under the tracks to a ditch on the north side of the tracks. A 24-inch concrete pipe carries drainage from the ditch to the Retention Pond. Runoff at Location 3 passes under the railroad tracks to a grass-lined ditch which flows to Fulton Creek. Runoff from the grassed area of the closed Reserve Pond flows overland to the northeast into Fulton Creek.

#### 4.3.3.3 Fulton Creek Peak Flow Predictions

Soil Conservation Service (SCS) techniques for predicting flows in Fulton Creek were used to predict peak flows in response to rainfall events. The details of these analyses are presented in Appendix H. Peak flows at the Fulton Creek Weir for the 2, 5, 10, 25, 50, and 100-year storms are presented in Table 4-5. These discharges have been computed based on average antecedent moisture conditions (AMC II) in accordance with SCS methods. Equivalent stage heights at the weir have been computed for these discharges and included in Table 4-5. Since these discharges are above the V notch weir, the peak height was computed by assuming the upper part of the weir to be a Broad Crested Weir. Based on these computations, the 100-year storm would result in a peak discharge of 1499 cfs and a stage height of 691.7 ft msl. Under such conditions, water would rise onto the slopes of the Retention Pond. Actual stage height and flow velocities, after site remediation, can only be computed for Fulton Creek based on the final design of the Fulton Creek channel.

The analyses also indicate that closure of the shallow Fresh Water Pond will only impact the runoff under dry antecedent moisture conditions (SCS AMC I). When full, the Fresh Water Pond passes water through as if it were a channel. The main difference in flow characteristics without the Fresh Water Pond would be the time to peak flow, which is a function of the condition of the pond at the time of runoff. Without the pond, peak flow will occur earlier and decline sooner.

## 4.4 GEOLOGY

### 4.4.1 Regional Geology

The geological and tectonic history of Oklahoma is basically characterized by marine sedimentation, which was periodically interrupted by episodes of uplift, gentle folding and erosion, which was followed subsequently by renewed sedimentation. Bedrock immediately underlying this portion of Oklahoma is comprised primarily of Pennsylvanian-age carbonates and shales with interbeds of sandstone and siltstone.

Tulsa County is located in the east-central portion of the northeastern Oklahoma Cherokee Platform. The Cherokee Platform is bounded on the east by the Ozark Uplift, on the west by the Nemaha Uplift, on the south by the Arbuckle Uplift, and on the southeast by the Arkoma Basin (see Figure 4-12). The tectonic activity in this area was associated with the final uplift of the Ozark and Ouachita Mountains. The remnants of this activity across Tulsa County are northeast to southwest trending folds, adjustment flexures and some faults. All of these tectonic features are inactive.

A geologic map of Tulsa County is presented in Figure 4-13. As shown on Figure 4-13, the surface geology of Tulsa County is characterized by outcrops of Pennsylvanian-age bedrock that are masked in many areas by recent Quaternary deposits. The Quaternary deposits and bedrock geology of Tulsa County are discussed below.

#### 4.4.1.1 Quaternary Deposits

Quaternary-age alluvial deposits underlie substantial portions of Tulsa County. These unconsolidated geological materials were deposited as flood plain alluvium, terrace alluvium, eolian sand, loess and colluvium.

##### Flood Plain Alluvium

Flood plain alluvium consists primarily of very fine to coarse sand with some fine gravel also associated near the base. Wood and other debris are often found near the base of these deposits. The distribution of flood plain alluvium is easy to map because it conforms to the flood plain of the streams. This type of deposit varies from a few inches in thickness to as much as 35 feet. Greatest thicknesses are normally beneath the central part of the flood plain thinning rapidly near the edges. In this region, the greatest thicknesses of flood plain alluvium are found along the Arkansas River.

##### Terrace Alluvium

Terrace alluvium consists primarily of fine to medium sand. However, locally, its composition is quite variable ranging from a clayey silt to a gravely coarse sand. These deposits are found on two terrace surfaces which represent remnants of former flood plain levels.

##### Eolian Sand

Eolian, or wind blown, sand occurs in sand dunes and sand sheets. It is normally found on the flood plain and terraces of the Arkansas River. This material consists of well-sorted fine to medium sand with an occasional small amount of silt. Sand sheets range in thickness from one (1) to three (3) feet. Dune sands occur regionally up to 15 feet thick.

### Loess

Loess is widespread north of the Arkansas River in central and eastern parts of Tulsa County. Loess is composed primarily of silt with some clay and very fine sand. It ranges in thickness from one (1) to three (3) feet.

### Colluvium

Colluvium, or unconsolidated materials that have moved down slope due to the influence of gravity, is widespread in Tulsa County mainly due to the large quantities of shale exposed at the surface. Shale is particularly susceptible to freeze and thaw as well as shrink and swell which enhance movement of materials down slope.

### 4.4.1.2 Regional Bedrock Geology

The rocks that outcrop in Tulsa are mid-Pennsylvanian in age and consist of the upper part of the Desmoinesian and all of the Missourian Series of the Pennsylvanian System. A regional stratigraphic column that identifies the component formations of these series in Tulsa County is presented in Figure 4-14.

In the general area of Tulsa County, a shallow dip in bedrock formations, just north of west at a rate of approximately 50 feet per mile, is observed. As a result, bedrock formations outcrop in a series of north-south bands across Tulsa County. The areal distribution of each rock formation outcropping in Tulsa County is shown in Figure 4-15. Figure 4-16 depicts the bedrock stratigraphy in a generalized east-west cross-section located just north of the Facility along 31st Street South.

The bedrock surface is an eroded surface producing a general surficial slope to the east. There are no significant structural features located on or in close proximity to the Facility and the Facility is located on a stable, fairly uniform, bedrock that has an approximate elevation of 690 feet msl.

The Facility lies on the outcrop of the Nowata Shale. In the immediate area of the Facility, all Pennsylvanian strata overlying the Nowata Shale have been removed by erosion or were not deposited in this area. Immediately underlying the Nowata Shale is the Oologah Formation. A description of the Nowata Shale and the Oologah Formation is presented below.

### Nowata Shale

The Nowata Shale is exposed at the surface over much of east-central Tulsa County where it is not masked by alluvial deposits. In Tulsa County, the Nowata Shale consists predominantly of shale that ranges in character from clayey to sandy shale. The Nowata Shale can be divided into five (5) distinct units (Bennison, 1972). The basal unit (Pn1) is a clay shale which is directly overlain by a flaggy, silty limestone unit (Pn2), followed by a calcareous shale (Pn3), a calcareous bioturbated sandstone (Pn4), and an upper shale (Pn5) that locally contains thin brown bioclastic limestone beds. The Nowata Shale beneath the Facility is the calcareous flagstone (Pn2) sequence that forms a low stony ridge in southeast Tulsa between Sheridan Avenue and Memorial Drive. South of Skelly Drive to 91st Street South, this sequence has wide distribution in the lower terrace of the rugged Southern Hills district of Tulsa. In Tulsa County, the Nowata Shale ranges in thickness from 30 feet in the east to 200 feet in the west. A section of over 200 feet of the Nowata Shale was encountered in the stratigraphic test well ST-1 in the northwest part of the Facility. The strata dip toward the west.

#### Oologah Formation

The Oologah Formation consists of three zones: (1) a lower limestone zone that consists of a light to dark gray, moderately fossiliferous, somewhat cherty limestone (Pawnee Limestone); (2) a middle shale zone that consists of a dark gray to black, calcareous, flaky shale (Bandera Shale); and (3) an upper limestone zone which consists of a light to dark gray, fossiliferous, massive to thinly-bedded limestone (Altamont Limestone). The Oologah Formation ranges in thickness from 40 feet to 100 feet and is exposed in eastern Tulsa County. The Oologah Limestone crops out at the intersection of 41st Street and South 129th East Avenue in Tulsa three miles east of the Facility. Where penetrated at a depth of more than 50 feet below ground surface, the Oologah Limestone generally yields highly mineralized groundwater. At a site five miles north and east of the Facility, the Oologah yields water from a depth of 82.7 feet with a concentration of chloride of 407 mg/l (personal communication with Mr. Forrest Miller of McDonnell Douglas-Tulsa).

### 4.4.2 Site Geology

As discussed in Chapter 3.0, the geology of the Facility has been investigated by drilling boreholes and sampling subsurface materials at eighteen different locations in the vicinity of the Fresh Water and Retention Ponds. These borings included three deep stratigraphic borings that were designed to penetrate and to characterize the bedrock at the site as well as shallow borings at each location to characterize unconsolidated overburden material and shallow bedrock.

The investigation has indicated that the area of the Facility north of the railroad tracks overlies a buried bedrock valley eroded into Nowata Shale bedrock and filled with alluvium and colluvium. The extent of the bedrock valley is illustrated in Figure 4-17. This valley, which is at the headwater of Fulton Creek, trends in an east/west direction.

The characteristics of the unconsolidated overburden materials and underlying bedrock identified during the investigation are discussed individually below.

### 4.4.2.1 Unconsolidated Overburden Materials

The unconsolidated overburden materials identified in the vicinity of the Fresh Water and Retention Ponds during the investigation include naturally deposited sediments, fill material, dross, and reworked sediments that may have originated on or offsite. Within the investigation area, the thickness of the overburden material ranges from a few feet to as much as 28 feet. The thickest portion of the overburden is located along the axis of the bedrock valley (see Figure 4-17) and extends along the axis from western property boundary to the eastern berm of Retention Pond and beginning of the Reserve Pond area. At the eastern berm of the Retention Pond the overburden material begins to thin eastward.

Naturally deposited unconsolidated materials overlying the Nowata Shale bedrock are comprised of sand, silt, clay, peat and occasional gravel. These materials are derived from weathering and erosion of the bedrock and deposition of colluvium and alluvium from the upper watershed. These materials are laterally and vertically variable as would be expected based on their depositional environment. However, this sediment can be broadly grouped into several basic units based on their location and physical characteristics. These units include a basal silty sand unit (Unit 1), an overlying brown mottled silty clay (Unit 2), a more surficial silty clay (Unit 3), and a peaty silty clay unit (Unit 4). In addition to these units, the waste dross material has been identified as Unit 5. Each of these units is described in more detail below.

Cross-sections have been developed to depict the distribution of overburden material. The location of the cross-sections are shown on Figure 4-18. The cross-sections are shown on Figures 4-19, 4-20, 4-21, and 4-22.

#### Unit 1

Unit 1 is the main alluvial deposit which occupies the old Fulton Creek channel. This unit is typically comprised of gravel-sized, yellow sandstone pieces mixed with medium-grained quartz sand, brown silt and brown clay. The gravel makes up less than 10 percent of the material. Field descriptions and laboratory analysis on selected samples (see Sections 3.2.1 and 3.2.4) indicate some variability within the unit. However, this unit can generally be characterized as a clayey sand and/or a well-graded sand-clay mixture. Because of their inherent variability, the Unit 1 materials can not be given a single classification based on the Unified Soil Classification System (USCS).

The blow count evaluation conducted during sampling of Unit 1 materials were generally low, ranging from the weight of hammer to 10 blows per foot of penetration. This indicates a low relative density and a soft consistency. In its present state, Unit 1 materials have poor bearing strengths.

An isopach map of Unit 1 is presented as Figure 4-23. The isopach map shows Unit 1 to be the thickest in the eastern portion of the site. This is the area wherein deposition of upland derived alluvium began. Unit 1 thins out quickly and disappears along the sides of the eroded bedrock valley.

### Unit 2

Unit 2 is a brown, mottled, silty clay classified as CL (clay low plasticity, silty clay) in the USCS. This silty clay is mottled tan, brown and yellow. Mottling is a characteristic description of a soil irregularly marked with patches of different colors, usually indicating seasonal wetness or poor aeration. Mottling is caused by oxidation of iron and manganese compounds. Unit 2 contains frequent small nodules of ironstone and manganese oxide. In very low aeration zones, this clay will have a greenish cast. Clays of this type are commonly developed in flood plains and in channel backwaters or slack water deposits.

Unit 2 varies from 0 to 15 feet in thickness. This unit is found in the old channel area of Fulton Creek. Where Unit 1 is present, the brown, mottled, silty clay of Unit 2 in general directly overlies Unit 1. Otherwise, the Unit 2 clay directly overlies bedrock. An isopach map of Unit 2 is presented in Figure 4-24. Unit 2 appears to be missing in the area of the embankment and replaced with peaty material identified as Unit 4 (see below). However, the Unit 4 peaty clays have also been included as part of Unit 2 for purposes of preparing this map. A contour map depicting the top of the clays underlying the Retention and Reserve Ponds is also shown in Figure 4-25. This figure was developed using data developed not only during this investigation but also during the previous ARS investigation which identified the surface of the clay beneath the dross. While the surface depicted on Figure 4-25 is primarily the top of Unit 2 clays, the top of Units 3 and 4 clays comprise limited portions of this surface as well. The top of clay contours shown in Figure 4-25 clearly show the outlines of the former Fulton Creek and downstream ponds as previously observed on aerial photographs (see Section 2.3).

Blow counts in this material range from weight of hammer (H) to 24, which indicates a material with medium relative density and stiff consistency. This material has fair to good bearing strength.

### Unit 3

Unit 3 is brown silty clay that is comprised of the most recent sediments as well as imported fill in the basin. Possibly some of Unit 3 may have been imported for embankment fill as well as Reserve Pond capping. Unit 3 is discontinuous but found throughout the site including in the berms of the Retention Pond and immediately overly bedrock in areas where Unit 2 is not present. The material is classified as CL (silty clay) in the USCS. Blow counts observed during sampling this material indicate a medium relative density and very stiff consistency. Foundation bearing strength would be satisfactory for this material.

### Unit 4

Unit 4 is a peaty silty clay material that was only encountered in two borings (P-8 and MWD-10). Fifteen feet of peaty silty clay was encountered in P-8 below the berm separating the two ponds. Four feet of the same material was encountered along the northern berm of the Retention Pond at MWD-10. The actual extent of this unit beneath the Fresh Water Pond and the Retention Pond has not been determined as no test borings were made within the ponds. This material most likely was deposited in the low energy backwater area of old Fulton Creek. Unit 4 is a soft material and unsuitable for foundations of any type.

### Unit 5

The dross disposed of in the Retention and Reserve Pond areas has been referred to as Unit 5. The dross in the Retention Pond and in the subsurface below the filled Reserve Pond is light gray with a silty texture. The blow counts observed during sampling dross indicated that the material was very soft.

### 4.4.2.1 Bedrock

Consistent with the regional description of geology, drilling at the site encountered a shale bedrock identified as the Nowata Shale. As shown in Figure 4-17, a buried bedrock valley has been eroded into Nowata Shale beneath the area of the Fresh Water and Retention Ponds. As discussed in Chapter 3, the characteristics of the bedrock have been investigated by hollow stem augering and split spooning into bedrock until refusal at eighteen different locations and the drilling of three deep stratigraphic borings (ST-1, ST-2, and ST-3). In addition, the deep stratigraphic borings were geophysically logged and tested for hydraulic conductivity using inflatable packer tests.

The investigation has identified a shallow layer of commonly weathered, tan or brown shale. This shallow, commonly weathered, brown shale layer was penetrable at many locations using the hollow stem auger and split spoons and was found to range in thickness from a few feet to as much as much 21 feet in ST-3. Underlying the brown shale layer is an extensive gray to dark gray shale that was found in the full 200-foot depth of stratigraphic boring ST-1. The bedrock cores and geophysical logs from the deep stratigraphic borings indicate that the deeper gray shale contains occasional interbeds of siltstone and sandstone. Below the weathered zone, the shale exhibits virtually no primary porosity, and any permeability the shale exhibits would be the result of secondary porosity due to such features as fracturing or other discontinuities. The coring and geophysical logs indicate that shallow bedrock is generally fractured but that the fractures decrease with depth. The logs and RQD's observed during coring in ST-1 indicate a very competent, tight shale below sixty feet. Evidence of fracturing was observed above this depth in boring ST-1, but packer tests (see Table 3-8) indicated no observable permeability (less than $10^{-7}$ cm/sec) in the intervals between 24 and 67 feet and between 84 and 100 feet. Packer testing of a narrow zone between 160 and 173 feet indicated a permeability of $7.8 \times 10^{-7}$ cm/sec. Although some shallow fracturing was observed in boring ST-2, particularly at 38 feet, a tight, competent zone at the bottom of the boring between 50 and 60 feet was identified. Packer testing indicated a permeability of $9.9 \times 10^{-7}$ cm/sec for this zone. Greater apparent fracturing was identified over the sixty-foot depth of boring ST-3, and packer tests indicated permeability ranging between $1.1 \times 10^{-4}$ and $2.6 \times 10^{-5}$ cm/sec.

## 4.5 HYDROGEOLOGY

### 4.5.1 Regional Hydrogeology

Based upon information derived from maps showing the Principal Ground-Water Resources and Recharge Areas of Oklahoma, printed and distributed by the Oklahoma State Department of Health (OSDH), no principal bedrock aquifers or recharge areas are located within six (6) miles of the Facility. The principal bedrock aquifer system identified in this portion of Oklahoma is the Vamoosa-Ada Aquifer system, which is present approximately 28 miles west of the Facility. At the Facility, the Vamoosa and Ada Formations have been completely removed by erosion.

While no principal bedrock aquifers or recharge areas occur locally, the rock formations occurring within six (6) miles of the Facility that are considered water-bearing are the Seminole, Holdenville, Lenapah, Nowata, Oologah, and Labette Formations (Oaks, 1952). Of these six formations only the Nowata, Oologah, and Labette Formations are present beneath the Facility. The remainder have been removed by erosion. All of these formations yield only very small amounts of fair to poor quality water as reported by the Oklahoma Geological Survey in Hydrologic Atlas No. 2 titled "Reconnaissance of the Water Resources of the Tulsa Quadrangle, Northeastern Oklahoma" (1971).

The term “water bearing” is used in this context to mean that the rock has potential to transmit water but in very limited quantities. Wells completed in bedrock formations in this area typically do not produce sufficient quantities of groundwater to supply water for domestic uses. However, information provided by Oaks (1952) states that a bedrock water supply well completed in Section 29-T19N-R13E, at approximately 41st and Lewis (John C. Day property) reported a groundwater yield of 80 gallons per hour from a blue shale from the depth interval 39 to 63 feet.

The absence of well-developed bedrock groundwater systems in the vicinity of the Facility is primarily due to the composition of the bedrock material (predominantly shale), tectonic stability of the area (reduced fracturing of bedrock strata), lack of transmissive substrata, and, to some degree, the presence of mineralized water within the bedrock. As discussed in Section 4.4.1, Tulsa County is situated on rock units which are predominantly composed of shale. The transmissivity of these rock types is very low and the groundwater does not move freely enough to produce usable volumes of groundwater. The groundwater that can be produced is usually of poor to very poor quality, primarily because the water is highly mineralized.

The Hydrologic Atlas No. 2, noted above, indicates that unconsolidated alluvial deposits occur within six miles of the Facility. These are primarily located along the flood plain of the Arkansas River as shown on Figure 4-26. The alluvial deposits are comprised predominantly of gravel, sand, silt and clay. They yield moderate to large quantities of fair to good quality water.

Information obtained from the OWRB identified six permitted groundwater users within six miles of the Facility. The names of these permitted users, permit numbers, locations of withdrawal and use of the groundwater withdrawn are listed on Table 4-6. The aquifers from which these permitted groundwater withdrawals are derived are not provided by the OWRB data base; however, the locations of each of these permits suggest that the groundwater is being produced from the Arkansas River alluvium. In each case, the permitted use is for irrigation or industrial purposes. The permitted usage ranges from 1 to 1,019 acre-feet per day.

RSA (1996) obtained all water well records available from the OWRB for a six-mile radius around the Facility. Twenty well records were received from the OWRB, all of which were records for geotechnical borings or shallow groundwater monitoring wells that were completed in alluvial material. It should be noted that the records of the OWRB consist of reports required for submittal to the Board for all Commercial well data reported by licensed firms since the licensing law of 1972, all domestic and stock well data reported by licensed firms from the 1982 licensing law and, if requested, all monitoring well data reported by licensed firms from the 1988 monitoring well licensing law. Wells drilled before each of the licensing dates were exempt from reporting requirements.

### 4.5.2 Site Hydrogeology

As previously discussed in Section 4.4.2, the investigation has revealed that the area of the Facility north of the railroad tracks overlies a buried bedrock valley eroded into Nowata Shale bedrock and filled with alluvium and colluvium. The extent of the bedrock valley is illustrated in Figure 4-17.

Groundwater flow in this bedrock valley has been investigated, in part, through the installation of twenty-three wells at eighteen different locations. At all but one of these locations, wells were screened at the top of bedrock (i.e., in the deep unconsolidated overburden and shallow weathered bedrock). These screening depths were selected based on initial indications that a relatively higher permeability material (Unit 1) immediately overlies bedrock at locations in the center of the bedrock valley. Wells screened at this depth were intended to define and monitor groundwater flow in this relatively more transmissive zone. Wells screened at the bedrock interface were also installed along the sides of the valley to better define groundwater flow into the bedrock valley.

In addition to these deeper wells, four wells were screened in the shallow overburden at or near the water table. Three of these wells were installed as part of well clusters at locations where deeper overburden wells were also installed. These shallow wells were located in areas within and immediately downgradient of the Retention Pond and Reserve Pond areas and were intended to define and monitor shallow groundwater flow from these areas. The shallow wells were also intended to help define the hydraulic relationship between groundwater in the shallow and deep overburden materials. Two wells (ST-2, and ST-3) were screened in deeper bedrock, well below the interface between bedrock and the overburden. The location of all wells is shown in Figure 3-1. A summary of construction details for all wells is presented in Table 3-6, and boring and well construction logs are presented in Appendix A.

#### 4.5.2.1 Hydraulic Conductivity Measurements

A wide range of subsurface materials has been identified beneath the site, including competent and fractured bedrock, fine and silty sands, silty clays, and dross. These materials should exhibit a wide range of hydraulic conductivities that can be expected to control direct groundwater movement at the site. Estimates of the hydraulic conductivities for natural unconsolidated material are readily available in the literature. Estimates of hydraulic conductivities based on their USCS classification are presented in Table 4-7. Ranges of bedrock hydraulic conductivities for bedrock materials are included in Table 4-8.

As discussed in Section 3.5, hydraulic conductivity testing of subsurface materials has been undertaken as part of this investigation. Slug tests have been used to measure the hydraulic conductivity of the screened materials in all monitoring wells and piezometers installed on site. A summary table of the results of these tests has been presented as Table 3-7. Because many of the wells have been screened over a range of materials and have not isolated specific units, the hydraulic conductivities measured by these tests frequently represent an average between units. Consequently, the results of these tests have to be interpreted carefully. However, in many wells the contrast between the permeabilities of the screened materials is such that the tests can be viewed as being dominated by the hydraulic properties of the more permeable materials. In such cases, the slug tests are viewed as yielding a hydraulic conductivity value representative of the more permeable material. This approach is particularly applicable for many of the wells installed at the bedrock interface in which the screens have been set across both the more permeable Unit 1 sands and the low permeability Unit 2 silty clays. Because of the apparent contrast in permeability of these materials, the results of these tests are viewed as representative of the more permeable Unit 1 sands.

The results of slug testing indicate that hydraulic conductivity values for the Unit 1 materials range between 2.12 x $10^{-5}$ and 3.32 x $10^{-3}$ cm/sec and average 1.11 x $10^{-3}$ cm/sec. Only monitoring well MWD-9 was available for testing Unit 2 materials. The average hydraulic conductivity measured in MWD-9 is of 2.06 x 10 $^{-4}$ cm/sec. MWD-9 is screened primarily across silts which are likely transitional deposits between the Unit 1 sands and the Unit 2 silty clays. Only one well, MWS-6, was also available for testing Unit 3 materials. The average hydraulic conductivity measured in MWS-6 was 3.50 x 10 $^{-4}$ cm/sec. MWS-6 is screened in the berm between the Retention Pond and Reserve Pond. This material was likely reworked to construct the berm and may not be representative of the Unit 3 silty clays throughout the site. No direct measurements have been obtained for Unit 2 mateirals since no screens were set exclusively across this zone. Consideration was given to laboratory hydraulic conductivity testing of Units 2, 3, and 4 materials. However, due to their poorly compacted condition, the process of sampling these materials would likely compress the samples and result in unrepresentatively low hydraulic conductivity measurements. Consequently such testing was not undertaken. Estimates based on USCS classifications indicate that the permeability of Unit 2 and Unit 3 silty clay materials should range between $10^{-6}$ and $10^{-8}$ cm/sec. Estimates for the Unit 4 peaty clay are not provided in Table 4-7, but the permeability of this material likely ranges between $10^{-3}$ and $10^{-6}$ cm/sec. Measured hydraulic conductivity values for the dross (Unit 5) range between 3.41 x $10^{-4}$ and 3.06 x $10^{-3}$ cm/sec and average 1.3 x $10^{-3}$ cm/sec. Limited measurements of the shallow, weathered shale have also been obtained during the slug testing. The measured permeability of the shallow weathered shale ranges between 1.60 x $10^{-6}$ and 5.55 x $10^{-4}$ cm/sec and averages 2.11 x $10^{-4}$ cm/sec. The wide range of measured permeabilities for the weathered shale is indicative of the differing degrees to which shallow shale is weathered at the site.

The hydraulic conductivity of the Nowata shale underlying the site has also been tested using inflatable packer tests. The result of these tests is reported in Table 3-8. The hydraulic conductivity measured for this material during the inflatable packer tests ranges from 1.8 x $10^{-4}$ cm/sec for shallow weathered and fractured bedrock to less than $10^{-7}$ cm/sec for deep, competent bedrock.

### 4.5.2.2 Groundwater Gradients and Flow Directions

A program of periodic water level monitoring has been undertaken as part of the investigation to evaluate groundwater flow at the Facility and to evaluate the hydraulic influences of the Fresh Water Pond, the Retention Pond, and Fulton Creek on groundwater beneath the site (see Section 3.6). These data indicate that water levels at the site are temporally variable, apparently responding primarily to recent and longer term precipitation patterns (see Table 3-9 and Section 4.5.2.3 below). The water level of the Fresh Water Pond is held relatively constant by the broken weir at the outfall into Fulton Creek. However, the water level in the Fresh Water Pond does respond to inflow into the pond from upgradient surface and ground water which, in turn, is influenced by antecedent precipitation. The measured water level in the Fresh Water Pond has ranged between 698.19 and 699.46 ft msl. The water level in the Retention Pond is much more variable and has been observed to be as high as 695.66 ft. msl after extreme storm events and dry (less than 690 ft. msl ) during extended dry periods. Groundwater levels have similarly been observed to be highly variable, with water level variations of as much as seven feet observed in individual wells.

In spite of the observed variability in water levels across the site, the water level data indicate that the general groundwater flow pattern beneath the northern portion of the Facility is relatively constant with a west to east flow along the axis of the bedrock valley. Contour maps of water levels measured in wells screened at the bedrock interface during April 1997, September 1998, and March 1999 are presented in Figures 4-27, 4-28, and 4-29. These dates represent the period of highest, lowest, and most recently observed groundwater levels. In spite of the significant differences in measured water levels, these potentiometric maps show a similar groundwater flow pattern.

The potentiometric contours depicted in Figures 4-27, 4-28, and 4-29 clearly show the eroded bedrock channel and overlying Unit 1 sands directing groundwater flow in the deeper unconsolidated overburden to the northeast along the axis of the bedrock valley. The contours indicate that groundwater enters the basin from the west as well as from the south along the side of the bedrock valley. It is expected that groundwater similarly enters the basin from the north along the opposing side of the valley, although water level data are not available to confirm this. Groundwater exits the site through the bedrock valley at the northeast corner of the Facility. A slight steep gradient is noticeable in the potentiometric contours in the area between wells MWD-6 and MWD-8. This steep gradient is likely caused by the finer grained Unit 1 sediments that have been identified in the immediate area of these wells (see sieve analysis reported in Table 3-5 and Appendix C). These finer grained sediments likely impede flow in this narrow portion of the bedrock valley and divert flow somewhat to the north and south where coarser grained materials have been identified in the sediments overlying bedrock. A slight increase in gradient toward Fulton Creek in the northeast corner of the Facility is also apparent during the driest period (September, 1999), indicating that Fulton Creek may exert a greater hydraulic influence on groundwater flow during such periods.

Contour maps of water levels measured in wells screened in shallow overburden deposits during April 1997, September 1998, and March 1999 are presented in Figures 4-30, 4-31, and 4-32. As depicted on these potentiometric maps, shallow groundwater flow patterns in the northeast of the Facility are similar to those observed in the deep overburden materials. Water level data are not available to define shallow groundwater flow along the northern boundary or southeastern corner of the Retention Pond. However, due to the likely hydraulic influence of Fulton Creek, shallow groundwater flow along the northern berm is expected to be northerly or northeasterly towards Fulton Creek. Based on the topography and the probable effect of groundwater mounding due to water levels in the Retention Pond, shallow groundwater likely flows locally to the east and south along the southeastern boundary of the Retention Pond.

Along the southwest boundary of the Retention Pond, the overburden is thin and shallow, and shallow groundwater flow is not differentiable from deeper groundwater flow patterns previously depicted along the bedrock interface (see Figures 4-27, 4-28, and 4-29). Thus, groundwater flow from the southwest likely recharges both the dross deposits in the Retention Pond and the deeper Unit 1 sediments that underlie the Retention Pond. Based on the difference between the water levels in the Fresh Water and Retention Ponds, shallow groundwater flow through the berm separating these two ponds is clearly from the Fresh Water Pond into the Retention Pond.

The water level data from the well clusters located in the downgradient portion of the Retention Pond clearly indicate a downward vertical gradient from the shallow overburden into the deeper Unit 1 sediments. The vertical gradient is spatially and temporally variable but clearly indicate the potential for flow from the Retention Pond and shallow overburden deposits into the deeper Unit 1 sediments. This vertical gradient is discussed in greater detail in Section 4.5.2.3 below.

Comparisons of the water level data from the deep overburden well (MWD-7) and bedrock well (ST-3) in the northeastern corner of the Facility indicate that the slight vertical gradient has generally, but not always, been upwards. The similarity between water levels in the deep overburden and bedrock in the northeastern corner of the Facility is indicative of a relatively high degree of hydraulic connection. This potential connection is also evidenced by the fracturing and relatively high hydraulic conductivities observed in bedrock in ST-3. However, the water quality from these two wells is significantly different (see Section 4.5.2.4), indicating that water from these two zones do not appear to be mixing.

Comparisons of the water level data from the deep overburden well (MWD-2) and bedrock well (ST-2) in the southwestern corner of the study area indicate significant downward vertical gradients. The significantly different water levels observed in the deep overburden and bedrock at this location is indicative of a low degree of hydraulic connection as also evidenced by the lack of fracturing and extremely low hydraulic conductivities observed in bedrock in ST-2. In addition, the water levels observed in ST-2 are significantly lower than those observed in ST-3 (approximately twenty feet lower), indicating that it is not likely that these two wells are monitoring hydraulically connected zones.

Darcy's law, in conjunction with the hydraulic conductivity of subsurface materials and groundwater gradients identified for the site, can be used to determine the velocity of shallow and deep groundwater flow. Darcy's Law can be written as:

$$V = K \bullet \frac{dh}{dl}$$

where:

V (q) = flow velocity (specific discharge) ($L^3/L^2T$ or L/T)
K = coefficient of permeability (hydraulic conductivity) (L/T)
dh/dl = hydraulic gradient (i) (dimensionless)

The velocity calculated by Darcy's Law (the Darcy velocity) is a volumetric flux and can be converted to the interstitial groundwater velocity through a material (the velocity at which groundwater actual moves through the subsurface) by dividing the volumetric flux by the effective porosity of that material. The total discharge through a section of the subsurface can be calculated by multiplying the Darcy velocity by the cross-sectional area perpendicular to groundwater flow.

Assuming a gradient of 0.017 ft/ft based on the potentiometric contours depicted in Figure 4-29 and an average hydraulic conductivity of 1.11 x $10^{-3}$ cm/sec, calculations using Darcy's Law indicate that the groundwater flux through the Unit 1 sands in the northeast corner of the Facility is 5.3 x $10^{-2}$ ft/day. Assuming an effective porosity of 0.15, the interstitial velocity is computed to be 0.35 ft/day. Assuming the thickness and width of the Unit 1 sands in the northeast corner of the Facility to be 8 feet and 300 feet, respectively, the discharge of groundwater through the Unit 1 sand at the northeast boundary of the Facility is computed to be 127.2 cubic feet per day. If the thickness of the flow zone is expanded to include an additional 10 feet of the weathered bedrock with an average hydraulic conductivity of 2.11 x $10^{-4}$ cm/sec, the discharge of groundwater through the Unit 1 sand at the northeast boundary of the Facility is computed to be 157.7 cubic feet per day.

### 4.5.2.3 Surface Water Influence on Ground Water Flow

The three bodies of surface water in the study area (Fresh Water Pond, the Retention Pond, and Fulton Creek) have a potentially significant influence on the groundwater regime beneath the northern portion of the Facility. These surface water bodies are potential sources of recharge to groundwater as well as to each other. While it has not been possible to investigate immediately beneath the ponds and creek, the geologic sampling from adjacent locations indicates that both of the ponds as well as the creek are likely underlain by a silty clay material identified as Unit 2 (see Section 4.4.2.1). Similarly, the berms surrounding the Retention Pond are primarily comprised of silty clay material identified as Unit 3 (see Section 4.4.2.1). These clays are low hydraulic conductivity materials that should limit the leakage of water from both ponds and Fulton Creek. The Fresh Water Pond has also been subject to decades of siltation which should further limit any potential leakage of water out of the pond.

The water level data collected during the investigation provide a number of insights into the relative hydraulic influences of both ponds and the creek on each other and on underlying groundwater flow. The water level data collected during the investigation have previously been presented in Table 3-9.

The water levels observed between April, 1997 and March, 1999 in the shallow wells surrounding the downgradient (eastern) portion of the Retention Pond (MWS-4, MWS -5, MWS-6, and MWS-11) are shown in Figure 4-33. A downward trend in water levels is clearly apparent in these shallow wells, particularly during the drought that occurred during the summer of 1998. During the summer of 1998, the water level in the Retention Pond similarly declined, and eventually the Retention Pond went dry in September. However, the drought broke and more than seven inches of rain fell in the Tulsa area during the first week of October 1998. In response, the water level in the Retention Pond increased dramatically in early October, but then quickly returned to levels consistent with those measured in early Summer, 1998. Similarly, the water levels in the shallow wells recovered with the rainfall in early October and, with the exception of MWS-6, approached and maintained water levels similar to those observed prior to the summer of 1998.

The water level data for the Fresh Water and Retention Ponds (FWP & RtP) are also plotted in Figure 4-33 for purposes of comparison. A staff gauge was not installed in the Retention Pond until June of 1998, and water level data for the Retention Pond is not available prior to this date. However, water levels in MWS-4 can be used as an approximate surrogate for water levels in the Retention Pond. Examination of the water levels in the two ponds and MWS-4 indicate that the fluctuations in water levels have been much greater in the Retention Pond than in the Fresh Water Pond. Water levels in the Fresh Water Pond have varied over a range of 1.27 feet, while the water levels in the Retention Pond or shallow dross (MWS-4) have varied over a range of nearly eight feet. If, the anomalously high October 1998 water level is ignored, the variation was over a range of 6.34 feet.

Comparison of the water levels in the Fresh Water Pond, Retention Pond, and shallow wells clearly indicates that the variation in groundwater levels corresponds much more closely with the Retention Pond than the Fresh Water Pond. For example, a comparison of the water level declines observed in the Fresh Water Pond and the shallow downgradient wells during the 1998 Summer drought indicates that the water level in the Fresh Water Pond declined only 0.71 feet while water levels in MWS-4, MWS-5, and MWS-6 declined 2.67, 1.54, and 1.84 feet, respectively. Comparisons of water level declines observed between April, 1997 and September 1998 indicate even more significant differences. During that period, the water level in the Fresh Water Pond dropped 0.48 feet while water levels dropped 5.57, 4.76, and 8.85 feet in MWS-4, MWS-5, and MWS-6, respectively.

These water level trends strongly suggest that recharge from the Fresh Water Pond does not play a dominant role in maintaining water levels in the Retention Pond and the shallow downgradient wells. The correlation between the water levels observed in the Retention Pond and the shallow downgradient wells strongly suggests that, as would be expected, water levels in the Retention Pond control the water levels in the shallow overburden materials.

The water levels in both wells comprising the downgradient well clusters are shown in Figure 4-34. However, it should be noted that water levels from wells MWS-4 and MWD-4 have been paired in Figure 4-34 as a cluster, although they are not at exactly the same location. The similarity in trends between water levels in the shallow and deep well pairs and Retention Pond are striking. The water level data from all the deep wells screened in the Unit 1 silty sands in the northeast area of the Facility are shown in Figure 4-35. The water levels depicted in Figure 4-35 also show similar patterns to that observed for the well pairs in Figure 4-34, with deep water level trends correlating to a much greater degree with the water level in the Retention Pond than with the water level in the Fresh Water Pond. This similarity suggests that the same factors that are influencing shallow water levels are also influencing water levels in the Unit 1 silty sands. These data also suggest that recharge from the Fresh Water Pond does not play a dominant role in maintaining water levels in the deep overburden materials in this portion of the Facility.

The water level data depicted in Figure 4-34 also show a downward gradient from the shallow to the deep overburden material, indicating the potential for flow of water from the Retention Pond to the silty sands overlying bedrock beneath the Retention Pond. However, the head differentials observed at the individual monitoring well clusters differ significantly, with the most significant head differential observed at the MW-5 cluster and the least significant observed at the MW-6 cluster. These head differentials suggest that a high degree of hydraulic isolation exists between shallow and deep overburden materials at the MW-5 cluster location, while a significant hydraulic connection may exist between these materials at or near the MW-6 location.

The water level data for the wells installed in the general area between the Fresh Water and Retention Ponds are plotted in Figure 4-36. Three piezometers (P-7, P-8, and P-10) have been installed directly in the berm between the two ponds. However, only the water levels in P-10 appear to follow closely the water levels in the Fresh Water Pond. In contrast, the water levels from P-7 and P-8 follow closely the water level in the Retention Pond and do not appear to be significantly influenced by the water level in the Fresh Water Pond. In addition, the water levels in P-10 are significantly higher than those in P-7 and P-8. However, the water level data from all three wells and the Retention Pond indicate that a gradient is generally present from the Unit 1 sands toward the Retention Pond. These gradients indicate a potential for groundwater recharge from the Unit 1 sands into the western end of the Retention Pond, although this potential is much higher at P-10 due to the much higher gradient present there.

The differences in water level elevations and trends between P-10 and P-7 and P-8, strongly suggest that the screened interval in P-10 may not be hydraulically connected with the screened intervals in P-7 and P-8. The boring logs (see Appendix A) indicate that the sands screened by P-10 lie between 686.6 and 690.6 feet msl, while the sands screened by the adjacent P-8 are much deeper lying between 675.5 and 682.5 msl. The piezometer P-10 is located on the side of the eroded bedrock valley where the bedrock surface is relatively shallow, while P-8 is located near the projected center of the eroded bedrock valley (see Figure 4-17). These elevations suggest that the sands screened by these two wells may not be continuous. It should also be noted that the historical aerial photography indicates that discharge from the Fresh Water Pond originally occurred from the southeast corner of the pond in the vicinity of P-10 (see Section 2.3). This area may have been the site of more recent deposition of sand and gravel and appears to have been an area of filling during plant operation.

The more shallow sands identified in the area of P-10 may provide a significant pathway for recharge into the Retention Pond from either the Fresh Water Pond or upgradient groundwater flowing along the top of bedrock from the south and southwest. Boring data from the previous ARS investigation indicated that top of clay in the southeast corner of the Retention Pond is as low as 685 feet msl (See Figure 4-25), indicating that there may not be much of a hydraulic barrier to flow from these sands into the Retention Pond.

The water level data for the wells installed in the upgradient portion of the study area are plotted in Figure 4-37. The water levels in the upgradient wells generally follow the pattern of water level fluctuations in the Fresh Water Pond. However, the magnitude of the observed fluctuations is generally much greater than that observed in the Fresh Water Pond. In addition, with the exception of the period of drought during the summer of 1998, water levels in the upgradient wells are above those observed in the Fresh Water Pond. These relative water levels indicate that, with the possible exception of drought periods, groundwater levels in the upgradient areas surrounding the Fresh Water Pond are not controlled by recharge (leakage) from the Fresh Water Pond. Rather, groundwater flow from the north, west, and south of the Fresh Water Pond is a source of potential recharge to the Fresh Water Pond. However, the similarity in the trends appears to indicate that water levels in both the upgradient groundwater and the Fresh Water Pond are responding to the same hydrologic influences.

The hydraulic relationships among Fulton Creek, shallow and deep groundwater, and water in the Fresh Water and Retention Ponds are shown in Figure 4-38. The water levels depicted on Figure 4-38 include those observed during the period of lowest observed water levels (September 1998) and during a period of relatively high water levels (March 1999). As shown in Figure 4-38, the elevation of Fulton Creek drops rapidly from west to east. In the western-most reach of the creek, the bottom of the creek is higher than the water level in the Retention Pond and this reach serves as a potential source of recharge to the Retention Pond. The extent of the reach which may recharge the Retention Pond varies with changes in the water level in the Retention Pond. Beyond this reach, the water level in the Retention Pond is above the bottom of Fulton Creek and shallow groundwater flow would tend to flow from the Retention Pond, through the berm, into Fulton Creek. The similarity between water levels in MWS-11 and the height of the adjacent stretch of Fulton Creek strongly suggests that Fulton Creek exerts hydraulic control on shallow groundwater levels in the creek vicinity, resulting in minimal fluctuations in nearby groundwater levels observed during either wet or dry periods. The water levels from the wells screened in the deeper Unit 1 sands also correlate surprisingly well with the elevation of the bottom of the Fulton Creek channel, potentially indicating a degree of hydraulic interconnection between Fulton Creek and the underlying Unit 1 sands. The deltaic deposits identified in the historical aerial photographs along the northern boundary of the Facility (see Section 2.3) may provide this hydraulic interconnection. The high hydraulic conductivities measured in the Unit 1 materials at MWD-11 and, to a lesser extent, at MWD-10 may also be indicative of this hydraulic interconnection.

#### 4.5.2.4 Groundwater Chemistry

A limited program to determine major ion chemistry of groundwater was conducted as part of this investigation. A summary of the results of these analyses is provided in Table 3-10. Additional groundwater sampling, including analyses for radionuclides, has been undertaken as part of a concurrent geochemistry study. The results of this additional groundwater sampling is reported and discussed in Meijer (1999).

The results of analyses for the major ion chemistry has indicated that there are significant differences between the waters present in the Fresh Water Pond and in the Retention Pond. Similarly, the groundwater chemistry observed downgradient from the Retention Pond is significantly different from that upgradient of the Retention Pond. Water from the Retention Pond is characterized by higher magnesium, potassium, and chloride concentrations but lower calcium concentrations than water from the Fresh Water Pond. The water from the Retention Pond also exhibits a much higher pH than water from the Fresh Water Pond. Groundwater downgradient from the Retention Pond generally shows characteristics similar to that of water from the Retention Pond, with higher magnesium, potassium, and chloride concentrations and pH but lower calcium concentrations than upgradient groundwater.

These data strongly suggest that water that has been in contact with the dross is present in wells downgradient from the Retention Pond, including MWD-5, MWD-8, and P-5. These wells are screened in the deeper Unit 1 material directly overlying bedrock, indicating that water originally in contact with the dross has likely infiltrated into the deeper overburden deposits. Although major ion chemistry indicates that leakage from the Retention Pond is occurring, analysis of radionuclide concentrations in soil and groundwater conducted as part of the concurrent geochemistry study indicates that thorium and radium have apparently not migrated in groundwater significant distances from the dross deposits. This is likely due to the high adsorption coefficients that have been measured for subsurface materials during the concurrent geochemistry study. Additional analysis and discussion of site geochemistry is available in Meijer (1999).

#### 4.5.2.5 Migration Pathways in Groundwater

There are several potential pathways for the migration of radionuclides in groundwater away from the Retention and Reserve Ponds. These potential pathways include shallow groundwater flow through the berms on the northern, eastern, and southeastern sides of the Retention and Reserve Ponds. Groundwater flow through the northern berms likely discharges to Fulton Creek. Surface water quality in Fulton Creek is monitored through the surface water sampling program at the Fulton Creek weir (see Section 3.8). Routine sampling and radioactivity measurements of surface water have indicated no significant impact on Fulton Creek. Wells MWS-5, MWS-6, MWS-11, and MWD-8 are currently available for monitoring of shallow groundwater quality along the eastern boundary of the Retention and Reserve Ponds. Potential migration pathways in groundwater also include migration through the underlying Unit 2 silty clays into and through the Unit 1 sands and shallow, weathered bedrock. Wells MWD-4, MWD-5, MWD-6, MWD-7, MWD-8, MWD-10, MWD-11, and P-5 are currently available for monitoring these pathways. A program of quarterly groundwater monitoring of all wells on the site for thorium, radium, and basic ions is currently being undertaken.

## 4.6 CONCEPTUAL MODEL OF SITE HYDROLOGY

Based on the data collected and analysis performed during this investigation, a qualitative conceptual hydrologic model has been developed for the site. Inflows into the basin delineated by the area of the Facility north of the railroad (the Kaiser Basin) include surface water, ground water, direct precipitation, and plant cooling water discharges. Outflows from the Kaiser Basin include into groundwater, surface water, and evaporation from the ponds.

### 4.6.1 Surface Water Inflows

The surface water hydrology of the site is discussed in Section 4.3.3. Surface water enters the Kaiser Basin through the upstream channel of Fulton Creek, which empties into the Fresh Water Pond. Surface water also directly enters Fulton Creek through the storm water drain located along the northern boundary of the Facility. Overland runoff from north, west and south also contributes surface water to the Kaiser Basin. Overland flow from the west, northwest, and southwest drains directly into the Fresh Water Pond. Overland runoff from the northern boundary of the Facility east of the Fresh Water Pond directly enters Fulton Creek. The remainder of the overland runoff from the south discharges either into the Retention Pond or a drainage ditch that drains into Fulton Creek. Precipitation also directly contributes to surface water on the site.

### 4.6.2 Ground Water Inflows

Groundwater inflows into the Kaiser Basin are discussed in Section 4.5.2. Groundwater enters the Kaiser Basin from the north, west, and south. These groundwater inflows are primarily through the silty clays that directly overlie bedrock in areas along the sides of the eroded bedrock valley, although some ground water may also enter the basin through the shallow, weathered bedrock zone. However, groundwater inflows into the basin via these pathways are likely to be limited by the relatively low permeability of the silty clays overlying bedrock and the shallow weathered bedrock. The potentially largest source for groundwater entering the basin is through the upgradient portion of the eroded bedrock valley that was found to be present below the study area. Although the upgradient extent of the bedrock valley has not been verified during the current investigation, the valley likely extends to the southwest from the southwest corner of the Fresh Water Pond (see Figure 4-17). If such an extension of the valley exists and if it is filled with relatively permeable sands such as were identified beneath the study area, this pathway likely provides the most significant contribution to groundwater flow from off-site sources.

### 4.6.3 Basin Outflows

Outflow from the Kaiser Basin via surface water occurs through discharges via Fulton Creek at the weir on the northeast corner of the Facility. Outflow from the basin via groundwater occurs through the Unit 1 sands in the bedrock valley at the northeast corner of the Facility. To a lesser extent, groundwater also discharges from the basin through the more shallow overburden materials along the eastern boundary of the site. Some water also leaves the basin through evaporation from the Fresh Water and Retention Ponds and Fulton Creek.

### 4.6.4 Intrabasin Exchanges between Surface and Ground Water

Within the basin, itself, there are a number of points of potential water exchange between surface and ground water. Along its northern, western and southern boundaries, the Fresh Water Pond receives some limited groundwater flow. Similarly, the Retention Pond receives limited recharge from groundwater along its southwest boundary. There may be limited leakage of surface water from the Retention Pond through the northern berm potentially into Fulton Creek. However, potentially the most significant exchanges between ground and surface water within the basin occur beneath the Fresh Water and Retention Ponds.

Surface water in the Fresh Water Pond can infiltrate through the bottom of the pond into the underlying Unit 1 sands. Similarly, surface water in the Fresh Water Pond can infiltrate through the berm between the Fresh Water and Retention Ponds, as well as through the shallow sands identified in the vicinity of piezometer P-10, into the Retention Pond. While analysis of the temporal trends in water levels indicate that the Fresh Water Pond is not the dominant influence on water levels in the Retention Pond or underlying Unit 1 Sands (see

Section 4.5.2.3), the Fresh Water Pond cannot be ignored as a source of water for both deep groundwater flow and the Retention Pond.

The gradients observed between groundwater in the Unit 1 sands and the surface water in the Retention Pond indicate that in the western portion of the Retention Pond there is a potential for deep groundwater to discharge into the Retention Pond, while in the central and eastern portions of the Retention Pond there is a potential for surface water in the Retention Pond to recharge groundwater in the Unit 1 sands. Analysis of water levels in the Retention Pond and in groundwater adjacent to and beneath the ponds appears to indicate that these water levels are responding to the same influences. Moreover, the lack of significant gradients between groundwater in the shallow and deep overburden material at the MW-6 cluster strongly suggests a significant hydraulic connection may exist in this general area between the Retention Pond and underlying Unit 1 sands. Thus, there is a strong potential for significant flows from the Retention Pond into both deep and shallow groundwater in the eastern portion of the Retention Pond.

The potential for significant flows from the Retention Pond into both deep and shallow groundwater in the eastern portion of the Retention Pond is supported by groundwater quality data. As discussed in Section 4.5.2.4, groundwater downgradient from the Retention Pond exhibits chemical characteristics that indicate that it has likely been in contact with the dross. The rapid decline in water levels in the Retention Pond immediately after the extreme rain event during the first week of October 1998 further supports the potential for leakage out of the Retention Pond. During the month after this rain event, the water level in the Retention Pond dropped more than 3.4 feet. Estimates of evaporation from nearby lakes in the Tulsa area indicate a potential evaporation from the pond of approximately 3 to 4 inches (see Table 4-2). Thus, the losses from the Retention Pond during this period far exceed any potential losses from evaporation and indicate that significant leakage occurred from the Pond during this period.

The borings conducted around the periphery of the Retention Pond indicate that the pond is underlain primarily by a silty clay material identified as Unit 2. The hydraulic conductivity estimated for this material ranges between $10^{-6}$ and $10^{-8}$ cm/sec (see Section 4.5.2.2). An infiltration rate of approximately 3 feet over a one-month period does not appear consistent with this range of permeabilities. The presence of higher permeability materials beneath limited areas of the Retention Pond is possible, particularly beneath the old Fulton Creek channel. The geologic log for monitoring well MWS-4 indicates the presence of a gray silt with sand and organic fibers at this location (see boring logs in Appendix A). Monitoring well MWS-4 is located in the general vicinity of the old Fulton Creek channel and may indicate the presence of higher permeability material beneath the Retention Pond. The deltaic deposits identified along the northern boundary in the historical aerial photographs may also contain higher permeability material that could permit greater leakage from the Retention Pond.

### 4.6.5 Estimating Basin Surface and Ground Water Flows

Data are not readily available for accurately estimating surface water flows into or out of the Kaiser Basin. Primarily due to a lack of definition of the upstream extent and characteristics of the eroded bedrock channel, data are similarly not readily available to estimate groundwater inflows into the basin. However, groundwater outflows from the basin can be estimated based on the groundwater gradients, hydraulic conductivity of subsurface material, and the distribution of subsurface materials along the eastern boundary of the Facility and, particularly, in the northeast corner of the Facility (see Section 4.5.2.2).

If the Fresh Water and Retention Ponds are drained during remediation, major sources of the groundwater recharge will be removed, and the outflow now observed along the eastern boundary of the Facility should be reduced. Should these surface water bodies be drained, impounded surface water will no longer recharge groundwater. Instead, surface water would likely be directly routed around the site in a reconfigured Fulton Creek. Under these conditions, the groundwater flow discharging from the site will be largely determined by groundwater inflows into the basin. Since current groundwater outflows from the site likely contain significant amounts of leakage from the Fresh Water and Retention Ponds, the currently available estimates for groundwater outflows from the site can only be used as an upper bound for groundwater discharge through site after drainage and removal of the Fresh Water and Retention Ponds.

# TABLE 4-1
# WEEKLY AND MONTHLY
# PRECIPITATION DATA FOR TULSA - SEPT 1996 TO APRIL 1999

| Date | W1 | W2 | W3 | W4 | Monthly Total |
|---|---|---|---|---|---|
| Aug-96 | 0.31 | 0.56 | 0.26 | 0.2 | 1.33 |
| Sep-96 | 0.01 | 1.71 | 0.27 | 2.88 | 4.87 |
| Oct-96 | 0.02 | 0 | 2.92 | 2.66 | 5.6 |
| Nov-96 | 3.86 | 0.05 | 1.85 | 1.45 | 7.21 |
| Dec-96 | 0 | 0.1 | 0 | 0 | 0.1 |
| Jan-97 | 0 | 0.25 | 0 | 0 | 0.25 |
| Feb-97 | 0.4 | 0 | 2.02 | 0.99 | 3.41 |
| Mar-97 | 0.13 | 0.2 | 0.05 | 1.25 | 1.63 |
| Apr-97 | 0.53 | 2.75 | 0.53 | 0.28 | 4.09 |
| May-97 | 0.56 | 0.6 | 0.06 | 0.44 | 1.66 |
| Jun-97 | 0.07 | 1.23 | 0.98 | 3.49 | 5.77 |
| Jul-97 | 1.56 | 1.42 | 1.68 | 0.92 | 5.63 |
| Aug-97 | 0.74 | 2.62 | 3.38 | 1.12 | 7.86 |
| Sep-97 | 0 | 0.23 | 0.32 | 2.51 | 3.06 |
| Oct-97 | 0 | 1.56 | 0.03 | 0.4 | 1.99 |
| Nov-97 | 0 | 0.89 | 0 | 0.73 | 1.62 |
| Dec-97 | 0.89 | 0.5 | 2.66 | 0.65 | 4.7 |
| Jan-98 | 2.2 | 3.53 | 0 | 0.75 | 6.48 |
| Feb-98 | 0.12 | 0.02 | 0.16 | 0 | 0.3 |
| Mar-98 | 2.72 | 1.01 | 2.56 | 1.04 | 7.34 |
| Apr-98 | 0.61 | 0 | 0 | 3.93 | 4.54 |
| May-98 | 1.1 | 0.25 | 0 | 1.11 | 2.46 |
| Jun-98 | 0.01 | 1.33 | 0.54 | 1.49 | 3.37 |
| Jul-98 | 1.42 | 2.84 | 0 | 0.05 | 4.31 |
| Aug-98 | 0.72 | 0.9 | 0 | 0.05 | 1.67 |
| Sep-98 | 0 | 2.39 | 2.53 | 0.21 | 5.13 |
| Oct-98 | 7.08 | 0 | 1.43 | 0.53 | 9.04 |
| Nov-98 | 2.03 | 0.37 | 0.02 | 0.84 | 3.26 |
| Dec-98 | 0.98 | 0 | 0.59 | 0 | 1.57 |
| Jan-99 | 0.26 | 0.02 | 0.84 | 1.89 | 3.01 |
| Feb-99 | 0.91 | 0.31 | 0.04 | 0 | 1.26 |
| Mar-99 | 0.12 | 2.79 | 0.51 | 0.13 | 3.55 |
| Apr-99 | 0.27 |  |  |  | 0.27 |

Source: National Climatic Data Center (Tulsa International Airport)

## TABLE 4-2

# Lake Evaporation at Skiatook Lake and Keystone Lake

6/26/98 to 3/10/99

| | Date | Skiatook Evap.(inches) |
|---|---|---|
| Skiatook Lake Evaporation Rates | 6/26/98 | 10.471 |
| | 7/7/98 | 10.411 |
| | 8/6/98 | 9.189 |
| | 9/9/98 | 7.53 |
| | 10/8/98 | 4.17 |
| | 11/5/98 | 2.71 |
| | 12/7/98 | 2.71 |
| | 1/13/99 | 2.37 |
| | 2/8/99 | 3.8 |
| | 3/10/99 | 4.8 |

| | Date | Keystone Evap.(inches) |
|---|---|---|
| Keystone Lake Evaporation Rates | 6/26/98 | 10.553 |
| | 7/7/98 | 10.53 |
| | 8/6/98 | 9.19 |
| | 9/9/98 | 7.66 |
| | 10/8/98 | 3.86 |
| | 11/5/98 | 2.49 |
| | 12/7/98 | 2.24 |
| | 1/13/99 | 2.26 |
| | 2/8/99 | 4.09 |
| | 3/10/99 | 4.34 |

Up until approximately June 1998, evaporation rates for Keystone and Skiatook Lakes were based upon 70% of the Class A pan evaporation at the respective lake project offices. Presently, evaporation rates are calculated by the U.S. Army Corps of Engineers using an emperical equation which considers the wind speed, temperature, solar radiation and relative humidity with meterological data from various NOAA and Corps of Engineers gauging stations.

# TABLE 4-3 STREAMFLOW DATA FOR MINGO CREEK AT 46TH STREET NORTH KAISER ALUMINUM EXTRUDED PRODUCTS, TULSA, OKLAHOMA

| Summary Statistics | 1991 Calendar Year | 1992 Water Year | Water Years 1988-92 |
|---|---|---|---|
| Annual Total (cfs) | 22750.8 | 27872.6 | |
| Annual Mean (cfs) | 62.3 | 76.2 | 75.8 |
| Highest Annual Mean | | | 97.7 (1988) |
| Lowest Annual Mean | | | 43.4 (1991) |
| Highest Daily Mean | 2260 (Dec 20) | 2260 (Dec 20) | 4000 (Aug 20, 1989) |
| Lowest Daily Mean | 1.3 (Aug 7) | 1.7 (Sept 18) | 1.3 (Aug 2, 1991) |
| Annual Seven-Day Min. | 1.7 (Aug 2) | 1.9 (Aug 24) | 1.6 (Oct 15, 1989) |
| Instantaneous Peak Flow | | 4590 (Dec 20) | 9920 (Aug 20, 1989) |
| Instantaneous Peak Stage | | 14.89 (Dec 20) | 21.92 (Aug 20, 1989) |
| Annual Runoff (Ac-Ft) | 45130 | 55290 | 54930 |

Note: Water Year runs from October 1991 to September 1992.
cfs = cubic feet per second

Source: United States Geological Survey, Water Data Report OK-92-1.

# TABLE 4-4

# STAGE-GAUGE DISCHARGE AT FULTON CREEK WEIR

# TULSA REMEDIATION PROJECT

| DATE | STAGE-GAUGE READING FRESH WATER POND GAUGE* HtFt | DISCHARGE AT FULTON CREEK WEIR Cfs | 5 DAY PRECEDING PRECIPITATION TOTAL (In) |
|---|---|---|---|
| 4/29/97 | 0.39 | .252 | 0.24 |
| 5/8/97 | 0.9 | 2.125 | 0.59 |
| 5/9/97 | 0.58 | 0.608 | 0.59 |
| 5/12/97 | 0.38 | 0.226 | 0.10 |
| 5/14/97 | 0.2 | 0.045 | 0.10 |
| 5/15/97 | 0.2 | 0.045 | 0.10 |
| 5/16/97 | 0.2 | 0.045 | 0.09 |
| 5/19/97 | 0.2 | 0.045 | 0.06 |
| 5/19/97 | 0.32 | 0.148 | 0.06 |
| 5/21/97 | 0.26 | 0.091 | 0.06 |
| 6/16/97 | 0.79 | 1.48 | 1.27 |
| 7/30/97 | 0.74 | 1.23 | 0.92 |
| 8/7/97 | 0.75 | 1.24 | 0.74 |
| 8/11/97 | 3.25 | 30.28 | 2.62 |
| 7/7/98 | 0.37 | 0.213 | 1.42 |
| 8/6/98 | 0.83 | 1.712 | 0.72 |
| 10/8/98 | 0.41 | 0.270 | 7.08 |
| 11/5/95 | 0.43 | 0.308 | 2.03 |
| 12/7/98 | 0.50 | 0.440 | 0.98 |
| 1/13/99 | 0.39 | 0.252 | 0.02 |
| 2/8/99 | 0.56 | 0.566 | 0.90 |
| 3/10/99 | 0.48 | 0.421 | 1.14 |

# TABLE 4-5

# PEAK DISCHARGE AT FULTON CREEK WEIR

| Storm Return Period | Volume Runoff Acre Feet | Peak Discharge | Estimated Peak Height at Weir | Estimated Elevation Peak Height at Weir Ft MSL |
|---|---|---|---|---|
| 2 Years | 69 | 545 | 8.4 | 687.7 |
| 5 Years | 99 | 779 | 9.4 | 688.7 |
| 10 Years | 121 | 954 | 10.1 | 689.4 |
| 25 Years | 143 | 1130.3 | 10.7 | 690.06 |
| 50 Years | 170 | 1344 | 11.6 | 691.0 |
| 100 Years | 190 | 1499 | 12.3 | 691.7 |

## TABLE 4-6 GROUNDWATER WITHDRAWAL PERMITS WITHIN 10-KM, KAISER ALUMINUM EXTRUDED PRODUCTS, TULSA, OKLAHOMA

| Permit # | Permittee | Location | Use | AcreFeet/Use |
|---|---|---|---|---|
| 87-547 | Tulsa County Parks Department | NE/NW/NW Sec 24, T18N, R12E<br>NW/NW/NW Sec 24, T18N, R12E<br>NW/NW/NW Sec 24, T18N, R12E<br>SE/NE/NW Sec 24, T18N, R12E<br>SE/NW/NW Sec 24, T18N, R12E<br>SW/NE/NW Sec 24, T18N, R12E<br>SW/NW/NW Sec 24, T18N, R12E<br>SW/SW/NW Sec 24, T18N, R12E | Irrigation | 256 |
| 49-112 | Sinclair Oil Corpation | SW/NE/NE Sec 23, T19N, R12E | Industrial | 1,019 |
| 84-527 | Kentube | NE/NE/NE Sec 26, T19N, R12E | Industrial | 10 |
| 81-869 | P.S.O. | NE/SE/NW Sec 17, T18N, R13E | Irrigation | 2 |
| 81-713 | Weinkauf, D. & J. | NE/NW/NW Sec 32, T19N, R13E | Irrigation | 1 |
| 55-1327 | Allan D. Davis | N/2 of NE Sec 13, T18N, R12E | Irrigation | 54 |

Source: Oklahoma Water Resources Board, 10/95.

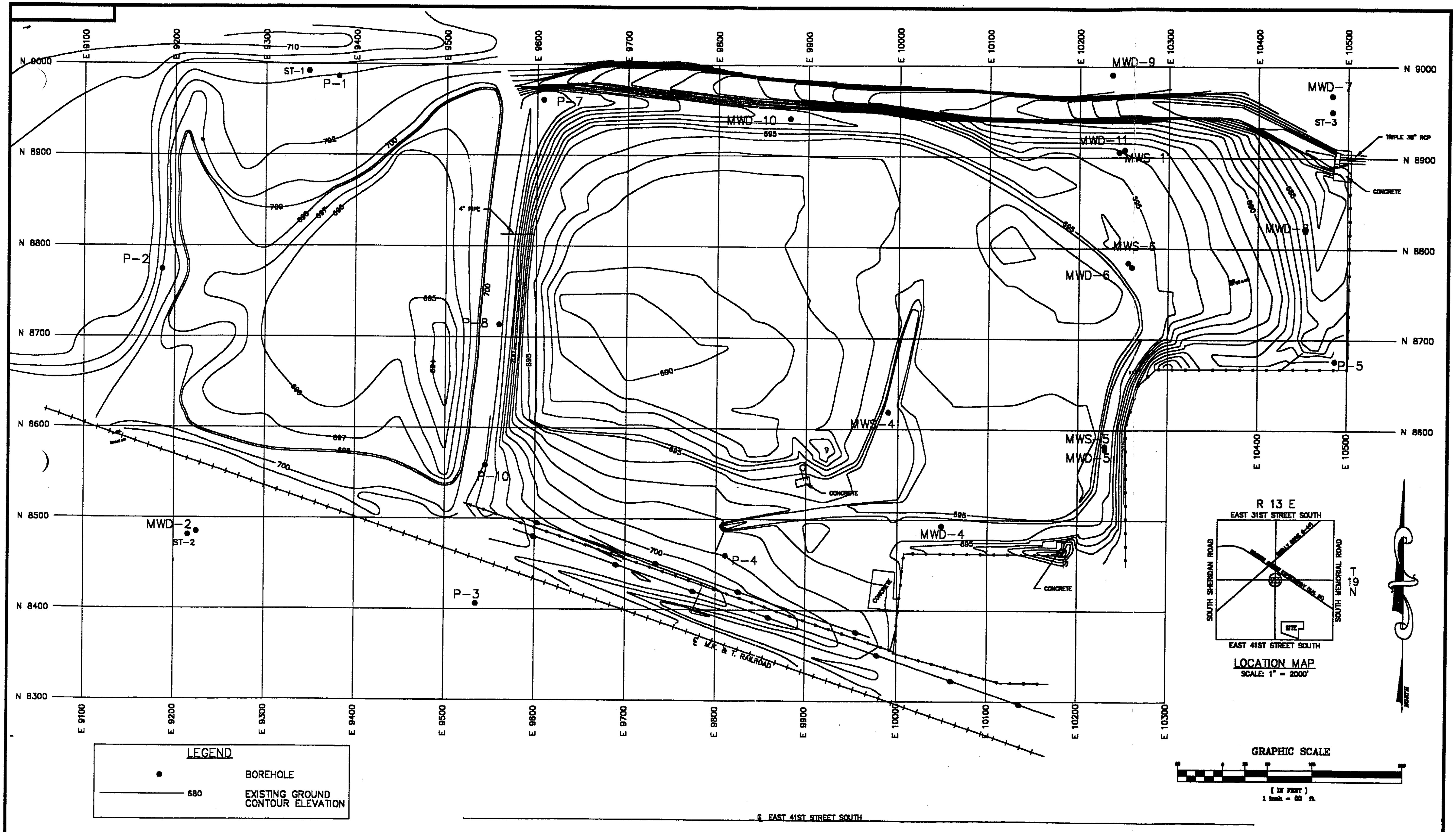
## Table 4-7 ·Engineering Properties of Unified Soil Classes

| | IMPORTANT PROPERTIES | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | PERMEABILITY | | | |
| TYPICAL NAMES | SHEAR STRENGTH | COMPRESS-IBILITY | WORKABILITY AS CONSTRUCTION MATERIAL | WHEN COMPACTED | K CM. PER SEC. | K FT. PER DAY | UNIFIED SOIL CLASSES |
| Well graded gravels, gravel-sand mixtures, little or no fines. | Excellent | Negligible | Excellent | Pervious | $K > 10^{-2}$ | $K > 30$ | **GW** |
| Poorly graded gravels, gravel-sand mixtures, little or no fines. | Good | Negligible | Good | Very Pervious | $K > 10^{-2}$ | $K > 30$ | **GP** |
| Silty gravels, gravel-sand-silt mixtures. | Good to Fair | Negligible | Good | Semi-Pervious to Impervious | $K = 10^{-3}$ to $10^{-6}$ | $K = 3$ to $3 \times 10^{-3}$ | **GM** |
| Clayey gravels, gravel-sand-clay mixtures. | Good | Very Low | Good | Impervious | $K = 10^{-6}$ to $10^{-8}$ | $K = 3 \times 10^{-3}$ to $3 \times 10^{-5}$ | **GC** |
| Well graded sands, gravelly sands, little or no fines. | Excellent | Negligible | Excellent | Pervious | $K > 10^{-3}$ | $K > 3$ | **SW** |
| Poorly graded sands, gravelly sands, little or no fines. | Good | Very Low | Fair | Pervious | $K > 10^{-3}$ | $K > 3$ | **SP** |
| Silty sands, sand-silt mixtures. | Good to Fair | Low | Fair | Semi-Pervious to Impervious | $K = 10^{-3}$ to $10^{-6}$ | $K = 3$ to $3 \times 10^{-3}$ | **SM** |
| Clayey sands, sand-clay mixtures. | Good to Fair | Low | Good | Impervious | $K = 10^{-6}$ to $10^{-8}$ | $K = 3 \times 10^{-3}$ to $3 \times 10^{-5}$ | **SC** |
| Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity. | Fair | Medium to High | Fair | Semi-Pervious to Impervious | $K = 10^{-3}$ to $10^{-6}$ | $K = 3$ to $3 \times 10^{-3}$ | **ML** |
| Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. | Fair | Medium | Good to Fair | Impervious | $K = 10^{-6}$ to $10^{-8}$ | $K = 3 \times 10^{-3}$ to $3 \times 10^{-5}$ | **CL** |
| Organic silts and organic silty clays of low plasticity. | Poor | Medium | Fair | Semi-Pervious to Impervious | $K = 10^{-4}$ to $10^{-6}$ | $K = 3 \times 10^{-1}$ to $3 \times 10^{-3}$ | **OL** |
| Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts. | Fair to Poor | High | Poor | Semi-Pervious to Impervious | $K = 10^{-4}$ to $10^{-6}$ | $K = 3 \times 10^{-1}$ to $3 \times 10^{-3}$ | **MH** |
| Inorganic clays of high plasticity, fat clays. | Poor | High to Very High | Poor | Impervious | $K = 10^{-6}$ to $10^{-8}$ | $K = 3 \times 10^{-3}$ to $3 \times 10^{-5}$ | **CH** |
| Organic clays of medium to high plasticity, organic silts. | Poor | High | Poor | Impervious | $K = 10^{-6}$ to $10^{-8}$ | $K = 3 \times 10^{-3}$ to $3 \times 10^{-5}$ | **OH** |
| Peat and other highly organic soils. | NOT SUITABLE FOR CONSTRUCTION | | | | | | **Pt** |

**Source:** U.S. Department of Agriculture Soil Conservation Service, SCS National Engineering Handbook, Section 8, 1968.

| Hydraulic conductivity, meters/day | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $10^4$ | $10^3$ | $10^2$ | $10^1$ | $1$ | $10^{-1}$ | $10^{-2}$ | $10^{-3}$ | $10^{-4}$ | $10^{-5}$ |
| Relative hydraulic conductivity | | | | | | | | | |
| Very high | | High | | | Moderate | | Low | | Very low |
| REPRESENTATIVE MATERIALS | | | | | | | | | |
| *Unconsolidated deposits* | | | | | | | | | |
| Clean gravel | – | Clean sand and sand and gravel | – | Fine sand | – | Silt, clay, and mixtures of sand, silt, and clay | | – | Massive clay |
| *Consolidated Rocks* | | | | | | | | | |
| Vesicular and scoriaceous basalt and cavernous limestone and dolomite | | – | Clean sandstone and fractured igneous and metamorphic rocks | | – | Laminated sandstone, shale, mudstone | | – | Massive igneous and metamorphic rocks |

**Table 4–8** Hydraulic conductivities for various classes of geologic materials (after Bureau of Reclamation[9]).



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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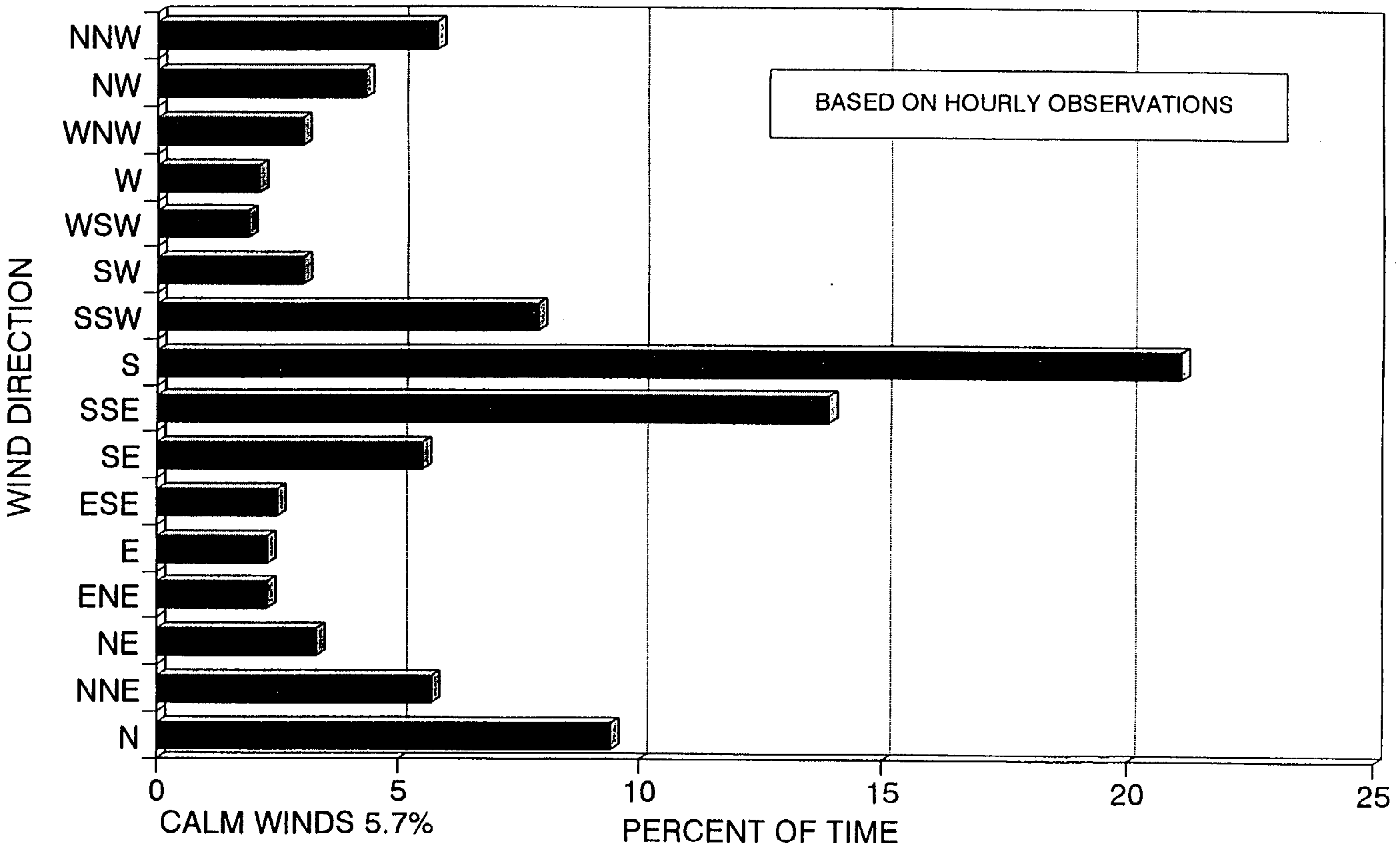
# TULSA REMEDIATION PROJECT

## SURFACE TOPOGRAPHY OF SITE

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: 1"=50' | PROJECT NUMBER: 1556-003 | DRAWING NUMBER: FIGURE 4-1 | REV.: |
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 | DATE: | | | | |



NATIONAL CLIMATIC DATA CENTER, 'INTERNATIONAL STATION METEOROLOGICAL CLIMATE SUMMARY', VERSION 2.1, JULY 2, 1992, NWS STATION # 723560

Figure Title: PERCENT OF OBSERVED SURFACE WIND DIRECTION, TULSA, OKLAHOMA (1948-1990)

Document Title: LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

**REF: RSA, INC. 1996**

Client: KAISER ALUMINUM EXTRUDED PRODUCTS

Location: 7311 EAST 41ST STREET
TULSA, OKLAHOMA

DATE: 11/1/95

SCALE: NO SCALE

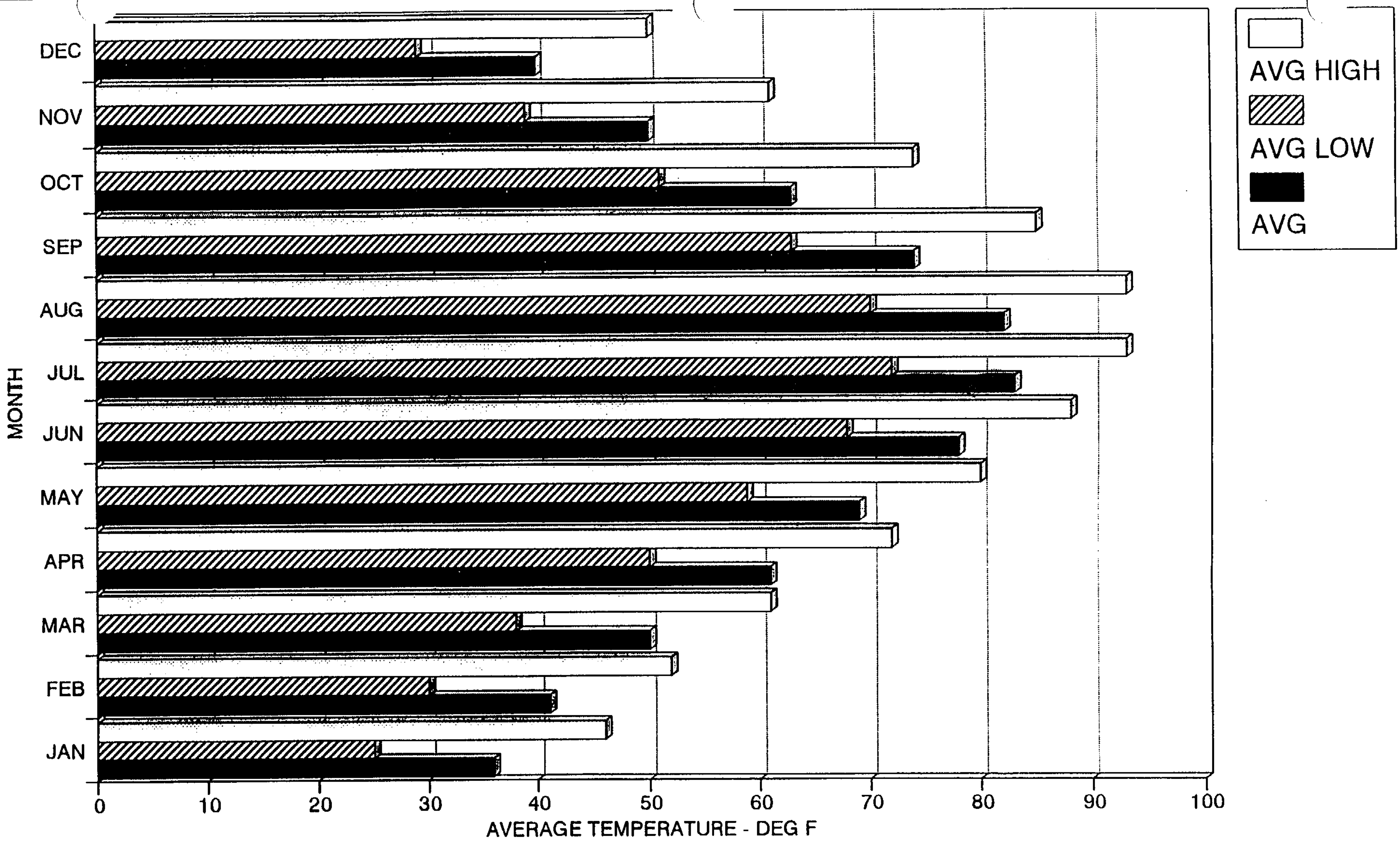
PROJECT NO: 9515901 F02

PREPARED BY: CM

CHECKED BY: CM

DRAFTED BY: GS

**FIGURE NO.:** 4-2



NATIONAL CLIMATIC DATA CENTER, 'INTERNATIONAL STATION METEOROLOGICAL CLIMATE SUMMARY', VERSION 2.1, JULY 2, 1992, NWS STATION #723560

Figure Title: AVERAGE TEMPERATURE BY MONTH, TULSA, OKLAHOMA (1948-1990)

Document Title: LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

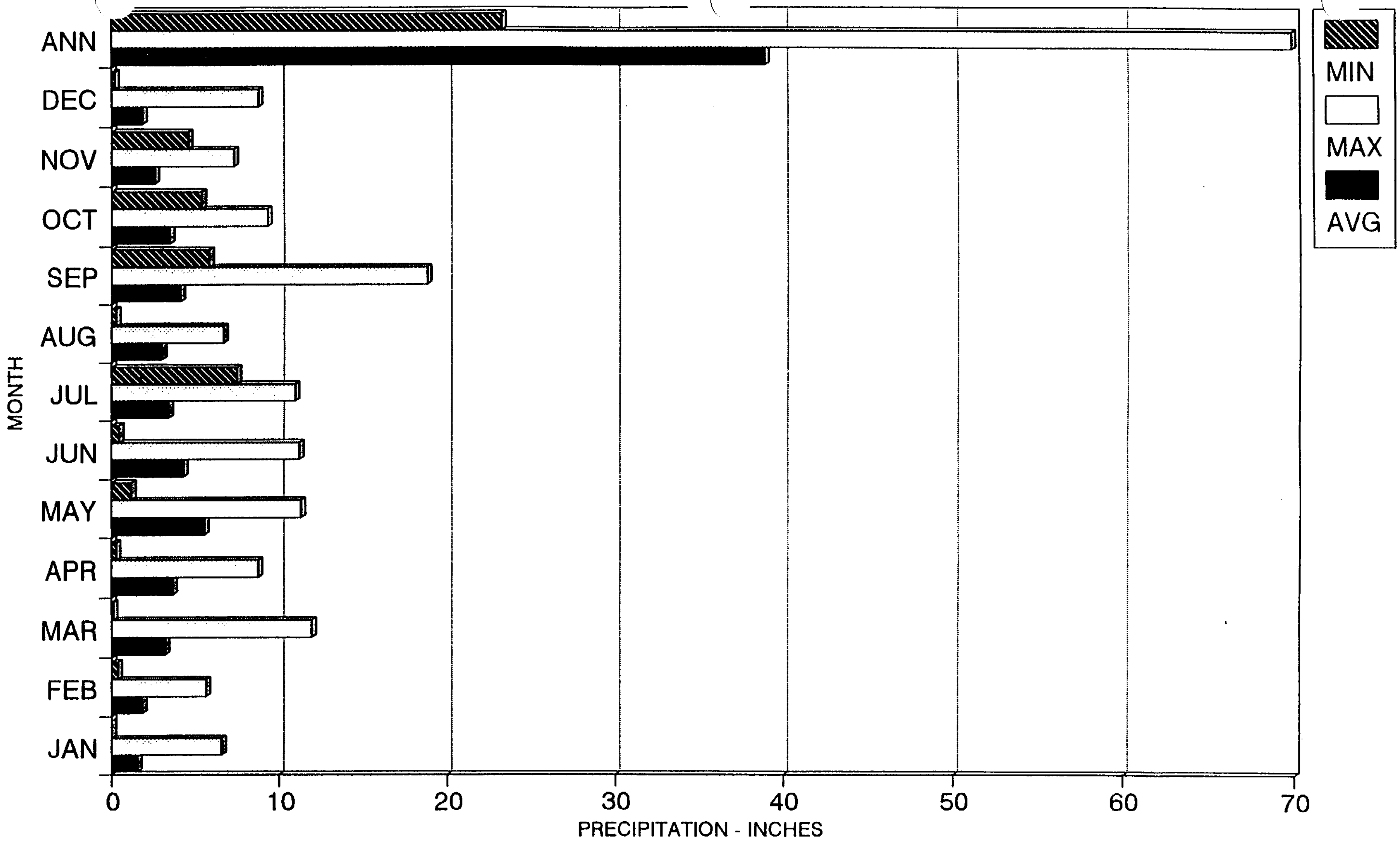
**REF: RSA, INC. 1996**

Client:
KAISER ALUMINUM
EXTRUDED PRODUCTS

Location:
7311 EAST 41ST STREET
TULSA, OKLAHOMA

DATE: 11/1/95
SCALE: NO SCALE
PROJECT NO: 9515901 F02

PREPARED BY: CM
CHECKED BY: CM
DRAFTED BY: GS
FIGURE NO.: 4-3



NATIONAL CLIMATIC DATA CENTER, 'INTERNATIONAL STATION METEOROLOGICAL CLIMATE SUMMARY', VERSION 2.1, JULY 2, 1992, NWS STATION #723560

Figure Title: PRECIPITATION BY MONTH,
TULSA, OKLAHOMA (1948-1990)

Document Title: LOCAL AND REGIONAL
ENVIRONMENTAL DATA REPORT

**REF: RSA, INC. 1996**

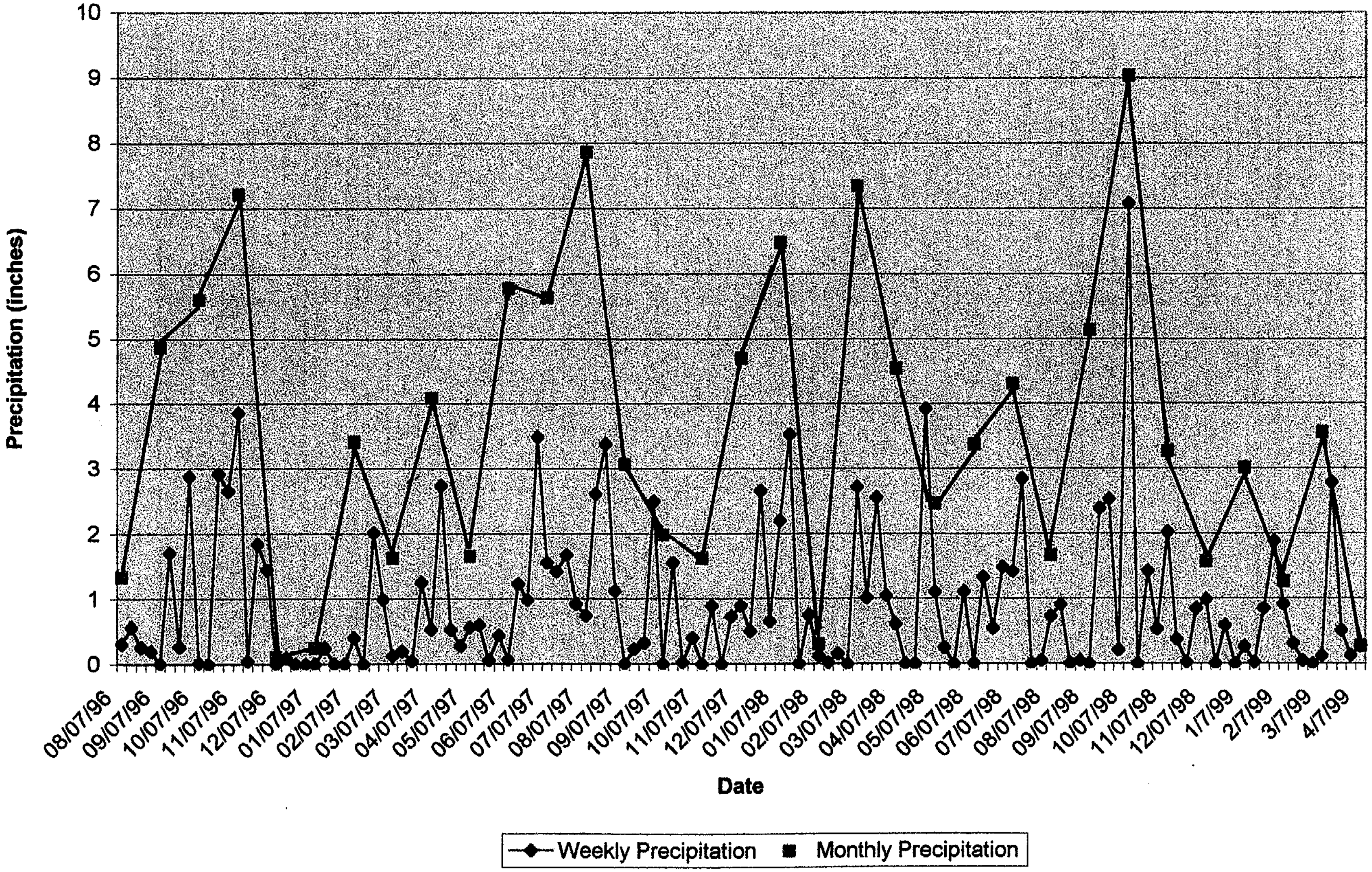
Client: KAISER ALUMINUM
EXTRUDED PRODUCTS

Location: 7311 EAST 41ST STREET
TULSA, OKLAHOMA

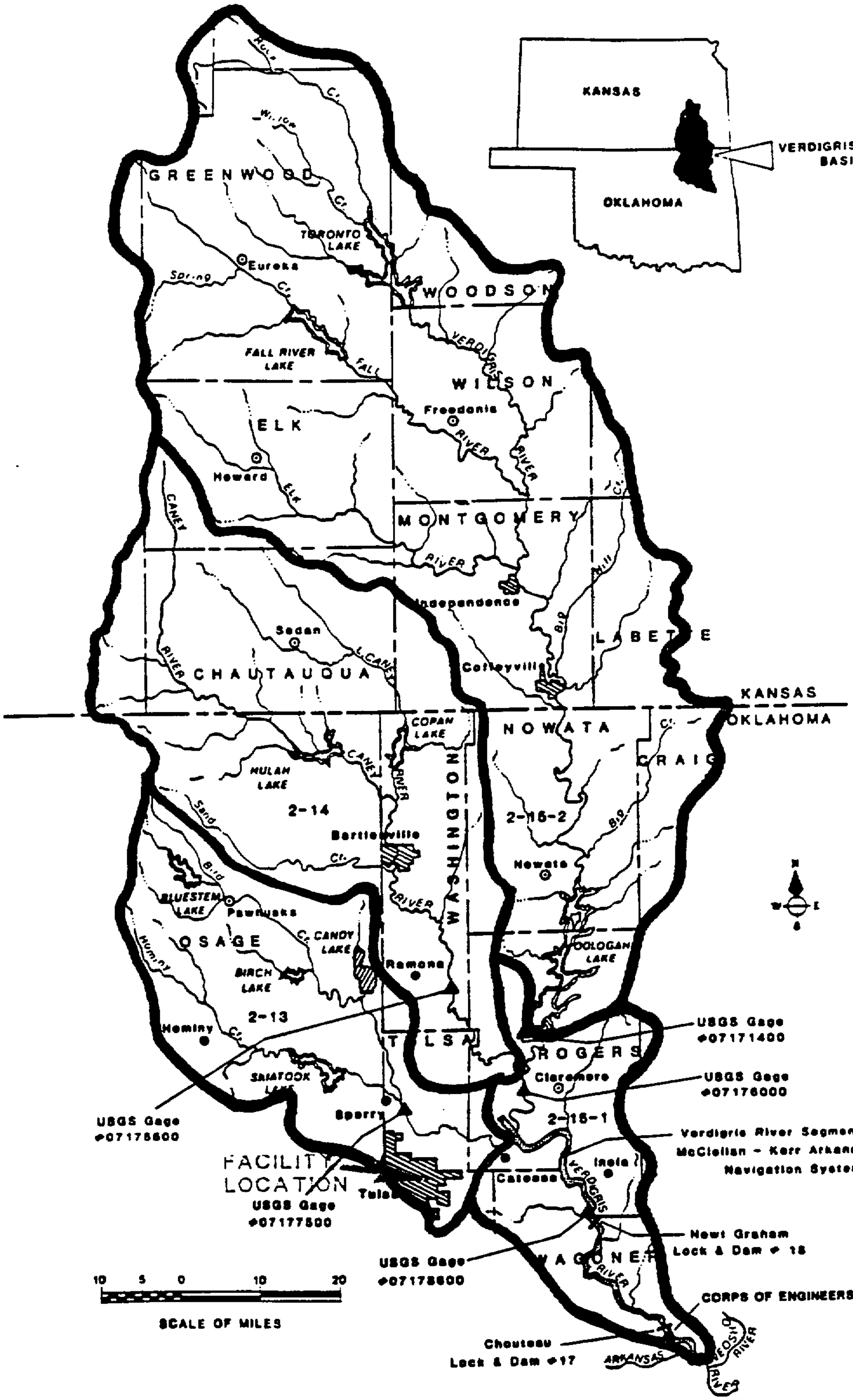
DATE: 11/1/95
SCALE: NO SCALE
PROJECT NO: 9515901 F02

PREPARED BY: CM
CHECKED BY: CM
DRAFTED BY: GS
**FIGURE NO.:** 4-4

Figure 4-5 Weekly and Monthly Precipitation from 8/7/96 to 4/30/99



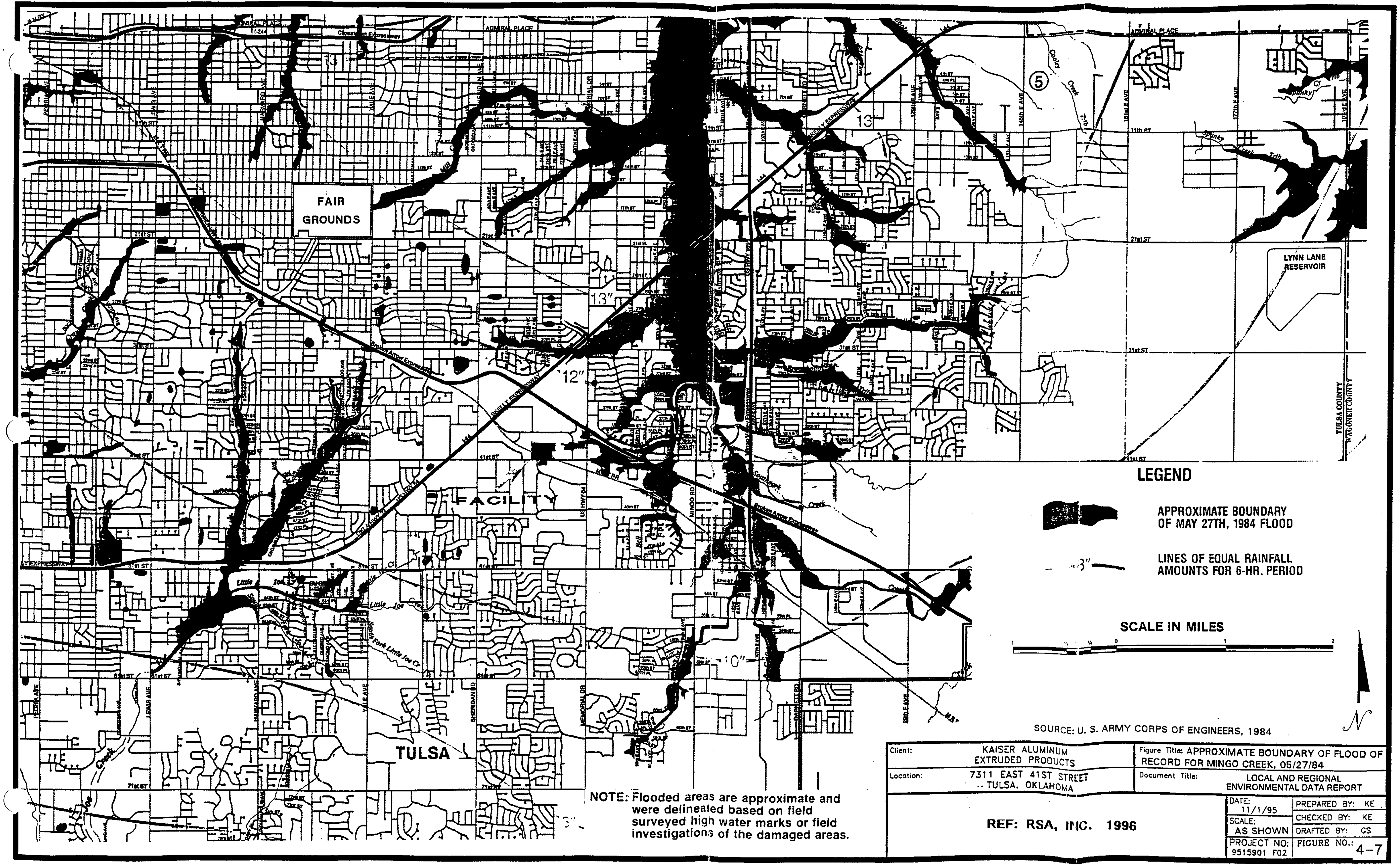
SOURCE: NATIONAL CLIMATIC DATA CENTER (TULSA INTERNATIONAL AIRPORT)



SOURCE: OKLAHOMA 305B REPORT, OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY, 1994

| | |
|---|---|
| Figure Title:<br>REGIONAL DRAINAGE BASINS | Client:<br>KAISER ALUMINUM<br>EXTRUDED PRODUCTS |
| Document Title:<br>LOCAL AND REGIONAL<br>ENVIRONMENTAL DATA REPORT | Location:<br>7311 EAST 41ST STREET<br>TULSA, OKLAHOMA |

| | | |
|---|---|---|
| REF: RSA, INC. 1995 | DATE:<br>11/1/95 | PREPARED BY: KE |
| | SCALE:<br>AS SHOWN | CHECKED BY: KE |
| | | DRAFTED BY: GS |
| | PROJECT NO:<br>9515901 F02 | FIGURE NO.:<br>4-6 |



SOURCE: U. S. ARMY CORPS OF ENGINEERS, 1984

NOTE: Flooded areas are approximate and were delineated based on field surveyed high water marks or field investigations of the damaged areas.

Client: KAISER ALUMINUM EXTRUDED PRODUCTS

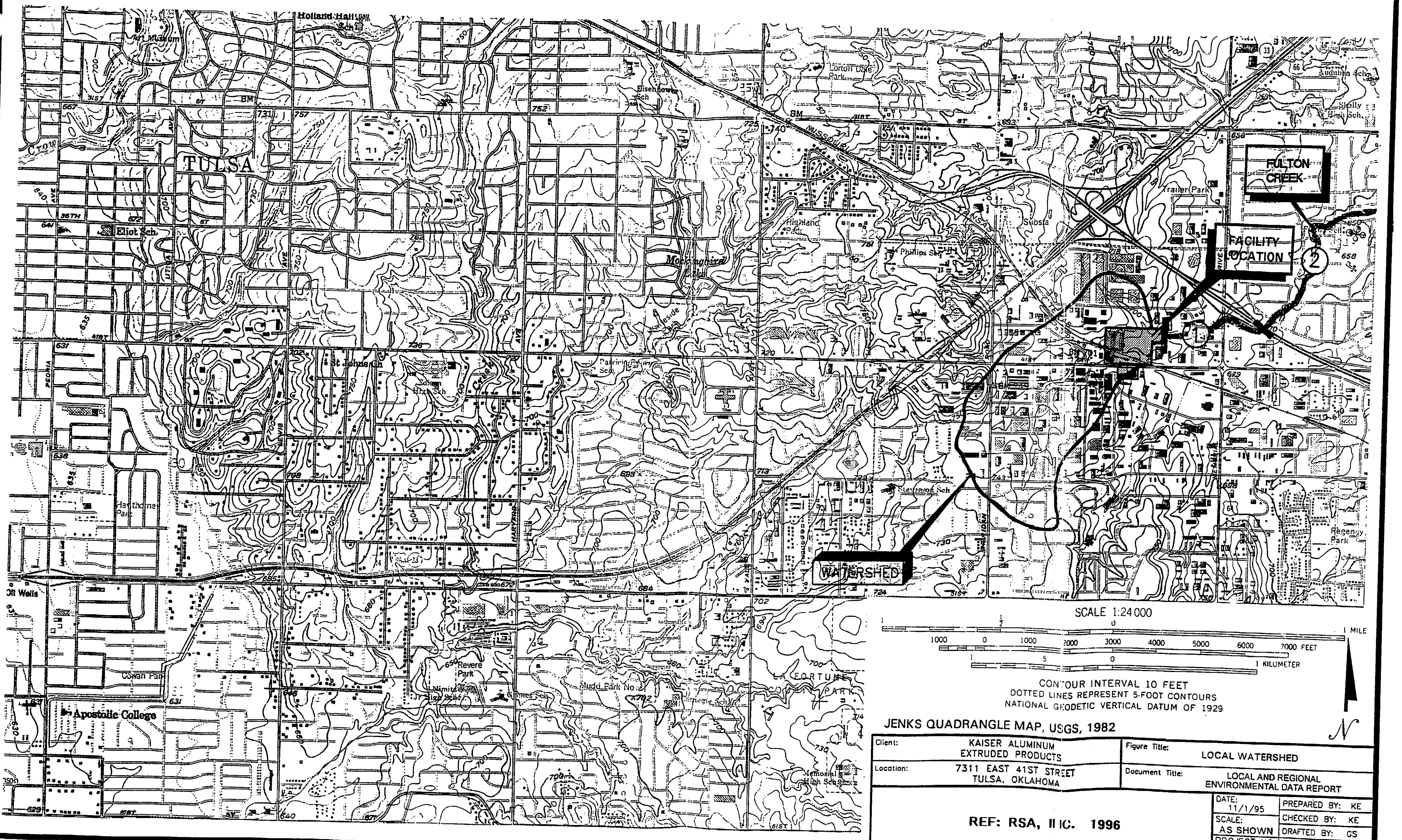
Location: 7311 EAST 41ST STREET -- TULSA, OKLAHOMA

Figure Title: APPROXIMATE BOUNDARY OF FLOOD OF RECORD FOR MINGO CREEK, 05/27/84

Document Title: LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

REF: RSA, INC. 1996

DATE: 11/1/95
PREPARED BY: KE
SCALE: AS SHOWN
CHECKED BY: KE
DRAFTED BY: GS
PROJECT NO: 9515901 F02
FIGURE NO.: 4-7



JENKS QUADRANGLE MAP, USGS, 1982

Client: KAISER ALUMINUM
EXTRUDED PRODUCTS

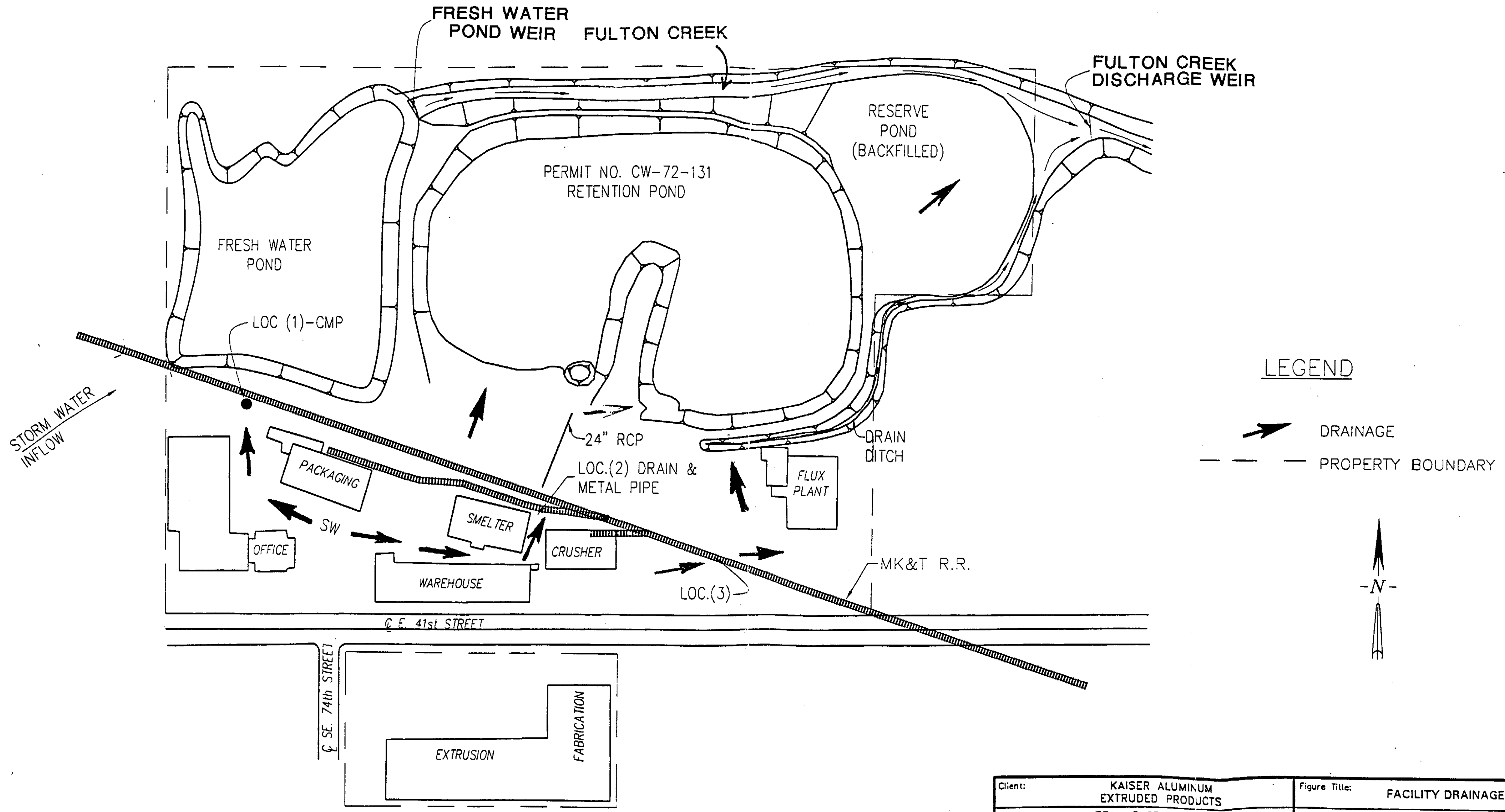
Location: 7311 EAST 41ST STREET
TULSA, OKLAHOMA

Figure Title: LOCAL WATERSHED

Document Title: LOCAL AND REGIONAL
ENVIRONMENTAL DATA REPORT

REF: RSA, INC. 1996

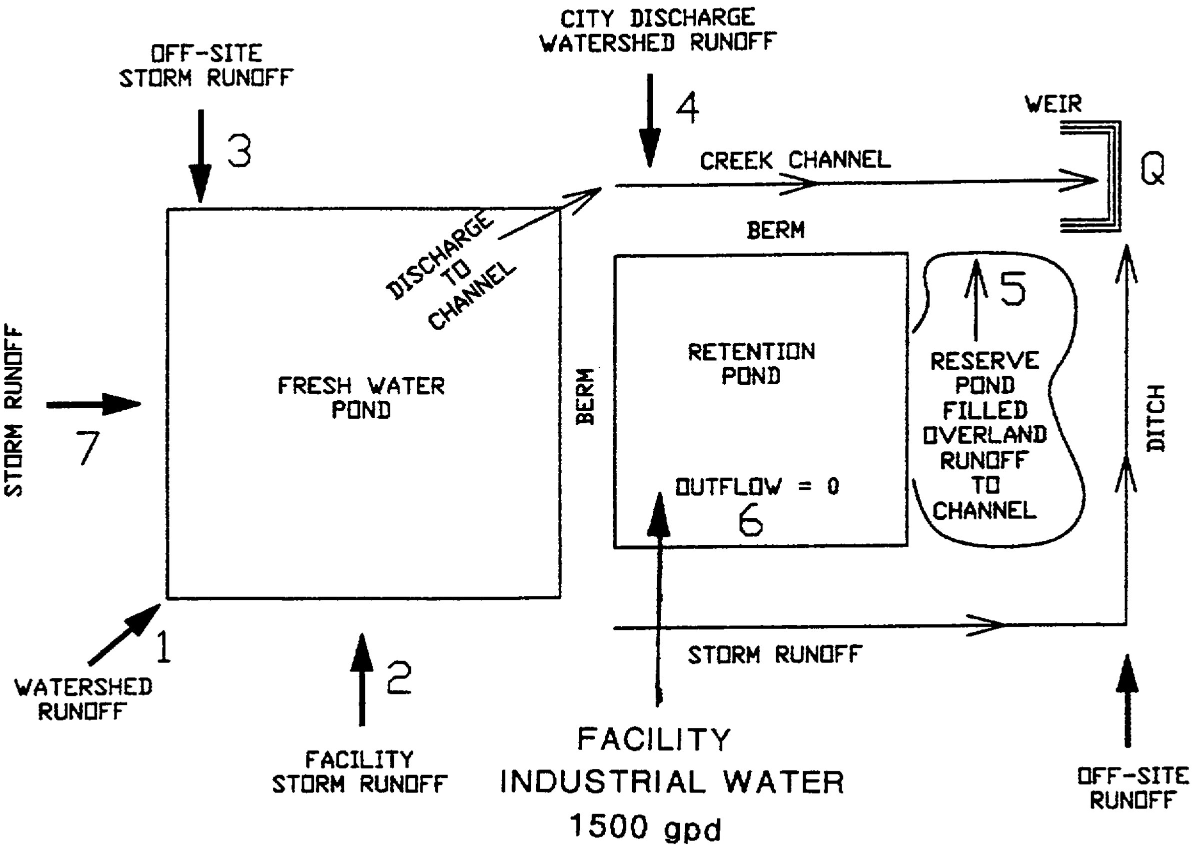
DATE: 11/1/95
SCALE: AS SHOWN
PROJECT NO: 9515901 F02
PREPARED BY: KE
CHECKED BY: KE
DRAFTED BY: GS
FIGURE NO.: 4-8



| | | | |
|---|---|---|---|
| Client: | KAISER ALUMINUM<br>EXTRUDED PRODUCTS | Figure Title: | FACILITY DRAINAGE MAP |
| Location: | 7311 EAST 41ST STREET<br>TULSA, OKLAHOMA | Document Title: | LOCAL AND REGIONAL<br>ENVIRONMENTAL DATA REPORT |

**REF: RSA. INC. 1996**

| | |
|---|---|
| DATE:<br>11/1/95 | PREPARED BY: KE |
| SCALE:<br>NOT TO SCALE | CHECKED BY: KE |
| | DRAFTED BY: GS |
| PROJECT NO:<br>9515901 F02 | FIGURE NO.:<br>4-9 |



FILE NAME: KISERHYD.DWG

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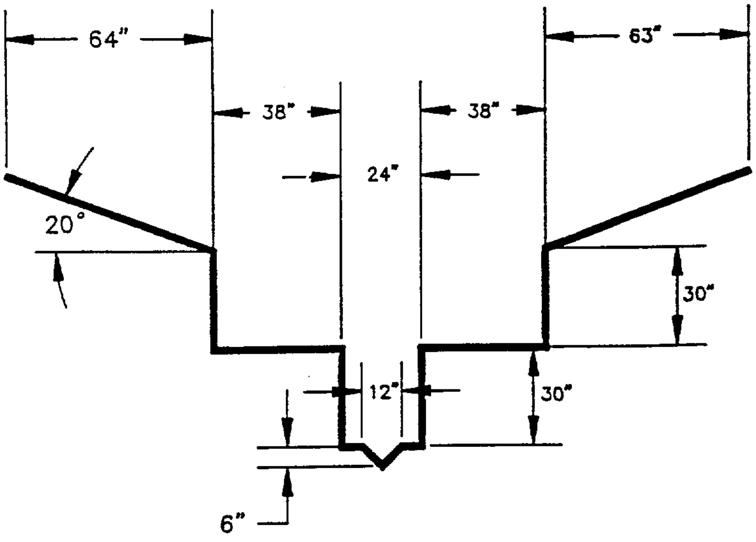
# CONCEPTUAL HYDROLOGIC MODEL

| | | |
|---|---|---|
| SCALE: N.T.S. | DATE: 8-18-97 | FIGURE NO. **FIGURE 4-10** |
| APPROVED BY: MRM | DRAWN BY: KDH | PROJECT NO. 1556-005 |



| DEPTH (FT) | FLOW (CFS) | DEPTH (FT) | FLOW (CFS) | DEPTH (FT) | FLOW (CFS) | DEPTH (FT) | FLOW (CFS) |
|---|---|---|---|---|---|---|---|
| 0.1 | 0.008 | 1.6 | 8.124 | 3.1 | 27.644 | 4.6 | 82.928 |
| 0.2 | 0.045 | 1.7 | 9.195 | 3.2 | 29.248 | 4.7 | 88.275 |
| 0.3 | 0.123 | 1.8 | 10.312 | 3.3 | 31.326 | 4.8 | 93.781 |
| 0.4 | 0.252 | 1.9 | 11.472 | 3.4 | 33.786 | 4.9 | 99.443 |
| 0.5 | 0.440 | 2.0 | 12.675 | 3.5 | 36.577 | 5.0 | 105.255 |
| 0.6 | 0.651 | 2.1 | 13.919 | 3.6 | 39.663 | 5.1 | 111.215 |
| 0.7 | 1.036 | 2.2 | 15.202 | 3.7 | 43.018 | 5.2 | 117.318 |
| 0.8 | 1.535 | 2.3 | 16.524 | 3.8 | 46.622 | 5.3 | 123.562 |
| 0.9 | 2.125 | 2.4 | 17.883 | 3.9 | 50.460 | 5.4 | 129.942 |
| 1.0 | 2.795 | 2.5 | 19.278 | 4.0 | 54.516 | 5.5 | 136.458 |
| 1.1 | 3.535 | 2.6 | 20.708 | 4.1 | 58.781 | | |
| 1.2 | 4.341 | 2.7 | 22.173 | 4.2 | 63.244 | | |
| 1.3 | 5.206 | 2.8 | 23.671 | 4.3 | 67.898 | | |
| 1.4 | 6.127 | 2.9 | 25.202 | 4.4 | 72.734 | | |
| 1.5 | 7.100 | 3.0 | 26.766 | 4.5 | 77.746 | | |

FILE NAME: KAISRWER.DWG

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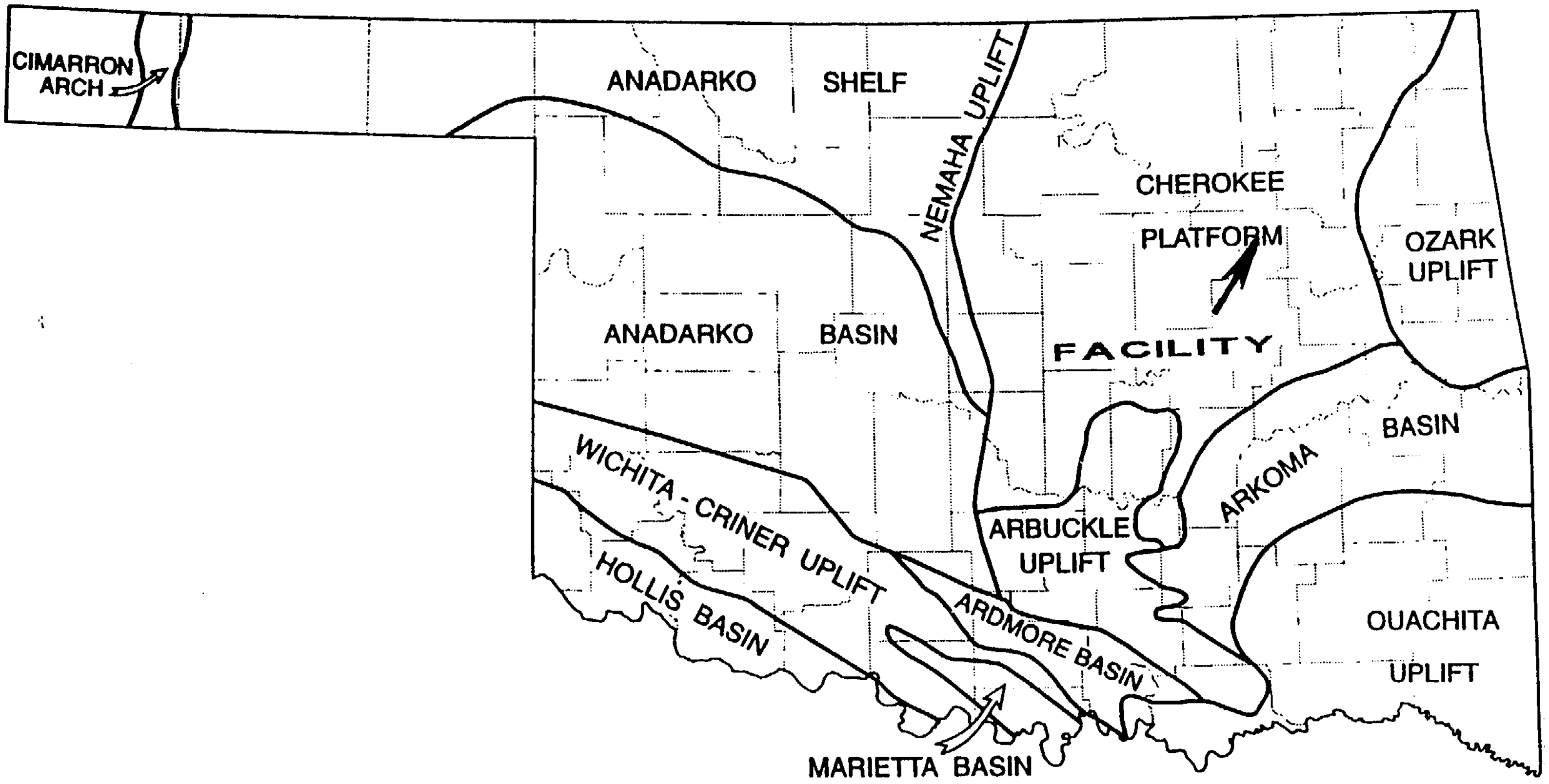
## V-NOTCH WEIR

| | | |
|---|---|---|
| SCALE:<br>1"=5' | DATE:<br>5-16-97 | FIGURE NO.<br>FIGURE 4-11 |
| APPROVED BY:<br>MRM | DRAWN BY:<br>RDH | PROJECT NO.<br>1556-005-002 |



SOURCE: OKLAHOMA EARTHQUAKE CATALOGUE, OKLAHOMA GEOLOGIC SURVEY, 1995

Figure Title:
PHYSIOGRAPHIC PROVINCES MAP OF OKLAHOMA

Document Title:
LOCAL AND REGIONAL
ENVIRONMENTAL DATA REPORT

Client:
KAISER ALUMINUM
EXTRUDED PRODUCTS

Location:
7311 EAST 41ST STREET
TULSA, OKLAHOMA

DATE:

SCALE:
NO SCALE

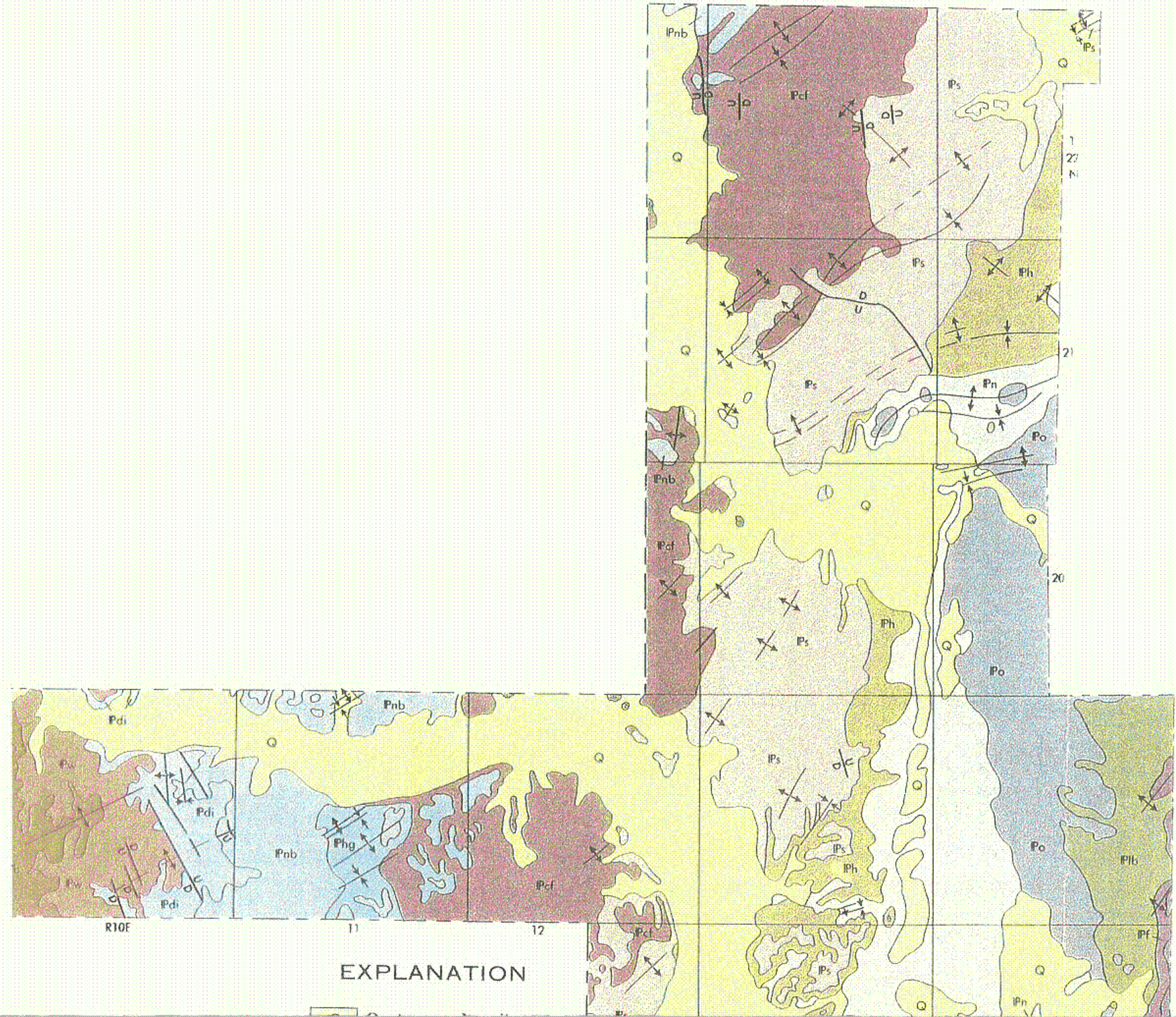
PROJECT NO:

PREPARED BY:

CHECKED BY:

DRAFTED BY:

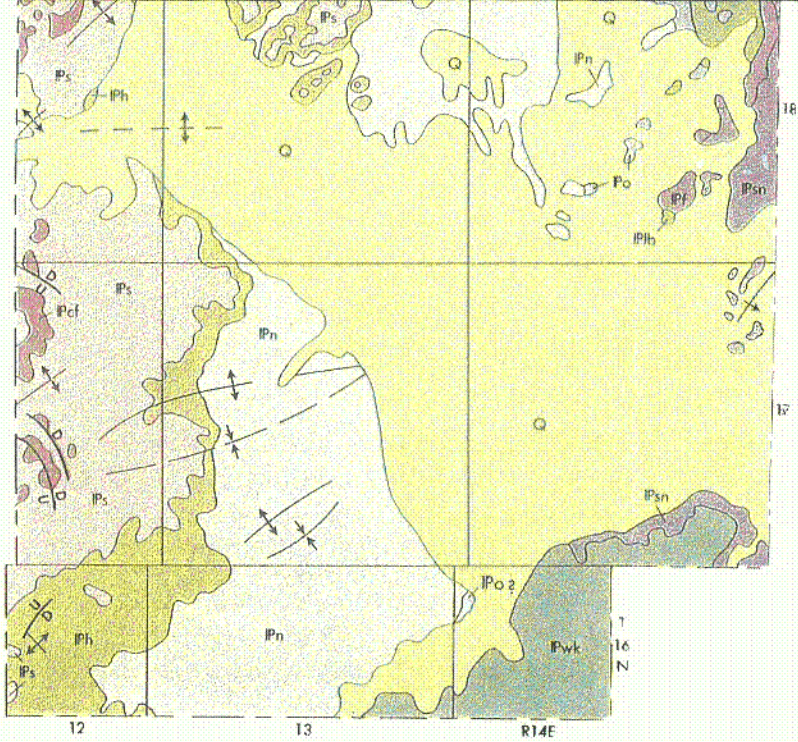
FIGURE NO.: 4-12



## EXPLANATION

## EXPLANATION

| | |
|---|---|
| Q | Quaternary deposits |
| IPb | Barnsdall Fm |
| IPw | Wann Fm |
| IPdi | Iola, Chanute, Dewey Fms. |
| IPnb | Nellie Bly Fm |
| IPhg | Hogshooter Ls |
| IPcf | Coffeyville Fm |
| IPs | Seminole Fm |
| IPh | Holdenville Fm |
| IPn | Nowata Sh |
| IPo | Oologah Ls |
| IPwk | Wewoka Fm |
| IPlb | Labette Fm |
| IPf | Fort Scott Fm |
| IPsn | Senora Fm |

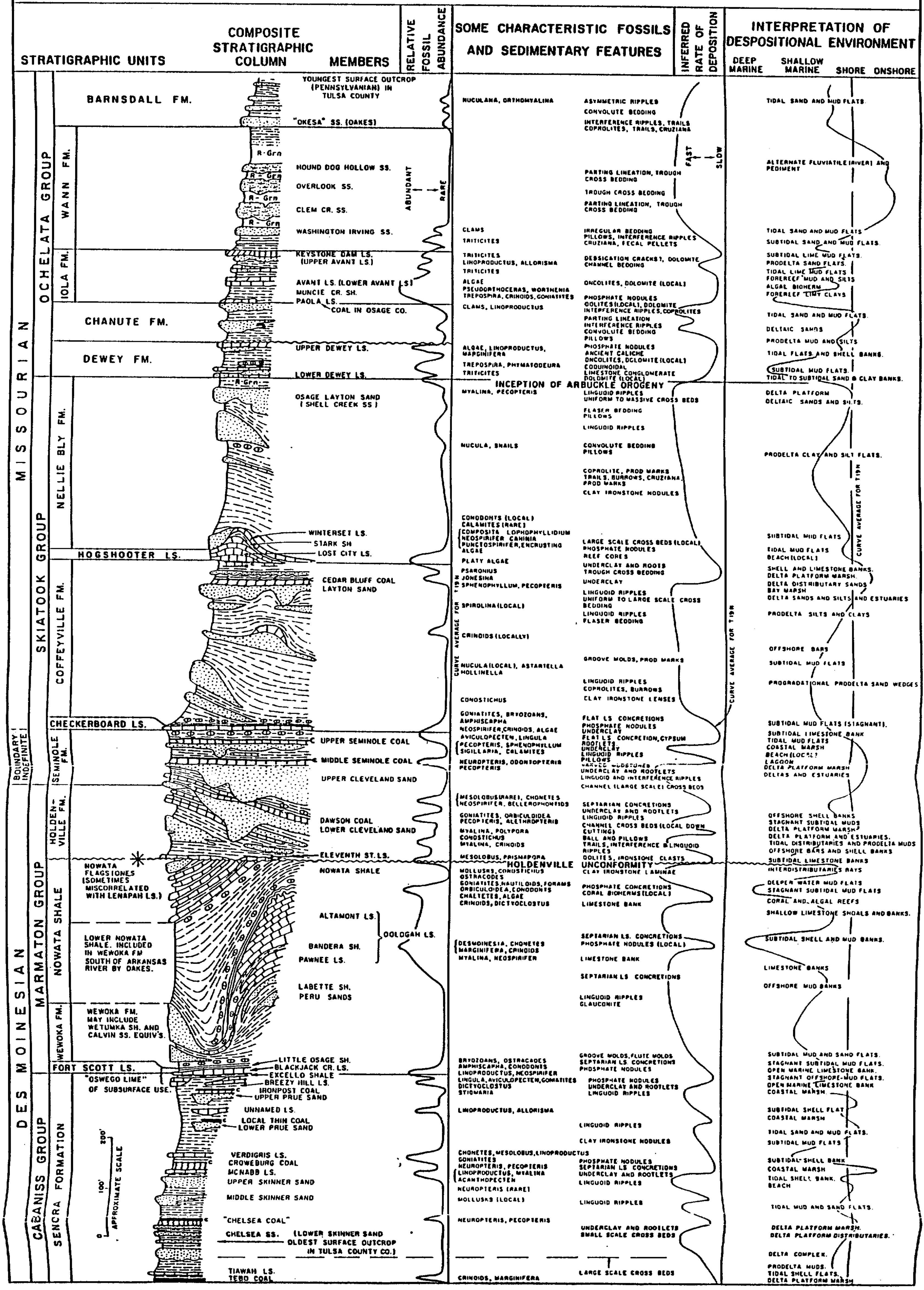


TECTONIC SKETCH MAP

SOURCE: TULSA'S PHYSICAL ENVIRONMENT, TULSA GEOLOGICAL SOCIETY, 1972

| | | | |
|---|---|---|---|
| Client: KAISER ALUMINUM<br>EXTRUDED PRODUCTS | | Figure Title: GENERAL GEOLOGIC MAP,<br>TULSA COUNTY | |
| Location: 7311 EAST 41ST STREET<br>TULSA, OKLAHOMA | | Document Title: LOCAL AND REGIONAL<br>ENVIRONMENTAL DATA REPORT | |
| REF: RSA,INC. 1996 | DATE: 11/1/95 | PREPARED BY: KE | |
| | SCALE: NO SCALE | CHECKED BY: KE | |
| | | DRAFTED BY: GS | |
| | PROJECT NO: 9515901 F02 | FIGURE NO 4-13 | |

# ENVIRONMENTAL ANALYSIS OF THE PENNSYLVANIAN ROCKS-TULSA CO.



* NOTE: HOLDENVILLE SHALE OF TULSA COUNTY IS THE PROBABLE LATERAL EQUIVALENT OF THE BASAL SEMINOLE FM IN THE SUBSURFACE OF CREEK AND ADJACENT COUNTIES THIS UNCONFORMITY TRUNCATES ABOUT 200 FEET OF NOWATA SHALE ACROSS TULSA CO.

LEGEND
- SANDSTONE
- LIMESTONE
- DOLOMITE
- GRAY SHALE
- BLACK SHALE
- R-Grn RED AND GREEN SHALE
- COAL
- UNDERCLAY
- LIMESTONE CONCRETIONS

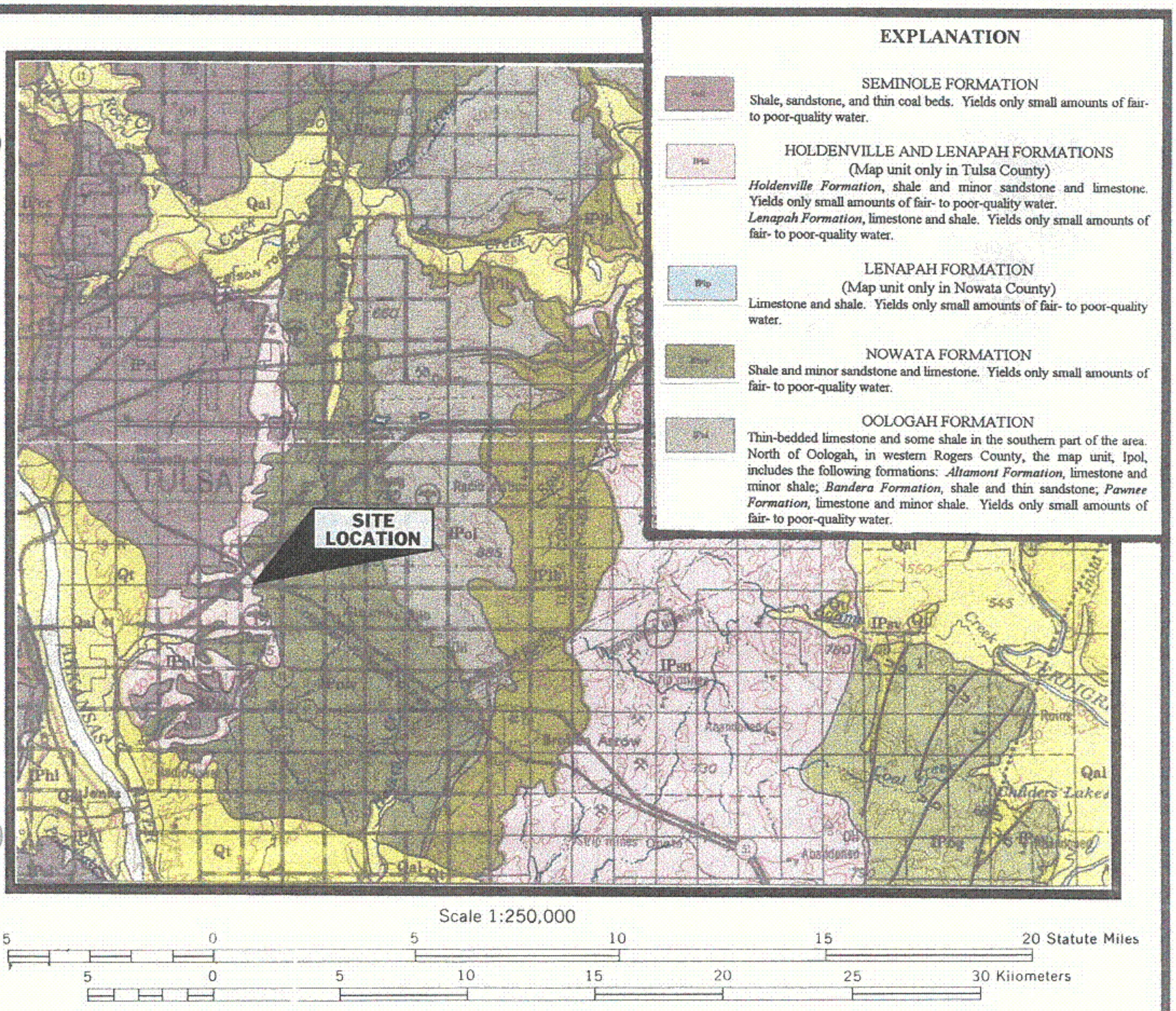
**PENNSYLVANIAN ROCKS OF TULSA COUNTY**

ALLAN BENNISON CONSULTANT, TULSA

BOB MCCONNATHY DRAFTING MAY, 1971

SOURCE: TULSA'S PHYSICAL ENVIRONMENT, TULSA GEOLOGICAL SOCIETY, 1972

| | | | |
|---|---|---|---|
| Client: KAISER ALUMINUM EXTRUDED PRODUCTS | | Figure Title: REGIONAL STRATIGRAPHIC COLUMN, TULSA COUNTY | |
| Location: 7311 EAST 41ST STREET TULSA, OKLAHOMA | | Document Title: LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT | |
| REF: RSA, INC. 1996 | | DAT | PREPARED BY: |
| | | SCALE: NO SCALE | CHECKED BY: |
| | | | DRAFTED BY: |
| | | PROJECT NO: | FIGURE NO: 4-14 |



## EXPLANATION

**SEMINOLE FORMATION**
Shale, sandstone, and thin coal beds. Yields only small amounts of fair- to poor-quality water.

**HOLDENVILLE AND LENAPAH FORMATIONS**
(Map unit only in Tulsa County)
*Holdenville Formation*, shale and minor sandstone and limestone. Yields only small amounts of fair- to poor-quality water.
*Lenapah Formation*, limestone and shale. Yields only small amounts of fair- to poor-quality water.

**LENAPAH FORMATION**
(Map unit only in Nowata County)
Limestone and shale. Yields only small amounts of fair- to poor-quality water.

**NOWATA FORMATION**
Shale and minor sandstone and limestone. Yields only small amounts of fair- to poor-quality water.

**OOLOGAH FORMATION**
Thin-bedded limestone and some shale in the southern part of the area. North of Oologah, in western Rogers County, the map unit, Ipol, includes the following formations: *Altamont Formation*, limestone and minor shale; *Bandera Formation*, shale and thin sandstone; *Pawnee Formation*, limestone and minor shale. Yields only small amounts of fair- to poor-quality water.

Contour interval: 100 feet
Supplementary contours at 50-foot intervals
Datum: Mean sea level

## RECONNAISSANCE OF THE WATER RESOURCES OF THE TULSA QUADRANGLE, NORTHEASTERN OKLAHOMA

MELVIN V. MARCHER AND ROY H. BINGHAM

1971

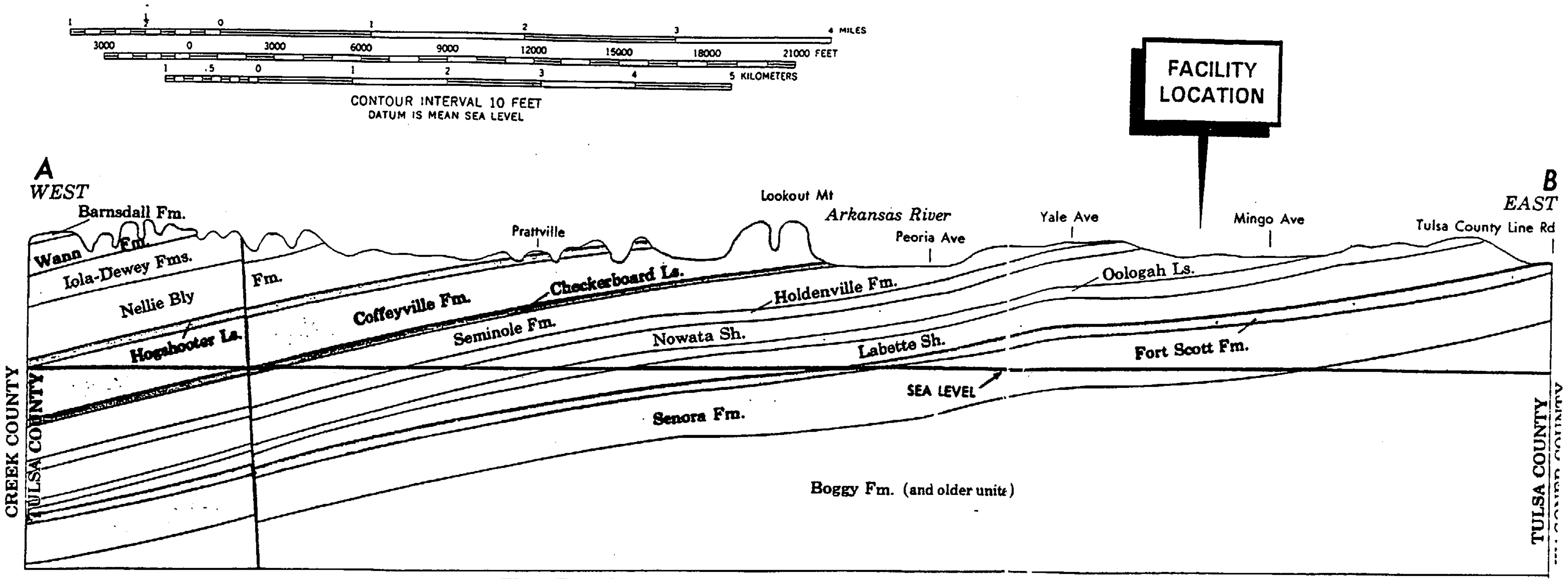
C8

A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.

ENGINEERING — ENVIRONMENTAL — CONSTRUCTION

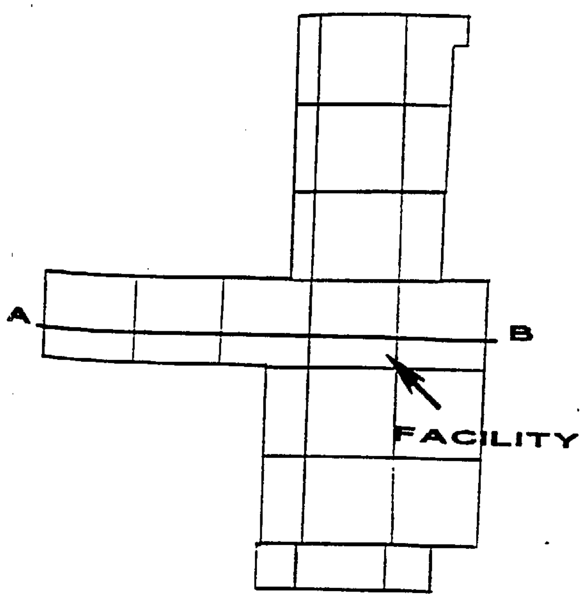
**GEOLOGY OF TULSA CO.**

| | | |
|---|---|---|
| SCALE:<br>NOTED | DATE:<br>8-21-97 | FIGURE NO.<br>FIGURE 4-15 |
| APPROVED BY:<br>MRM | DRAWN BY:<br>KDH | PROJECT NO.<br>1556-005 |



West-East Geologic Cross Section Along 31st Street South

SCALE: HORIZONTAL, 1 inch=3 miles
VERTICAL, 1 inch=1,000 feet



TULSA COUNTY

SOURCE: TULSA'S PHYSICAL ENVIRONMENT, TULSA GEOLOGICAL SOCIETY, 1972

Client: KAISER ALUMINUM
EXTRUDED PRODUCTS

Location: 7311 EAST 41ST STREET
TULSA, OKLAHOMA

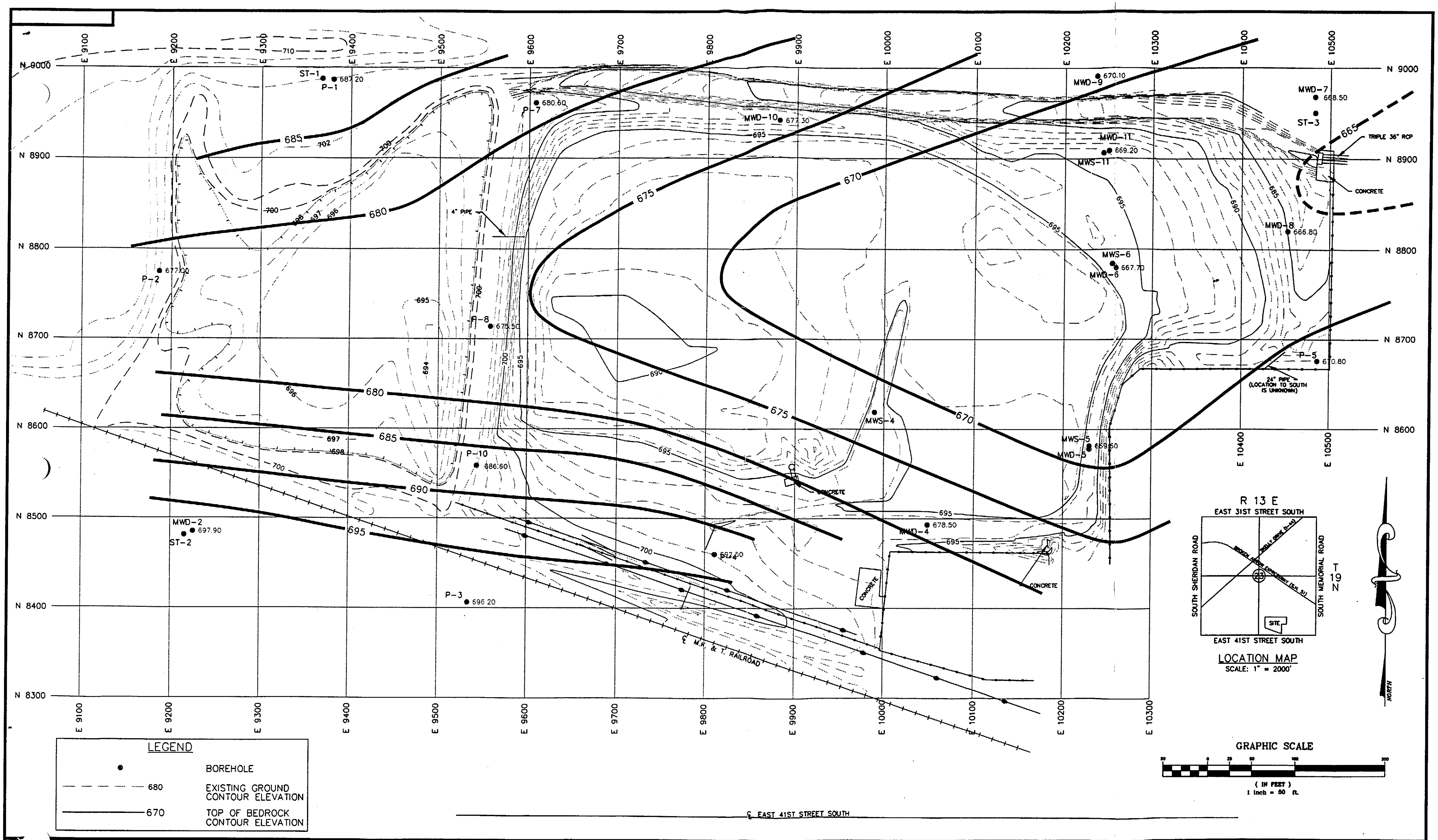
Figure Title: GENERALIZED WEST-EAST (A-B) CROSS-SECTION, TULSA COUNTY

Document Title: LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

REF: RSA, INC. 1996

DATE: 11/1/95
SCALE: NO SCALE
PROJECT NO: 9515901 F02

PREPARED BY: KE
CHECKED BY: KE
DRAFTED BY: GS
FIGURE NO 4-16



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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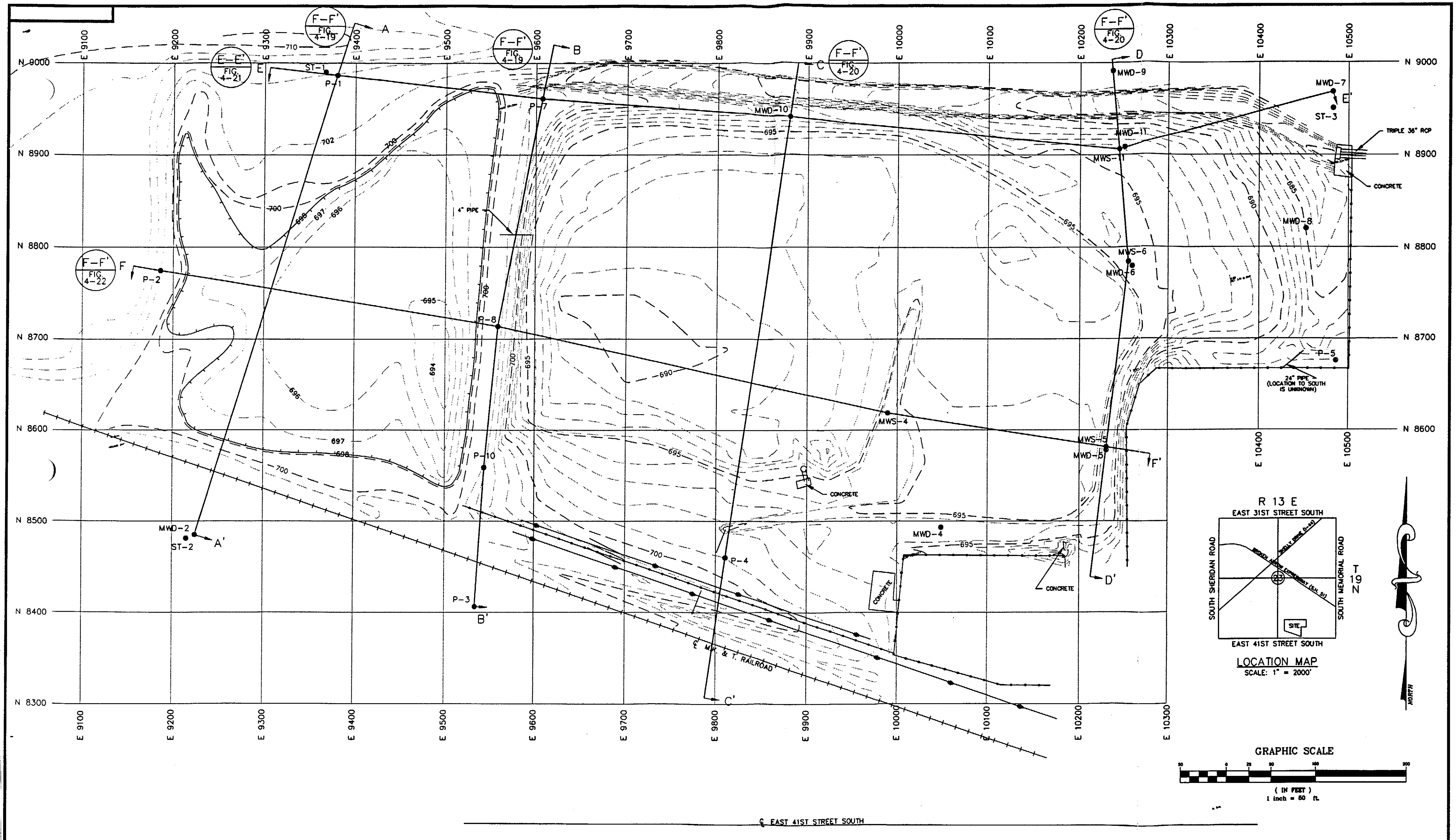
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

| | | | |
|---|---|---|---|
| DRAWN: ALB | CHECKED BY: MRM | MATERIALS BY: | ENGINEER: ALB |
| DATE: 5-2-1997 | DATE: 5-8-1997 | DATE: | DATE: 5-2-1997 |

# TULSA REMEDIATION PROJECT

## TOP OF BEDROCK ELEVATION CONTOURS

| APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV. |
|---|---|---|---|---|
| DATE: | 1"=50' | 1556-003 | FIGURE 4-17 | |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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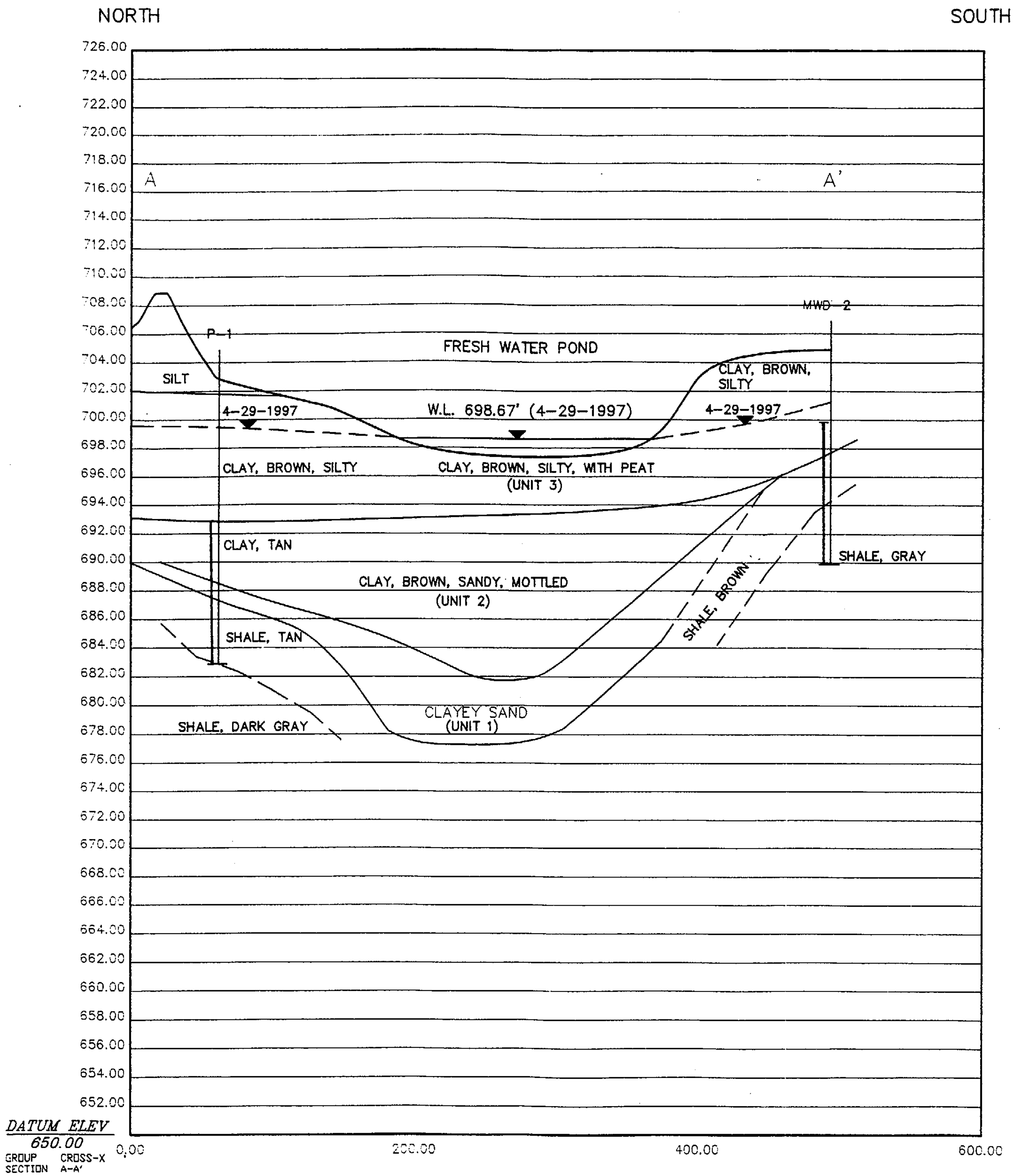
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

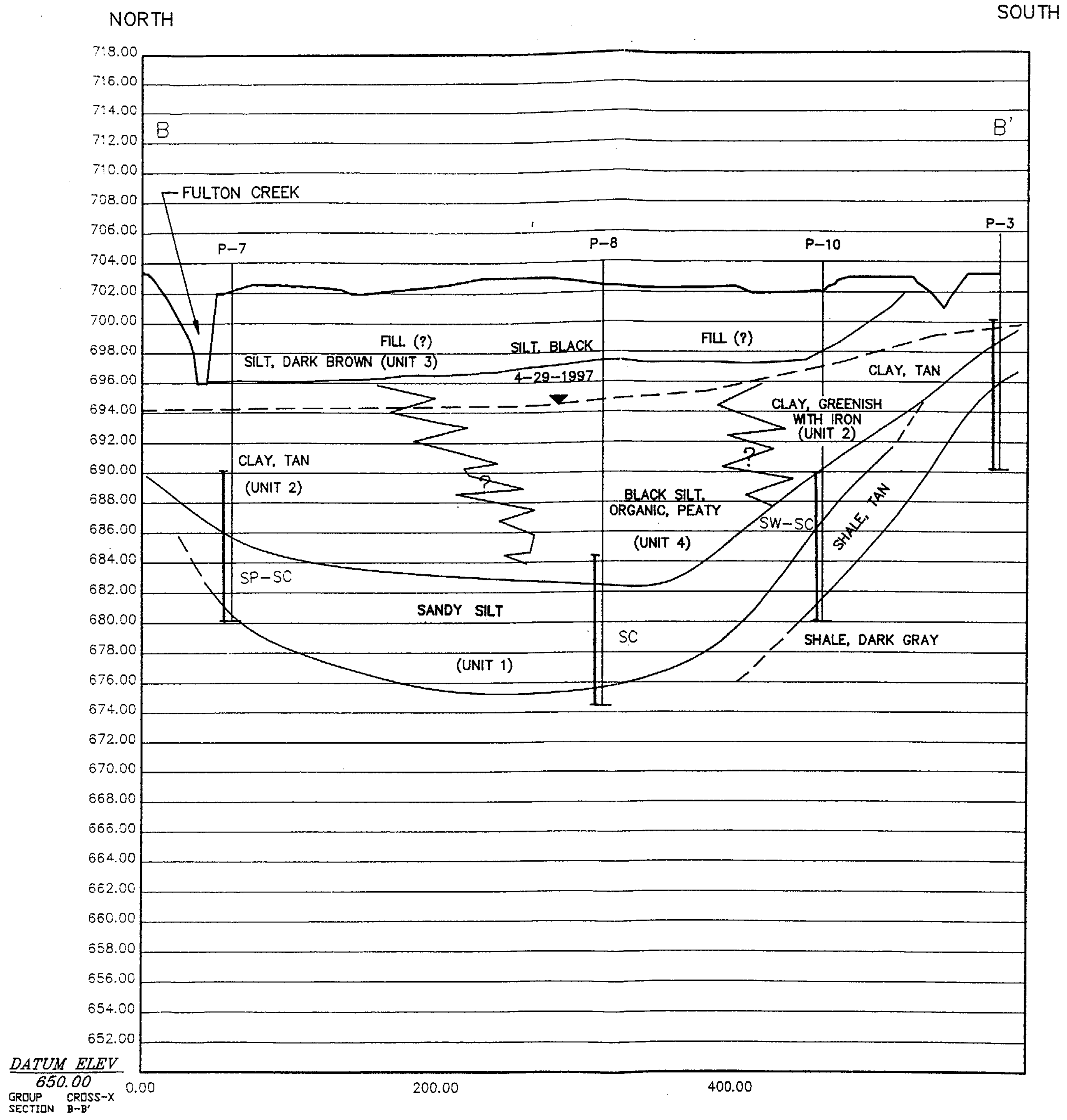
| | | | |
|---|---|---|---|
| DRAWN ALB | CHECKED BY MRM | MATERIALS BY: | ENGINEER: ALB |
| DATE: 5-2-1997 | DATE: 5-8-1997 | DATE: | DATE: 5-2-1997 |

# TULSA REMEDIATION PROJECT

## CROSS-SECTION LOCATIONS

| APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV: |
|---|---|---|---|---|
| DATE: | 1"=50' | 1556-003 | FIGURE 4-18 | |





I SCREENED INTERVAL

▼ WATER LEVEL

SCALE
VERTICAL: 1" = 5'
HORIZONTAL: 1" = 50'

GENERAL NOTES

See Figure 4-18 for cross-section location & orientation

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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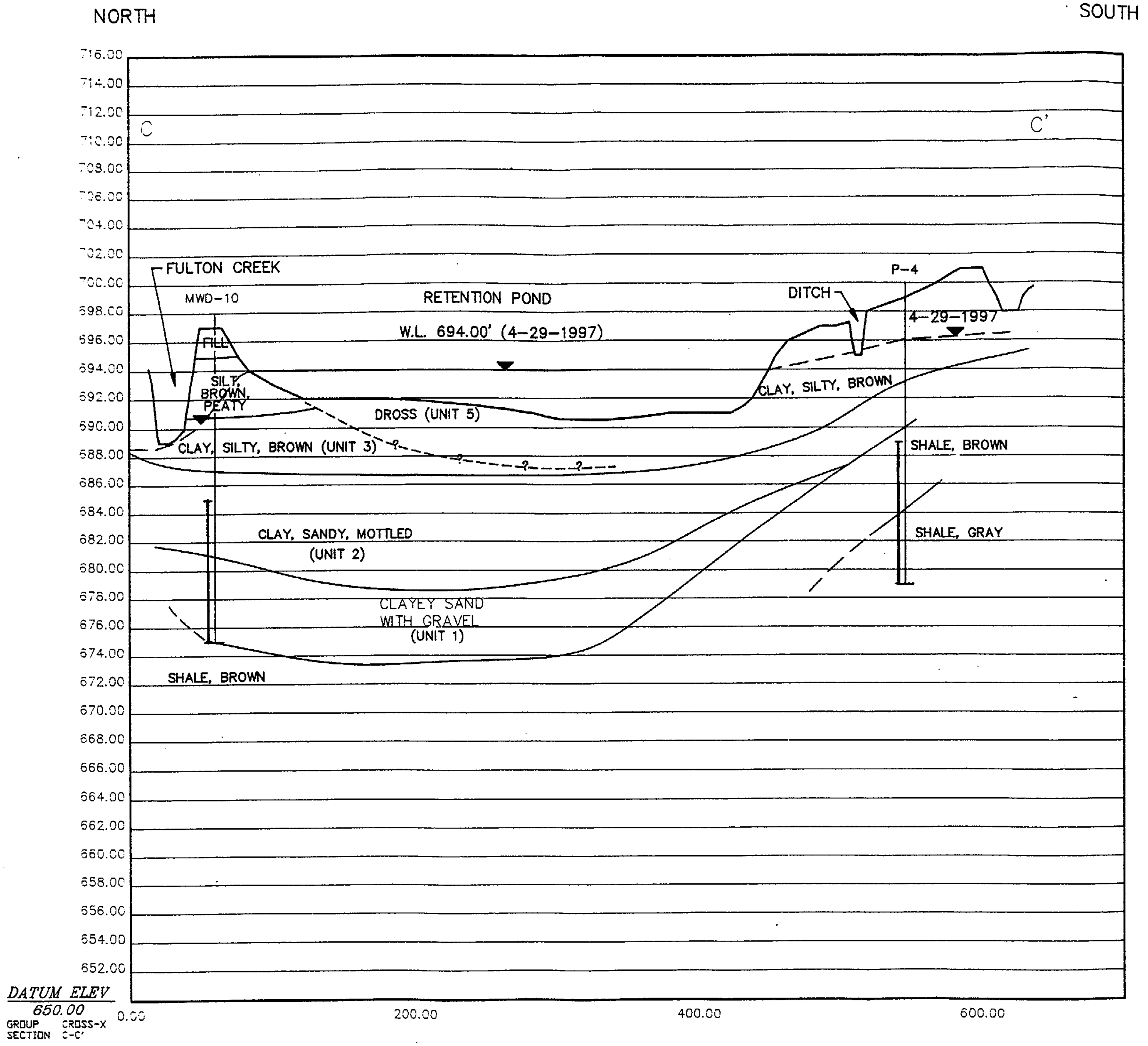
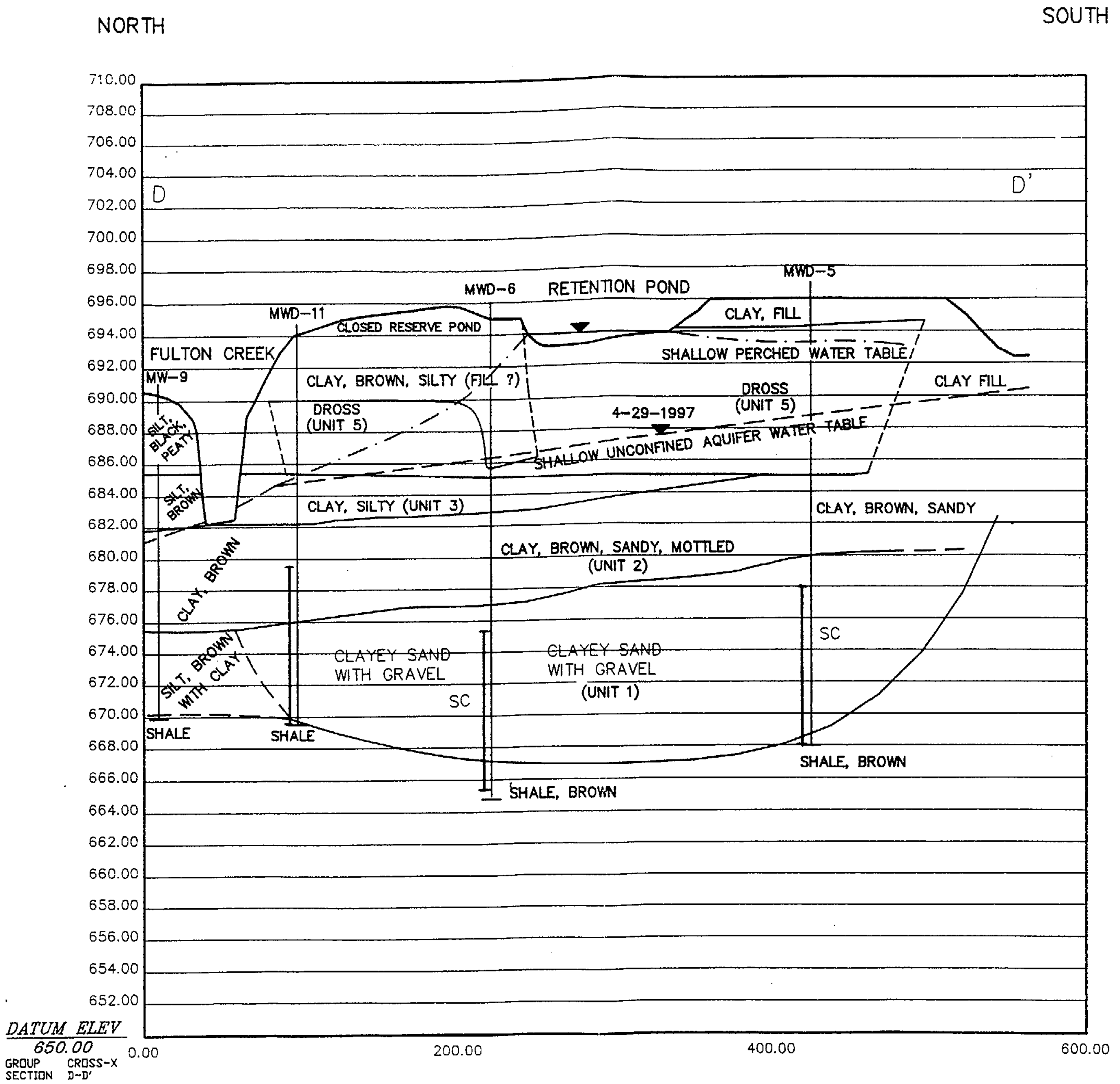
# TULSA REMEDIATION PROJECT

## GEOLOGIC CROSS-SECTIONS A-A' , B-B'

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DRAWN: ALB | CHECKED BY: MRM | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: NOTED | PROJECT NUMBER: 1556-003 | DRAWING NUMBER: FIGURE 4-19 | REV.: |
| DATE: 5-2-1997 | DATE: 5-8-1997 | DATE: | DATE: 5-2-1997 | DATE: | | | | |





I SCREENED INTERVAL

▼ WATER LEVEL

SCALE
VERTICAL: 1" = 5'
HORIZONTAL: 1" = 50'

GENERAL NOTES

1. See Figure 4-18 for cross-section location & orientation

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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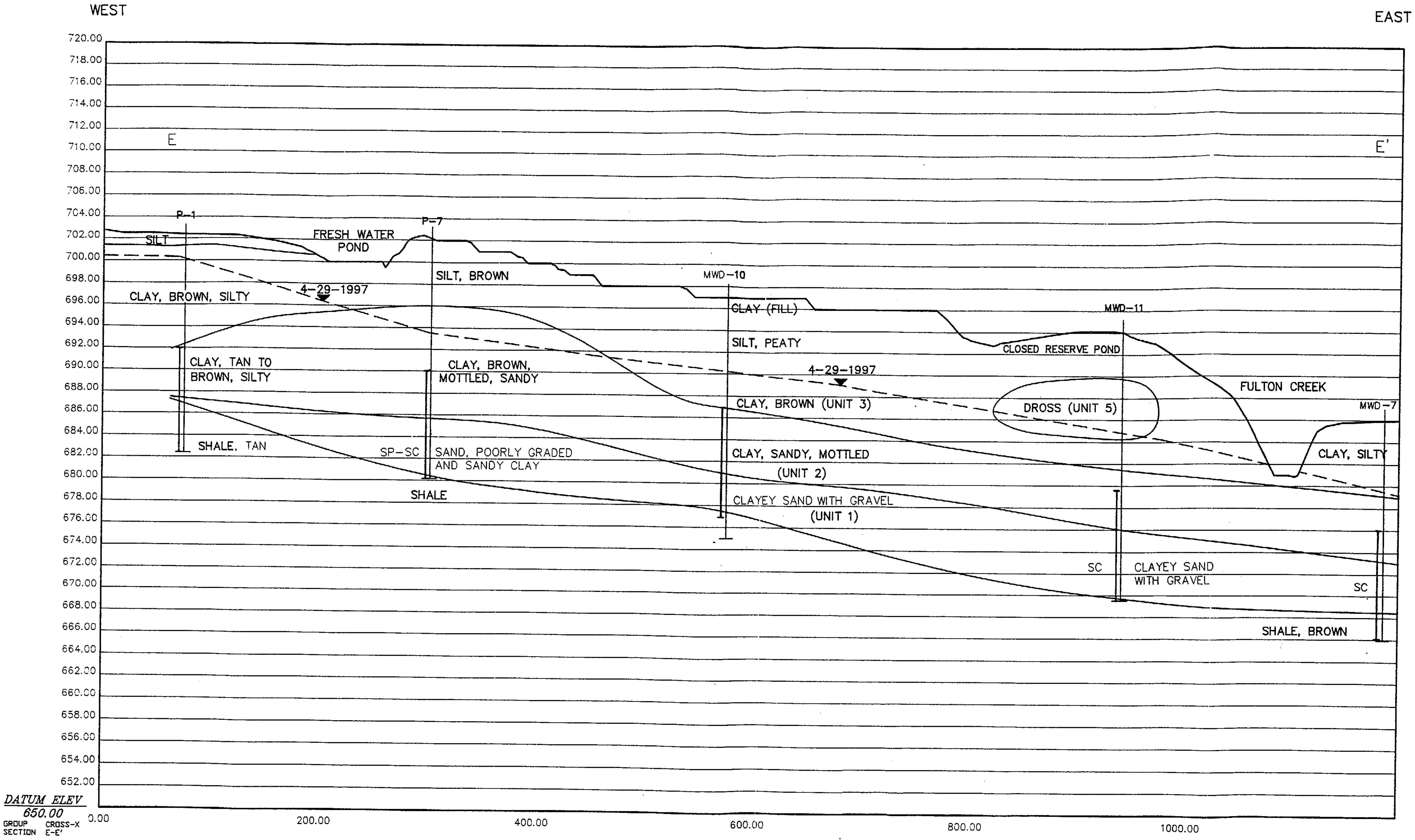
DRAWN: ALB
DATE: 5-2-1997
CHECKED BY: MRM
DATE: 5-8-1997
MATERIALS BY:
DATE:
ENGINEER: ALB
DATE: 5-2-1997

TULSA REMEDIATION PROJECT
GEOLOGIC CROSS-SECTIONS
C-C' , D-D'

APPROVED BY:
DATE:
SCALE: NOTED
PROJECT NUMBER: 1556-003
DRAWING NUMBER: FIGURE 4-20
REV.:



I SCREENED INTERVAL

▼ WATER LEVEL

SCALE
VERTICAL: 1" = 5'
HORIZONTAL: 1" = 50'

GENERAL NOTES

See Figure 4-18 for cross-section location & orientation

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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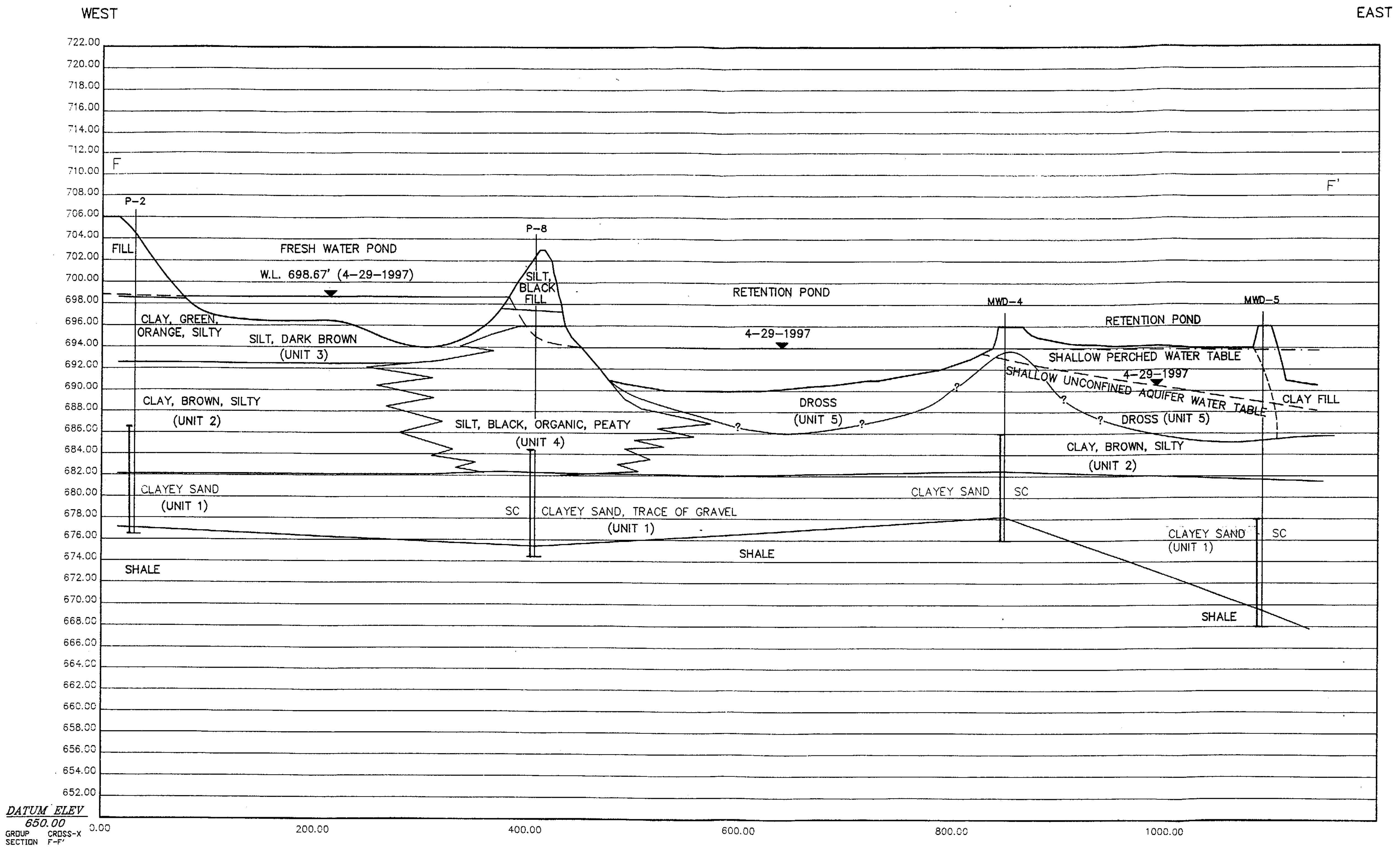
| DRAWN: ALB | CHECKED BY: MRM | MATERIALS BY: | ENGINEER: ALB |
|---|---|---|---|
| DATE: 5-2-1997 | DATE: 5-8-1997 | DATE: | DATE: 5-2-1997 |

# TULSA REMEDIATION PROJECT

## GEOLOGIC CROSS-SECTIONS E-E'

| APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV.: |
|---|---|---|---|---|
| DATE: | NOTED | 1556-003 | FIGURE 4-21 | |



SCREENED INTERVAL

▼ WATER LEVEL

SCALE
VERTICAL: 1" = 5'
HORIZONTAL: 1" = 50'

GENERAL NOTES

See Figure 4-18 for cross-section location & orientation

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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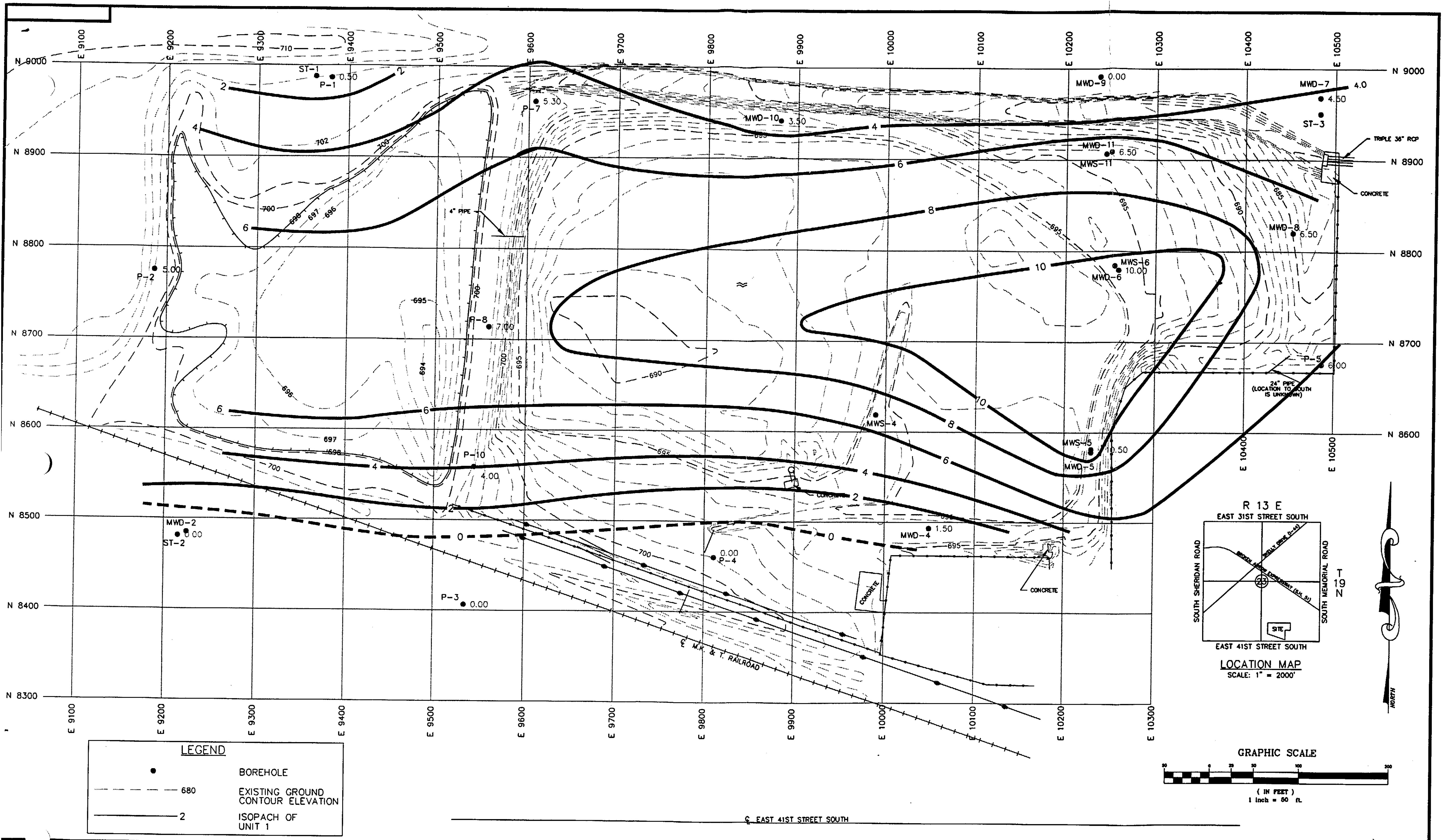
## TULSA REMEDIATION PROJECT

### GEOLOGIC CROSS-SECTIONS
### F-F'

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DRAWN: ALB | CHECKED BY: MRM | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: NOTED | PROJECT NUMBER: 1556-003 | DRAWING NUMBER: FIGURE 4-22 |
| DATE: 5-2-1997 | DATE: 5-8-1997 | DATE: | DATE: 5-2-1997 | DATE: | | | REV.: |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|

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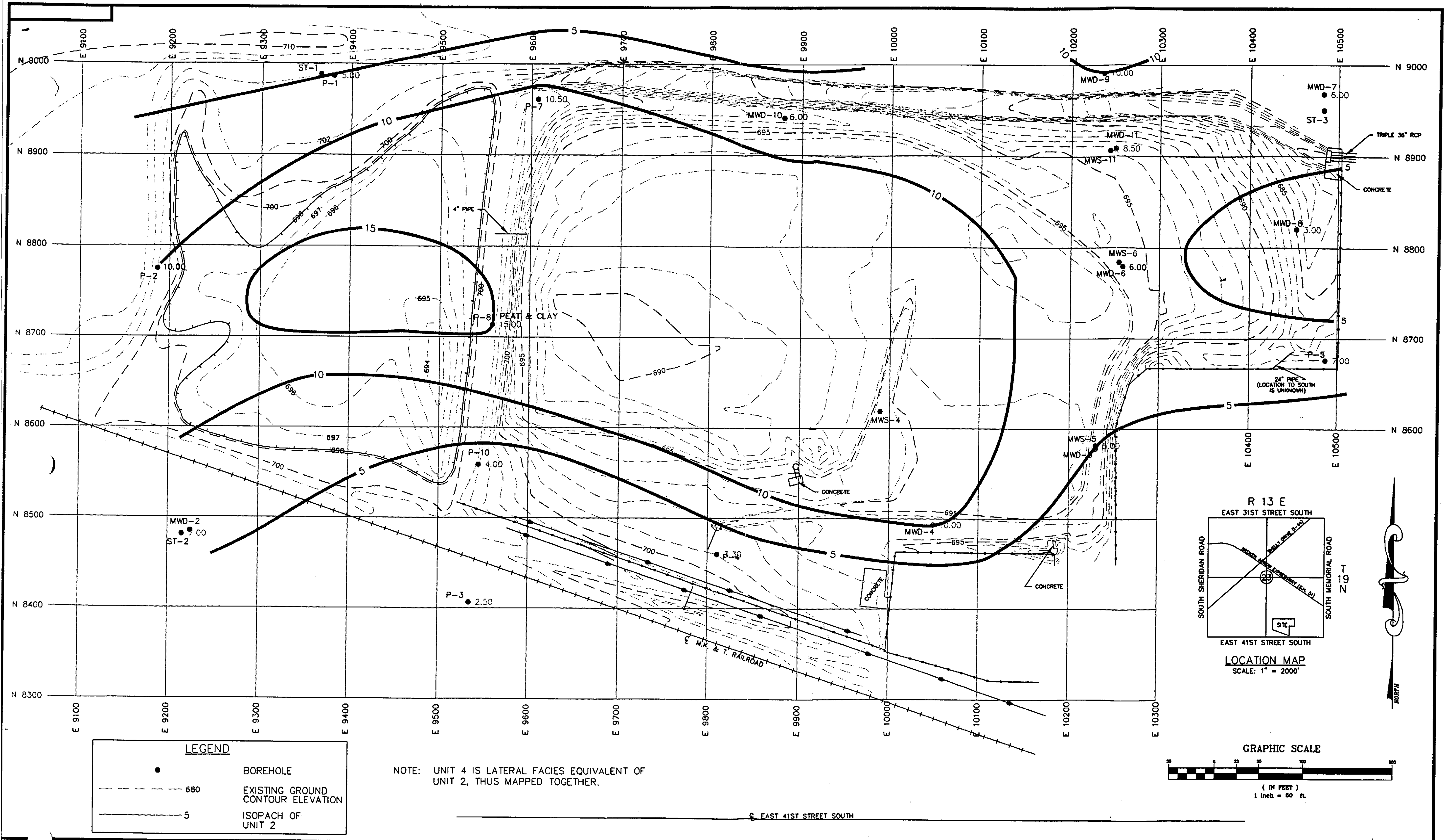
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

DRAWN: ALB
DATE: 5-2-1997
CHECKED BY: MRM
DATE: 5-8-1997
MATERIALS BY:
DATE:
ENGINEER: ALB
DATE: 5-2-1997

# TULSA REMEDIATION PROJECT

## ISOPACH OF UNIT 1
## (CLAYEY SAND)

APPROVED BY:
DATE:
SCALE: 1"=50'
PROJECT NUMBER: 1556-003
DRAWING NUMBER: FIGURE 4-23
REV:



NOTE: UNIT 4 IS LATERAL FACIES EQUIVALENT OF UNIT 2, THUS MAPPED TOGETHER.

GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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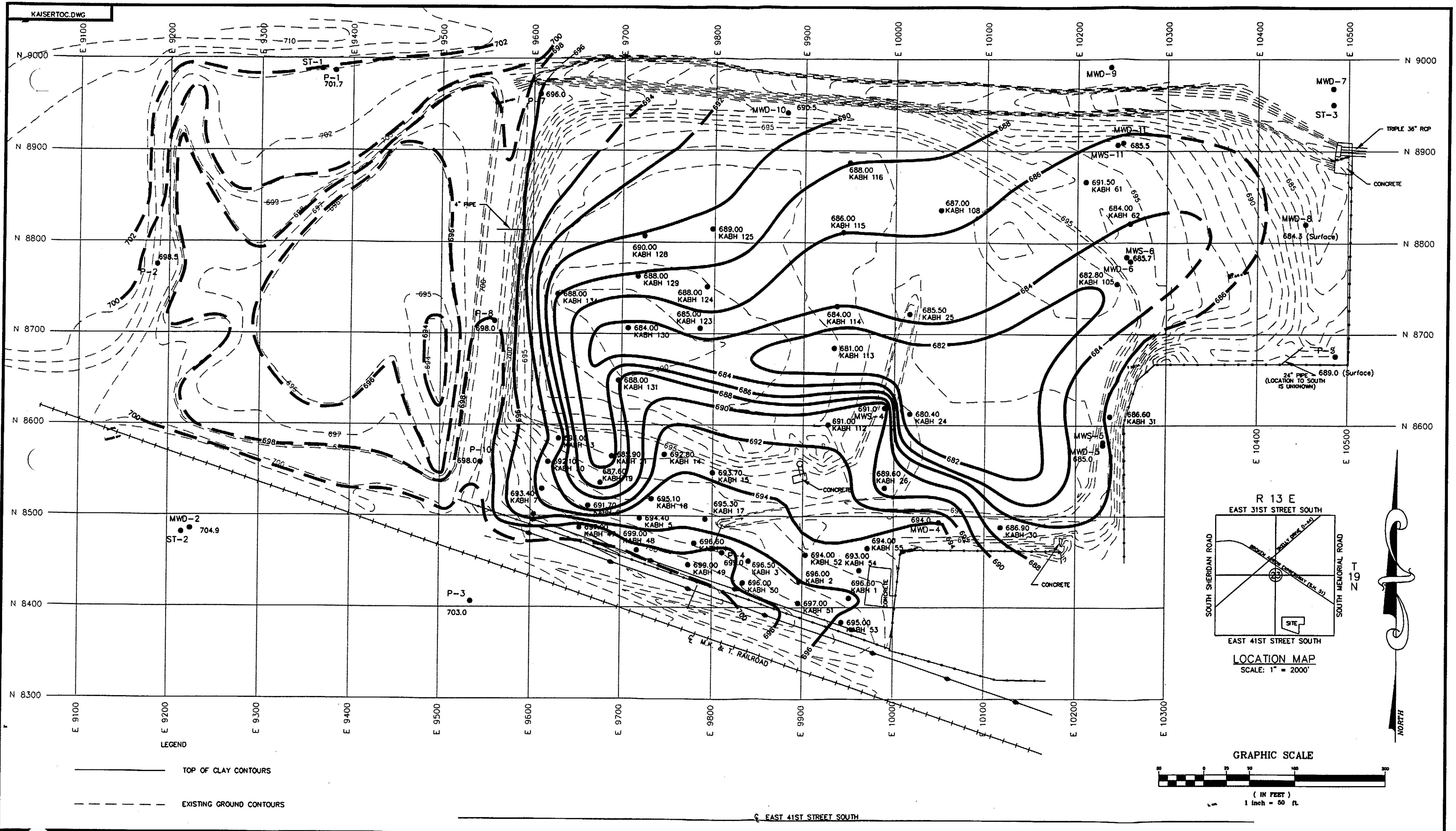
# TULSA REMEDIATION PROJECT

## ISOPACH OF UNIT 2
## (CLAY)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DRAWN: ALB | CHECKED BY: MRM | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: 1"=50' | PROJECT NUMBER: 1556-003 | DRAWING NUMBER: FIGURE 4-24 | REV: |
| DATE: 5-2-1997 | DATE: 5-8-1997 | DATE: | DATE: 5-2-1997 | DATE: | | | | |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |

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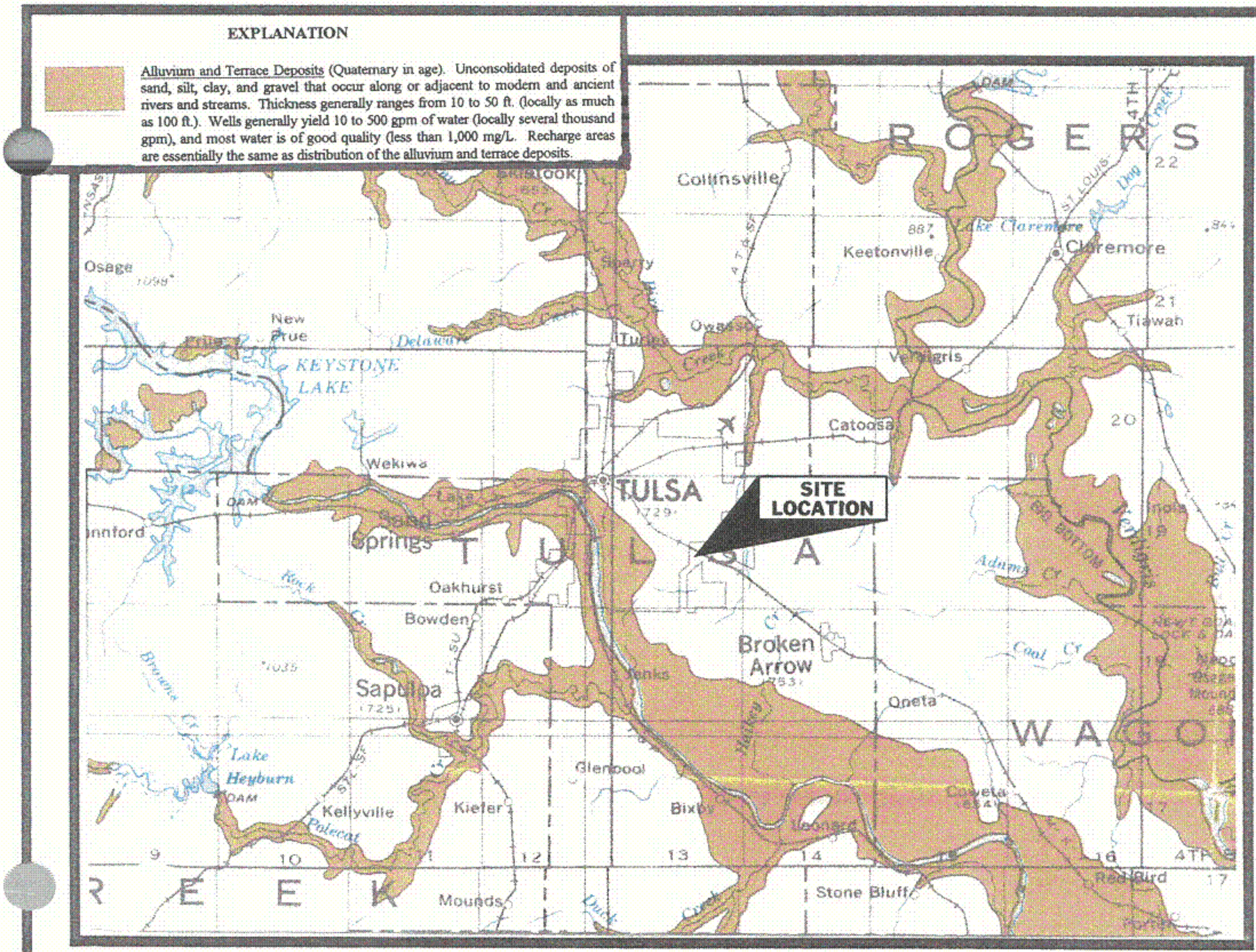
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

| DRAWN BY: RDH | CHECKED BY: IT | MATERIALS BY: MRM | ENGINEER: RDH | APPROVED BY: MRM | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV. |
|---|---|---|---|---|---|---|---|---|
| DATE: 1-29-98 | DATE: 1-29-98 | DATE: | DATE: 1-29-98 | DATE: 1-29-98 | 1"=50' | 1556-003 | FIGURE 4-25 | |

# TULSA REMEDIATION PROJECT
# TOP OF CLAY CONTOUR MAP



EXPLANATION

▨ Alluvium and Terrace Deposits (Quaternary in age). Unconsolidated deposits of sand, silt, clay, and gravel that occur along or adjacent to modern and ancient rivers and streams. Thickness generally ranges from 10 to 50 ft. (locally as much as 100 ft.). Wells generally yield 10 to 500 gpm of water (locally several thousand gpm), and most water is of good quality (less than 1,000 mg/L. Recharge areas are essentially the same as distribution of the alluvium and terrace deposits.

## OGS - UNCONSOLIDATED ALLUVIUM AND TERRACE DEPOSITS

### SHEET 1

C9

Scale 1:500,000

1 inch equals approximately 8 miles

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometres

A & M ENGINEERING AND
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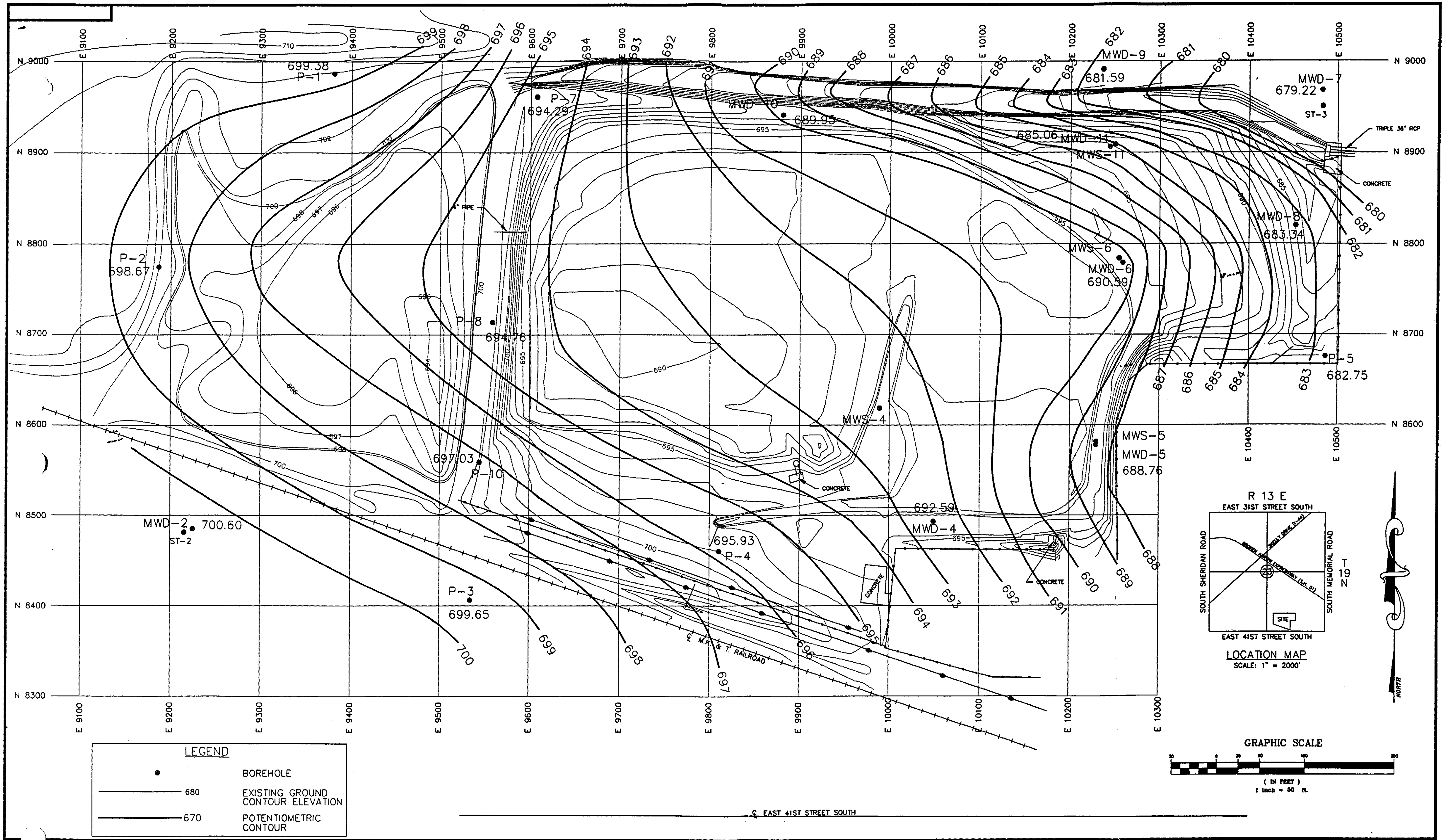
ENGINEERING — ENVIRONMENTAL — CONSTRUCTION

**ALLUVIAL AQUIFERS IN TULSA CO.**

| SCALE: | DATE: | FIGURE NO. |
|---|---|---|
| **NOTED** | **8-21-97** | **FIGURE 4-26** |
| APPROVED BY: | DRAWN BY: | PROJECT NO. |
| **MRM** | **KDH** | **1556-005** |



LEGEND

| | |
|---|---|
| ● | BOREHOLE |
| ——— 680 | EXISTING GROUND CONTOUR ELEVATION |
| ━━━ 670 | POTENTIOMETRIC CONTOUR |

GENERAL NOTES

REVISIONS

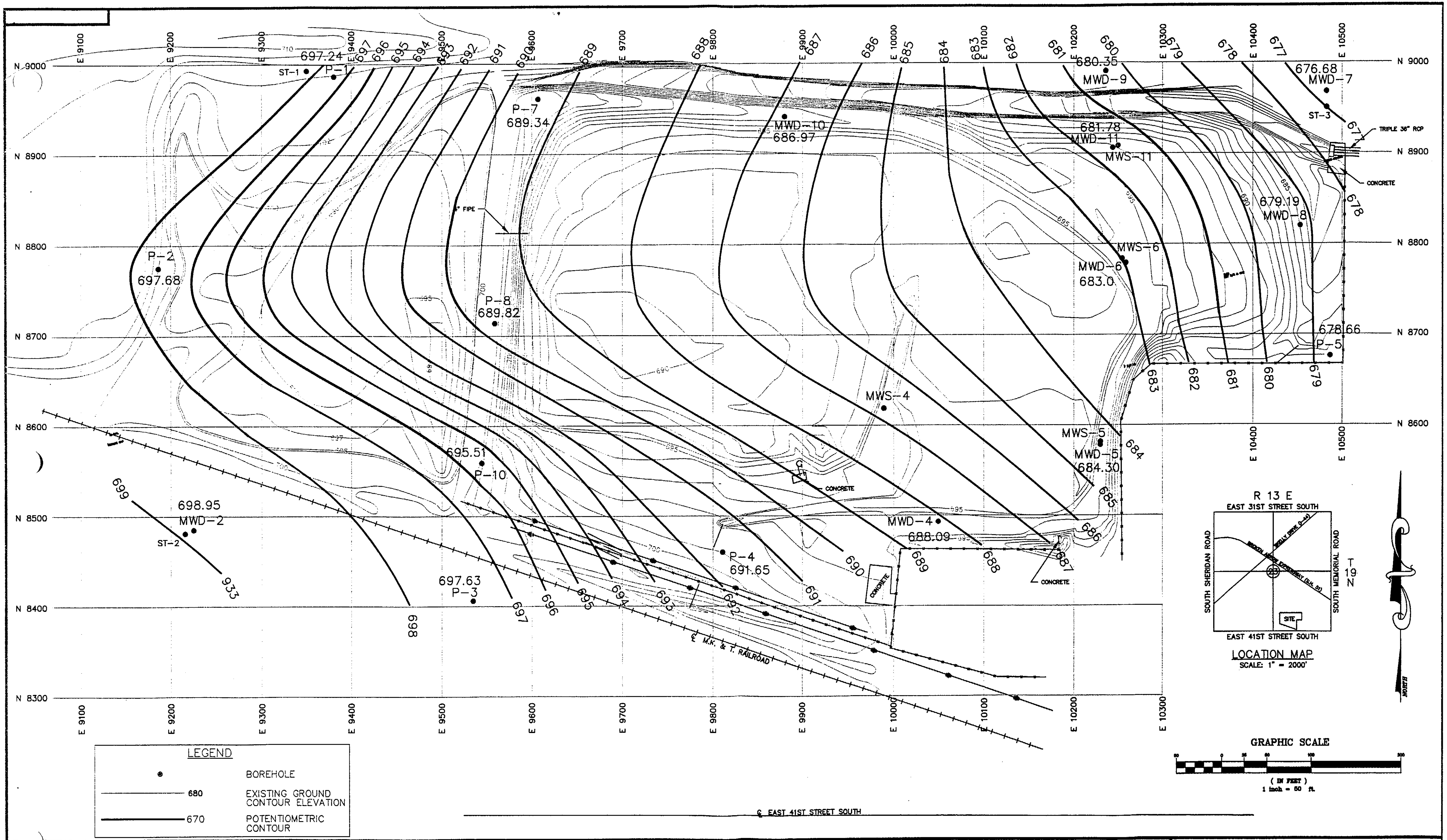
| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|

A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.

ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

# TULSA REMEDIATION PROJECT
## DEEP OVERBURDEN
## POTENTIOMETRIC CONTOUR MAP
## APRIL 1997

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV.: |
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 | DATE: | 1"=50' | 1556-003 | FIGURE 4-27 | |



GENERAL NOTES

file: kiaser poten map deep.dwg

REVISIONS

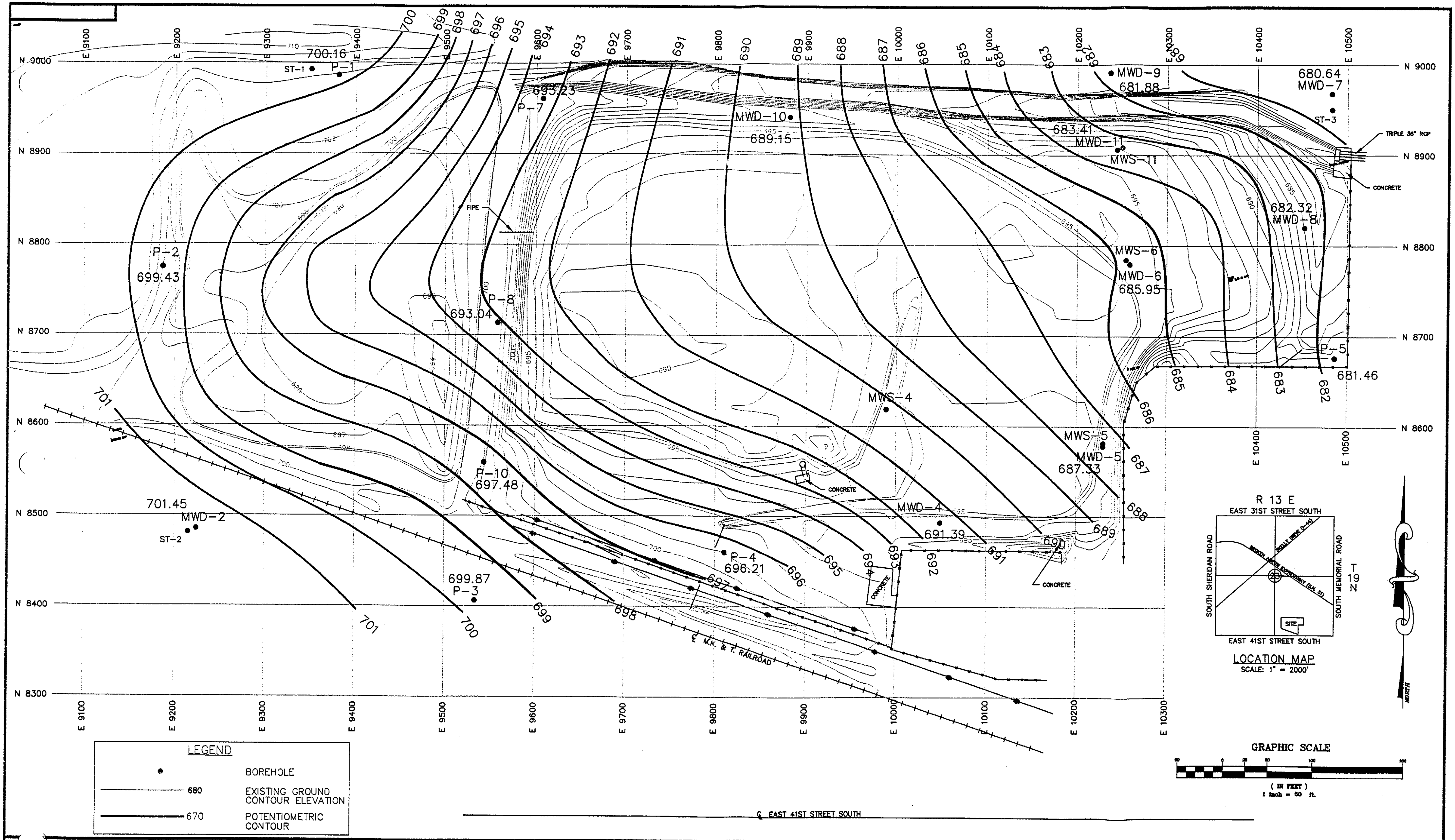
| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|

A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

DRAWN: PLS
DATE: 4-15-1999
CHECKED BY: IT
DATE: 4-15-99
MATERIALS BY:
DATE:
ENGINEER: ALB
DATE: 5-2-1997

# TULSA REMEDIATION PROJECT
## DEEP OVERBURDEN
## POTENTIOMETRIC CONTOUR MAP
## SEPTEMBER 1998

APPROVED BY:
DATE:
SCALE: 1"=50'
PROJECT NUMBER: 1556-003
DRAWING NUMBER: 4-28
REV.:



GENERAL NOTES

file: klaser poten map deep.dwg

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  |

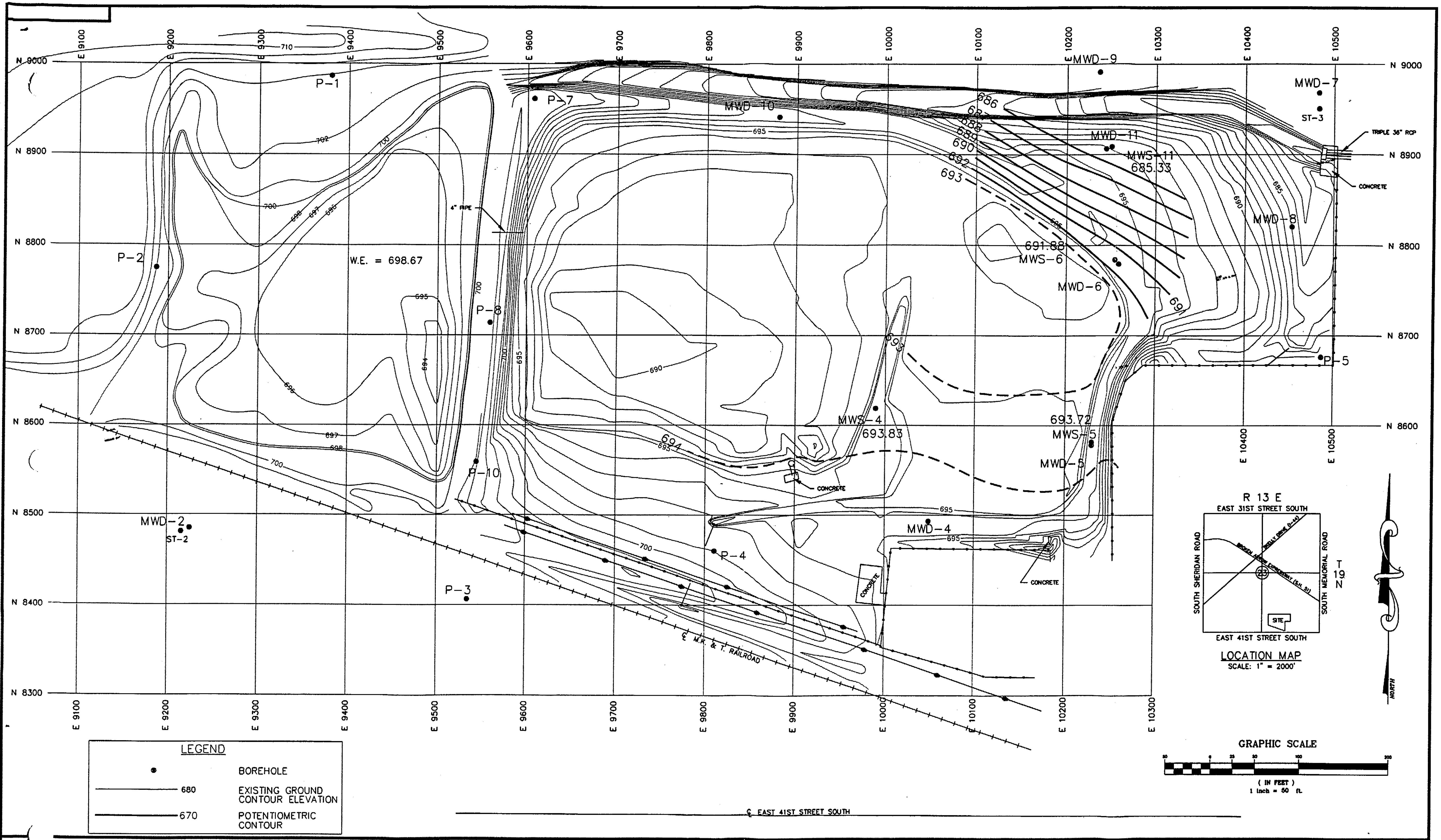
A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

| | | | |
|---|---|---|---|
| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB |
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 |

# TULSA REMEDIATION PROJECT
## DEEP OVERBURDEN
## POTENTIOMETRIC CONTOUR MAP
MARCH 1999

| APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV.: |
|---|---|---|---|---|
| DATE: | 1"=50' | 1556-003 | 4-29 |  |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|
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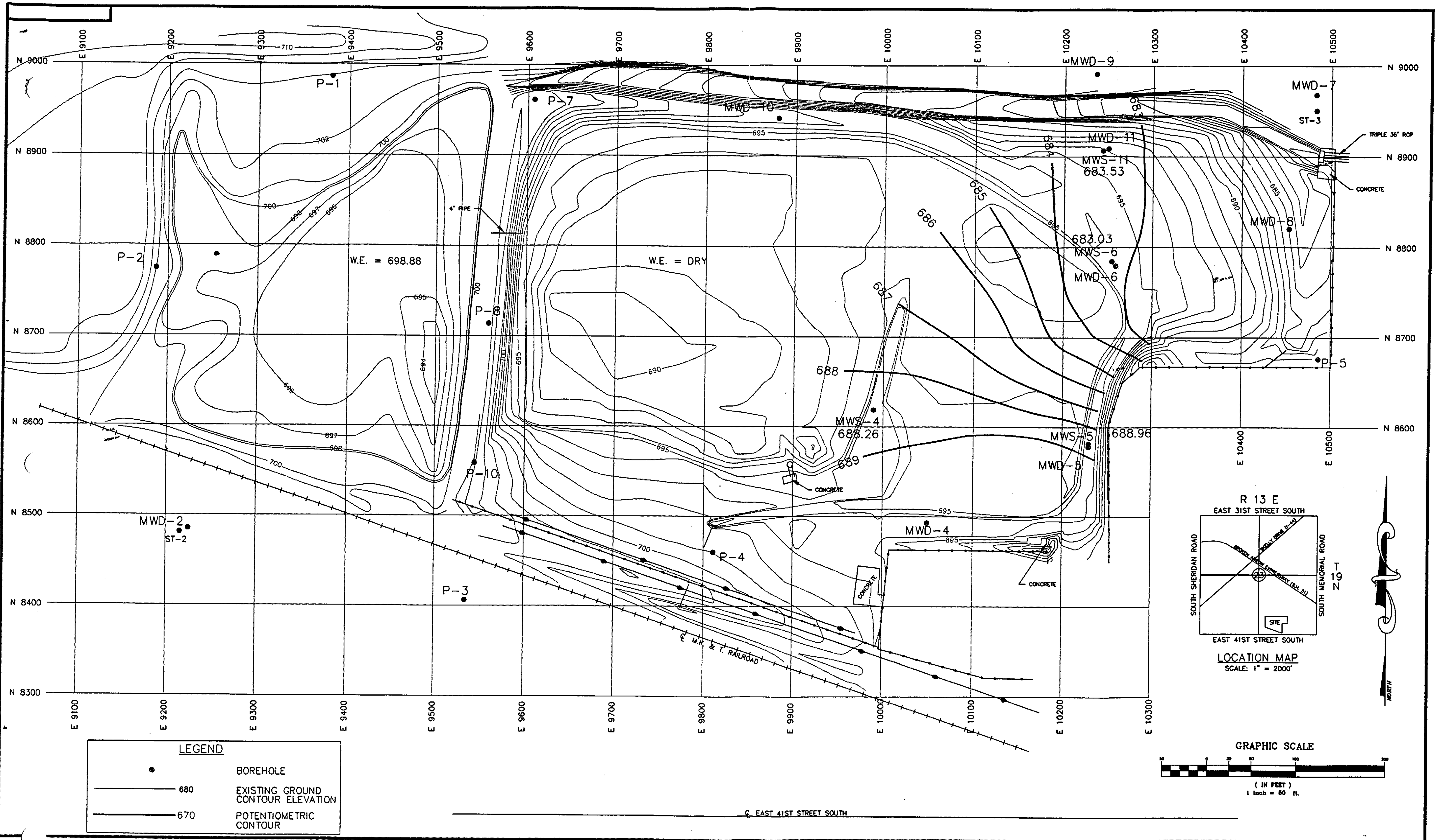
A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

# TULSA REMEDIATION PROJECT
## SHALLOW OVERBURDEN
## POTENTIOMETRIC CONTOUR MAP
## APRIL 1997

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: 1"=50' | PROJECT NUMBER: 1556-003 | DRAWING NUMBER: FIGURE 4-30 | REV.: |
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 | DATE: | | | | |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
|---|---|---|---|---|---|---|---|---|---|

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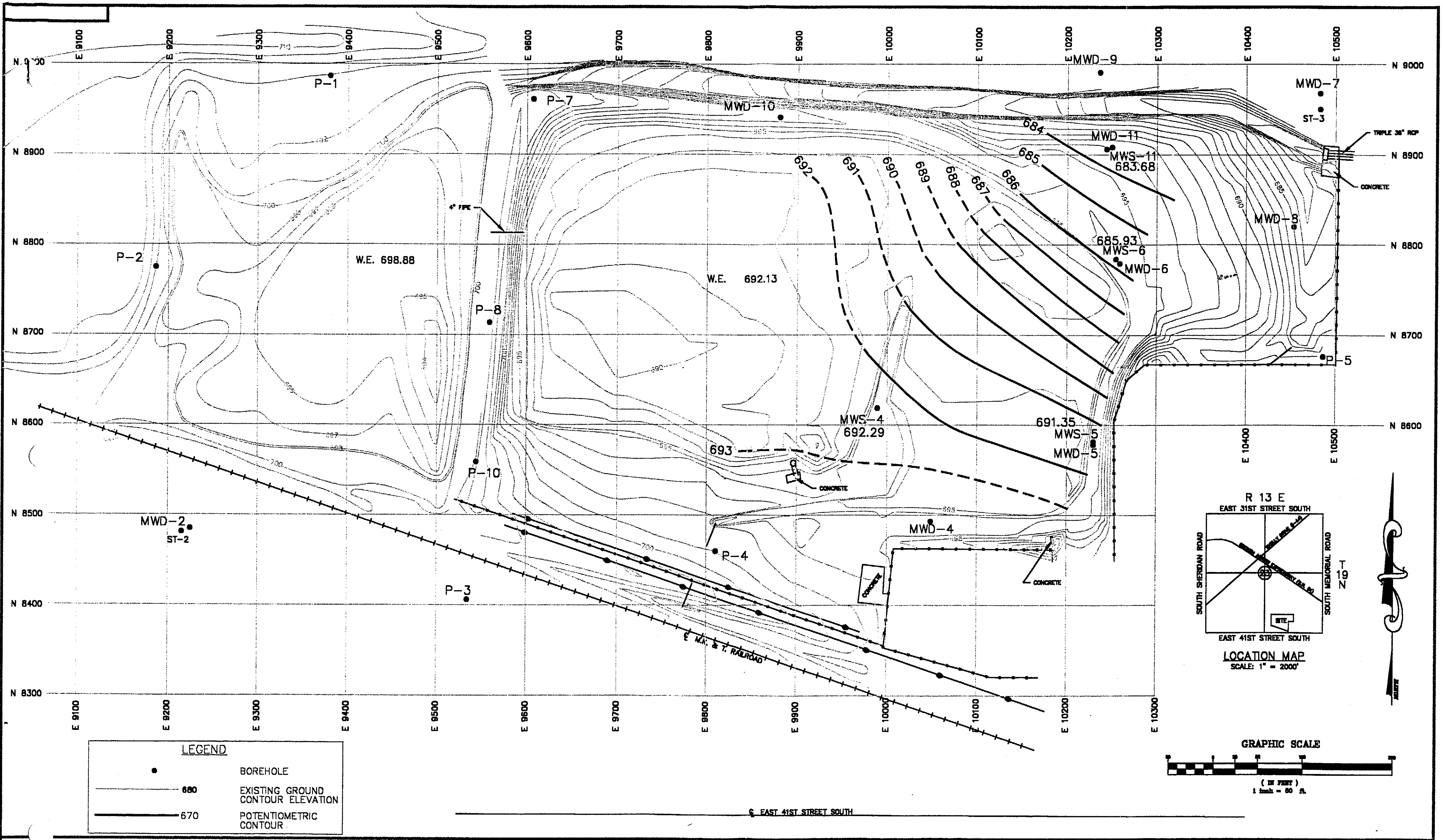
ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

# TULSA REMEDIATION PROJECT
## SHALLOW OVERBURDEN
## POTENTIOMETRIC CONTOUR MAP
## SEPTEMBER 1998

| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV.: |
|---|---|---|---|---|---|---|---|---|
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 | DATE: | 1"=50' | 1556-003 | FIGURE 4-31 | |



GENERAL NOTES

REVISIONS

| NO. | DESCRIPTION | BY | CHECKED | DATE | NO. | DESCRIPTION | BY | CHECKED | DATE |
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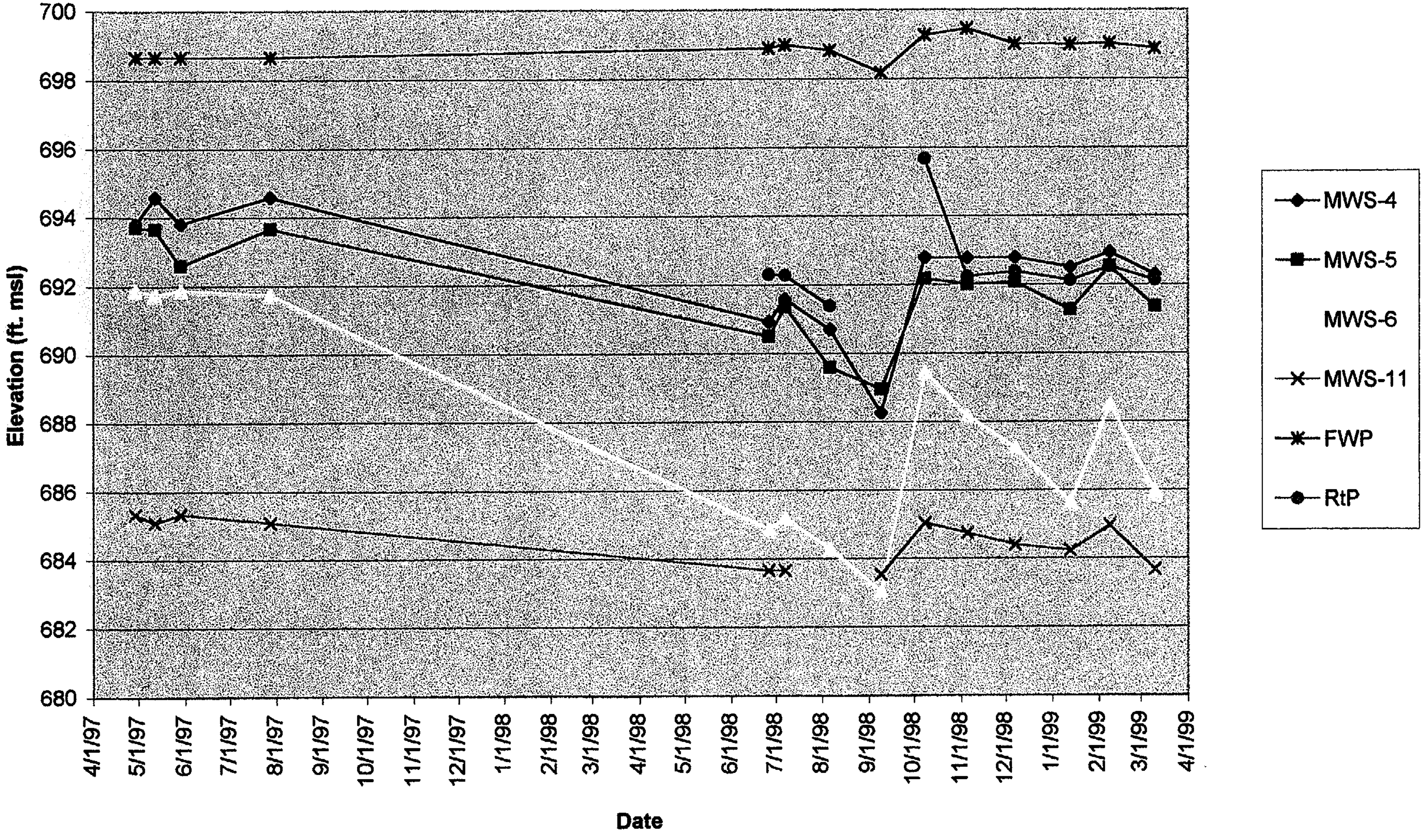
ENVIRONMENTAL SERVICES, INC.

ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

# TULSA REMEDIATION PROJECT
## SHALLOW OVERBURDEN
## POTENTIOMETRIC CONTOUR MAP
## MARCH 1999

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| DRAWN: PLS | CHECKED BY: IT | MATERIALS BY: | ENGINEER: ALB | APPROVED BY: | SCALE: | PROJECT NUMBER: | DRAWING NUMBER: | REV.: |
| DATE: 4-15-1999 | DATE: 4-15-99 | DATE: | DATE: 5-2-1997 | DATE: | 1"=50' | 1556-003 | FIGURE 4-32 | |

## Figure 4-33 Shallow Down Gradient Groundwater Levels



## Figure 4-34 Groundwater Levels in Downgradient Well Clusters

Figure 34a. Groundwater Level Trends in MW-4 Cluster

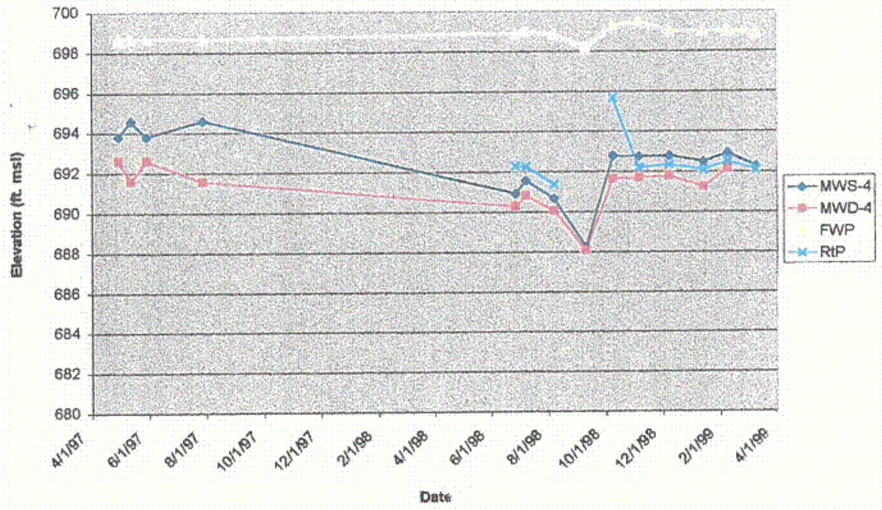


Figure 34b. Groundwater Level Trends in MW-5 Cluster

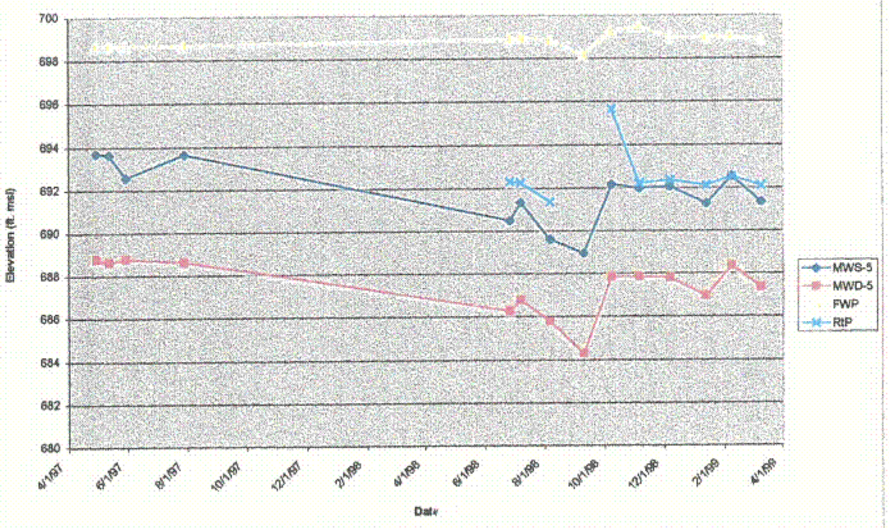


Figure 34c. Groundwater Level Trends in MW-6 Cluster

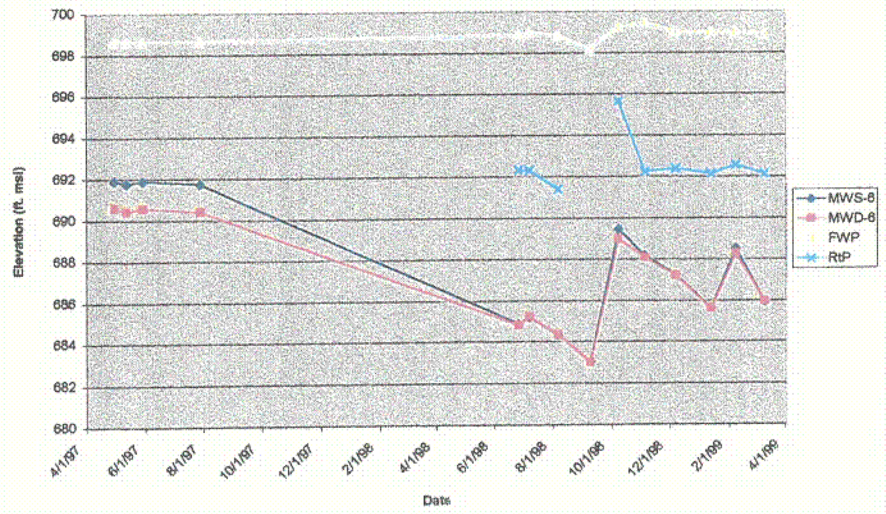
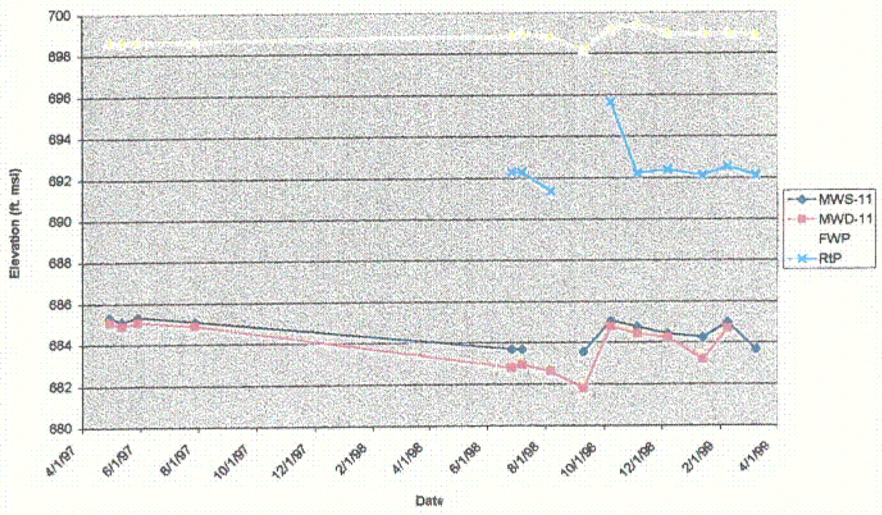
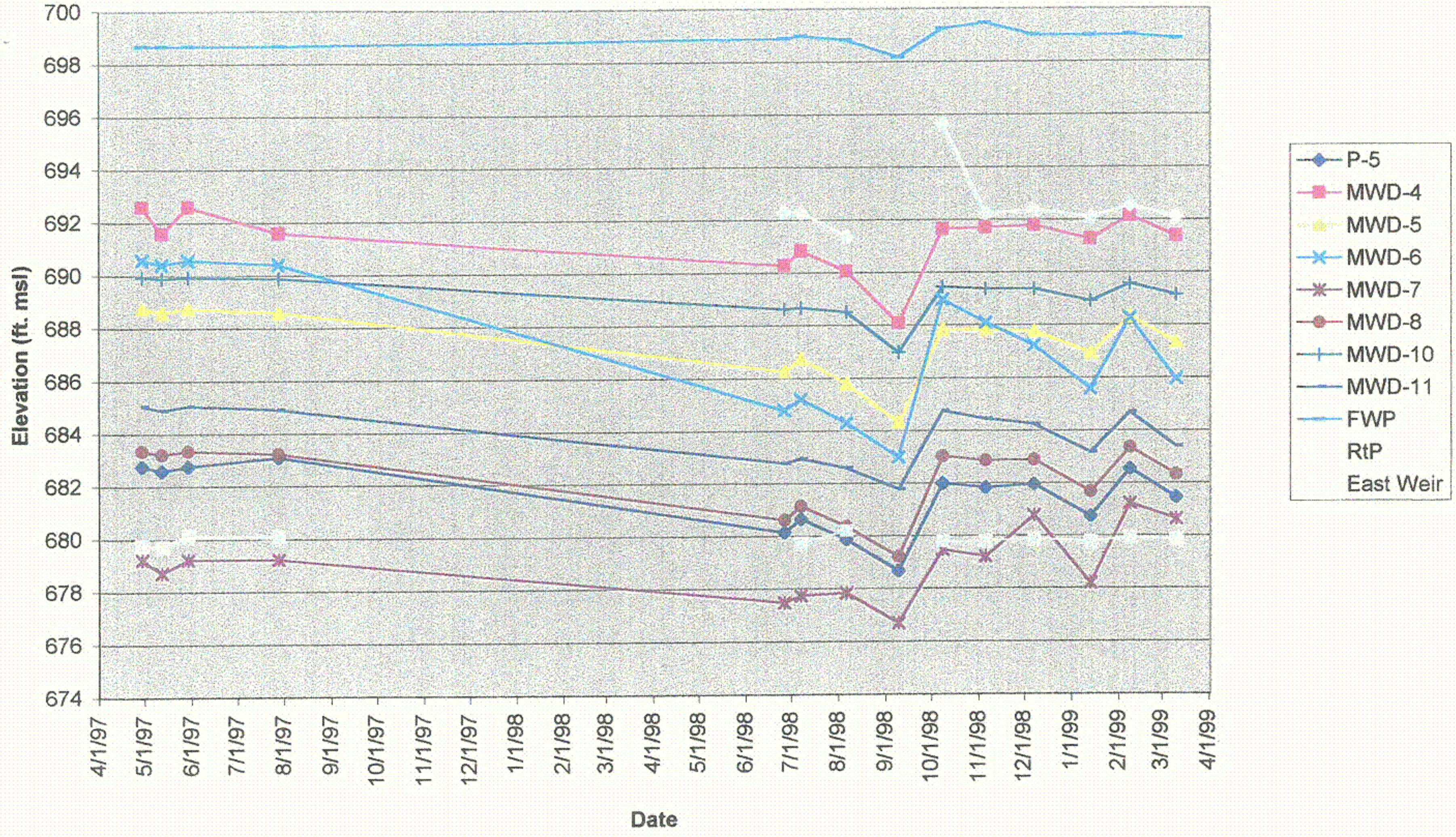


Figure 34d. Groundwater Level Trends in MW-11 Cluster



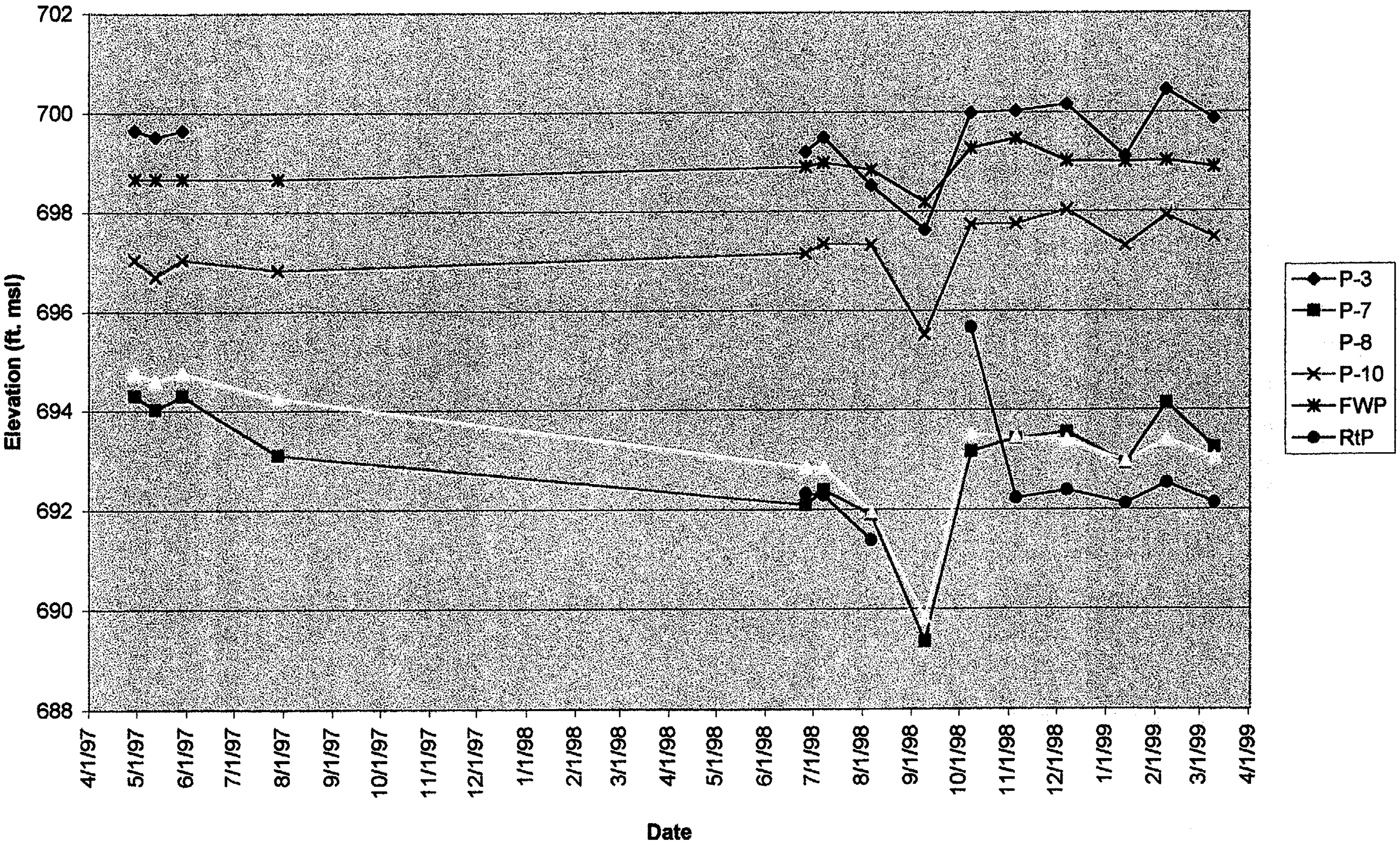
C10

## Figure 4-35 Deep (Unit 1) Down Gradient Groundwater Levels

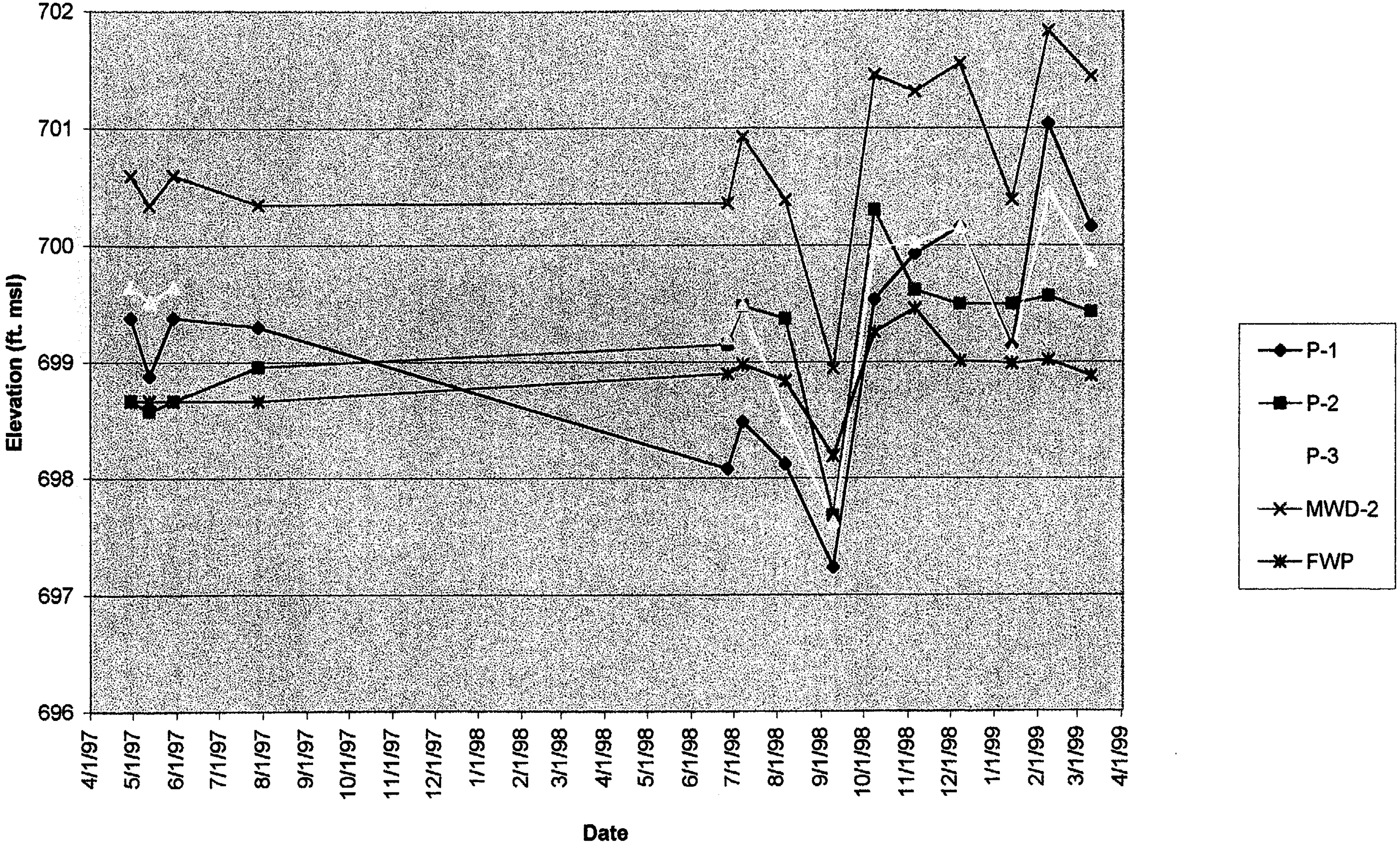


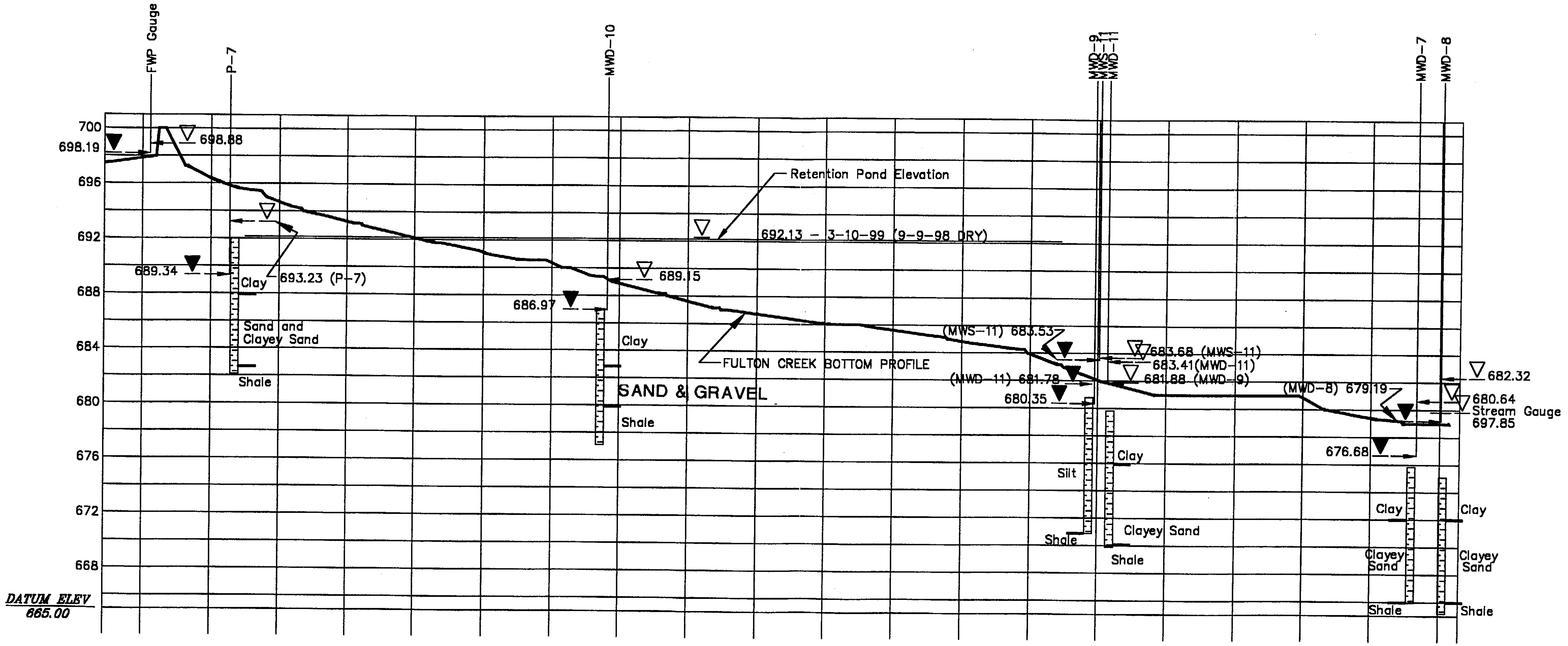
C-11

## Figure 4-36 Groundwater Levels in Wells between Freshwater and Retention Ponds



## Figure 4-37 Upgradient Groundwater Levels





## LEGEND

SCREENED INTERVAL

▼→ SEPTEMBER 9, 1998 WATER ELEVATIONS

←▽ MARCH 10, 1999 WATER ELEVATIONS

FULTON CREEK BOTTOM PROFILE

—P-7 PROJECTED WELL POINT LOCATION

HORIZONTAL
GRAPHIC SCALE

( IN FEET )
1 inch = 40 ft.

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| | | | |
|---|---|---|---|
| SCALE:<br>NOTED | DATE:<br>4/15/99 | FIGURE NO.<br>4-38 | **TULSA REMEDIATION PROJECT** |
| APPROVED BY:<br>IT | DRAWN BY:<br>JDA | PROJECT NO.<br>1556-013 | FULTON CREEK PROFILE AND PROJECTED MONITOR WELLS AND WATER LEVELS |

# 5.0 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 SURFACE WATER HYDROLOGY

The Facility lies at the headwaters of Fulton Creek. From the Facility, Fulton Creek flows north and east approximately two miles to Mingo Creek. From the Fulton Creek/Mingo Creek confluence, Mingo Creek flows north approximately nine (9) miles where it enters Bird Creek. Bird Creek flows to the east approximately 10 miles to the confluence with the Verdigris River. The OWRB has designated beneficial uses for Mingo Creek but domestic or municipal drinking water is not included in these beneficial uses. According to the OWRB, surface water withdrawals occur on Bird Creek for irrigation purposes. The first public water supply withdrawal downstream of the Facility occurs from the Verdigris River by the water treatment plant for the City of Broken Arrow, Oklahoma. However, the plant has operated since 1982 on an emergency basis only. The last time the plant operated was in 1991.

The Facility occupies approximately 23 acres of a 297-acre watershed. The only water bodies within the watershed are the Fresh Water Pond and the Retention Pond on the Facility. The dominant features of the Facility hydrologic regime are the two ponds and the excavated Fulton Creek channel. A previous study has indicated that the ponds and creek on the Facility have a role in the City's storm water management, but the role is due primarily to the fact that off-site storm water from the watershed is routed through the Facility. Soil Conservation Service techniques for predicting flows in Fulton Creek were used to predict peak discharges in response to rainfall events. Peak discharges in Fulton Creek at the discharge weir for the 2, 5, 10, 25, 50, and 100-year storms have been estimated. Equivalent stage heights at the weir have been computed for these discharges. Some remediation options may change the configuration of Fulton Creek, and alter the projected stage heights and flow velocities for the estimated peak discharges. The peak discharges and stage heights estimated during this investigation provide a basis for evaluating remediation alternatives, but it may become necessary to calculate stage heights and flow velocities for such remediation options.

The analyses conducted during the investigation also indicate that closure of the Fresh Water Pond will only impact the runoff under dry antecedent moisture conditions (SCS AMC I). When full, the Fresh Water Pond passes water through as if it were a channel. The main difference in flow characteristics without the Fresh Water Pond would be the time to peak flow which is a function of the level of the Pond at the time of runoff. Without the Pond, peak flow, will occur earlier and decline sooner.

## 5.2 GEOLOGY

The site geology identified during the investigation is consistent with the regional geology defined in the literature. The investigation confirmed that the Nowata Shale immediately underlies the Facility and extends to a depth of at least 200 feet. A buried bedrock valley, eroded in the Nowata Shale, has been identified beneath the northern portion of the Facility. This buried bedrock valley trends in an east/west direction and underlies the Fresh Water and Retention Ponds. The unconsolidated materials overlying bedrock range in thickness from a few feet to as much as 28 feet, with the thickest overburden present in the center of the eroded bedrock valley. These overburden materials consist of naturally deposited sediments, fill material, dross, and reworked sediments that may have originated on- or off-site. The naturally deposited material is comprised of sand, silt, clay, peat and occasional gravel. These materials are laterally and vertically variable. A layer of more permeable, sandy deposits has been identified in the bedrock valley immediately overlying bedrock. These more permeable deposits are overlain by less permeable silty clay deposits. These silty clay deposits generally underlie both the Fresh Water and Retention Ponds.

The basic bedrock and overburden geology beneath the study area has been identified during the investigation. Depending on the identification of remediation alternatives options, additional investigations may be needed to better define off-site geologic features, such as the degree to which the eroded bedrock valley extends from beneath the Fresh Water Pond towards the southwest beyond the Facility boundary, the character of overburden materials present in any such extension, the full lateral extent of the eroded bedrock valley and the characteristics of the overlying overburden materials in the off-site area south and east of the Reserve Pond area.

The identification of specific remediation alternatives also may result in the need to further characterize some highly localized, on-site geologic features of potential importance that are, as yet, not fully characterized. Most notably, the presence and configuration of the channel and overlying deltaic deposits identified along the north boundary of the Facility in the aerial photographs require further investigation.

## 5.3 HYDROGEOLOGY

Review of the regional hydrogeology has indicated that there are no principal bedrock aquifers in the vicinity of the Facility. Bedrock formations in the vicinity of the Facility, including the Nowata Shale that immediately underlies the site, are considered water bearing. However, these formations yield only very small amounts of fair to poor quality water. Wells completed in bedrock formations in this area typically do not produce sufficient quantities of groundwater to supply water for domestic use.

Information obtained from the OWRB identified six permitted groundwater users within six miles of the Facility, but the location of these permits suggests that the groundwater is being produced from the Arkansas River Alluvium. These alluvial deposits are comprised of gravel sand, silt and clay and yield moderate to large quantities of fair to good quality water. However, they are hydraulically isolated from the shallow overburden material at the plant.

Based on the contrast between the hydraulic conductivities of subsurface materials identified beneath the site, the higher permeability silty sands immediately overlying bedrock in the bedrock valley provide the most significant pathway for groundwater flow beneath the site. Deep groundwater flow through these more permeable deposits is from west to east along the axis of the bedrock valley. While water levels are temporally variable, the groundwater flow directions are relatively constant. Shallow groundwater flow is influenced by surface water and topography to a greater extent than deeper groundwater flow. Shallow groundwater flow in the northeastern portion of the Facility, in the general area of the Reserve Pond, is similar to deep groundwater flow. Shallow groundwater flow along the northern berm of the Retention and Reserve Ponds, however, is expected to be northerly or northeasterly towards Fulton Creek. Along the southeastern boundary of the Retention Pond, shallow groundwater likely flows locally to the east and south due to the effects of groundwater mounding in the immediate vicinity of the Retention Pond.

Based solely on the expected hydraulic conductivities of the silty clays found to underlie the Fresh Water and Retention Ponds, significant leakage from these ponds into sands immediately overlying bedrock would not be expected. Analysis of water level data has confirmed that the Fresh Water Pond exerts limited influence on water levels in the Retention Pond and underlying Unit 1 sands. However, water level trends in the Retention Pond correlate well with water levels in the underlying shallow and deep overburden, indicating that these water levels are likely responding to the same influences. Moreover, a downward gradient is observed between the Retention Pond and deep overburden, indicating potential recharge of the deep overburden by the Retention Pond. Water level data indicate that these vertical gradients are spatially variable. Adjacent to the northeast corner of the Retention Pond, these downward gradients all but disappear, potentially indicating significant hydraulic interconnection between the Retention Pond and underlying deep overburden deposits in this general location. This apparent hydraulic interconnection may result from the localized presence of higher permeability materials such as deposits in the center of the old Fulton Creek channel or the deltaic deposits observed along the northern boundary of the Facility in aerial photographs predating construction of the Facility and the Retention Pond. However, such localized deposits have not been clearly identified during the investigation. Other data suggest that leakage may be occurring from the Retention Pond. These include geochemical data and observed water level changes in the Retention Pond in response to extreme rain events. In spite of this potential leakage from the Retention Pond, geochemical data indicate that thorium and radium have not migrated in groundwater significant distances from the dross deposits. This is likely due to the high adsorption coefficients that have been measured for thorium and radium in subsurface materials.

Several potential pathways for the migration of radionuclides in groundwater away from the Retention and Reserve Ponds have been identified during the investigation. These potential pathways include shallow groundwater flow through the berms on the northern, eastern, and southeastern sides of the Retention and Reserve Ponds. Groundwater flow through the northern berms likely discharges to Fulton Creek. Routine sampling and radioactivity measurements of surface water have indicated no significant impact on Fulton Creek. Potential migration pathways in groundwater also include migration through the underlying Unit 2 silty clays into and through the deep overburden material and shallow, weathered bedrock. Discharges from the Facility through this pathway would largely be confined to the more permeable sands deposited directly overlying bedrock in the bedrock valley underlying the northeast corner of the Facility. The interstitial groundwater flow velocities through these more permeable, deep overburden deposits have been estimated to be 0.35 feet/day or 127.75 feet/year.

The investigation has identified a number of sources for water entering the basin in the northern portion of the Facility. These include ground and surface water inflows as well as direct precipitation. A number of pathways for water leaving the basin have been identified, including ground and surface water discharges as well as pond evaporation. Within the basin, itself, a number of potential pathways for the exchange of water between the surface and ground water systems have been identified. The investigation resulted in an estimate of groundwater discharges from the Facility. No estimates have been made of the other water inflows, outflows, and exchanges.

Although the relative contributions from surface and ground water inflows into the basin to the current groundwater discharges from the site have not been quantified, it is likely that a remediation alternative that included drainage of the Fresh Water and Retention Ponds would remove major sources of the groundwater outflow now observed along the eastern boundary of the Facility. Under such conditions, the groundwater flow discharging from the site would be largely determined by groundwater inflows into the basin. As a result, for the design of certain remediation alternatives it may become important to define further the underlying subsurface flow through the basin.

## 5.4 GEOTECHNICAL CONSIDERATIONS

The unconsolidated overburden beneath the study area was tested for various geotechnical properties during the investigation. Some of the most significant geotechnical data obtained during the investigation were the blow counts observed during the split spoon sampling of the overburden material. The blow counts observed during split spoon sampling provide a qualitative measure of the strength of subsurface materials and indicate the relative density and consistency of the sampled soils. The blow counts observed during the sampling of the deeper sandy materials (Unit 1) and the immediately overlying silty clays (Unit 2) indicate that these materials are generally loose and have a low relative density and a soft consistency. These materials have a poor bearing strength in their present loose state and do not provide a stable base for engineered structures in their current condition.

These materials, particularly the Unit 1 sands, will likely require further consolidation before an engineered structure such as a cap or engineered cell could be built on them. Otherwise, the long-term integrity of such structures may be jeopardized by settling. Consolidation of these materials will require a reduction in pore water pressure within the deeper Unit 1 sands. The degree of consolidation required and the time required to achieve this degree of consolidation can only be determined after specific evaluation of the potential remedial alternatives for the site. A variety of engineering options would be available, however, to achieve the necessary consolidation.

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# APPENDIX A

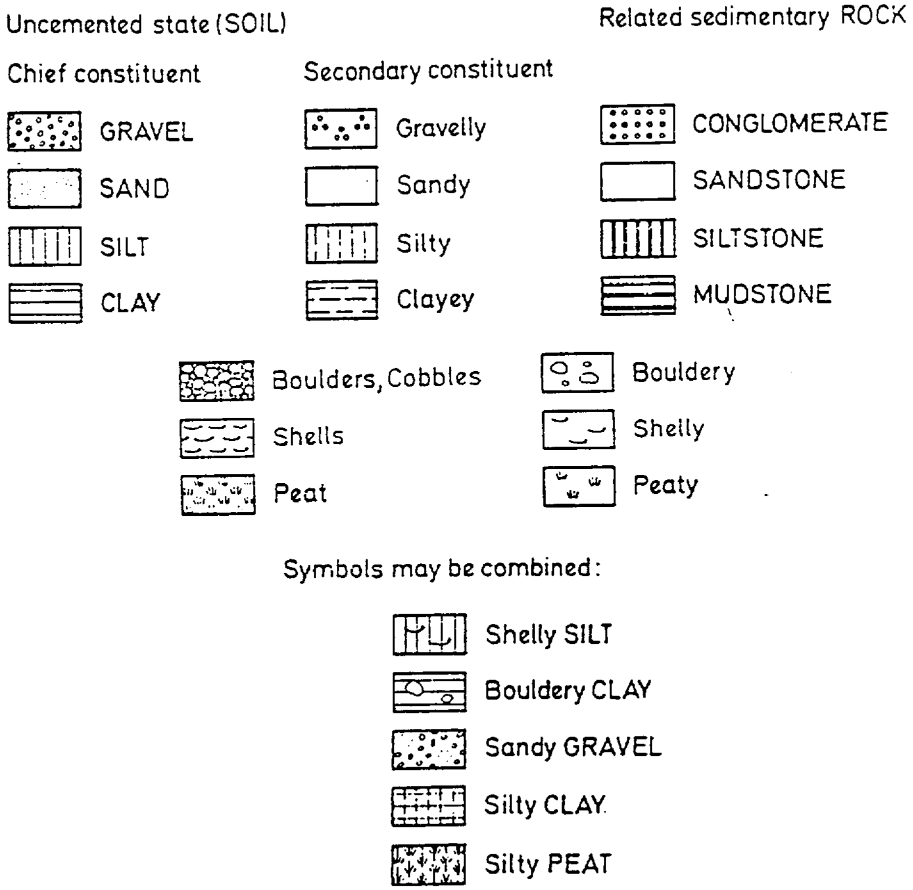
# SAMPLE LOGS FROM MONITOR WELLS

## SYMBOLS FOR SOILS

*While the proposed symbols are primarily intended for use in logs and sections, usually on a large scale, they can also be used for plans and maps. For the latter it may be advantageous to lighten the ornament by spacing it more widely or by using thinner lines.*

Symbols are given for the four divisions of soils based on particle size. Each symbol has two variants, one for use when the material is the chief soil constituent, the other for use when it is the secondary constituent. The symbols for the corresponding rocks, in which the particles are cemented, are given here as well as in their appropriate sub-section to illustrate the unity of the symbolism.

*Examples of soil types*



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The idea of using vertical lines for the silt symbol was taken from Hvorslev, M. J. 1948. *Subsurface exploration and sampling of soils for civil engineering purposes.* Waterways Experimental Station, Vicksburg, Miss. This symbol was originally used by the U.S. Corps of Engineers, Vicksburg District, and subsequently has been followed by the Norwegian Geotechnical Unit and the Ontario Department of Highways, among others.

# GENERAL NOTES

## SAMPLE IDENTIFICATION

The Unified Soil Classificaton System is used to identify the soil unless otherwise noted.

## SOIL PROPERTY SYMBOLS

N: Standard "N" penetration: Blows per foot of a 140 pound hammer falling 30 inches on a 2 inch O.D. split-spoon.

Qu: Unconfined compressive strength, TSF.

Qp: Penetrometer value, unconfined compressive strength, TSF.

Mc: Water content, %.

LL: Liquid limit, %.

PI: Plasticity index, %.

δd: Natural dry density, PCF.

▼: Apparent groundwater level at time noted after completion of boring.

## DRILLING AND SAMPLING SYMBOLS

SS: Split-Spoon - 1 3/8" I.D., 2" O.D., except where noted.
ST: Shelby Tube - 3" O.D., except where noted.
AU: Auger Sample.
DB: Diamond Bit.
CB: Carbide Bit.
WS: Washed Sample.

## RELATIVE DENSITY AND CONSISTENCY CLASSIFICATION

| TERM (NON-COHESIVE SOILS) | STANDARD PENETRATION RESISTANCE |
|---|---|
| Very Loose | 0-4 |
| Loose | 4-10 |
| Medium | 10-30 |
| Dense | 30-50 |
| Very Dense | Over 50 |

| TERM (COHESIVE SOILS) | Qu - (TSF) |
|---|---|
| Very Soft | 0 - 0.25 |
| Soft | 0.25 - 0.50 |
| Firm (Medium) | 0.50 - 1.00 |
| Stiff | 1.00 - 2.00 |
| Very Stiff | 2.00 - 4.00 |
| Hard | 4.00+ |

## PARTICLE SIZE

| | | | | | |
|---|---|---|---|---|---|
| Boulders | 8 in.+ | Coarse Sand | 5mm-0.6mm | Silt | 0.074mm-0.005mm |
| Cobbles | 8 in.-3 in. | Medium Sand | 0.6mm-0.2mm | Clay | -0.005mm |
| Gravel | 3 in.-5mm | Fine Sand | 0.2mm-0.074mm | | |

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

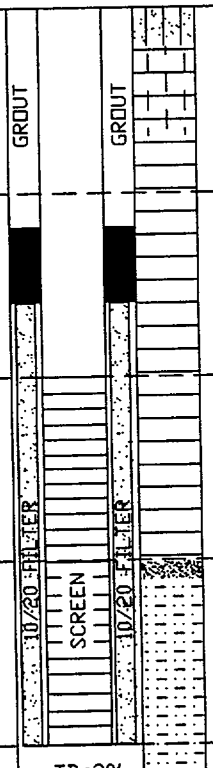
| | | |
|---|---|---|
| SITE NAME AND LOCATION<br>KAISER ALUMINUM<br>7311 EAST 41ST STREET<br>TULSA, OKLAHOMA 74147 | DRILLING METHOD: 2" SPLIT SPOON<br>BORING REAMED WITH 6" FLIGHT AUGERS<br>SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER | BORING NO. P-1<br>SHEET 1 OF 1 |

WEATHER MUGGY
TEMP WARM
G.L. ELEV. 702.7
DATUM MSL
TOC ELEV. 706.36

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 0745 | TIME 0935 |
| DATE 3-18-97 | DATE 3-18-97 |

DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10-20
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 10



| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | DESCRIPTION OF MATERIAL |
|---|---|---|---|---|
| 0–1 | | | | 0-1' BROWN SILT, LOAM, CLAYEY |
| 1–3.5 | | | | 1'-3.5' DARK BROWN SILTY CLAY |
| 3.5–10 | CORED | | | 3.5' - 10' CLAY, BROWN |
| 10–15 | 7<br>7<br>9<br>23<br>17 | 35 | | 10'-15' TAN CLAY |
| 15–15.5 | | | | 15'-15.5' LAG GRAVEL |
| 15.5–20.5 | 41<br>22<br>57<br>38<br>85 | | | 15.5'-20.5' BROWN WEATHERED SHALE |
| 20.5–26 | 50<br>80 | 47 | TD=20' | 20.5'-26' GRAY SHALE ENCOUNTERED IN ORIGINAL BORING ONLY |

NOTES

WELL LOCATED ON PROPERTY'S NORTHWEST CORNER-ACCESS THROUGH PARKING AREA GATE SITUATED NORTH OF FULTON CREEK

FIRST HOLE DRILLED ON 3-6-97 & SET 10 FEET OF SURFACE CASING- THEN LATER ABANDONED ORIGINAL BORING & OFFSET TO DRILL ANOTHER ON 3-18-97

THE ORIGINAL HOLE WAS PLUGGED AND THE HOLE OFFSET 20 FEET TO THE WEST WAS COMPLETED TO 20 FEET IN DEPTH ON 3-18-97

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY PETER SCHULTZE

DATE MARCH 18, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOONS/2' DIAMETER

BORING NO. P-2
SHEET 1 OF 1

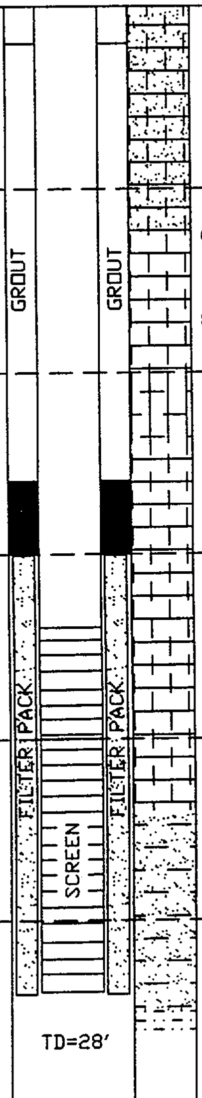
| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| DATE 3-19-97 | DATE 3-19-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MISTY
TEMP CHILLY
G.L. ELEV. 704.5
DATUM MSL
TOC ELEV. 708.06
DRILL RIG DAISY/KENT DK-40
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 16-40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 10
0.0010

| DEPTH IN FEET | BLOW COUNT | CPM |
|---|---|---|
| 5 | | |
| | | 41 |
| | 3 | |
| | 6 | 35 |
| | 11 | |
| 10 | 25 | 30 |
| | 14 | |
| | 16 | 41 |
| | 12 | |
| | 21 | 39 |
| 15 | 8 | |
| | 14 | 33 |
| | 5 | |
| | 8 | 31 |
| | 4 | |
| 20 | 8 | 41 |
| | 8 | |
| | 6 | 41 |
| | 8 | |
| | 13 | 45 |
| 25 | 5 | |
| | 4 | 39 |
| | 21 | |
| | 50 | 34 |

WELL TYPICAL / SYMBOL



DESCRIPTION OF MATERIAL

0-6' FILL MATERIAL, SILTY SAND AND CLAY

6'-8' GREEN & ORANGE CLAY/BECOMING MORE SILTY WITH DEPTH,ROOTS AND DECOMPOSED VEG.

8'-10' BROWN SILTY CLAY

10'-12' CLAYEY SILT, GREEN TO BROWN

12'-22' BROWN-GRAY SILTY CLAY WEATHERED BROWN SHALE

22'-27.5' CLAYEY SAND, BROWN VERY LOOSE AT 24'

27.5'-28' SHALE, GRAY

NOTES

WELL LOCATED ON WEST SIDE OF FRESHWATER POND- HOPE LUMBER ACCESS

INSTALLED #16/40 GRAVEL FILTER & #10 SCREEN

DRILLED WITH AIR

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR STRATTON (JOHN & WILLIAM)

LOGGED BY SCOTT McREYNOLDS

DATE MARCH 19, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS

SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER

BORING NO. P-3

SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 09:45 am | TIME 10:45 am |
| DATE 3-24-97 | DATE 3-24-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SUNNY TEMP WARM

G.L. ELEV. 703.4

DATUM MSL TOC ELEV. 707.14

DRILL RIG CME 75

TYPE GRAVEL: 16/40

CASING DIA: 2 INCH

SCREEN DIA: 2"

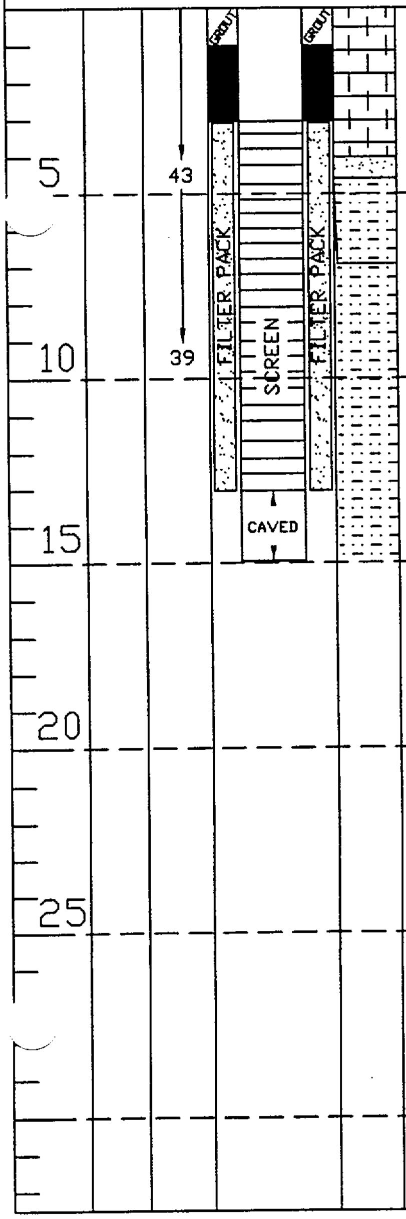
ANGLE BEARING

TYPE BENTONITE: SODIUM

SLOT SIZE: 0.0010

SAMPLE HAMMER TORQUE FT.-LBS

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|



0-4' HARD BROWN SILTY CLAY

4'-4.5' HARD SILTSTONE

4.5'-7' HARD BROWN WEATHERED SHALE

7'-15' GRAY SHALE/WET

TD=13'

WELL LOCATED SOUTH OF THE EXCLUSION AREA AND RAILROAD TRACKS IN NORTH/SOUTH LINE WITH ENBANKMENT BETWEEN THE FRESH WATER POND AND RETENTION POND

FILTER PACK- 10/40

WATER AT 9 FEET AFTER DRILLING

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY PETER SCHULTZE

DATE MARCH 24, 1997 CHK'D BY MRM

# SOIL BORING LOG

A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS

SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER

BORING NO. P-4

SHEET 1 OF 1

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| DATE<br>3-19-97 | DATE<br>3-19-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MISTY

TEMP CHILLY

G.L. ELEV. 698.2

DATUM MSL

TOC ELEV. 701.27

DRILL RIG CME 75

ANGLE

BEARING

SAMPLE HAMMER TORQUE FT.-LBS

TYPE GRAVEL: 10/20

TYPE BENTONITE: SODIUM

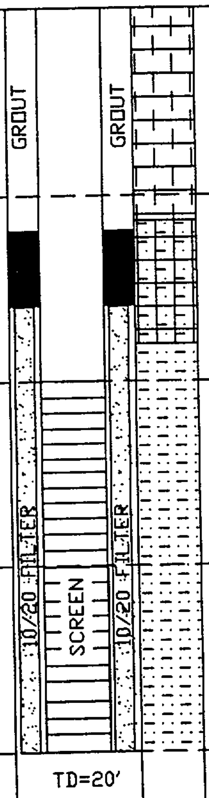
CASING DIA: 2 INCH

SCREEN DIA: 2"

SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL |
|---|---|---|---|
| | 5 | | ONE INCH DROSS ON TOP |
| | 12 | 58 | |
| | 16 | | 1 INCH-5.7' YELLOW/BROWN SILTY CLAY |
| | 23 | 51 | |
| 5 | 8 | | |
| | 18 | 54 | |
| | 18 | | |
| | 40 | 42 | 5.7'-9' WEATHERED SHALE WITH BROWN CLAY/SILT |
| | 33 | | |
| 10 | 60 | 51 | |
| | | 48 | 9'-15' BROWN WEATHERED SHALE |
| | | 49 | |
| 15 | | | |
| | | | 15'-20' GRAY SHALE |
| 20 | | | |
| 25 | | | |

WELL TYPICAL / SYMBOL



NOTES

WELL LOCATED ON SOUTH SIDE OF RETENTION POND- NEAR THE DRAINAGE DITCH

HOLE WAS DRY AFTER DRILLING- CAVED TO 16 FEET BY 3-21-97. FLUSHED HOLE & SET PIPE ON 3-21-97

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY MURRAY R. McCOMAS

DATE MARCH 19, 1997

CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS

BORING NO. P-5

SHEET 1 OF 1

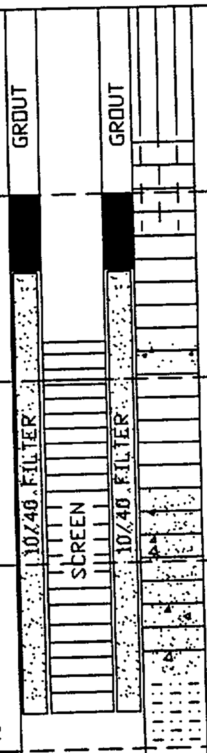
SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 1330 | 1450 |
| DATE | DATE |
| 3-21-97 | 3-21-97 |

WEATHER SUNNY
TEMP WARM
G.L. ELEV. 688.8
DATUM MSL
TOC ELEV. 691.95
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | 5 | |  | | 0-3.5' BROWN SILT AND FILL | WELL LOCATED IN SOUTHWEST CORNER OF PROPERTY'S EASTERN PORTION SITUATED EAST OF THE DRAINAGE DITCH |
| | 6 | 34 | | | | |
| | 6 | | | | | |
| | 7 | 37 | | | 3.5-6' BROWN SILTY CLAY AND ORGANIC FIBERS | |
| 5 | 7 | | | | | |
| | 13 | 31 | | | | |
| | 7 | | | | | |
| | 15 | 32 | | | | |
| | 7 | | | | 6'-13' MOTTLED CLAY WITH IRON NODULES | |
| 10 | 16 | 38 | | | GRAVEL AT 9' | |
| | 6 | | | | | |
| | 12 | 36 | | | | |
| | 6 | | | | | |
| | 11 | 34 | | | | |
| 15 | H | | | | | H REFERS TO THE WEIGHT OF THE HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER |
| | 2 | 30 | | | 13'-18' WELL GRADED SAND WITH CLAY AND TRACE OF GRAVEL SW-SC | |
| | 7 | | | | | |
| | 12 | 24 | | | | |
| | 21 | | | | | |
| 20 | 50 | 32 | | | 18'-20' BROWN WEATHERED SHALE | |
| 25 | | | | | | |

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY PETER SCHULTZE

DATE MARCH 21, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

SITE NAME AND LOCATION

KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

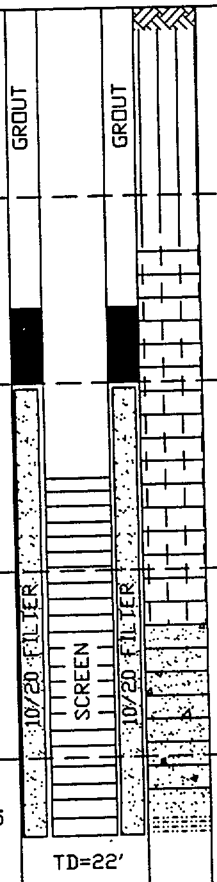
DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOONS/2' DIAMETER

BORING NO. P-7
SHEET 1 OF 1

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 0940 | TIME 1135 |
| DATE 3-18-97 | DATE 3-18-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MUGGY TEMP WARM
G.L. ELEV. 702.4
DATUM MSL TOC ELEV. 706.35
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/20
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|
| | 8 | | 0-6 INCHES TOPSOIL | WELL LOCATED ON NORTH SIDE OF EMBANKMENT BETWEEN FRESH WATER POND AND RETENTION POND |
| | 13 | 37 | | |
| | 10 | | 6 INCHES-6' DARK BROWN ORGANIC SILT NON-PLASTIC | |
| | 14 | 33 | | |
| 5 | 8 | | | |
| | 15 | 43 | | |
| | 10 | | | |
| | 16 | 45 | | |
| | 10 | | | |
| 10 | 20 | 41 | | |
| | 9 | | | |
| | 17 | 42 | 6'-16.5' BROWN SILTY CLAY WITH MOTTLED GRAY | WET AT 12 FEET |
| | 6 | | | |
| | 12 | 26 | | |
| 15 | 7 | | | |
| | 12 | 38 | | |
| | 6 | | | |
| | 10 | 31 | | |
| | 5 | | 16.5'-21.8' POORLY GRADED SAND WITH CLAY AND YELLOW SANDSTONE GRAVEL SP-SC | |
| 20 | 8 | 37 | | |
| | 3 | | | |
| | 5 | 35 | 21.8'-22' BROWN SHALE | |
| 25 | | | | |

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY MURRAY R. McCOMAS CHK'D BY MRM

DATE MARCH 18, 1997

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOONS/2' DIAMETER

BORING NO. P-8
SHEET 1 OF 1

SITE NAME AND LOCATION

KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

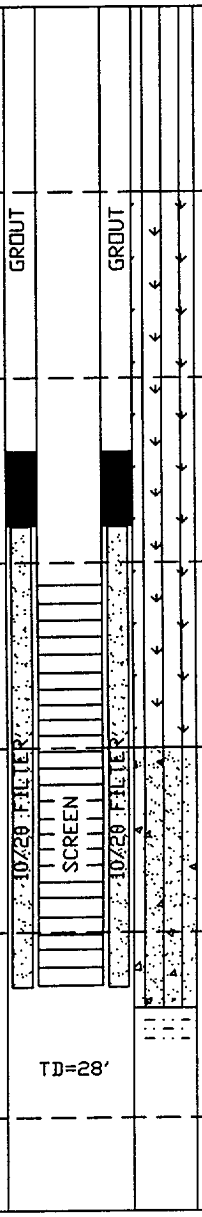
| DRILLING | |
|---|---|
| START | FINISH |
| TIME 1245 | TIME 1442 |
| DATE 3-18-97 | DATE 3-18-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SPRINKLING TEMP COLD
G.L. ELEV. 702.5
DATUM MSL TOC ELEV. 702.99
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/20
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM |
|---|---|---|
| | 3 | |
| | 7 | 57 |
| | 9 | |
| | 10 | 40 |
| 5 | 5 | |
| | 7 | 50 |
| | H | |
| | 2 | 28 |
| | 2 | |
| 10 | 2 | 25 |
| | H | |
| | 6 | 21 |
| | H | |
| | 6 | 36 |
| 15 | H | |
| | 5 | 34 |
| | H | |
| | 7 | 38 |
| | 5 | |
| 20 | 6 | 41 |
| | H | |
| | 7 | 42 |
| | H | |
| | 7 | 36 |
| 25 | 28 | |
| | 30 | 44 |
| | 23 | |
| | 18+ | 28 |
| 30 | | |

WELL TYPICAL / SYMBOL



| DESCRIPTION OF MATERIAL | NOTES |
|---|---|
| 0-5' DARK BROWN SILT, TRACE OF CLAY | WELL LOCATED IN MIDDLE OF BERM BETWEEN RETENTION POND & FRESH WATER POND |
| 5'-20' VERY SOFT BLACK SILT WITH MIXED ORGANIC MATTER PEATY | HOLE SQUEEZED SO COULD NOT SET PIPE. FLUSHED HOLE ON 3-21-97 THEN SET WELL 0910-1110 USING STRATTON DRILLING<br>H REFERS TO THE WEIGHT OF THE HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER |
| 20'-27' SANDY SILT (TR CLAY) WITH GREEN/GRAY SAND & YELLOW GRAVEL | |
| 27'-28' SHALE | |

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING
STRATTON DRILLING FINISHED HOLE

LOGGED BY MURRAY R. McCOMAS
DATE MARCH 18, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER

BORING NO. P-10
SHEET 1 OF 1

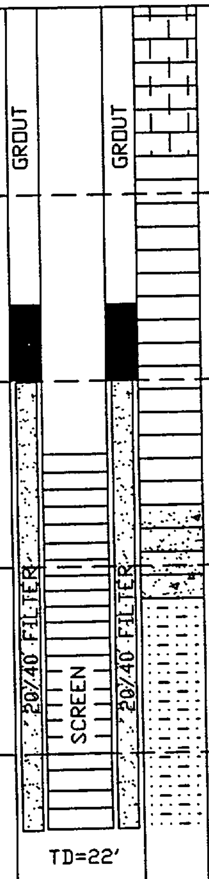
SITE NAME AND LOCATION

KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 1420 | TIME 1530 |
| DATE 3-17-97 | DATE 3-17-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SUNNY
TEMP COOL
G.L. ELEV. 702.6
DATUM MSL
TOC ELEV. 706.19
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | 7 | | | | | WELL LOCATED ON SOUTH END OF EMBANKMENT BETWEEN FRESH WATER POND & RETENTION POND |
| | 9 | 49 | | | | |
| | 5 | | | | 0-4' BROWN SILTY CLAY | |
| | 6 | 51 | | | | |
| 5 | 6 | | | | | |
| | 10 | 36 | | | 4'-8' MOTTLED CLAY FILL | |
| | 4 | | | | | |
| | 5 | 39 | | | | |
| | 6 | | | | 8'-13.5' GREENISH/GRAY CLAY WITH IRON NODULES | |
| 10 | 19 | 33 | | | | |
| | 8 | | | | | |
| | 17 | 45 | | | | |
| | 8 | | | | | |
| | 16 | 45 | | | 13.5'- 16' WELL GRADED SAND WITH CLAY SW-SC | |
| 15 | 5 | | | | | |
| | 9 | 47 | | | | |
| | 16 | | | | | |
| | 42 | 48 | | | 16'-21' TAN WEATHERED SHALE | |
| | 47 | | | | | |
| 20 | 76 | 48 | | | | |
| | 38 | | | | 21'-22' GRAY SHALE | |
| | 53 | | | | | |
| 25 | | | | | | |
| 30 | | | | | | |

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY PETER SCHULTZE

CHK'D BY MRM

DATE MARCH 17, 1997

# SOIL BORING LOG

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER

BORING NO. MWD-2
SHEET 1 OF 1

SITE NAME AND LOCATION

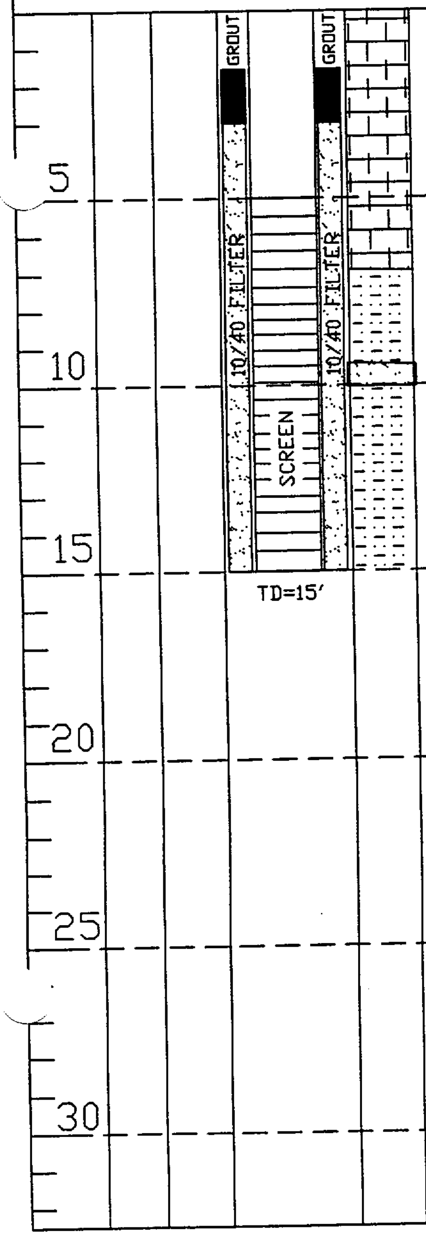
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 0915 | TIME 1015 |
| DATE 3-19-97 | DATE 3-19-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MISTY
TEMP CHILLY
G.L. ELEV. 704.9
DATUM MSL
TOC ELEV. 708.48
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | | | | | 0-7' BROWN SILTY CLAY | WELL MWS-2 IS AN OFFSET TO THE ORIGINAL ST-2 WELL |
| | | | | | 7'-9.5' BROWN SHALE & CLAY/1/2" COAL SEAM AT 9 FEET | |
| | | | | | 9.5'-10' SILTSTONE | |
| | | | | | 10'-15' GRAY SHALE | |



FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR STRATTON DRILLING

LOGGED BY SCOTT McREYNOLDS

DATE MARCH 19, 1997 CHK'D BY MRM

# SOIL BORING LOG

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOONS/2" DIAMETER

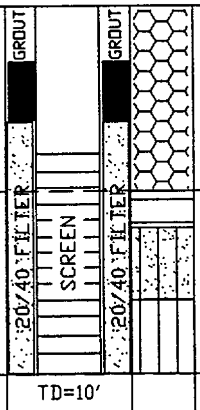
BORING NO. MWS-4
SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 0910 | TIME 0945 |
| DATE 3-19-97 | DATE 3-19-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MISTY TEMP CHILLY
G.L. ELEV. 696.0
DATUM MSL
TOC ELEV. 699.35
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/20
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL |
|---|---|---|---|
| | 14 | | |
| | 16 | 179 | |
| | 6 | | 0-5' GRAY DROSS |
| | 10 | 107 | |
| 5 | 5 | | |
| | 6 | 145 | 5'-6' GREEN/BROWN CLAY |
| | H | | |
| | 4 | 52 | 6'-8' BROWN SILT WITH FINE SAND & ORGANIC FIBERS |
| | 8 | | |
| 10 | 9 | 52 | 8'-10' GRAY SILT |
| 15 | | | |
| 20 | | | |
| 25 | | | |
| 30 | | | |

NOTES

WELL LOCATED ON SPIT IN RETENTION POND-ATOP DROSS

H REFERS TO THE WEIGHT OF THE HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER

FILE: D:DCA/PJ/KAISLOG1

DRILLING CONTR TERRACON DRILLING

LOGGED BY MURRAY R. McCOMAS

DATE MARCH 19, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

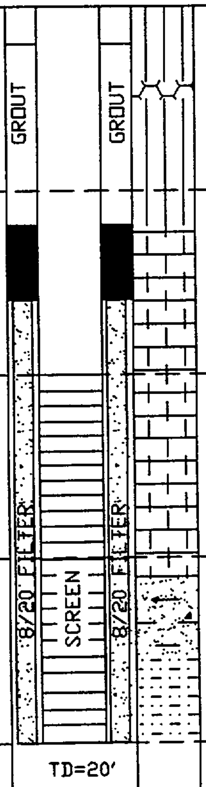
DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

BORING NO. MWD-4
SHEET 1 OF 1

| | | | | | |
|---|---|---|---|---|---|
| WATER LEVEL | | | | | |
| TIME | | | | | |
| DATE | | | | | |
| CASING DEPTH | | | | | |

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 0950 | 1100 |
| DATE | DATE |
| 3-19-97 | 3-19-97 |

WEATHER MISTY TEMP CHILLY
G.L. ELEV. 696.0
DATUM MSL TOC ELEV. 700.24
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 8/20
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|
| | 9 | | 0-2' BROWN/BLACK SILT | WELL LOCATED ON SOUTH BERM/EAST OF SPIT |
| | ROCK | 59 | | |
| | 8 | | 2'-2.4' GRAY DROSS | |
| | 13 | 51 | 2.4'-6' BLACK/BROWN SILT | |
| 5 | 6 | | | |
| | 15 | 46 | | |
| | 9 | | | |
| | 19 | 41 | | |
| | 6 | | 6'-15.5' BROWN/ORANGE CLAY SILTY WITH ORANGE MOTTLING AND BLACK NODULES | |
| 10 | 18 | 48 | | |
| | 8 | | | |
| | 16 | 52 | | |
| | 8 | | CLAY, ORANGE, MOTTLED | |
| | 17 | 44 | | |
| 15 | 8 | | | |
| | 16 | 43 | | |
| | 8 | | 15.5'-17.5' CLAYEY SAND YELLOW SANDSTONE GRAVEL | |
| | 34 | 52 | | |
| | | | 17.5'-20' BROWN WEATHERED SHALE | |
| 20 | | | | |
| 25 | | | | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON DRILLING

LOGGED BY MURRAY R. McCOMAS

DATE MARCH 19, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS

BORING NO. MWS-5

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

SHEET 1 OF 1

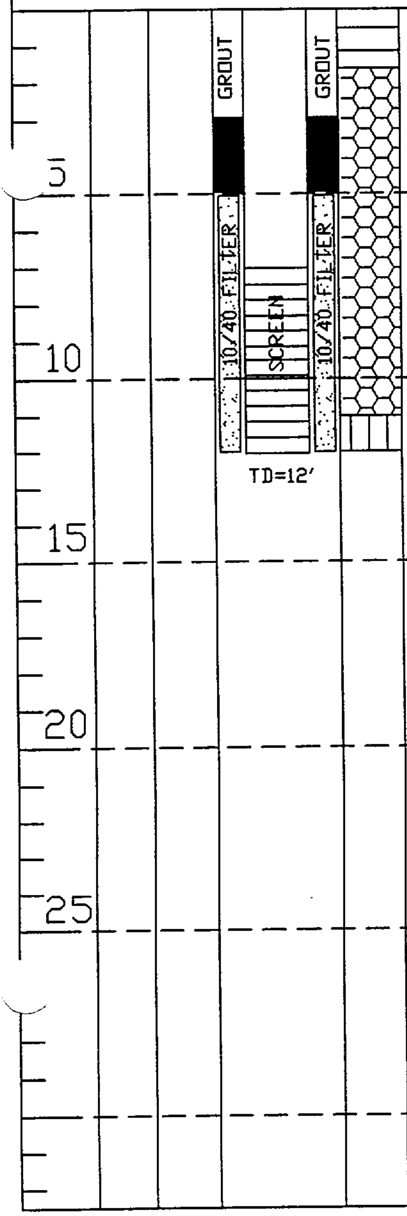
| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

DRILLING

| START | FINISH |
|---|---|
| TIME 1510 | TIME 1540 |
| DATE 3-19-97 | DATE 3-19-97 |

WEATHER MISTY
TEMP CHILLY
G.L. ELEV. 696.0
DATUM MSL
TOC ELEV. 700.12
DRILL RIG CME 75
TYPE GRAVEL: 10/40
CASING DIA: 2 INCH
SCREEN DIA: 2'
ANGLE
BEARING
TYPE BENTONITE: SODIUM
SLOT SIZE: 0.0010
SAMPLE HAMMER TORQUE FT.-LBS

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|



0-1.5' BROWN CLAY

1.5'-11' GRAY DROSS, WET

11'-12' GRAY BROWN SILT

WELL LOCATED ON SOUTH BERM/EAST OF SPIT

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON DRILLING

LOGGED BY MURRAY R. McCOMAS

DATE MARCH 19, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2" DIAMETER

BORING NO. MWD-5
SHEET 1 OF 1

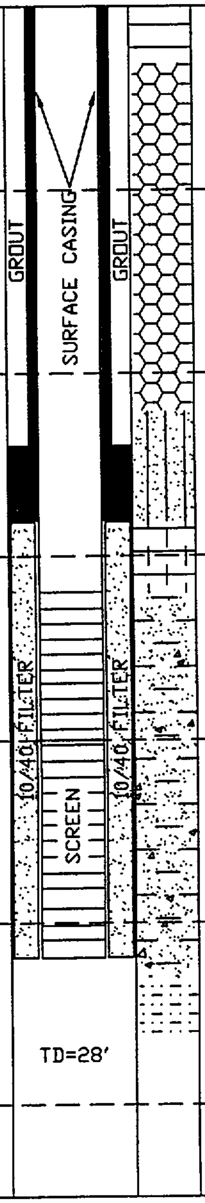
SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME 1257 | TIME 1435 |
| DATE 3-19-97 | DATE 3-19-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MISTY    TEMP CHILLY
G.L. ELEV. 696.1
DATUM MSL    TOC ELEV. 699.76
DRILL RIG CME 75
ANGLE    BEARING
SAMPLE HAMMER TORQUE    FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 0.0010

DRILLING CONTR TERRACON DRILLING



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL |
|---|---|---|---|
| | 5 | | 0-1.5' BROWN CLAY |
| | 11 | 55 | |
| | 3 | | |
| | 6 | 50 | |
| 5 | H | | |
| | 3 | 50 | 1.5'-11' GRAY DROSS, WET, LOOSE RUNNING INTO HOLE |
| | 5 | | |
| | 6 | 220 | |
| | H | | |
| 10 | H | 236 | |
| | 8 | | 11'-14' SILT, SANDY, GRAY/BROWN |
| | 13 | 272 | |
| | 2 | | |
| | 6 | 60 | |
| 15 | 7 | | 14'-16' BROWN SILTY CLAY |
| | 18 | 63 | 16'-26.5' CLAYEY SAND BROWN SANDSTONE FRAGMENTS |
| | 7 | | |
| | 11 | 61 | |
| | 2 | | |
| 20 | 6 | 45 | |
| | 7 | | |
| | 18 | 50 | |
| | 6 | | |
| | 16 | 41 | |
| 25 | 11 | | |
| | 30 | 40 | 26.5'-28' BROWN SHALE |
| | 30 | | |
| | 50 | 46 | |

NOTES

WELL LOCATED ON BERM EAST SIDE OF RETENTION POND

ORIGINAL HOLE PLUGGED WITH QUIKSET TO AVOID CROSS CONTAMINATION. REDRILL 3-21-97 & SET 8 INCH CASING 0-12 FEET/ DRILL OUT UNDER CASING TO SET WELL.

H REFERS TO THE WEIGHT OF THE HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER

FILE: D:DCA/PJ/KAISLOG2

LOGGED BY MURRAY R. McCOMAS    CHK'D BY MRM
DATE MARCH 19, 1997

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2" SPLIT SPOON
BORING REAMED WITH 6" FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2" DIAMETER

BORING NO. MWS-6
SHEET 1 OF 1

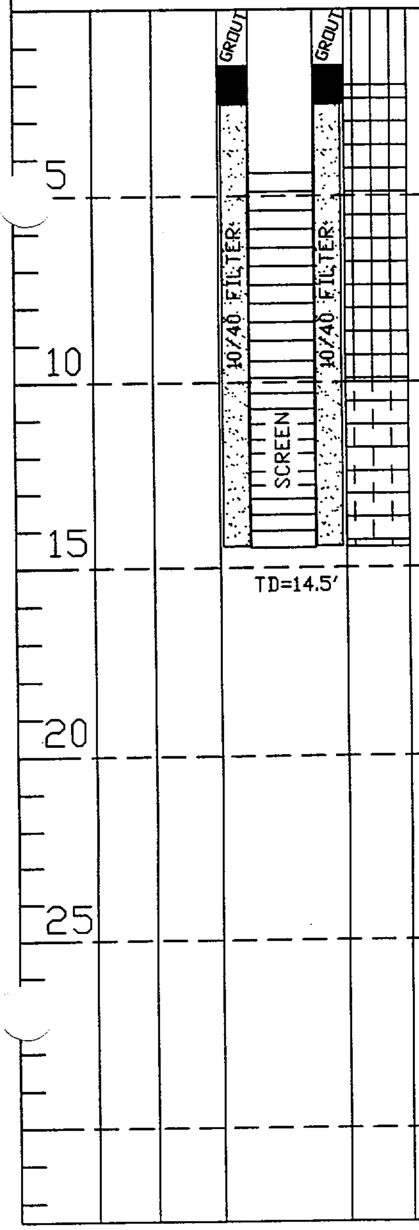
SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 1030 | 1130 |
| DATE | DATE |
| 3-20-97 | 3-20-97 |

WEATHER SUNNY TEMP COOL
G.L. ELEV. 695.6
DATUM MSL TOC ELEV. 699.55
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2"
SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| 0-2' | | | | | DARK BROWN SILT | WELL OFFSET TO MWD-6 |
| 2-10' | | | | | DARK BROWN ORGANIC SILT WITH CLAY | |
| 10'-14.5' | | | | | DARK BROWN SILTY CLAY WITH ORGANIC MATTER AND IRON NODULES | |



FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON DRILLING

LOGGED BY PETER SCHULTZE

DATE MARCH 20, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

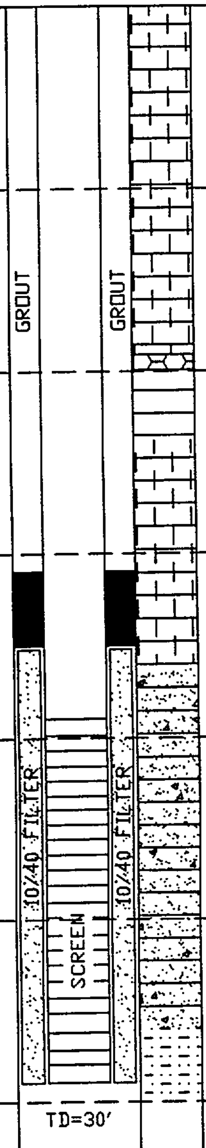
DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

BORING NO. MWD-6
SHEET 1 OF 1

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 0800 | 1022 |
| DATE | DATE |
| 3-20-97 | 3-20-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SUNNY TEMP COOL
G.L. ELEV. 695.7
DATUM MSL
TOC ELEV. 699.62
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL |
|---|---|---|---|
| | 6 | | |
| | 13 | 45 | |
| | 6 | | |
| | 11 | 48 | |
| 5 | 5 | | 0-9.5' DARK BROWN SILTY CLAY |
| | 10 | 36 | |
| | 7 | | |
| | 11 | 43 | |
| | 8 | | |
| 10 | 9 | 87 | 9.5'-10' GRAY DROSS |
| | 7 | | 10'-12' BROWN CLAY WITH ORGANIC MATTER |
| | 8 | 40 | |
| | 7 | | |
| | 9 | 36 | |
| 15 | 3 | | |
| | 9 | 36 | 12'-18' BROWN/TAN SILTY CLAY MOTTLED WITH IRON NODULES |
| | 8 | | |
| | 13 | 37 | |
| | 5 | | |
| 20 | 9 | 43 | |
| | 4 | | |
| | 8 | 38 | |
| | 3 | | 18'-28' SANDY CLAY WITH GRAVEL SC |
| | 8 | 37 | |
| 25 | 5 | | |
| | 9 | 33 | |
| | 5 | | |
| | 13 | 50 | |
| | | | 28'-30' BROWN WEATHERED SHALE |

NOTES

WELL LOCATED AT WEST EDGE OF FILLED RESERVE POND LOCATED ADJACENT TO THE RETENTION POND

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON DRILLING

LOGGED BY SCOTT McREYNOLDS CHK'D BY MRM

DATE MARCH 20, 1997

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS

BORING NO. MWD-7
SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

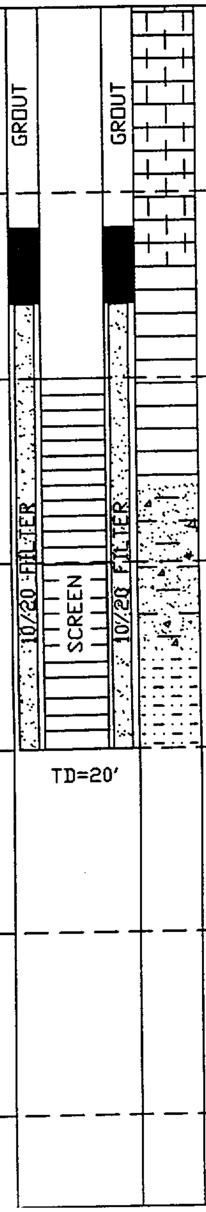
SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 0840 | 1035 |
| DATE | DATE |
| 3-20-97 | 3-20-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SUNNY TEMP COOL
G.L. ELEV. 686.0
DATUM MSL TOC ELEV. 689.83
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | 5 | | | | | WELL LOCATED AT NORTHEAST CORNER OF PROPERTY ON NORTH SIDE OF FULTON CREEK/BESIDE ST-3 |
| | 6 | | | | | |
| | 5 | | | | 0-7' MOTTLED GRAY SILTY CLAY | |
| | 11 | | | | | |
| 5 | 5 | | | | | |
| | 12 | | | | | |
| | 7 | | | | | |
| | 13 | | | | | |
| | 8 | | | | | |
| 10 | 14 | | | | 7'-13' TAN/BROWN/GRAY MOTTLED PLASTIC CLAY | |
| | 8 | | | | | |
| | 16 | | | | | |
| | 4 | | | | | |
| | 10 | | | | | |
| 15 | 10 | | | | | |
| | 14 | | | | 13'-17.5' CLAYEY SAND, WITH GRAVEL | |
| | 2 | | | | | |
| | 13 | | | | | |
| | 30 | | | | 17.5'-20' WEATHERED SHALE | |
| 20 | 56 | | | | | |
| 25 | | | | | | |



FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR STRATTON DRILLING

LOGGED BY MURRAY R. McCOMAS/SCOTT McREYNOLDS (OBSERVER)

CHK'D BY MRM

DATE MARCH 20, 1997

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS

SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

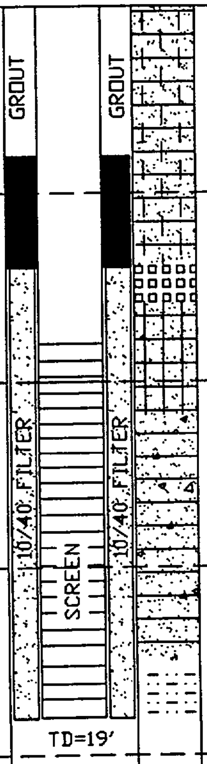
BORING NO. MWD-8
SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 1040 | 1145 |
| DATE | DATE |
| 3-21-97 | 3-21-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SUNNY TEMP COOL
G.L. ELEV. 684.3
DATUM MSL
TOC ELEV. 688.15
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|
| | 2 | | | |
| | 7 | 32 | | WELL LOCATED IN NORTHEAST LOW PART OF FILLED RESERVE POND-(THIS IS A FIELD ADDED WELL LOCATION) |
| | 4 | | 0-7' SILTY CLAY & SANDY FILL | |
| | 5 | 45 | | |
| 5 | 2 | | | |
| | 2 | 55 | | |
| | 3 | | | |
| | 3 | 45 | 7'-8' BRICK FRAGMENTS | |
| | H | | | H REFERS TO THE WEIGHT OF THE HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER |
| 10 | 3 | 30 | 8'-11' SANDY CLAY WITH SILT/SOFT & WET | |
| | 4 | | | |
| | 14 | 29 | | |
| | 3 | | | |
| | 8 | 27 | 11'-17.5' CLAYEY SAND WITH SANDSTONE GRAVEL PIECES SC | |
| 15 | 5 | | | |
| | 7 | 31 | | |
| | 5 | | | |
| | 20 | 31 | | |
| | | | 17.5'-19' BROWN SHALE | |
| 20 | | | | |
| 25 | | | | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON DRILLING

LOGGED BY PETER SCHULTZE

DATE MARCH 21, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

DRILLING METHOD: AIR ROTARY

SAMPLING METHOD: 2' SPLIT SPOON/2" DIAMETER

BORING NO. MWD-9

SHEET 1 OF 1

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 1125 | 1330 |
| DATE | DATE |
| 3-20-97 | 3-20-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER CLEAR

TEMP COOL

G.L. ELEV. 690.6

DATUM MSL

TOC ELEV. 692.86

DRILL RIG DAISY/KENT DK 40

TYPE GRAVEL: 10/40

CASING DIA: 2 INCH

SCREEN DIA: 2"

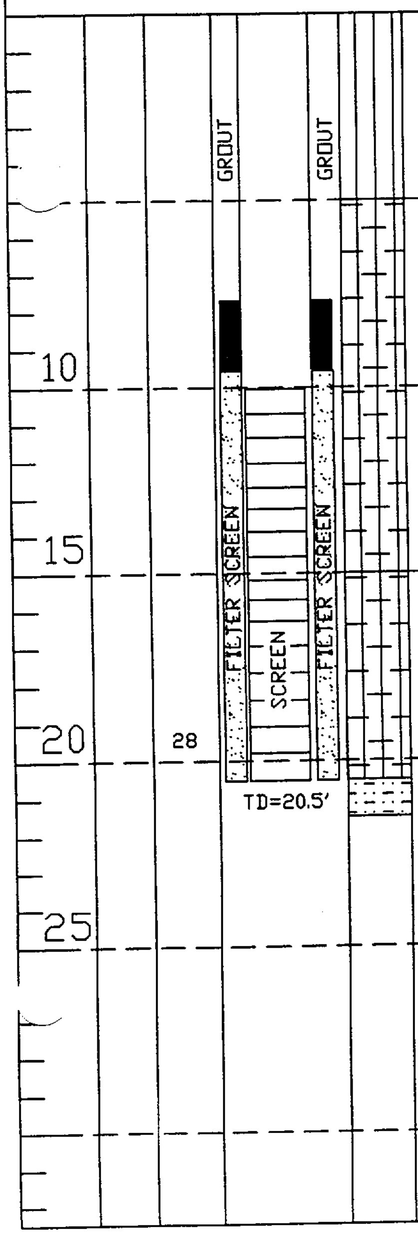
ANGLE

BEARING

TYPE BENTONITE: SODIUM

SLOT SIZE: 0.0010

SAMPLE HAMMER TORQUE FT.-LBS



| DESCRIPTION OF MATERIAL | NOTES |
|---|---|
| 0-5' BLACK SILT WITH ORGANIC FIBERS | WELL LOCATED NORTH OF FULTON CREEK, SOUTH OF FENCE LINE. ACCESS THROUGH SAIA TRUCKING AIR DRILLED<br>COLLECT 5' SAMPLE FOR DESCRIPTION ONLY |
| 5'-15' BROWN SILT WITH CLAY & BLACK SPECS | |
| 15'-20.5' BROWN SILT/MOIST | |
| SHALE BROWN | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR STRATTON DRILLING

LOGGED BY MURRAY R. McCOMAS

DATE 3-20-97 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

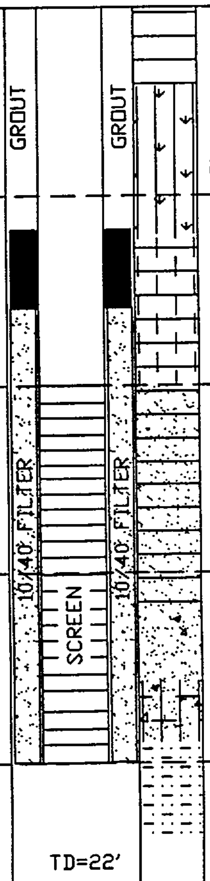
BORING NO. MWD-10
SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 0755 | 0915 |
| DATE | DATE |
| 3-18-97 | 3-18-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER MUGGY TEMP WARM
G.L. ELEV. 696.8
DATUM MSL TOC ELEV. 700.50
DRILL RIG CME 75
ANGLE BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/20
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010



| DEPTH IN FEET | BLOW COUNT | CPM | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|
| | 6 | | | WELL LOCATED ATOP BERM ON NORTH SIDE OF RETENTION POND |
| | 12 | 35 | 0-2' BLACK CLAY FILL | |
| | 8 | | | |
| | 13 | 35 | | |
| 5 | 8 | | 2'-6' BROWN SILT/ORGANIC (PEATY ORGANIC SILT) | |
| | 14 | 36 | | |
| | 9 | | | |
| | 17 | 40 | 6'-10' GRAY/BROWN SILTY CLAY | |
| | 8 | | | |
| 10 | 16 | 37 | | |
| | 8 | | | |
| | 16 | 34 | | |
| | 8 | | 10'-16' GRAY SANDY CLAY MOTTLED WITH ORANGE | |
| | 15 | 31 | | FIRST WATER AT 14 FEET |
| 15 | 5 | | | |
| | 9 | 45 | 16'-18' SAND AND GRAVEL | H REFERS TO WEIGHT OF HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER |
| | H | | | |
| | H | 37 | | |
| | 16 | | 18'-19.5' SILT AND CLAYEY SAND WITH GRAVEL (SANDSTONE PIECES) | |
| 20 | 19 | 34 | | |
| | 32 | | 19.5'-22' BROWN SHALE | |
| | 90 | 44 | | |
| 25 | | | | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON DRILLING

LOGGED BY MURRAY R. McCOMAS

CHK'D BY MRM

DATE MARCH 18, 1997

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

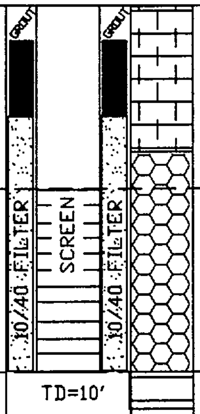
BORING NO. MWS-11
SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

| DRILLING | START | FINISH |
|---|---|---|
| TIME | 1315 | 1430 |
| DATE | 3-20-97 | 3-20-97 |

WATER LEVEL
TIME
DATE
CASING DEPTH

WEATHER
TEMP
G.L. ELEV.
DATUM
TOC ELEV.
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL:
TYPE BENTONITE:
CASING DIA:
SCREEN DIA:
SLOT SIZE:



| DEPTH IN FEET | BLOW COUNT | CPS | DESCRIPTION OF MATERIAL |
|---|---|---|---|
| | 5 | | |
| | 9 | 46 | 0-4' BROWN SILTY CLAY |
| | 10 | | |
| | 7 | 65 | |
| 5 | H | | |
| | 1 | 182 | |
| | H | | 4'-10' GRAY DROSS |
| | H | 134 | |
| | H | | |
| 10 | 2 | 93 | BROWN CLAY ENCOUNTERED AT 10 FEET |
| 15 | | | |
| 20 | | | |
| 25 | | | |

NOTES

WELL LOCATED ON NORTH SIDE OF FILLED RESERVE POND/ON SOUTH SIDE OF FULTON CREEK (REPLACES MWS-8 LOCATION)

H REFERS TO THE WEIGHT OF THE HAMMER-NO BLOW COUNT/SPLIT SPOON PENETRATED WITH THE WEIGHT OF THE HAMMER

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR STRATTON DRILLING

LOGGED BY SCOTT McREYNOLDS

DATE MARCH 20, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

DRILLING METHOD: 2' SPLIT SPOON
BORING REAMED WITH 6' FLIGHT AUGERS
SAMPLING METHOD: 2' SPLIT SPOON/2' DIAMETER

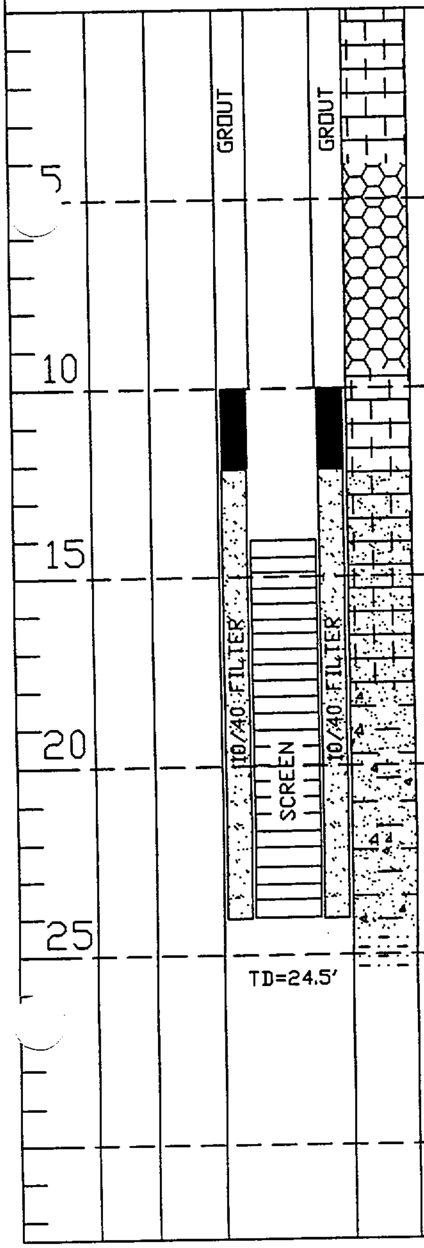
BORING NO. MWD-11
SHEET 1 OF 1

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| 1030 | 1130 |
| DATE | DATE |
| 3-21-97 | 3-21-97 |

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER SUNNY
TEMP WARM
G.L. ELEV. 693.7
DATUM MSL
TOC ELEV. 697.83
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL: 10/40
TYPE BENTONITE: SODIUM
CASING DIA: 2 INCH
SCREEN DIA: 2'
SLOT SIZE: 0.0010

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|



0-4' BROWN SILTY CLAY

4'-9.5' GRAY DROSS

9.5'-12' SILTY CLAY

12'-18' SILTY CLAY WITH SAND

18'-24.5' CLAYEY SAND AND TRACE OF SANDSTONE GRAVEL

SHALE ENCOUNTERED RIGHT AT 24.5'

WELL LOCATED ON NORTH SIDE OF FILLED RESERVE POND/ON SOUTH SIDE OF FULTON CREEK-OFFSETS MWS-11

DRILL TO 11' WITH 14" AUGER

8-INCH SURFACE CASING SET 0 - 11'

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR STRATTON DRILLING

LOGGED BY SCOTT McREYNOLDS

DATE MARCH 21, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 14" FLIGHT AUGER 0-20 FEET

BORING NO. ST-1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

SHEET 1 OF 4

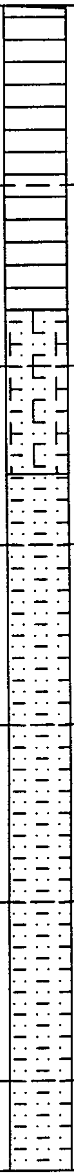
SAMPLING METHOD:

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| DATE 3-6-97 | DATE |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER
TEMP
G.L. ELEV.
DATUM MSL
TOC ELEV.
DRILL RIG CME 75
TYPE GRAVEL:
CASING DIA:
SCREEN DIA:
ANGLE
BEARING
TYPE BENTONITE:
SURFACE CASING 10" AT 0-20 FEET
SLOT SIZE:
SAMPLE HAMMER TORQUE FT.-LBS

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|



- 0-17' TAN CLAY
- 10
- 17'-26' BROWN-BLUE WEATHERED SHALE
- 20
- 26'-30' GRAY-BLUE SHALE WITH BANDS OF BLUE TAN SILT/SHALE LAYERS
- 30
- 30'-32.3' BLACK TO BLUE-GRAY SHALE, SOFT, RED-BROWN IRON STREAKS.
- SOFT AND FISSLE 31'-32'
- 32.2'-200 BLACK SHALE, HARD
- 38'-39.6' BRITTLE, FRACTURED VERTICALLY
- 40
- 50
- 58.5' TAN-BLACK SILTSTONE BAND,NON-CALCITIC
- 60

NOTES:

TESTHOLE PLUGGED AND ABANDONED-PUMPED GROUT FROM 200 FEET TO SURFACE.

SPLIT SPOONS 0-20 FEET

CORED 20'-80'

AIR DRILLED 80'-200'

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON (0-80')/STATTON (80'-200')

LOGGED BY PETER SCHULTZE

DATE MARCH 6, 1997 CHK'D BY

# SOIL BORING LOG

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

DRILLING METHOD: 14" FLIGHT AUGER 0-20 FEET

BORING NO. ST-1

SHEET 2 OF 4

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

SAMPLING METHOD:

DRILLING

| START | FINISH |
|---|---|
| TIME | TIME |
| DATE 3-6-97 | DATE |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER TEMP

G.L. ELEV.

DATUM MSL

TOC ELEV.

DRILL RIG CME 75

TYPE GRAVEL:

CASING DIA:

SCREEN DIA:

ANGLE BEARING

TYPE BENTONITE:

SURFACE CASING 10" AT 0-20 FEET

SLOT SIZE:

SAMPLE HAMMER TORQUE FT.-LBS

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | | | | | BRACHIOPOD<br>64.5', 65.7', 66.5', 68.5' & 69' SILTSTONE LAYER, HARD, NON-CALCITIC, EACH 1" THICK | |
| 70 | | | | | | |
| | | | | | 75' BECOMING SANDY, VERY FINE GRAINED, BANDED | |
| | | | | | 79' SILTSTONE LAYER, 1/4" THICK | |
| 80 | | | | | 80'-200' BLACK SHALE, HARD | AIR DRILLED 80'-200' |
| 90 | | | | | | |
| 100 | | | | | | |
| 110 | | | | | | |
| 120 | | | | | | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON (0-80')/STATTON (80'-200')

LOGGED BY PETER SCHULTZE

DATE MARCH 6, 1997 CHK'D BY MRM

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

| | |
|---|---|
| SITE NAME AND LOCATION | KAISER ALUMINUM<br>7311 EAST 41ST STREET<br>TULSA, OKLAHOMA 74147 |
| DRILLING METHOD: | 14" FLIGHT AUGER 0-20 FEET |
| SAMPLING METHOD: | |
| BORING NO. | ST-1 |
| SHEET | 3 OF 4 |
| DRILLING START TIME | |
| DRILLING FINISH TIME | |
| DRILLING START DATE | 3-6-97 |
| DRILLING FINISH DATE | |
| WATER LEVEL | |
| TIME | |
| DATE | |
| CASING DEPTH | |
| WEATHER | |
| TEMP | |
| G.L. ELEV. | |
| DATUM | MSL |
| TOC ELEV. | |
| DRILL RIG | CME 75 |
| TYPE GRAVEL: | |
| CASING DIA: | |
| SCREEN DIA: | |
| ANGLE | |
| BEARING | |
| TYPE BENTONITE: | |
| SURFACE CASING | 10" AT 0-20 FEET |
| SLOT SIZE: | |
| SAMPLE HAMMER TORQUE FT.-LBS | |

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | | | | | 80'-200' BLACK SHALE, HARD | AIR DRILLED 80'-200' |
| 30 | | | | | | |
| 140 | | | | | 80'-200' BLACK SHALE, HARD | AIR DRILLED 80'-200' |
| 150 | | | | | | |
| 160 | | | | | | |
| 170 | | | | | | |
| 180 | | | | | | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON (0-80')/STATTON (80'-200')

LOGGED BY PETER SCHULTZE

DATE MARCH 6, 1997 CHK'D BY MRM

# SOIL BORING LOG

A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

DRILLING METHOD: 14' FLIGHT AUGER 0-20 FEET

SAMPLING METHOD:

BORING NO. ST-1

SHEET 4 OF 4

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| DATE<br>3-6-97 | DATE |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER
TEMP
G.L. ELEV.
DATUM MSL
TOC ELEV.
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL:
TYPE BENTONITE:
CASING DIA:
SURFACE CASING 10" AT 0-20 FEET
SCREEN DIA:
SLOT SIZE:

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|
| | | | | | 80'-200' BLACK SHALE, HARD | AIR DRILLED 80'-200' |
| 190 | | | | | | |
| 200 | | | | | TD = 200' | |
| 210 | | | | | | |
| 220 | | | | | | |
| 230 | | | | | | |
| 240 | | | | | | |

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON (0-80')/STATTON (80'-200')

LOGGED BY PETER SCHULTZE

DATE MARCH 6, 1997 CHK'D BY MRM

# SOIL BORING LOG

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

DRILLING METHOD: 14' FLIGHT AUGER 0-13 FEET

BORING NO. ST-2

SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

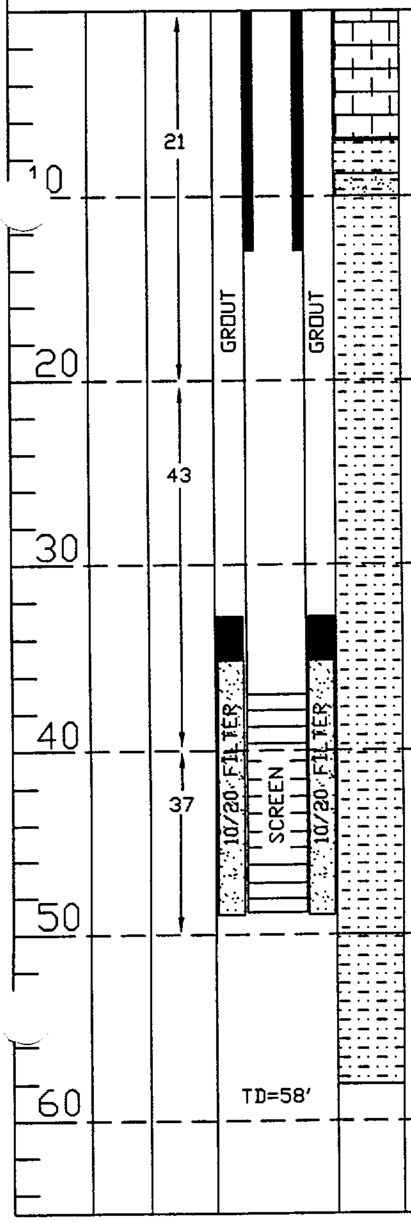
SAMPLING METHOD:

| | | | | |
|---|---|---|---|---|
| WATER LEVEL | | | | |
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| | |
| DATE | DATE |
| 3-14-97 | 3-17-97 |

WEATHER
TEMP
G.L. ELEV.
DATUM MSL
TOC ELEV.
DRILL RIG CME 75
ANGLE
BEARING
SAMPLE HAMMER TORQUE FT.-LBS
TYPE GRAVEL:
TYPE BENTONITE:
CASING DIA:
SURFACE CASING
8' AT 0-13 FEET
SCREEN DIA:
SLOT SIZE:

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|



0-7' BROWN SILTY CLAY/MOIST

7'-9' TAN SHALE

9'-9.5' DARK GRAY SHALE/SILTSTONE SEAM

9.5'-50' GRAY SHALE/HARD FISSLE

BLACK FRACTURED SHALE LAYER AT 38.8 FEET

WELL STARTED BY PETER SCHULTZE/COMPLETED BY IRFAN TANER

8-INCH SURFACE CASING 0 - 13'

CORED 13' - 50' AIR DRILLED 50' - 58'

BACKFILL 48' TO 58' WITH BENSEAL HOLE PLUG

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR STRATTON DRILLING

LOGGED BY PETER SCHULTZE

CHK'D BY MRM

DATE MARCH 14-17, 1997

# SOIL BORING LOG

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**

DRILLING METHOD: 14" FLIGHT AUGER 0-20 FEET

BORING NO. ST-3

SHEET 1 OF 1

SITE NAME AND LOCATION
KAISER ALUMINUM
7311 EAST 41ST STREET
TULSA, OKLAHOMA 74147

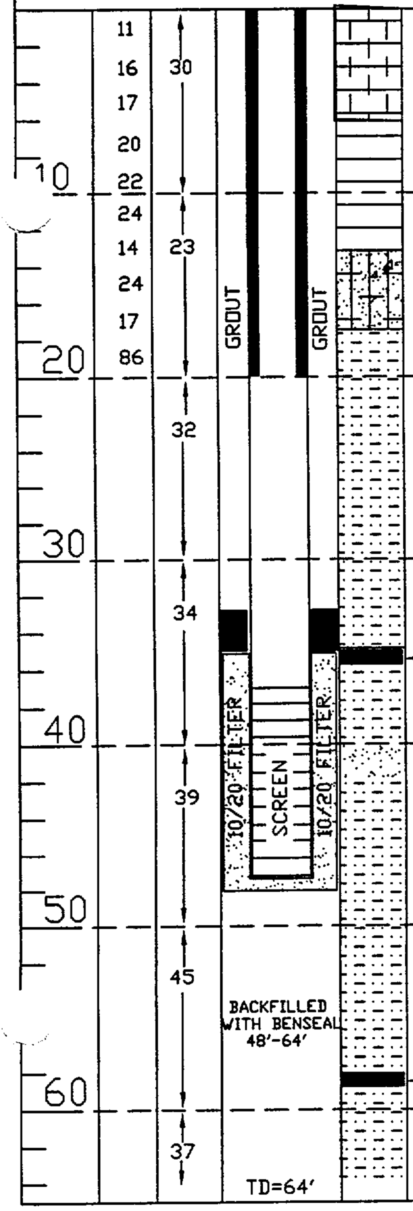
SAMPLING METHOD:

| DRILLING | |
|---|---|
| START | FINISH |
| TIME | TIME |
| DATE | DATE 4-11-97 |

| WATER LEVEL | | | | |
|---|---|---|---|---|
| TIME | | | | |
| DATE | | | | |
| CASING DEPTH | | | | |

WEATHER
TEMP
G.L. ELEV.
DATUM MSL
TOC ELEV.
DRILL RIG CME 75
TYPE GRAVEL:
CASING DIA:
SCREEN DIA:
ANGLE
BEARING
TYPE BENTONITE:
SURFACE CASING 10" AT 0-20 FEET
SLOT SIZE:
SAMPLE HAMMER TORQUE FT.-LBS

| DEPTH IN FEET | BLOW COUNT | CPM | WELL TYPICAL | SYMBOL | DESCRIPTION OF MATERIAL | NOTES |
|---|---|---|---|---|---|---|



DESCRIPTION OF MATERIAL

0-6' TAN SILTY CLAY

6'-13' MOTTLED GRAY CLAY

13'-17.5' CLAYEY SAND WITH SILT AND GRAVEL

12'-40' DARK GRAY SHALE

HARD SILTSTONE LAYER

40'-42' SOFT & LOOSE SAND (FRACTURE FILL?)

42'-64' DARK GRAY SHALE/HARD

HARD SILTSTONE LAYER

NOTES

SPLIT SPOON SAMPLES 0-20 FEET

SET 10" SURFACE CASING FROM 0-20 FEET

SINGLE PACKER TEST FROM SURFACE TO 21 FEET ON 3-31-97

CORED FROM 20'- 54'

SINGLE PACKER TEST FROM SURFACE TO 48.7 FEET ON 3-31-97

AIR DRILLED FROM 54'-64'

FILE: D:DCA/PJ/KAISLOG2

DRILLING CONTR TERRACON (0-54')/STRATTON (54'-64')

LOGGED BY IRFAN TANER

CHK'D BY MRM

DATE APRIL 11, 1997

# APPENDIX B

# GEOPHYSICAL LOGS FROM STRATIGRAPHIC TESTS

# GEOPHYSICAL LOGGING

The three stratigraphic test holes were logged using downhole geophysical logging techniques. Each hole was logged by Century Geophysical Corporation. The suite of logs included SP (Spontaneous Potential), Gamma Ray, Caliper (Hole Diameter), Resistivity and Density. Geophysical logging involves lowering sensing devices in a borehole and recording a physical parameter that may be interpreted in terms of formation characteristics such as groundwater quality, quantity and physical structure of the borehole.

The spontaneous potential method measures natural electric potentials within the rock. The potentials are produced by electrochemical cells formed by electrical conductivity differences of drilling fluid (water in this case) and groundwater in permeable zones. Where no sharp contrasts occur in permeable zones, potential logs may be a straight line. Potential values range from zero to several hundred millivolts. Potential logs are read in terms of positive and negative deflections from an arbitrary baseline, usually associated with an impermeable formation of considerable thickness.

Natural gamma ray logging records the natural gamma radiation from unstable isotopes of potassium, uranium and thorium. In general, the natural gamma activity of clayey formations is significantly higher than that of quartz sands and carbonate rocks. The most important application to hydrogeology is identification of lithology, particularly clay or shale units.

Within an uncased well, current and potential electrodes can be lowered to measure electrical resistivities of the surrounding media and to obtain a trace of their variation with depth. The result is a resistivity log which is affected by fluid in the well, well diameter, character of the surrounding strata and by groundwater.

The caliper log provides a record of the average diameter of the borehole. These logs aid in the location of fractures, rock openings and washed out zones.

The density log is actually a gamma-gamma log. The primary applications of the gamma log are for identification of lithology and measurement of bulk density and porosity of rocks. This log is the result of gamma radiation originating from a source probe and recorded after it is backscattered and attenuated within the borehole and surrounding formation. The source generally contains cobalt-60 or cesium-137 which is shielded from a sodium iodide detector built into the probe.

Using the suite of downhole geophysical logs, A & M Engineering was able to define fractured zones, permeable zones, changes in lithology and general water quality in the Nowata Shale.

**Century GEOPHYSICAL CORP.**

ST-1

COMPANY : A & M ENGINEERING
WELL : ST-1
LOCATION/FIELD : KAISER ALUMINUM
COUNTY : TULSA
STATE : OK

OTHER SERVICES:

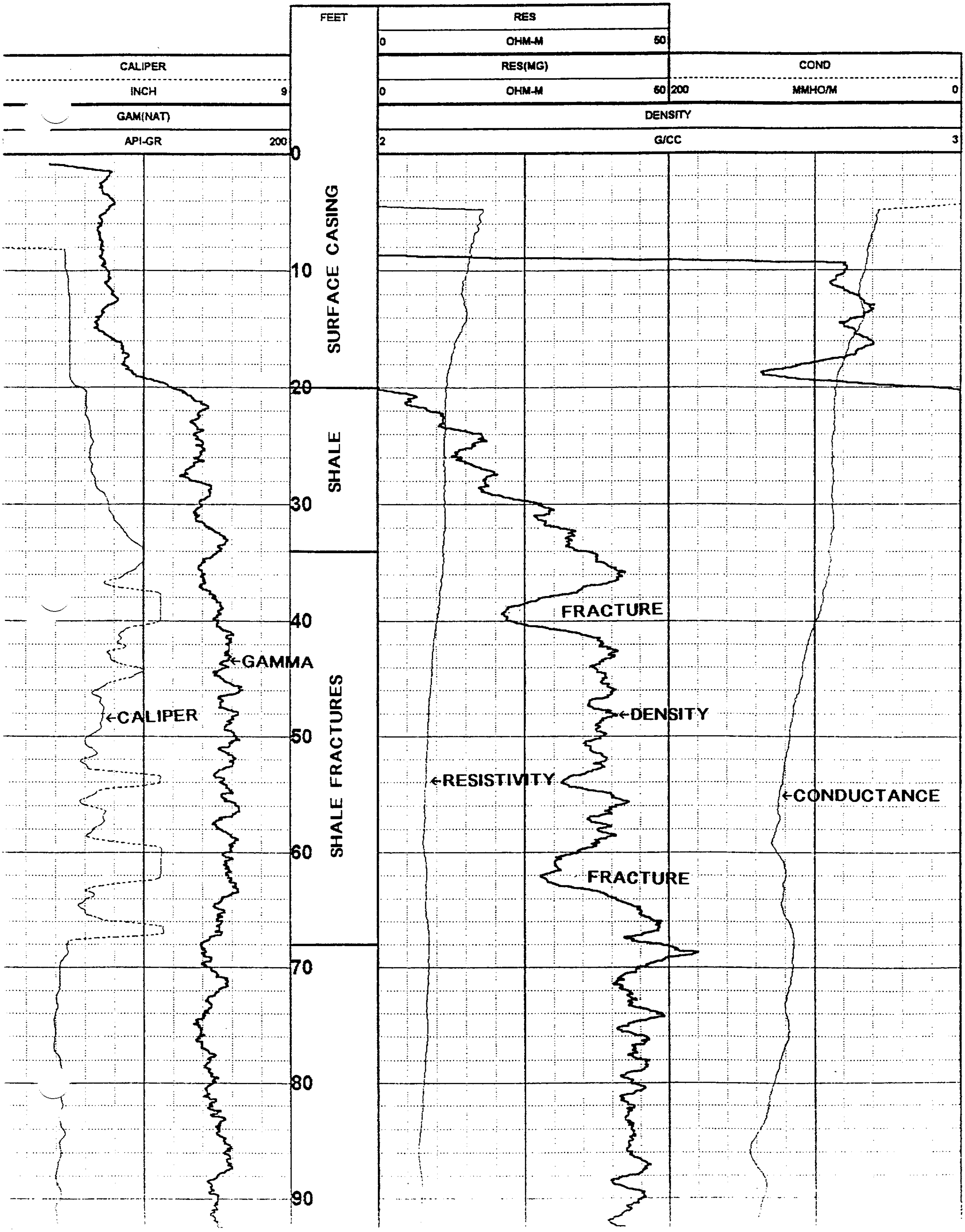
| | | | | | |
|---|---|---|---|---|---|
| SECTION | : | TOWNSHIP | : | RANGE | : |
| DATE | : 03/19/97 | PERMANENT DATUM | : GL | ELEVATIONS: | |
| DEPTH DRILLER | : 200 | ELEV. PERM. DATUM | : GL | KB | : N/A |
| LOG BOTTOM | : 199.10 | LOG MEASURED FROM | : GL | DF | : N/A |
| LOG TOP | : 0.20 | DRL MEASURED FROM | : GL | GL | : |
| CAS[illegible] RILLER | : 20 | LOGGING UNIT | : 9403 | | |
| CA[illegible] TYPE | : PVC | FIELD OFFICE | : TULSA,OK | | |
| CASING THICKNESS | : .25 | RECORDED BY | : B. PETERSON | | |
| BIT SIZE | : 6.0 | BOREHOLE FLUID | : H20 | FILE | : ORIGINAL |
| MAGNETIC DECL. | : 8.5 | RM | : | TYPE | : 9511A |
| MATRIX DENSITY | : 2.71 | RM TEMPERATURE | : 00 | LOG | : 3. |
| FLUID DENSITY | : 1.11 | MATRIX DELTA T | : 57 | PLOT | : |
| NEUTRON MATRIX | : SANDSTONE | FLUID DELTA T | : 210 | THRESH: | 5000 |

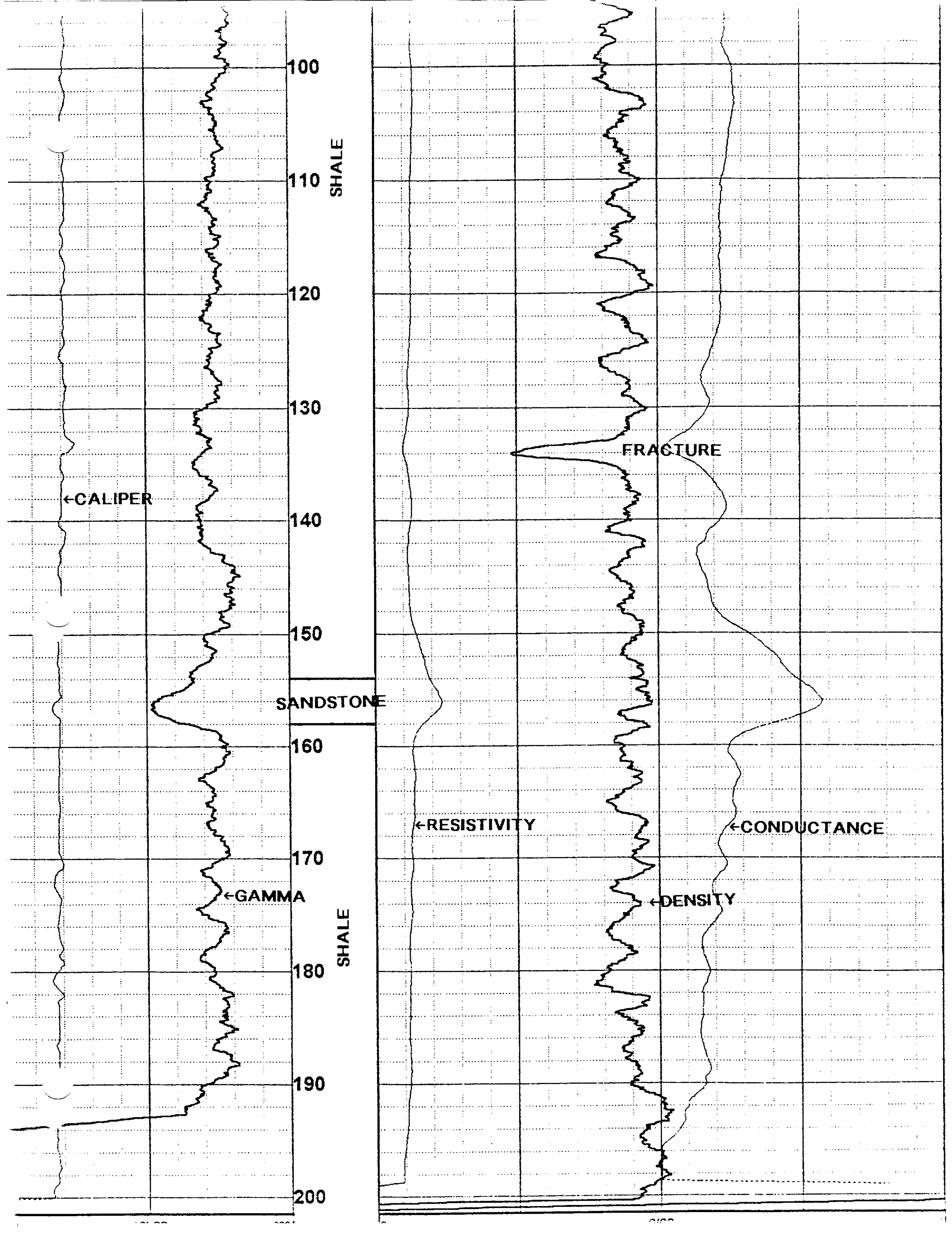
REMARKS:

NONE

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS

FIGURE 4-12


FEET
RES
0
OHM-M
50
CALIPER
RES(MG)
COND
INCH
9
0
OHM-M
50
200
MMHO/M
0
GAM(NAT)
DENSITY
API-GR
200
2
G/CC
3
0
10
20
30
40
50
60
70
80
90
SURFACE CASING
SHALE
SHALE FRACTURES
FRACTURE
←GAMMA
←CALIPER
←DENSITY
←RESISTIVITY
←CONDUCTANCE
FRACTURE


100
110
SHALE
120
130
FRACTURE
←CALIPER
140
150
SANDSTONE
160
←RESISTIVITY
←CONDUCTANCE
170
←GAMMA
←DENSITY
SHALE
180
190
200

GAM(NAT)

5 INCH 9

CALIPER

FEET

DENSITY

0 OHM-M 50

RES(MG)

0 OHM-M 50

RES

200 MMHO/M 0

COND

CGC

Century
GEOPHYSICAL CORP.

ST-2

COMPANY : A & M ENGINEERING
WELL : ST-2
LOCATION/FIELD : KAISER ALUMINUM
COUNTY : TULSA
STATE : OK

OTHER SERVICES:

SECTION :
TOWNSHIP :
RANGE :

DATE : 03/19/97
DEPTH DRILLER : 60
LOG BOTTOM : 59.40
LOG TOP : -1.20

PERMANENT DATUM : GL
ELEV. PERM. DATUM : GL
LOG MEASURED FROM: GL
DRL MEASURED FROM : GL

ELEVATIONS:
KB : N/A
DF : N/A
GL :

CA[illegible] DRILLER : 13
CASING TYPE : PVC
CASING THICKNESS: .25

LOGGING UNIT : 9403
FIELD OFFICE : TULSA,OK
RECORDED BY : B. PETERSON

BIT SIZE : 6.0
MAGNETIC DECL. : 8.5
MATRIX DENSITY : 2.71
FLUID DENSITY : 1.11
NEUTRON MATRIX : SANDSTONE

BOREHOLE FLUID : H20
RM :
RM TEMPERATURE : 00
MATRIX DELTA T : 57
FLUID DELTA T : 210

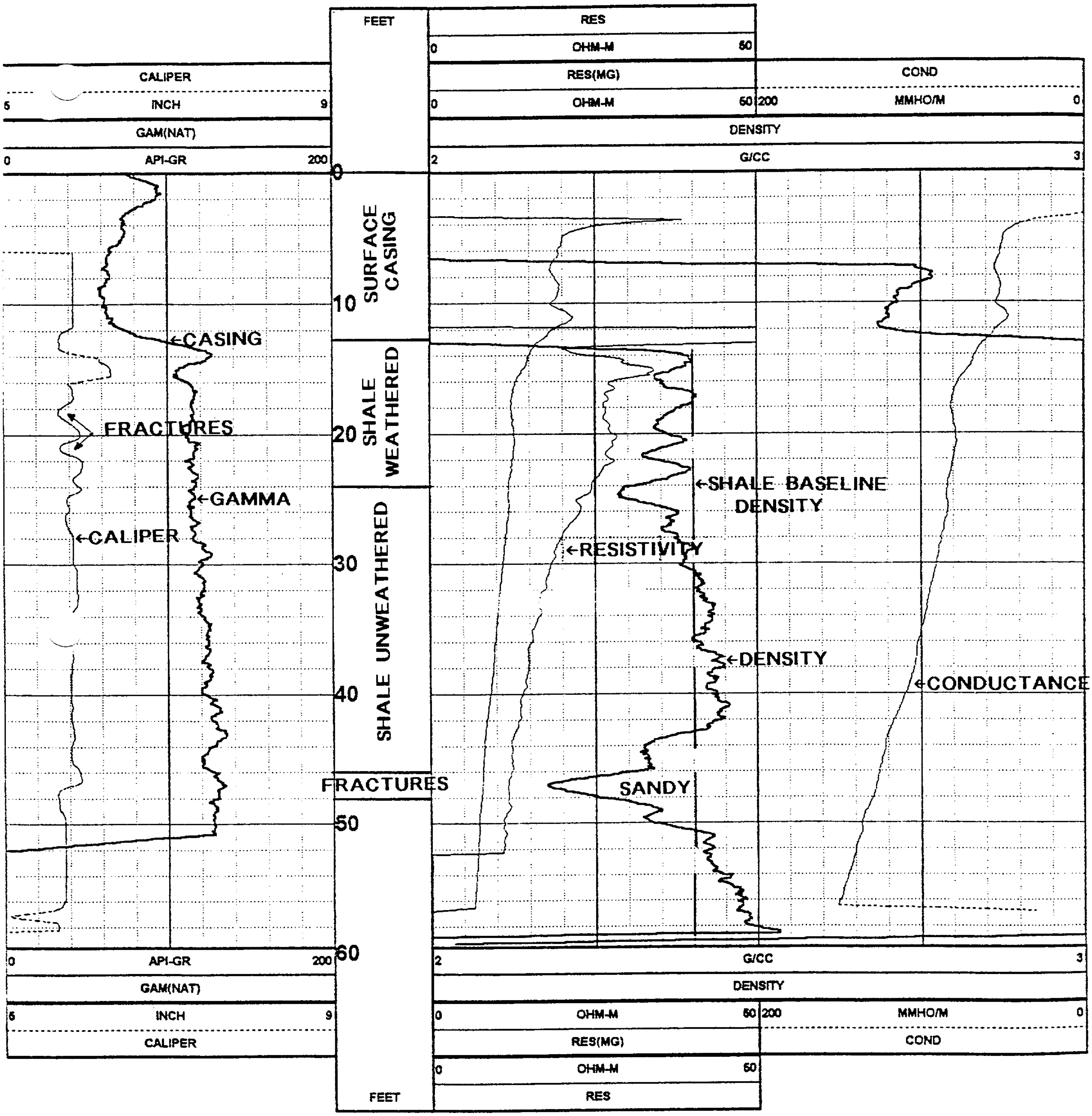
FILE : ORIGINAL
TYPE : 9030AA
LOG : 5.
PLOT :
THRESH: 5000

REMARKS:

NONE

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS

FIGURE 4-13


FEET
RES
0 OHM-M 50
RES(MG)
0 OHM-M 50
COND
200 MMHO/M 0
DENSITY
2 G/CC 3
CALIPER
5 INCH 9
GAM(NAT)
0 API-GR 200
0
10
20
30
40
50
60
SURFACE CASING
SHALE WEATHERED
SHALE UNWEATHERED
FRACTURES
←CASING
FRACTURES
←GAMMA
←CALIPER
←SHALE BASELINE DENSITY
←RESISTIVITY
←DENSITY
←CONDUCTANCE
SANDY
0 API-GR 200
GAM(NAT)
5 INCH 9
CALIPER
2 G/CC 3
DENSITY
0 OHM-M 50
RES(MG)
200 MMHO/M 0
COND
0 OHM-M 50
RES
FEET

CGC

Century GEOPHYSICAL CORP.

ST-3

COMPANY : A & M ENGINEERING
WELL : ST-3
LOCATION/FIELD : KAISER ALUMINUM
COUNTY : TULSA
STATE : OK
SECTION :

OTHER SERVICES:

TOWNSHIP :

RANGE :

DATE : 03/19/97
DEPTH DRILLER : 60
LOG BOTTOM : 66.30
LOG : 2.00

PERMANENT DATUM : GL
ELEV. PERM. DATUM : GL
LOG MEASURED FROM: GL
DRL MEASURED FROM : GL

ELEVATIONS:
KB : N/A
DF : N/A
GL :

CA DRILLER : 20
CASING TYPE : PVC
CASING THICKNESS: .25

LOGGING UNIT : 9403
FIELD OFFICE : TULSA,OK
RECORDED BY : B. PETERSON

BIT SIZE : 6.0
MAGNETIC DECL. : 8.5
MATRIX DENSITY : 2.71
FLUID DENSITY : 1.11
NEUTRON MATRIX : SANDSTONE

BOREHOLE FLUID : H20
RM :
RM TEMPERATURE : 00
MATRIX DELTA T : 57
FLUID DELTA T : 210

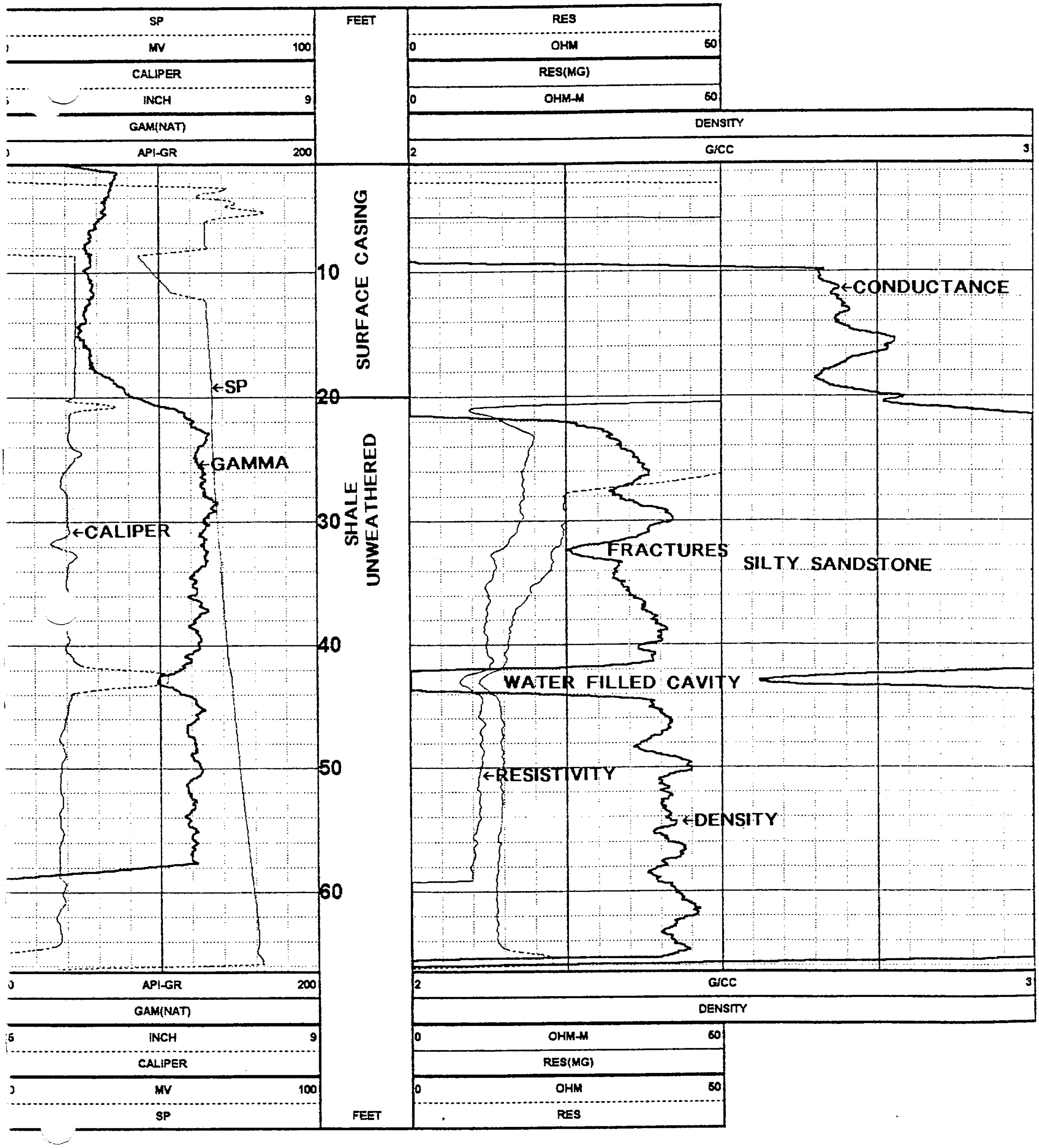
FILE : ORIGINAL
TYPE : 9060A
LOG : 0.
PLOT :
THRESH: 5000

REMARKS:

NONE

ALL SERVICES PROVIDED SUBJECT TO STANDARD TERMS AND CONDITIONS

FIGURE 4-14


SP
MV 100
CALIPER
INCH 9
GAM(NAT)
API-GR 200
FEET
RES
0 OHM 50
RES(MG)
0 OHM-M 50
DENSITY
2 G/CC 3
SURFACE CASING
SHALE UNWEATHERED
10
20
30
40
50
60
←SP
←GAMMA
←CALIPER
←CONDUCTANCE
FRACTURES
SILTY SANDSTONE
WATER FILLED CAVITY
←RESISTIVITY
←DENSITY
0 API-GR 200
GAM(NAT)
5 INCH 9
CALIPER
0 MV 100
SP
FEET
2 G/CC 3
DENSITY
0 OHM-M 50
RES(MG)
0 OHM 50
RES

# APPENDIX C

# SIEVE ANALYSIS OF SAMPLES

MWD-5

>50% pass No 4

< 50% pass No 200

> 12% pass No 200

LL = 27.7

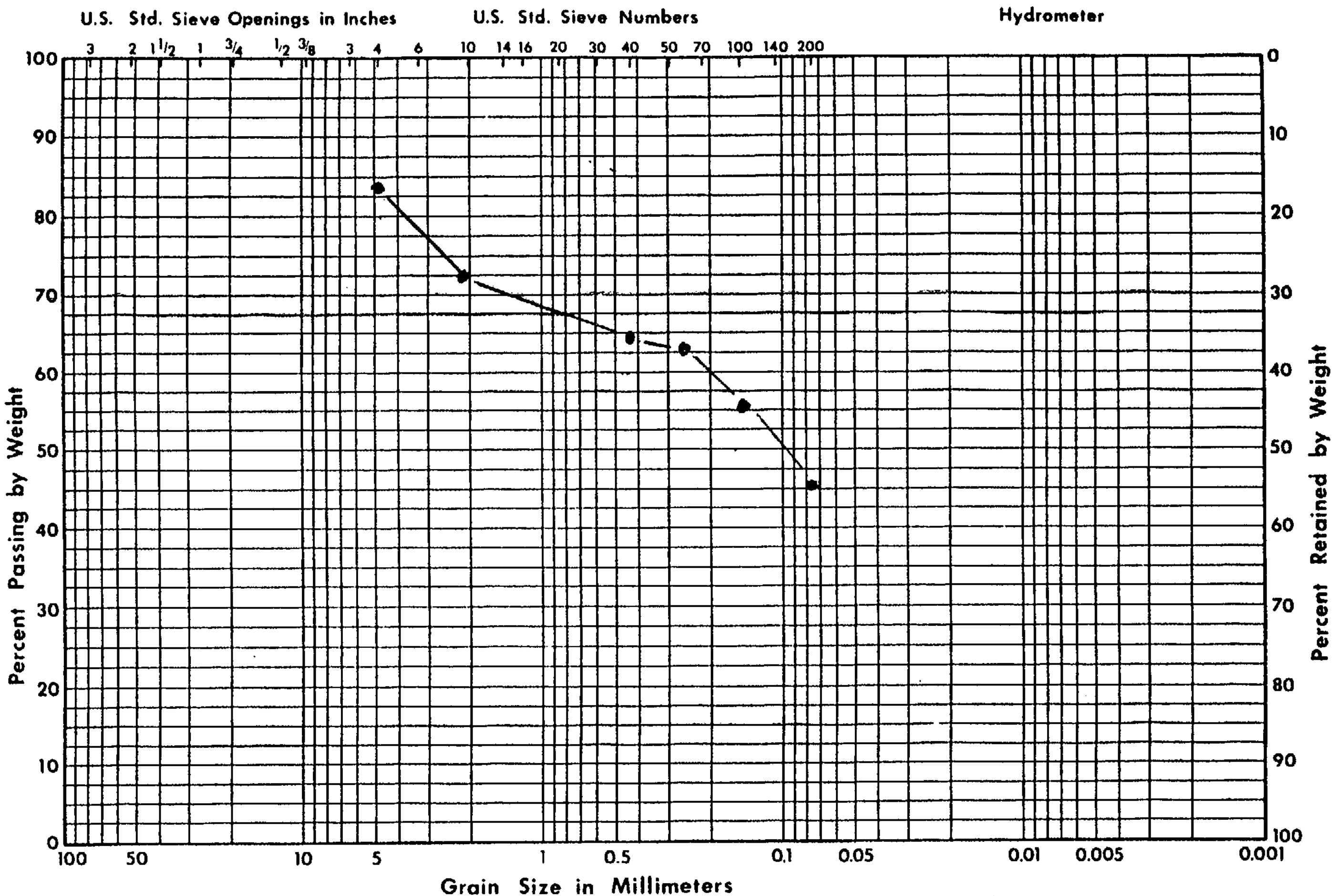
PI = 10.9

Fines classify as CL

Soil has 15% gravel

Soil is SC with gravel

## MECHANICAL ANALYSIS GRAPH



| | GRAVEL | | SAND | | | SILT or CLAY |
|---|---|---|---|---|---|---|
| | Coarse | Fine | Coarse | Medium | Fine | |

$D_{10}$= ____________

$D_{15}$= ____________ $5D_{15}$= ____________ $20D_{15}$= ____________

$D_{30}$= ____________

$D_{60}$= ____________

$D_{85}$= ____________ $5D_{85}$= ____________

$$C_u = \frac{D_{60}}{D_{10}} = \frac{(\quad)}{(\quad)} =$$

$$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(\quad)^2}{(\quad)(\quad)} =$$

SC clayey sand with gravel

MWD-6

>50% pass No 4
<50% pass No 200
>12% pass No 200
LL 33

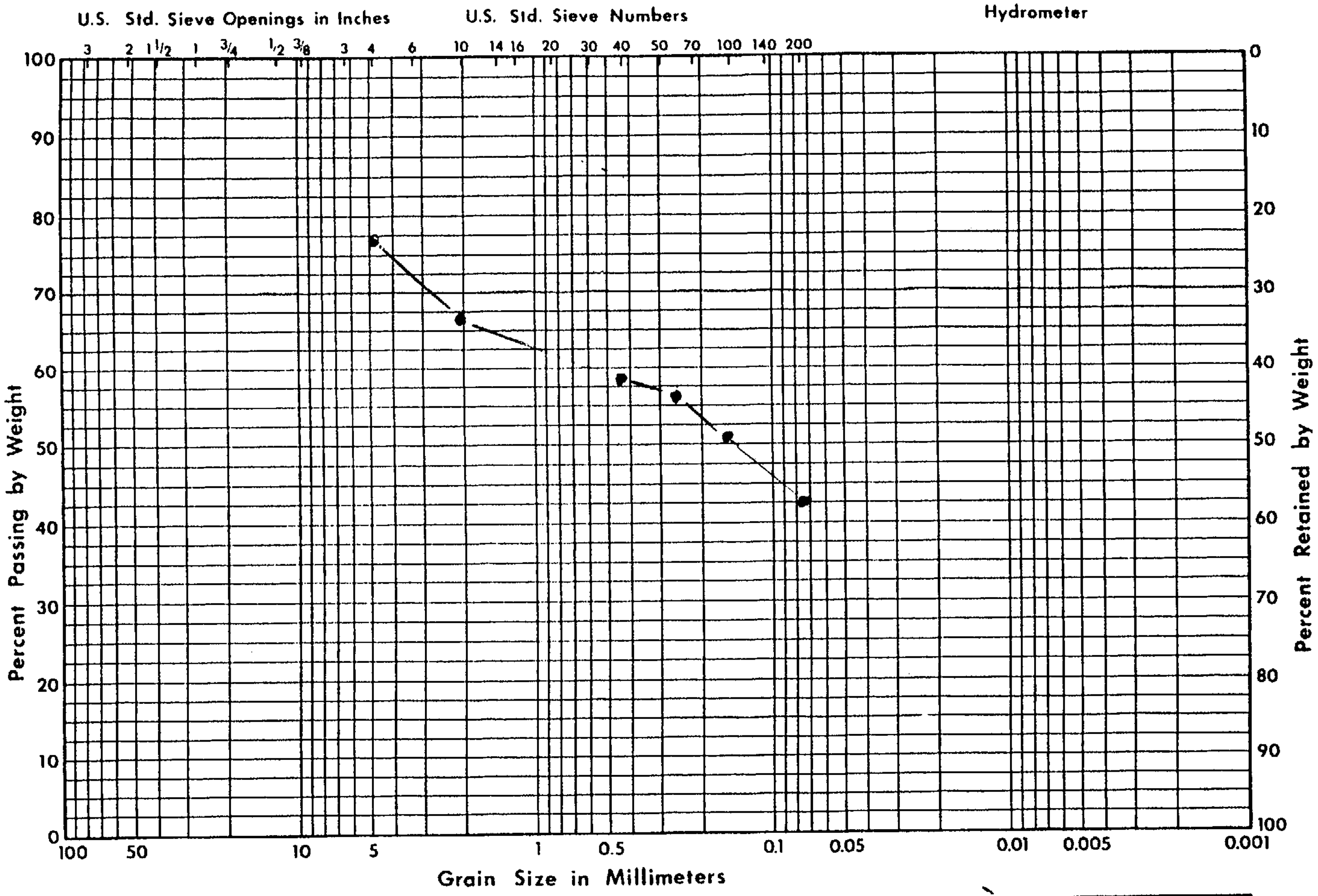
PI 14.9

Fines classify as CL

Soil has >15% gravel

Soil is SC with gravel

## MECHANICAL ANALYSIS GRAPH MWD-6



| | | | | | | |
|---|---|---|---|---|---|---|
| | GRAVEL | | SAND | | | SILT or CLAY |
| | Coarse | Fine | Coarse | Medium | Fine | |

$D_{10}$= ____________

$D_{15}$= ____________ $5D_{15}$= ____________ $20D_{15}$= ____________

$D_{30}$= ____________

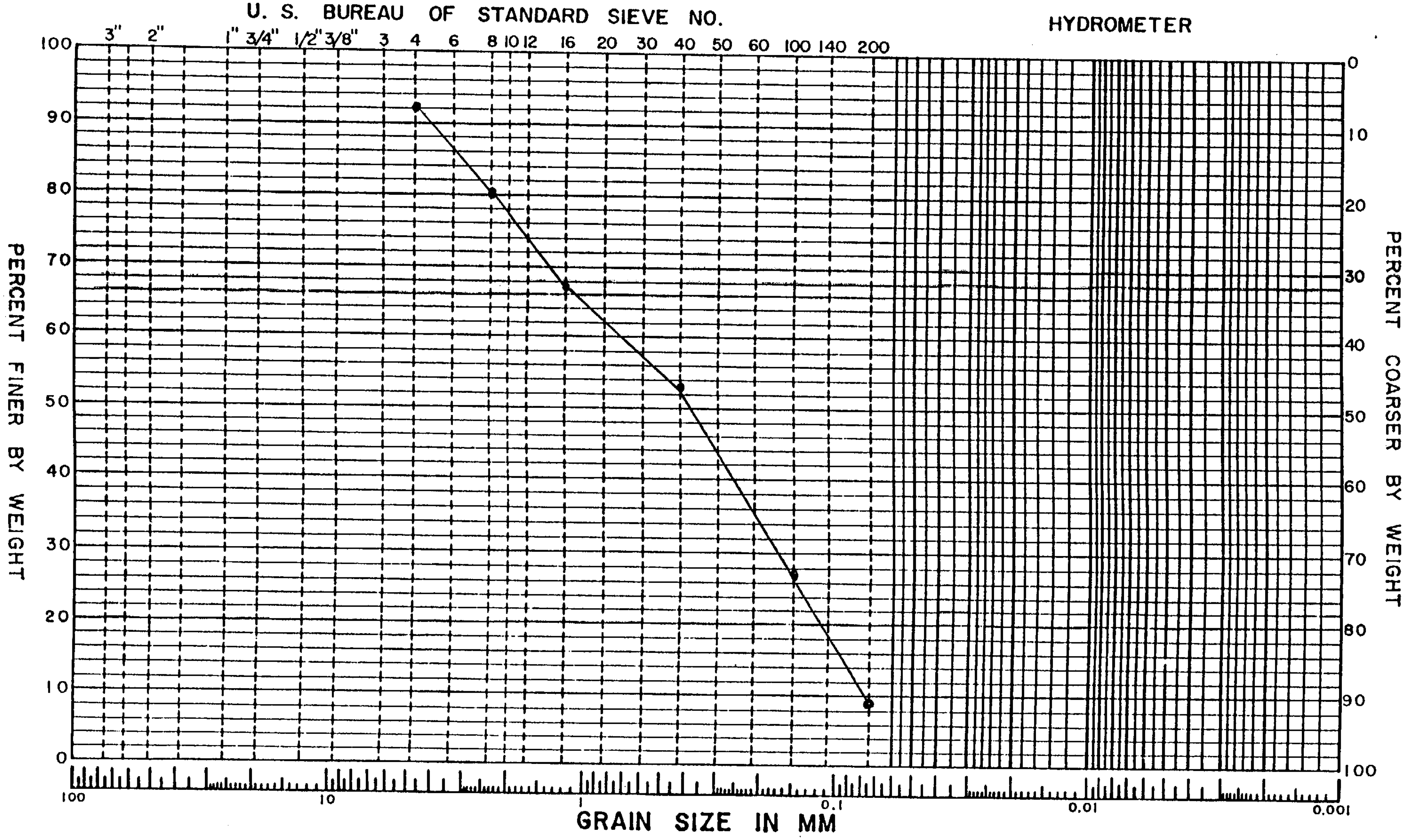
$D_{60}$= ____________

$D_{85}$= ____________ $5D_{85}$= ____________

$$C_u = \frac{D_{60}}{D_{10}} = \frac{(\quad)}{(\quad)} =$$

$$C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})} = \frac{(\quad)^2}{(\quad)(\quad)} =$$

# GRAIN SIZE DISTRIBUTION DIAGRAM



CLIENT Kaiser

PROJECT Tulsa Remediation

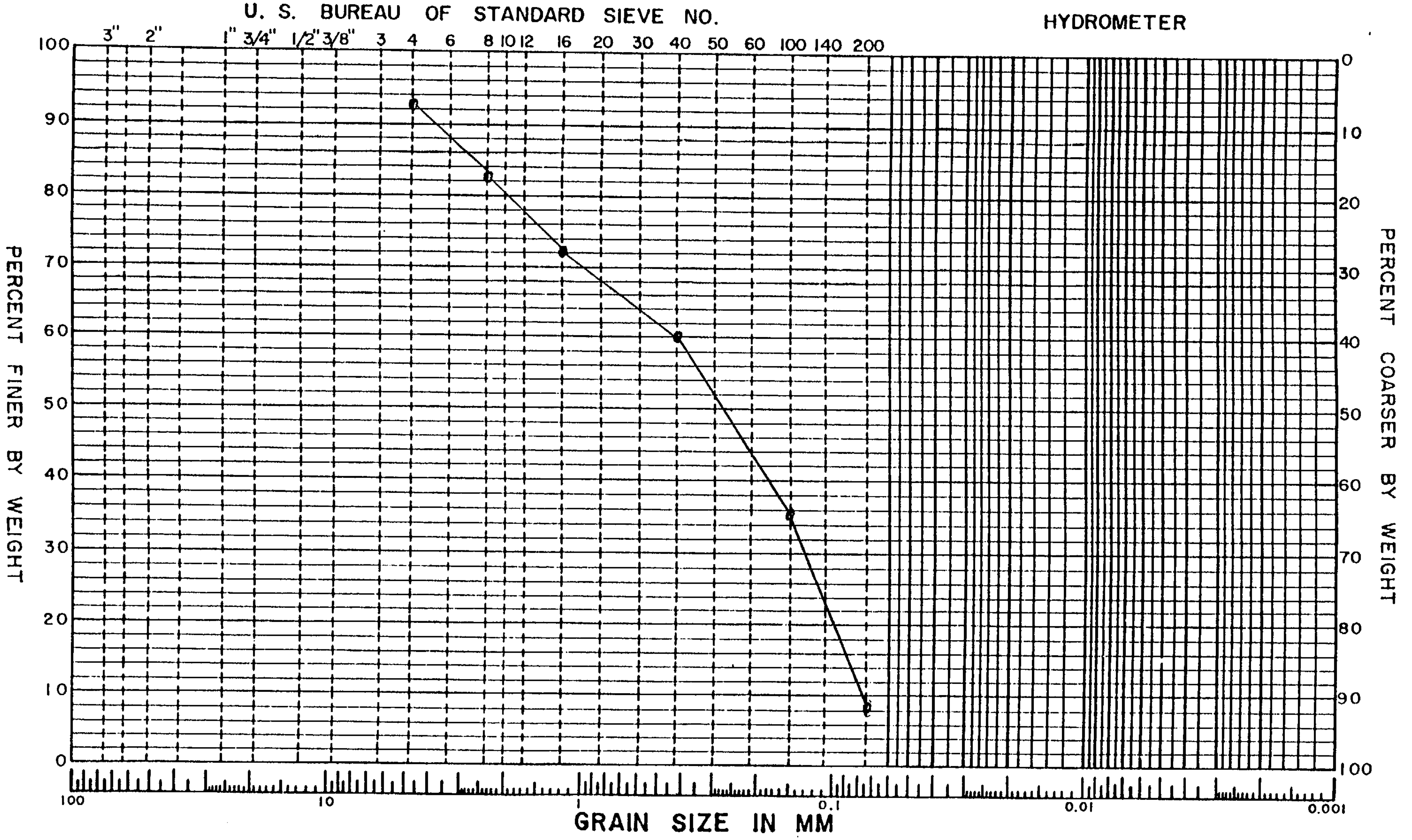
HOLE NO. P5 DEPTH FROM 13 TO 18

>50 % pass No 4
< 50 % pass No 200
< 9% pass No 200

classify as SW-SC

$C_u = \frac{D_{60}}{D_{10}} = \frac{.8}{.075} = 10 > 6 = SW$

# GRAIN SIZE DISTRIBUTION DIAGRAM



>50% pass No. 4

<50% pass No. 200

≤9% pass 200

CLIENT Kaiser

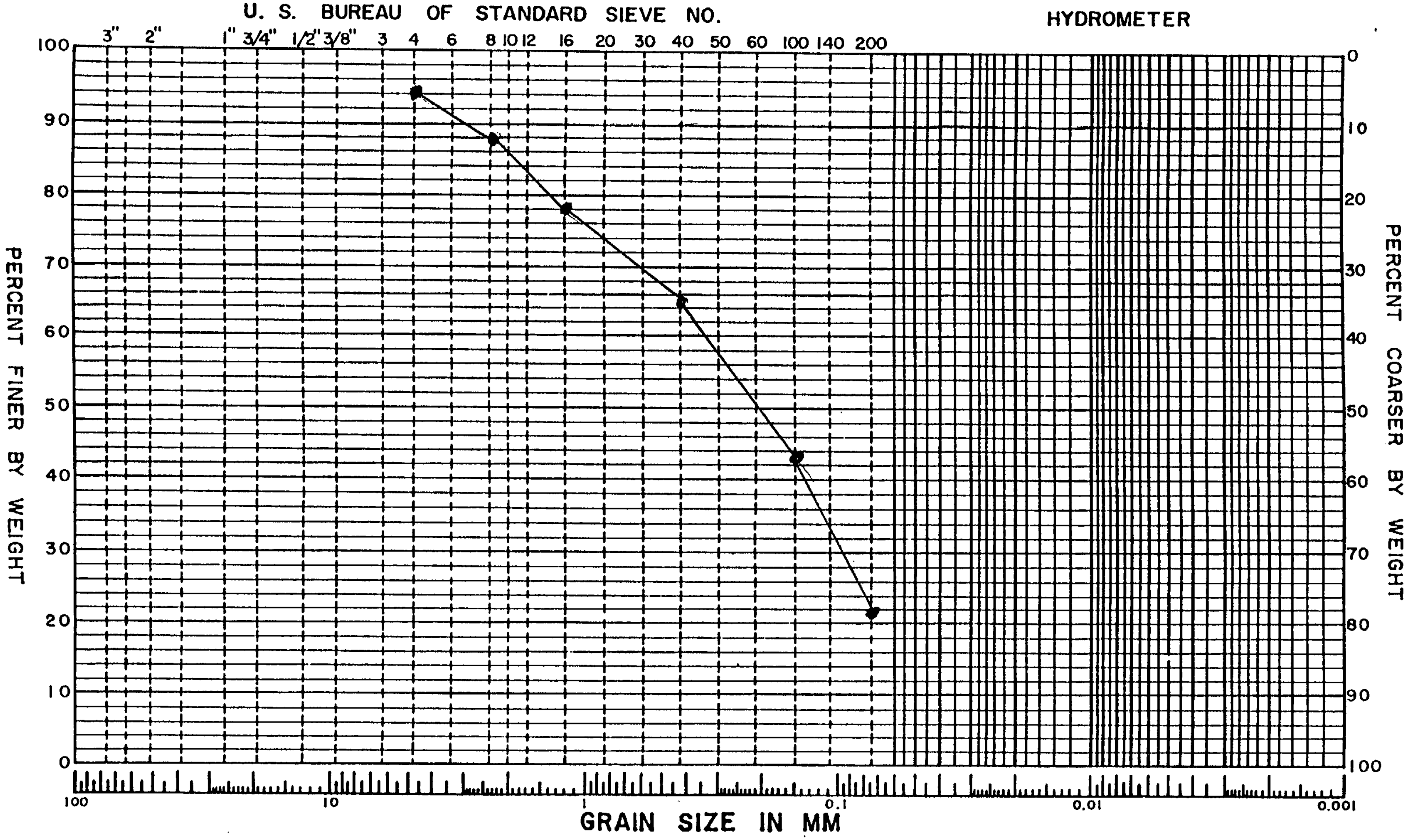
PROJECT Tulsa Remediation Project

HO' NO. P-7 DEPTH FROM 18 TO 22

Classify as SP-SC

$C_u = \frac{D_{60}}{D_{10}} = \frac{0.4}{0.075} = 5.3 < 6 = SP$

# GRAIN SIZE DISTRIBUTION DIAGRAM



> 50 % pass No 4

< 50 % pass No 200

> 12 % pass No 200

Classify As SC

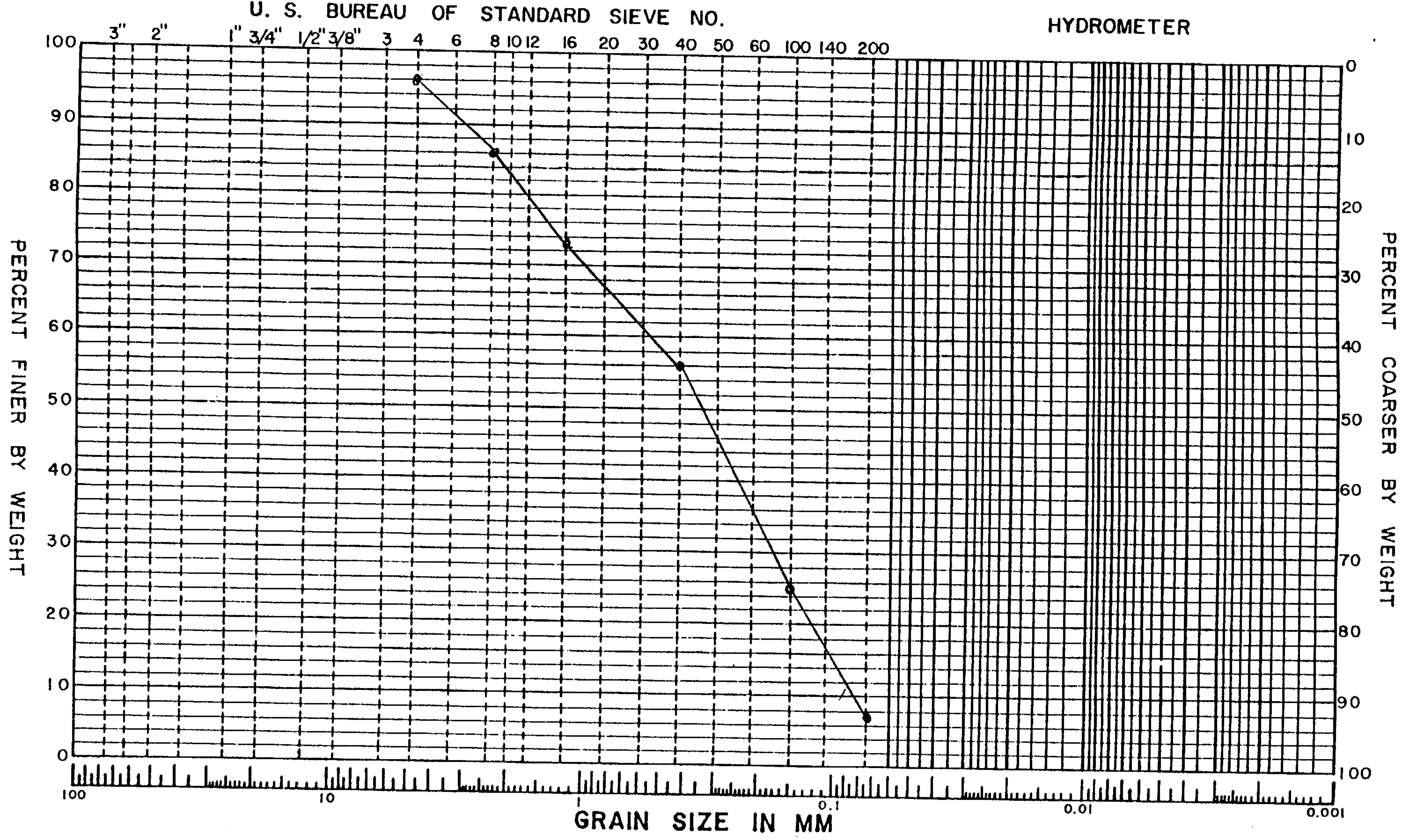
Clayey Sand

CLIENT ______

PROJECT Kaiser Tulsa Remediation

HOLE NO. P-8 DEPTH FROM 18 TO 26

# GRAIN SIZE DISTRIBUTION DIAGRAM



CLIENT Kaiser

PROJECT Tulsa Remediation Project

HOLE NO R-10 DEPTH FROM 12 TO 16

> 50 % pass No. 4

< 50 % pass No. 200

7.5 % pass No. 200

$C_u = \frac{D_{60}}{D_{10}} = \frac{.5}{.08} = 6.5 > 6 = SW$

Classify AS SW-SC

# ATTERBERG LIMITS

SOIL SAMPLE MWD 5

LOCATION 16 → 26½ ft composite

BORING NO.

SAMPLE NO.

SPECIFIC GRAVITY, Gs

TEST NO. 1

DATE 4-26-99 → 4-27-99

TESTED BY. ROH

## PLASTIC LIMIT

| DETERMINATION NO. | 1 | 2 | 3 |
|---|---|---|---|
| CONTAINER NO. | 3 | 6 | 9 Lid |
| WT. CONTAINER + WET SOIL IN g | 20.78 | 20.70 | 15.01 |
| WT. CONTAINER + DRY SOIL IN g | 20.43 | 20.35 | 14.47 |
| WT. WATER, Ww IN g | .35 | .35 | .54 |
| WT. CONTAINER IN g | 18.30 | 18.20 | 11.42 |
| WT. DRY SOIL, Ws, IN g | 2.13 | 2.15 | 3.05 |
| WATER CONTENT, w, IN % | 16.43 | 16.28 | 17.70 |

## NATURAL WATER CONTENT

| 1 | 2 | 3 |
|---|---|---|
|  |  |  |
|  |  |  |
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|  |  |  |
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|  |  |  |
|  |  |  |

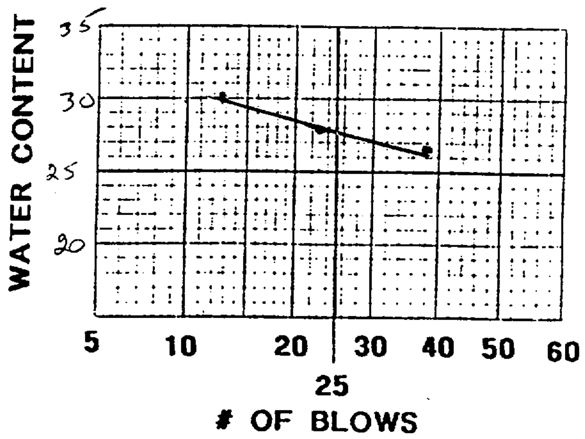
## LIQUID LIMIT

| DETERMINATION NO. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| NO. OF BLOWS | 38 | 23 | 13 |  |  |
| CONTAINER NO. | 10 | 14 | 3A |  |  |
| WT. CONTAINER + WET SOIL IN g | 27.24 | 27.40 | 29.48 |  |  |
| WT. CONTAINER + DRY SOIL IN g | 25.37 | 25.40 | 26.50 |  |  |
| WT. WATER, Ww, IN g | 1.87 | 2.0 | 2.98 |  |  |
| WT. CONTAINER IN g | 18.35 | 18.23 | 16.57 |  |  |
| WT. DRY SOIL, Ws IN g | 7.02 | 7.17 | 9.93 |  |  |
| WATER CONTENT, w, IN % | 26.62 | 27.89 | 30.01 |  |  |

## SHRINKAGE LIMIT

| DETERMINATION NO. | 1 | 2 |
|---|---|---|
| UNDISTURBED OR REMOLDED SOIL PAT |  |  |
| WT. DRY SOIL PAT Ws, IN g |  |  |
| WT. CONTAINER + HG. IN g |  |  |
| WT. CONTAINER IN g |  |  |
| WT. HG. IN g |  |  |
| VOL. SOIL PAT, V, IN cc |  |  |
| SHRINKAGE LIMIT, Ws, IN % |  |  |

**FLOW CURVE**



## RESULT SUMMARY

| [✓ PLASTIC LIMIT] | NATURAL WATER CONTENT | [✓ LIQUID LIMIT] | SHRINKAGE LIMIT | B VALUE | PLASTICITY INDEX | FLOW INDEX | TOUGHNESS INDEX |
|---|---|---|---|---|---|---|---|
| 16.80 |  | 27.75 |  |  | 10.95 |  |  |

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# SIEVE ANALYSIS

SOIL SAMPLE MWD-5

LOCATION

BORING NO. SAMPLE DEPTH

SAMPLE NO.

SPECIFIC GRAVITY, Gs

SOIL SAMPLE WEIGHT

CONTAINER NO.

WT. CONTAINER + DRY SOIL IN (lb) 1.71

WT. CONTAINER IN (lb) 0.52

WT. DRY SOIL IN (lb) 1.19

TEST NO.

DATE 4-27-99

TESTED BY JDA

| SIEVE NO. | SIEVE OPENING IN mm | WT. SIEVE IN (lb) | WT. SIEVE + SOIL IN (lb) | WT. SOIL RETAINED IN (lb) | PERCENT RETAINED | CUMULATIVE PERCENT RETAINED | PERCENT FINER |
|---|---|---|---|---|---|---|---|
| 4 | | 1.03 | 1.23 | 0.20 | 16.81 | 16.81 | 83.19 |
| 10 | | 0.96 | 1.09 | 0.13 | 10.92 | 27.73 | 72.27 |
| 40 | | 0.76 | 0.85 | 0.09 | 7.56 | 35.29 | 64.71 |
| 60 | | 0.80 | 0.82 | 0.02 | 1.68 | 36.97 | 63.03 |
| 100 | | 0.76 | 0.85 | 0.09 | 7.56 | 44.53 | 55.47 |
| 200 | | 0.75 | 0.87 | 0.12 | 10.08 | 54.61 | 45.39 |
| PAN | | 0.83 | 1.37 | 0.55 | 45.39 | 100.00 | 0 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

.65

# ATTERBERG LIMITS

SOIL SAMPLE MWD6

LOCATION 18→29' composite

BORING NO.

SAMPLE NO.

SPECIFIC GRAVITY, Gs

TEST NO. 2

DATE 4-26-99 ⇒ 4-27-99

TESTED BY. ROH

## PLASTIC LIMIT

| DETERMINATION NO. | 1 | 2 | 3 |
|---|---|---|---|
| CONTAINER NO. | 2 | 5 | 4 |
| WT. CONTAINER + WET SOIL IN g | 15.40 | 15.88 | 15.39 |
| WT. CONTAINER + DRY SOIL IN g | 14.80 | 15.18 | 14.81 |
| WT. WATER, Ww IN g | 0.6 | 0.7 | 0.58 |
| WT. CONTAINER IN g | 11.47 | 11.39 | 11.56 |
| WT. DRY SOIL, Ws, IN g | 3.33 | 3.79 | 3.25 |
| WATER CONTENT, w, IN % | 18.02 | 18.47 | 17.85 |

## NATURAL WATER CONTENT

| 1 | 2 | 3 |
|---|---|---|
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

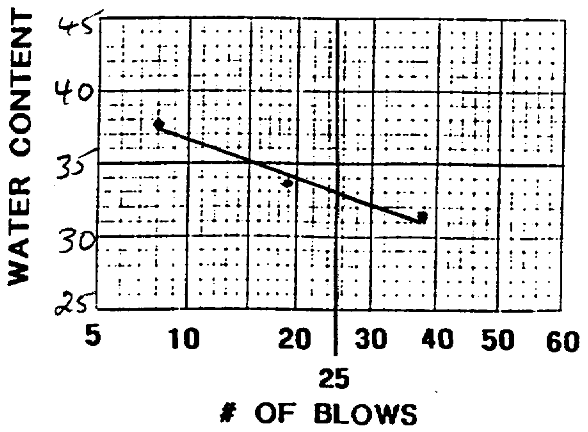
## LIQUID LIMIT

| DETERMINATION NO. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| NO. OF BLOWS | 38 | 19 | 8 |  |  |
| CONTAINER NO. | 9 | 7 | 6 Lid |  |  |
| WT. CONTAINER + WET SOIL IN g | 23.74 | 19.45 | 21.88 |  |  |
| WT. CONTAINER + DRY SOIL IN g | 22.46 | 17.40 | 19.03 |  |  |
| WT. WATER, Ww, IN g | 1.28 | 2.05 | 2.85 |  |  |
| WT. CONTAINER IN g | 18.40 | 11.33 | 11.41 |  |  |
| WT. DRY SOIL, Ws IN g | 4.06 | 6.07 | 7.62 |  |  |
| WATER CONTENT, w, IN % | 31.53 | 33.77 | 37.40 |  |  |

## SHRINKAGE LIMIT

| DETERMINATION NO. | 1 | 2 |
|---|---|---|
| UNDISTURBED OR REMOLDED SOIL PAT |  |  |
| WT. DRY SOIL PAT Ws, IN g |  |  |
| WT. CONTAINER + HG. IN g |  |  |
| WT. CONTAINER IN g |  |  |
| WT. HG. IN g |  |  |
| VOL. SOIL PAT, V, IN cc |  |  |
| SHRINKAGE LIMIT, Ws, IN % |  |  |

FLOW CURVE



## RESULT SUMMARY

| PLASTIC LIMIT | NATURAL WATER CONTENT. | LIQUID LIMIT | SHRINKAGE LIMIT | B VALUE | PLASTICITY INDEX | FLOW INDEX | TOUGHNESS INDEX |
|---|---|---|---|---|---|---|---|
| 18.11 |  | 33 |  |  | 14.89 |  |  |

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# SIEVE ANALYSIS

SOIL SAMPLE mWD-6

LOCATION Composite 18' → 28'

BORING NO. mWD-6 SAMPLE DEPTH

SAMPLE NO.

SPECIFIC GRAVITY, Gs

SOIL SAMPLE WEIGHT

CONTAINER NO.

WT. CONTAINER + DRY SOIL IN (lb) 4.35

WT. CONTAINER IN (lb) 1.44

WT. DRY SOIL IN (lb) 2.91

TEST NO.

DATE 4-26-99

TESTED BY JDA

2.24

| SIEVE NO. | SIEVE OPENING IN mm | WT. SIEVE IN (lb) | WT. SIEVE + SOIL IN (lb) | WT. SOIL RETAINED IN (lb) | PERCENT RETAINED | CUMULATIVE PERCENT RETAINED | PERCENT FINER |
|---|---|---|---|---|---|---|---|
| 4 | | 1.03 | 1.70 | 0.67 | 23.02 | 23.02 | 76.98 |
| 10 | | 0.96 | 1.25 | 0.29 | 9.97 | 32.99 | 67.01 |
| 40 | | 0.76 | 1.01 | 0.25 | 8.59 | 41.58 | 58.42 |
| 60 | | 0.80 | 0.86 | 0.06 | 2.06 | 43.64 | 56.36 |
| 100 | | 0.76 | 0.93 | 0.17 | 5.84 | 49.48 | 50.52 |
| 200 | | 0.74 | 0.98 | 0.24 | 8.25 | 57.73 | 42.27 |
| PAN | | 0.83 | 2.06 | 1.23 | 42.27 | 100.00 | 0 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

# ATTERBERG LIMITS

SOIL SAMPLE P-5 (13-18')
LOCATION KIASER
BORING NO. P-5
SAMPLE NO. COMPOSITE
SPECIFIC GRAVITY, Gs
TEST NO. 1
DATE 5/7/95
TESTED BY. PLS

## PLASTIC LIMIT

| DETERMINATION NO. | 1 | 2 | 3 |
|---|---|---|---|
| CONTAINER NO. | 60 | 64 | 61 |
| WT. CONTAINER + WET SOIL IN g | 6.54 | 5.59 | 5.94 |
| WT. CONTAINER + DRY SOIL IN g | 5.75 | 4.94 | 5.24 |
| WT. WATER, Ww IN g | | | |
| WT. CONTAINER IN g | 0.89 | 0.83 | 0.98 |
| WT. DRY SOIL, Ws, IN g | 4.86 | 4.01 | 4.26 |
| WATER CONTENT, w, IN % | 16.3 | 18.7 | 16.4 |

## NATURAL WATER CONTENT

| 1 | 2 | 3 |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

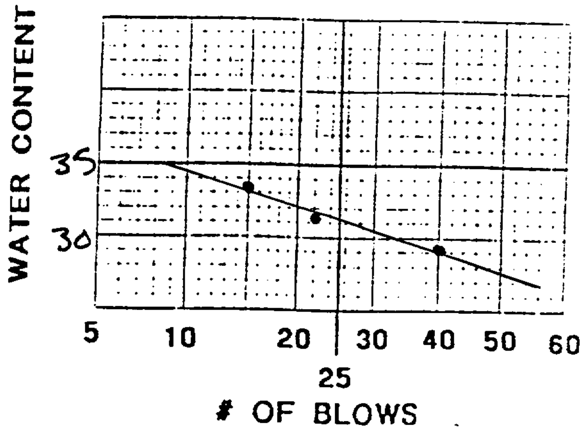
## LIQUID LIMIT

| DETERMINATION NO. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| NO. OF BLOWS | 40 | 22 | 15 | | |
| CONTAINER NO. | 65 | 62 | 63 | | |
| WT. CONTAINER + WET SOIL IN g | 20.25 | 25.02 | 23.57 | | |
| WT. CONTAINER + DRY SOIL IN g | 15.42 | 19.35 | 17.92 | | |
| WT. WATER, Ww, IN g | | | | | |
| WT. CONTAINER IN g | 1.03 | 1.18 | 1.00 | | |
| WT. DRY SOIL, Ws IN g | 14.89 | 18.17 | 16.92 | | |
| WATER CONTENT, w, IN % | 29.1 | 31.2 | 33.4 | | |

## SHRINKAGE LIMIT

| DETERMINATION NO. | 1 | 2 |
|---|---|---|
| UNDISTURBED OR REMOLDED SOIL PAT | | |
| WT. DRY SOIL PAT Ws, IN g | | |
| WT. CONTAINER + HG. IN g | | |
| WT. CONTAINER IN g | | |
| WT. HG. IN g | | |
| VOL. SOIL PAT, V, IN cc | | |
| SHRINKAGE LIMIT, Ws, IN % | | |

FLOW CURVE



## RESULT SUMMARY

| PLASTIC LIMIT | NATURAL WATER CONTENT | LIQUID LIMIT | SHRINKAGE LIMIT | B VALUE | PLASTICITY INDEX | FLOW INDEX | TOUGHNESS INDEX |
|---|---|---|---|---|---|---|---|
| 17 | | 31 | | | 14 | | |

# ATTERBERG LIMITS

SOIL SAMPLE P-7 (18-22')
LOCATION KIASER
BORING NO. P-5
SAMPLE NO. COMPOSITE
SPECIFIC GRAVITY, Gs
TEST NO. 1
DATE 5/7/99
TESTED BY. PCS

## PLASTIC LIMIT

| DETERMINATION NO. | 1 | 2 | 3 |
|---|---|---|---|
| CONTAINER NO. | 7(L) | 4(L) | 1(L) |
| WT. CONTAINER + WET SOIL IN g | 15.43 | 16.38 | 14.82 |
| WT. CONTAINER + DRY SOIL IN g | 14.82 | 15.64 | 14.23 |
| WT. WATER, Ww IN g | | | |
| WT. CONTAINER IN g | 11.33 | 11.57 | 11.22 |
| WT. DRY SOIL, Ws, IN g | 3.49 | 4.07 | 3.01 |
| WATER CONTENT, w, IN % | 17.5 | 18.2 | 19.6 |

## NATURAL WATER CONTENT

| 1 | 2 | 3 |
|---|---|---|
| | | |
| | | |
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| | | |
| | | |

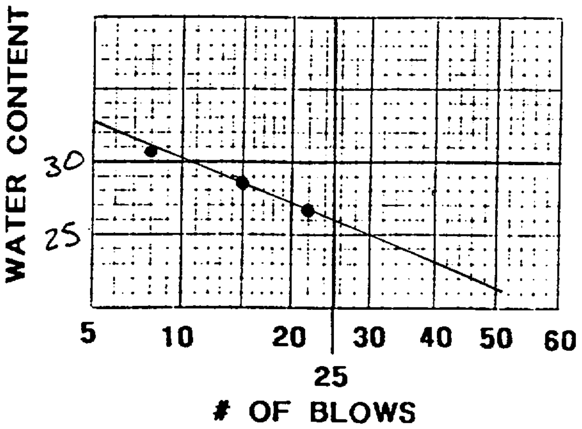
## LIQUID LIMIT

| DETERMINATION NO. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| NO. OF BLOWS | 21 | 15 | 8 | | |
| CONTAINER NO. | 3 | 9 | 2A | | |
| WT. CONTAINER + WET SOIL IN g | 43.18 | 42.79 | 41.63 | | |
| WT. CONTAINER + DRY SOIL IN g | 37.95 | 37.39 | 35.54 | | |
| WT. WATER, Ww, IN g | | | | | |
| WT. CONTAINER IN g | 18.30 | 18.37 | 15.49 | | |
| WT. DRY SOIL, Ws IN g | 19.65 | 19.02 | 20.05 | | |
| WATER CONTENT, w, IN % | 26.6 | 28.4 | 30.4 | | |

## SHRINKAGE LIMIT

| DETERMINATION NO. | 1 | 2 |
|---|---|---|
| UNDISTURBED OR REMOLDED SOIL PAT | | |
| WT. DRY SOIL PAT Ws, IN g | | |
| WT. CONTAINER + HG. IN g | | |
| WT. CONTAINER IN g | | |
| WT. HG. IN g | | |
| VOL. SOIL PAT, V, IN cc | | |
| SHRINKAGE LIMIT, Ws, IN % | | |

**FLOW CURVE**



## RESULT SUMMARY

| PLASTIC LIMIT | NATURAL WATER CONTENT | LIQUID LIMIT | SHRINKAGE LIMIT | B VALUE | PLASTICITY INDEX | FLOW INDEX | TOUGHNESS INDEX |
|---|---|---|---|---|---|---|---|
| 18 | | 26 | | | 8 | | |

# ATTERBERG LIMITS

SOIL SAMPLE P-8 (18-26')

LOCATION KIASER
BORING NO. P-8
SAMPLE NO. COMPOSITE
SPECIFIC GRAVITY, Gs

TEST NO. 1
DATE 5/7/95
TESTED BY. PLS

## PLASTIC LIMIT

| DETERMINATION NO. | 1 | 2 | 3 |
|---|---|---|---|
| CONTAINER NO. | 54 | 51 | 50 |
| WT. CONTAINER + WET SOIL IN g | 4.86 | 5.09 | 5.05 |
| WT. CONTAINER + DRY SOIL IN g | 4.25 | 4.42 | 4.41 |
| WT. WATER, Ww IN g | | | |
| WT. CONTAINER IN g | 1.14 | 1.04 | 1.22 |
| WT. DRY SOIL, Ws, IN g | 3.11 | 3.38 | 3.19 |
| WATER CONTENT, w, IN % | 19.6 | 19.8 | 20.1 |

## NATURAL WATER CONTENT

| 1 | 2 | 3 |
|---|---|---|
| | | |
| | | |
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| | | |
| | | |
| | | |
| | | |

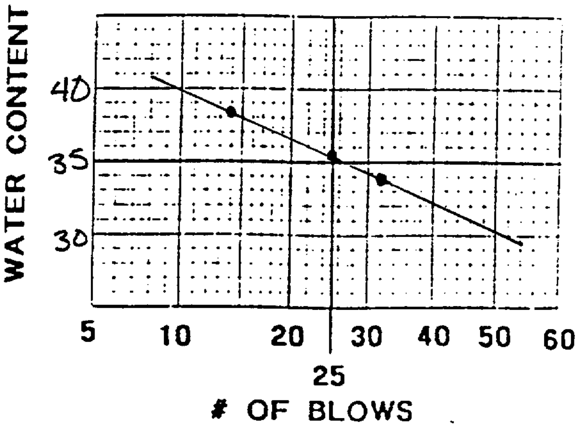
## LIQUID LIMIT

| DETERMINATION NO. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| NO. OF BLOWS | 832 | 25 | 14 | | |
| CONTAINER NO. | 55 | 52 | 53 | | |
| WT. CONTAINER + WET SOIL IN g | 20.23 | 19.94 | 21.01 | | |
| WT. CONTAINER + DRY SOIL IN g | 15.38 | 14.95 | 15.47 | | |
| WT. WATER, Ww, IN g | | | | | |
| WT. CONTAINER IN g | 1.09 | 0.89 | 0.96 | | |
| WT DRY SOIL, Ws IN g | 14.29 | 14.06 | 14.51 | | |
| WATER CONTENT, w, IN % | 33.9 ~~4.85~~ | 35.5 | 38.2 | | |

## SHRINKAGE LIMIT

| DETERMINATION NO. | 1 | 2 |
|---|---|---|
| UNDISTURBED OR REMOLDED SOIL PAT | | |
| WT DRY SOIL PAT Ws, IN g | | |
| WT. CONTAINER + HG. IN g | | |
| WT. CONTAINER IN g | | |
| WT. HG. IN g | | |
| VOL. SOIL PAT, V, IN cc | | |
| SHRINKAGE LIMIT, Ws, IN % | | |

FLOW CURVE



## RESULT SUMMARY

| PLASTIC LIMIT | NATURAL WATER CONTENT | LIQUID LIMIT | SHRINKAGE LIMIT | B VALUE | PLASTICITY INDEX | FLOW INDEX | TOUGHNESS INDEX |
|---|---|---|---|---|---|---|---|
| 20 | | 35 | | | 15 | | |

# ATTERBERG LIMITS

SOIL SAMPLE P-10 (12-16')

LOCATION KIASER

BORING NO. P-10

SAMPLE NO. Composite

SPECIFIC GRAVITY, Gs

TEST NO. 1

DATE 5/7/99

TESTED BY. PLS

## PLASTIC LIMIT

| DETERMINATION NO. | 1 | 2 | 3 |
|---|---|---|---|
| CONTAINER NO. | 6(L) | 2(L) | 5(L) |
| WT. CONTAINER + WET SOIL IN g | 15.21 | 14.65 | 15.22 |
| WT. CONTAINER + DRY SOIL IN g | 14.63 | 14.17 | 14.61 |
| WT. WATER, Ww IN g | | | |
| WT. CONTAINER IN g | 11.39 | 11.40 | 11.39 |
| WT. DRY SOIL, Ws, IN g | 3.24 | 2.77 | 3.22 |
| WATER CONTENT, w, IN % | 16.67 | 17.3 | 18.9 |

## NATURAL WATER CONTENT

| 1 | 2 | 3 |
|---|---|---|
| | | |
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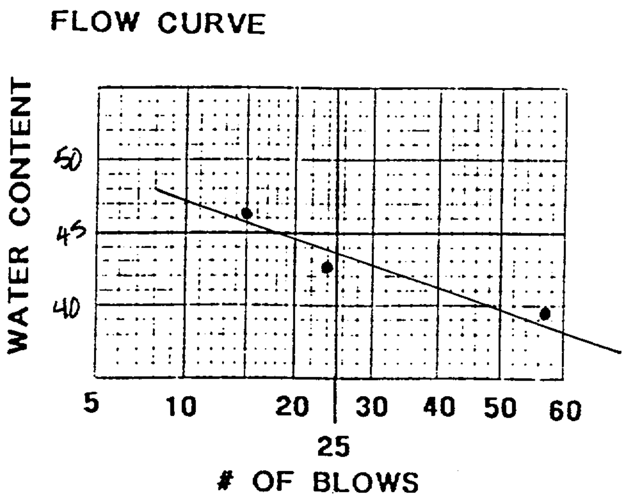
| | | |
| | | |
| | | |

## LIQUID LIMIT

| DETERMINATION NO. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| NO. OF BLOWS | 57 | 24 | 15 | | |
| CONTAINER NO. | 7 | 6 | 10 | | |
| WT. CONTAINER + WET SOIL IN g | 33.37 | 35.97 | 41.97 | | |
| WT. CONTAINER + DRY SOIL IN g | 28.89 | 30.65 | 34.52 | | |
| WT. WATER, Ww, IN g | | | | | |
| WT. CONTAINER IN g | 17.53 | 18.25 | 18.35 | | |
| WT. DRY SOIL, Ws IN g | 11.36 | 12.4 | 16.17 | | |
| WATER CONTENT, w, IN % | 39.4 | 42.9 | 46.1 | | |

## SHRINKAGE LIMIT

| DETERMINATION NO. | 1 | 2 |
|---|---|---|
| UNDISTURBED OR REMOLDED SOIL PAT | | |
| WT. DRY SOIL PAT Ws, IN g | | |
| WT. CONTAINER + HG. IN g | | |
| WT. CONTAINER IN g | | |
| WT. HG. IN g | | |
| VOL. SOIL PAT, V, IN cc | | |
| SHRINKAGE LIMIT, Ws, IN % | | |



## RESULT SUMMARY

| PLASTIC LIMIT | NATURAL WATER CONTENT | LIQUID LIMIT | SHRINKAGE LIMIT | B VALUE | PLASTICITY INDEX | FLOW INDEX | TOUGHNESS INDEX |
|---|---|---|---|---|---|---|---|
| 18 | | 44 | | | 26 | | |

CL

# APPENDIX D

# SLUG TEST DATA AND ANALYSES

# Appendix D
# Slug Test Data and Analyses

Slug testing was undertaken during the investigation to assist in determining the hydraulic conductivity of overburden materials at the site. Threee series of tests were conducted. The first series, conducted in April 1997, was performed on a limited set of wells using a rising head slug test. During these tests a pump was used to remove a large volume of water, in some cases nearly evacuating the well totally. The water level recovery was tehn observed and recorded. The second series of tests, conducted in January 1998, was performed on the entire set of wells screened in the overburden (with the exception of MWD-7) using a falling head test. These tests were performed by inserting a slug into the well and observing and recording the recovery of the water level in the well. The third series of tests, conducted in May 1999, were performed on a limited number of wells using a falling and rising head tests. The wells selected for this series were primarily wells screened at or near to water table and were selected to verify hydraulic conductivity measurements obtained during the previous falling head tests. These tests were performed by inserting a slug into the well, allowing the water level to equilibrate, and removing the slug. The recovery of the water level in the well was again observed and recorded. Further details regarding the procedures used during each testing event is provided and subsequent analysis is provided below.

## 1997 Slug Testing Procedures

The slug/bail method was used for collecting data to calculate hydraulic conductivity at each well site. Prior to any removal of water from the well, all equipment was decontaminated. A depth to water and depth to the bottom of casing from the top of casing (TOC) was measured and prior to lowering the pump and transducer into the well.

The data recorder was then programmed at the surface. A Solinst Model 3001 Levellogger was utilized for data collection. This instrument is a pressure transducer which measures water pressure against a sensor which then coverts the value into a depth of water. Prior to installation in the well, the depth to water from TOC, well ID and start time are downloaded in to the transducer using a laptop computer. The transducer was then lowered into the well along with the pump. The pump used for removing water from the well was a small electric pump capable of removing 1.5 gallons of water per minute. This value will vary slightly depending of the depth of the well. The pump was then started at designated time which the transducer was programmed. The well was then pumped dry until the water level could no longer be lowered within the well. The pump was then removed from the well running so that backwash from the discharge hose would not interfere with the water level in the well. The transducer was left in the well to collect data.

After a period of time the water level was checked to determine if it had recovered. If the well had sufficiently recovered the transducer was removed from the well and the data was retrieved into the laptop computer. The transducer was then reprogrammed and the next well was tested.

## 1998 Slug Testing Procedures

An electronic water level indicator is utilized to measure the static water level from the top of the surface casing. A Levelogger Model 3001 transducer is placed into the monitoring well to measure the water pressure which relates to water level. A slugger made of PVC pipe five foot long and 1.35 inches in diameter is used to raise water level a known volume. The slugger has a volume of 0.051 cubic feet (0.4 gallon) and is capable of displacing about 2.5 feet in a 2- inch diameter well.

The static water level is measured and recorded for each piezometer. If the water level is below the top of the screen, then a known volume of distilled water is added to the well to raise the water level above the screen. If the water level is above the screen, then the slugger is used for the testing.

If additional water is required to raise the water level in the well, the Levelogger Model 3001 is programmed at the surface. Programming of the Levelogger consists of connecting the transducer to an optical reader and inputting the well ID, initial water level, time, data, reading increment, and present barometric pressure. Wen the Levelogger is programmed it is turned on and lowered to the bottom of the piezometer. A small bracket is used to prevent the transducer from resting directly on the bottom of the piezometer. The transducer is stabilized at the bottom. The slug is then quickly lowered (or water is added) directly above the transducer causing an instantaneous rise in the water level within the piezometer (typically from one to two feet). The initial water level displacement is measured using the electronic water level indicator for later comparison with the transducer data. As the water level recovers to its original state, measurements are periodically recorded using the electronic water level.

The Levelogger is programmed to collect readings in one second intervals. Water levels recover to within 10 percent of the original water level during each test. After the water level recovers, a final water level is measured and recorded prior to removal of the slug or the Levelogger. The Levelogger is then removed from the piezometer and immediately connected to a computer to download all the data into a file for hydraulic conductivity determination.

## 1999 Slug Testing Procedures

The procedures used in the 1999 slug testing are detailed in the attached Procedure for Slug Testing.

## Analyses of Slug Test Data

All slug test data were evaluated using the method developed by Hvorslev (1951). All data were analyzed using the widely used pump testing analysis program AquiferTest (Version 2.0) developed by Waterloo Hydrogeologic, Inc. The Hvorslev method of analysis is described in detail in the attached documentation from the AquiferTest Manual.

As indicated on page 22 of the attached AquiferTest documentation, it is generally necessary to apply a factor for an effective radius whenever the water falls within the screened portion of the well during testing. During the tests conducted at Kaiser, this was occasionally the case, particularly during the 1997 rising head tests. In some cases, the water level was present in the screened portion of the well during portions of the test, while being present about the screen during other portions of the tests. This frequently resulted in an inflection in the recovery curves and necessitated the fitting of separate lines to the different portions of the curve and using the effective radius parameter as appropriate. In the following analyses, these different fits, when present, have been identified as S1 and S2 portions of the data. The results of both analyses have been averaged to provide a single hydraulic conductivity determination for the test.

# WORK PLAN

# FOR SLUG TEST SELECTED WELLS AT KAISER/TULSA FACILITY

May 21, 1999

Reviewed By Richard H. Kuhlthau, Ph.D.

## 1. PURPOSE AND OBJECTIVES

The purpose of the work proposed in this plan is to obtain data slug test data from selected wells at the Kaiser site. The wells identified for testing have been selected to verify previous hydraulic conductivity determinations from that well or to test previously untested wells. The wells selected for testing are primarily shallow wells in which the static water level during previous falling head slug test was located within or near the well screen or gravel pack. Several wells have also been selected based on irregularities in the previous response data.

## 2. SCOPE

### 2.1 Locations to be tested.

Test the following 10 wells: P-3, P-4, MWS-2, MWS-4, MWS-6, MWD-7, MWD-8, MWD-9, MWS-11, MWD-11. Note that MWS-6 and MWS-11 will not likely contain sufficient water for testing. If data is available from previous testing that show limited response and can be included in Appendix, P-4 does not need to be retested.

## 3.0 PROCEDURES

### 3.1 Test Procedures

Use A&M Procedure entitled Procedure for Testing a Well Using a Solid Slug dated May 21, 1999.

### 3.2 Data Analyses

Analyze data from all wells tested for both falling and rising head tests using Hvorslev method. For three randomly selected wells, verify tests using Bouwer and Rice method for both falling and rising head tests.

# Procedure for Slug Testing a Well Using a Solid Slug

May 21, 1999

A & M Engineering and Environmental Service, Inc.
10010 E. 16th Street
Tulsa, OK 74128 -4813

## 1. Purpose

To provide a procedure for performing and documenting single well slug tests using a solid slugger. Procedure is intended to ensure that test design, documentation, and resulting data are suitable for subsequent analyses using standard slug test analysis methods to determine hydraulic conductivity of formations screened by subject well.

## 2. Scope

This procedure should be used for the collection of both falling head and rising head data during a single slug test conducted through the insertion and subsequent removal of a solid slug. Procedure provide for the collection of water level recovery data using a pressure transducer.

## 3. Responsibilities

The users of this procedure are responsible for properly following this procedure. The A&M field supervisor is responsible for ensuring that the appropriate equipment is available at the sampling site, that the equipment has been properly calibrated and decontaminated prior to initiation of the sampling activity and that the personnel have been trained to use this procedure and other quality assurance procedures as required for the field testing to be performed. The users of this procedure, A&M Site Manager, and the A&M Client Site Manager are responsible for ensuring that all applicable health and safety procedures are carefully followed during the implementation of this procedure.

## 4. Equipment and Supplies

The following equipment and supplies should be assembled prior to initiating the sampling operation:

4.1 Field notebook. A field notebook dedicated to the Project site must be obtained prior to the initiation of field work. The field notebook can be either a hard bound engineering logbook, a three-ring binder, or other suitable notebook. This notebook will only be used to enter information relating to the slug testing efforts in the field.

4.2 This Procedure, well construction data, well location map, field data from previous slug testing events, and water level data from recent water level measuring events.

4.4 Well keys.

4.3 A mechanical device (slugger) for insertion into and removal from the well to induce an initial displacement of the water in the well. The slugger must be of sufficiently small diameter to permit entry into the subject wells and to freely allow movement of water through the casing past the slugger. The slugger should be of suitable diameter and length to induce a sufficient displacement to provide an adequate sequence of data for test analyses. The slugger should be connected to a rope or graduated tape.

For shallow (less than 25-foot depth) wells constructed with 2-inch O.D, PVC casing and screened in low to moderate permeability (hydraulic conductivity ranging between $10^{-2}$ to $10^{-7}$ cm/sec) materials, the standard slugger is a 5-foot long, 1.35-inch outer diameter device. The slugger is weighted with deionized water and has a volume of 0.51 cubic feet (0.4 gallons). Fully immersed, this slugger should raise the water level in a 2-inch well approximately 2.5 feet.

4.6 Data Logger (pressure transducer) capable of reliably and accurately measuring and time and concurrent water level in well during recovery of induced displacement. Accompanying means for retrieving and storing data during/after test is similarly required.

Standard equipment is a Solinst Levellogger Model 3001 Pressure Transducer . Data are taken form levellogger by laptop computer. Win Book xP33 MHZ is standard laptop computer used for this purpose.

4.7 Electronic water level measuring device with graduated tape capable of measuring water levels to within 0.01 foot accuracy.

4.8 Distilled water for rinsing equipment between wells.

4.9 Five gallon bucket or other suitable container for collecting rinse water.

4.10 Plastic Sheeting.

## 5. Preparation for Collection of Water Samples in Field

Prior to initiating field operations, the field crew supervisor must check that all the equipment listed in section 3.0 of this procedure is available for transfer to the project site. The A&M field supervisor will notify the Client representative once all the equipment is available for transfer. The Client representative and A&M field supervisor will review the wells to be tested and any special concerns or issues regarding the testing program.

Prior to testing, all equipment entering the will be and cleaned according to the procedure given below.

## 6. Decontamination Procedure

All equipment prior to entering the well must be thorough cleaned and rinsed with distilled water. Between wells, all equipment must be rinsed with distilled water. Rinse water is to be collected in a five gallon bucket or other suitable container and disposed of in a suitable manner. A clean plastic sheet should be placed or other suitable surface should be prepared at each well to prevent contamination of equipment.

## 7. Slug Testing Procedure for a Well or Piezometer

7.1 Prepare working space for field measurements. Lay a clean plastic sheet adjacent to well or otherwise prepare suitable, clean surface to prevent contamination of equipment.

7.2 Unlock cover to well. Grasp the monitor well cap with both hands and gently remove. Care must be taken to not let the inside of the cap touch anything while removed from the well.

7.2 Rinse the probe and the cable of the water level meter with deionized (DI) water and collect the rinse water in a five gallon plastic bucket. Slowly lower the depth indicator probe into the well until the meter indicates that water has been reached. Using the permanent measuring point designated on the casing, the depth at which the water was encountered will be mentally noted (the meter will be read to the nearest 0.01 ft.). The probe will be raised until it is no longer in the water and then will be lowered again until the meter indicates that water has been reached. The depth will be mentally noted. If the first and second values do not agree within 0.01 ft., repeat the steps above until the two readings agree within 0.01 ft. Once a stable depth to water has been confirmed, recorded the static water level in the field notebook.

7.3 Slowly lower the water level probe into the well until it has hit bottom. Read and mentally note the depth where tension in the cable is relieved as the weighted end touches the bottom of the well. Slowly raise the probe above the bottom and then lower it again to the bottom to take an independent reading. If the two readings are within 0.1 ft, record the value; if not, take additional readings until a consistent result is obtained. Readings will be recorded to the nearest 0.1 ft as measured from the permanent measuring point on the casing.

7.4 Slowly remove the probe if necessary for subsequent insertion of pressure transducer.

7.5 Calculate height of standing water column in well and record in field log book. If height of standing column in well is less than 4.0 feet, discontinue test, replace and lock well cap, move to next well. **Do not add water to raise water level above top or screen.**

7.6 Based on measured height of standing column of water in the well, determine if there is sufficient water standing in the well to fully submerse the slugger with bottom bracket/cage for transducer (for standard slugger with bottom bracket, 6.0 feet of water standing in well is required to submerse slugger). If sufficient water is not standing in well to submerse the slugger and bottom bracket, clearly note this in the field log book so that appropriate correction factors can be applied for the effective casing radius as necessary to account for the volume of the casing occupied by the slugger. Based on measured depth of well and height of slugger and bottom transducer bracket, calculate and record in the field log book the depth to which the slugger will have to lowered in the well to sit on the transducer bracket at the bottom of the well. Measure and mark that depth on the rope or graduated tape attached to the slugger.

7.7 Establish criterion for determining completion of rising and falling head tests. Computing 5% of the expected displacement of water level induce by slugger (for fully submersed standard slugger, 0.05 x 2.5 feet or 0.125 feet or 1.5 inches). Compute criterion for falling head test by adding 5% of expected displacement to the height of static water level in well (if using depth of static water in well, subtract 5% of expected displacement from depth of static water in well). Compute criterion for rising head test by subtracting 5% of expected displacement from the height of static water level in well (if using depth of static water in well, add 5% of expected displacement to depth of static water in well).

7.8 Program the data logger by connecting the transducer to an optical reader and inputting the well ID, initial water level, time, date, reading increment and present barometric pressure. Program the data logger to collect readings at one second or other suitable intervals based on the expected response of the well. Based on existing information regarding permeability of subsurface material and expected well response, estimate time to complete both falling head and rising head tests and program data logger to record for that period of time. Attach bracket to bottom of transducer to prevent transducer from sitting directly on bottom of well. Turn pressure transducer on, insert data logger into well, and lower to the bottom of well.

7.9 Insert and quickly lower the slugger to the bottom of well so that it sits directly on the transducer bracket. Verify that slugger has been lowered to depth identified above in Step 7.6 by comparing the mark on the rope or graduated tape attached to the slugger to the top of the casing. If a discrepancy is noted, quickly attempt to reposition the slugger to the proper depth. If unable to do so, record in the field log book the depth to which the bottom of the slugger has actually been lowered into the well and proceed with the test.

7.10 Insert electronic water level probe and periodically measure the water level in well. When water level in well returns to the criterion water level computed in Step 7.7 above for a falling head test, remove electronic water level probe. Then quickly remove slugger from well.

7.11 Reinsert electronic water level probe into well and periodically measure water level in well. When water level in well returns to the criterion water level computed in Step 7.7 above for a rising head test, terminate test.

7.12 Review water level data with laptop computer to verify adequacy of data. If data found not adequate, repeat test.

7.13 Once adequacy of test data verified, remove water level probe and pressure transducer from well. Rinse with distilled water, collecting rinse water in a 5-gallon bucket or other suitable container.

7.14 Replace and lock well cap.

7.15 Make final entry into field log book for well, including label for computer file in which data for test is stored. Note any important observations and/or any deviations with procedure during test. Make backup copy of data file on floppy disk.

User's Manual

# AquiferTest Version 2.0

The Intuitive Aquifer Test Analysis Package
With Report Quality Graphical Output.

waterloo
hydrogeologic
SOFTWARE • CONSULTING • TRAINING

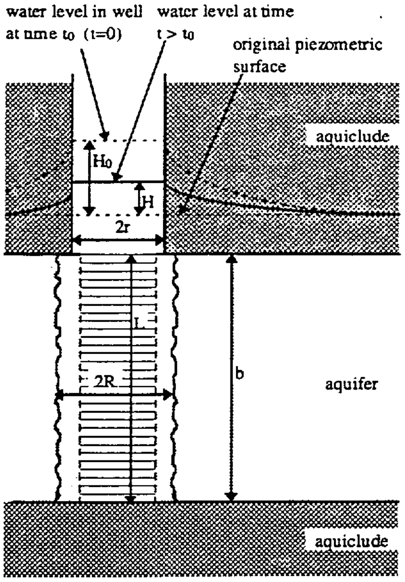
# Hvorslev Slug/Bail Test (confined/unconfined full or partial penetration)

The Hvorslev (1951) slug/bail test is designed to estimate the hydraulic conductivity of the aquifer material surrounding the screen of a piezometer. In a slug test, a solid "slug" is lowered into the piezometer instantaneously raising the water level in the piezometer. In a bail test, water is removed instantaneously lowering the water level in the piezometer.

The rate of inflow or outflow, q, at the piezometer tip at any time t is proportional to K of the soil and the unrecovered head difference:

$$q(t) = \pi r^2 \frac{dh}{dt} = FK(H-h)$$

The following figure illustrates the principle for the case of a slug test:



Hvorslev defined the *time lag*, $T_L$ (the time required for the initial injection/extraction to dissipate, assuming a constant flow rate) as:

$$T_L = \frac{\pi r^2}{FK}$$

where:

r is the effective radius of the piezometer,
F is a shape factor that depends on the dimensions of the piezometer intake, and
K is the bulk hydraulic conductivity within the radius of influence.

Substituting the time lag into the initial equation results in the following solution:

$$K = \frac{\pi r^2 \left( \ln \frac{H}{H_0} \right)}{Ft}$$

where:

H is the displacement as a function of time and

$H_0$ is initial displacement.

The field data are plotted with log $H/H_o$ on the y-axis and time on the x-axis. The value of $T_L$ is taken as the time which corresponds to $H/H_o = 0.37$ and $K$ is determined from the equation above. Hvorslev evaluated $F$ for the most common piezometers, where the length if the intake is greater than eight times the screen radius, and produced the following general solution for $K$:

$$K = \frac{r^2 \ln(L / R)}{2\, LT_L}$$

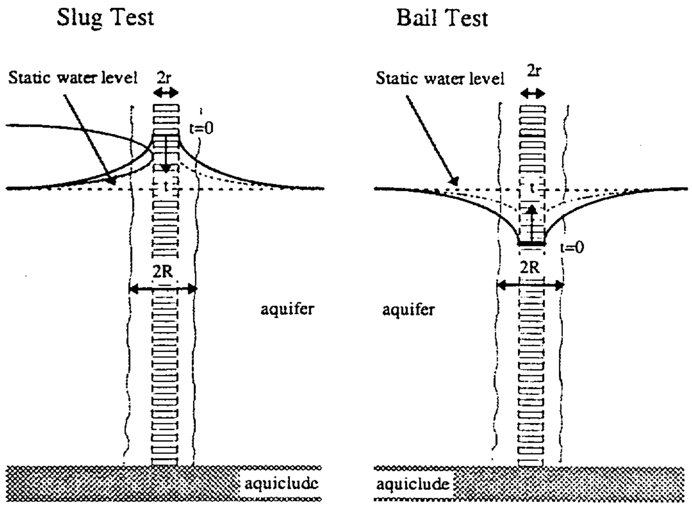
where:

$L$ is the screen length

$R$ is the radius of the well including the gravel

$T_L$ is the time lag when $H/H_0 = 0.37$

The effective piezometer radius, $r$, should be specified as the radius of the piezometer unless the water level falls within the screened portion of the aquifer during the slug test as indicated in the following figures.



In this case, the effective radius can be calculated as follows:

$$r_{eff} = \left[r^2(1-n)+nR^2\right]^{1/2}$$

where: $n$ is the porosity.

In cases where the water level drops within the screened interval, the plot of $H/H_0$ vs. $t$ will often produce a plot which seems to have an initial slope and a smaller slope at later time. In this case the fit should be obtained for the second straight line portion (Bower, 1989)

The assumptions with the Hvorslev solution are as follows:

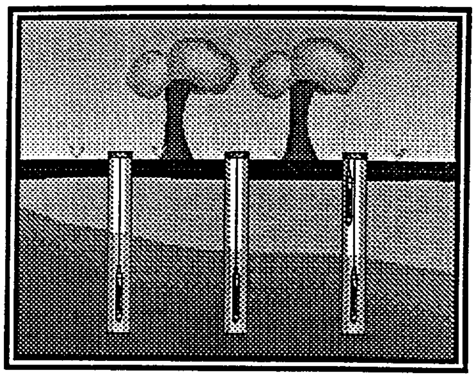
- non-leaky confined aquifer of "apparently" infinite extent
- homogeneous, isotropic or anisotropic aquifer of uniform thickness
- watertable is horizontal prior to the test
- instantaneous injection/withdrawal of a volume of water resulting in an instantaneous change in head
- inertia of water column and non-linear well losses are negligible
- fully or partially penetrating well
- the well is considered to be of an infinitesimal width
- flow is horizontal toward/away from the well.

The data requirements for the Hvorslev solution are:

- drawdown / recovery vs. time data at an pumping well
- observations beginning from time zero onward (the observation at t=0 is taken as the initial displacement value, $H_0$, and thus it must be a non-zero value).

# Levelogger™

Model 3001



# Operating Manual
# F15, F30, and F100 Models

# 1997
# Slug Test Data

**A&M Engineering**
10[illegible]. 16th Street
Tu[illegible]
ph.(918) 665-6575

slug/bail test analysis
HVORSLEV's method

Page 1

Project: Kaiser, Tulsa, OK

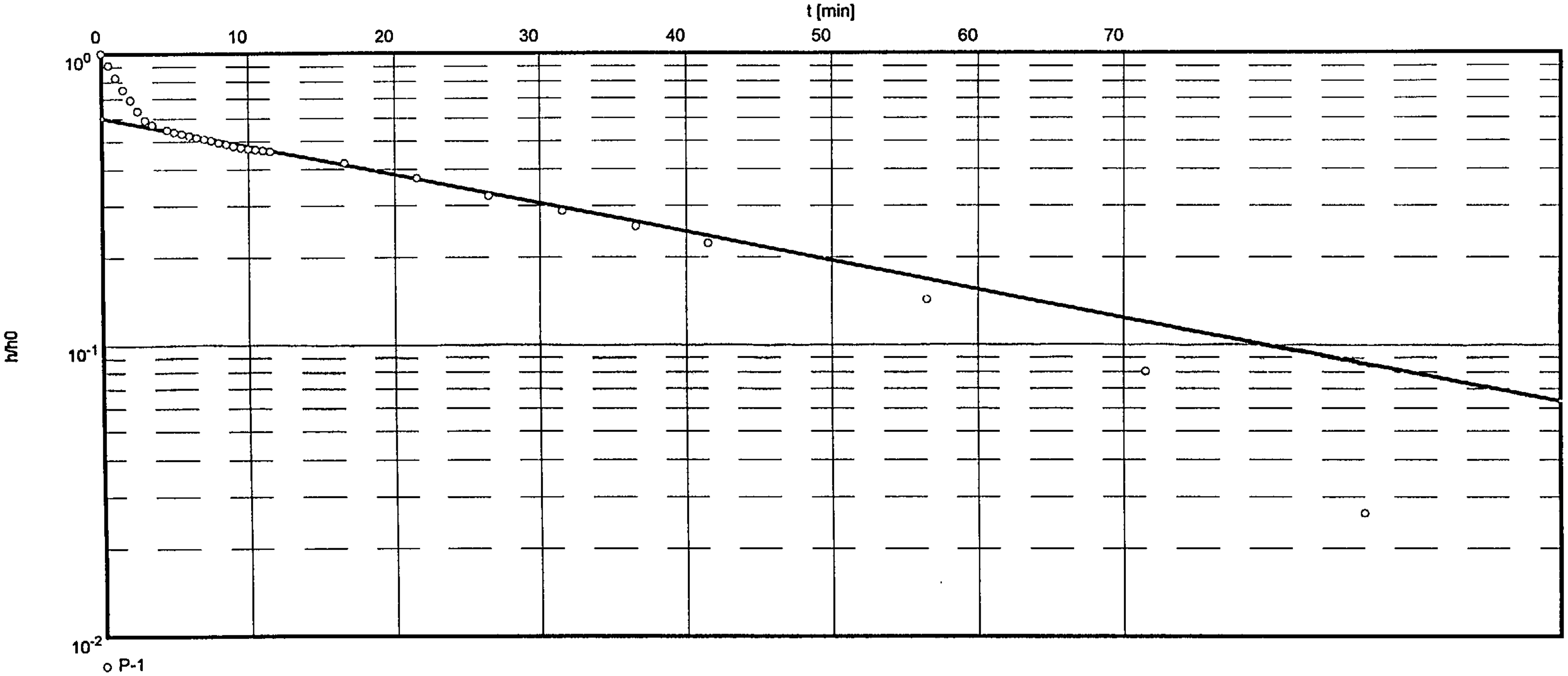
Evaluated by: pls

Date: 24.04.1999

Slug Test No. 1

Test conducted on: 9/7/97

P-1



Hydraulic conductivity [ft/min]: $1.35 \times 10^{-4}$

Hydraulic conductivity (cm\sec): 6.86 x 10-5 (S1)

Static Water Depth Below TOC: 7.48 ft
Total Well Depth Below TOC: 23.54 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
| **A& gineering**<br>100 6th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 2<br>Project: Kaiser, Tulsa, OK<br>Evaluated by: pls — Date: 24.04.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 9/7/97 |
| P-1 | P-1 |

Static water level: 7.48 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0.00 | 22.64 | 15.16 | |
| 2 | 0.50 | 21.30 | 13.82 | |
| 3 | 1.00 | 20.00 | 12.52 | |
| 4 | 1.50 | 18.88 | 11.40 | |
| 5 | 2.00 | 17.99 | 10.51 | |
| 6 | 2.50 | 17.12 | 9.64 | |
| 7 | 3.00 | 16.45 | 8.97 | |
| 8 | 3.50 | 16.14 | 8.66 | |
| 9 | 4.50 | 15.78 | 8.30 | |
| 10 | 5.00 | 15.63 | 8.15 | |
| 11 | 5.50 | 15.54 | 8.06 | |
| 12 | 6.00 | 15.42 | 7.94 | |
| 13 | 6.50 | 15.30 | 7.82 | |
| 14 | 7.00 | 15.20 | 7.72 | |
| 15 | 7.50 | 15.12 | 7.64 | |
| 16 | 8.00 | 14.99 | 7.51 | |
| 17 | 8.50 | 14.89 | 7.41 | |
| 18 | 9.00 | 14.79 | 7.31 | |
| 19 | 9.50 | 14.70 | 7.22 | |
| 20 | 10.00 | 14.63 | 7.15 | |
| 21 | 10.50 | 14.58 | 7.10 | |
| 22 | 11.00 | 14.53 | 7.05 | |
| 23 | 11.50 | 14.48 | 7.00 | |
| 24 | 16.50 | 13.86 | 6.38 | |
| 25 | 21.50 | 13.14 | 5.66 | |
| 26 | 26.50 | 12.39 | 4.91 | |
| 27 | 31.50 | 11.84 | 4.36 | |
| 28 | 36.50 | 11.34 | 3.86 | |
| 29 | 41.50 | 10.86 | 3.38 | |
| 30 | 56.50 | 9.66 | 2.18 | |
| 31 | 71.50 | 8.70 | 1.22 | |
| 32 | 86.50 | 7.88 | 0.40 | |
| 33 | 94.50 | 7.48 | 0.00 | |

**A&M gineering**
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slug/bail test analysis
HVORSLEV's method

Page 1

Project: Kaiser, Tulsa, OK

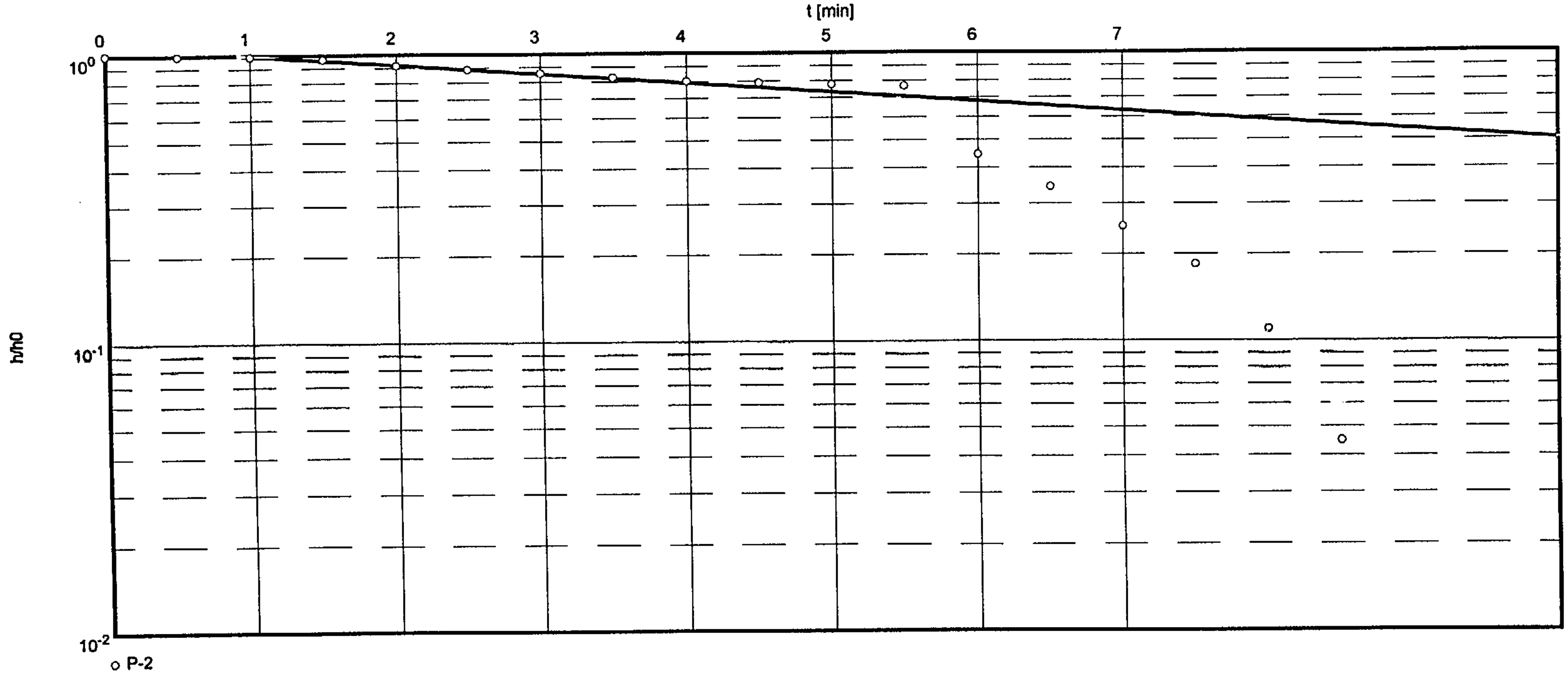
Evaluated by: pls

Date: 24.04.1999

Slug Test No. 1

Test conducted on: 4/27/97

P-2



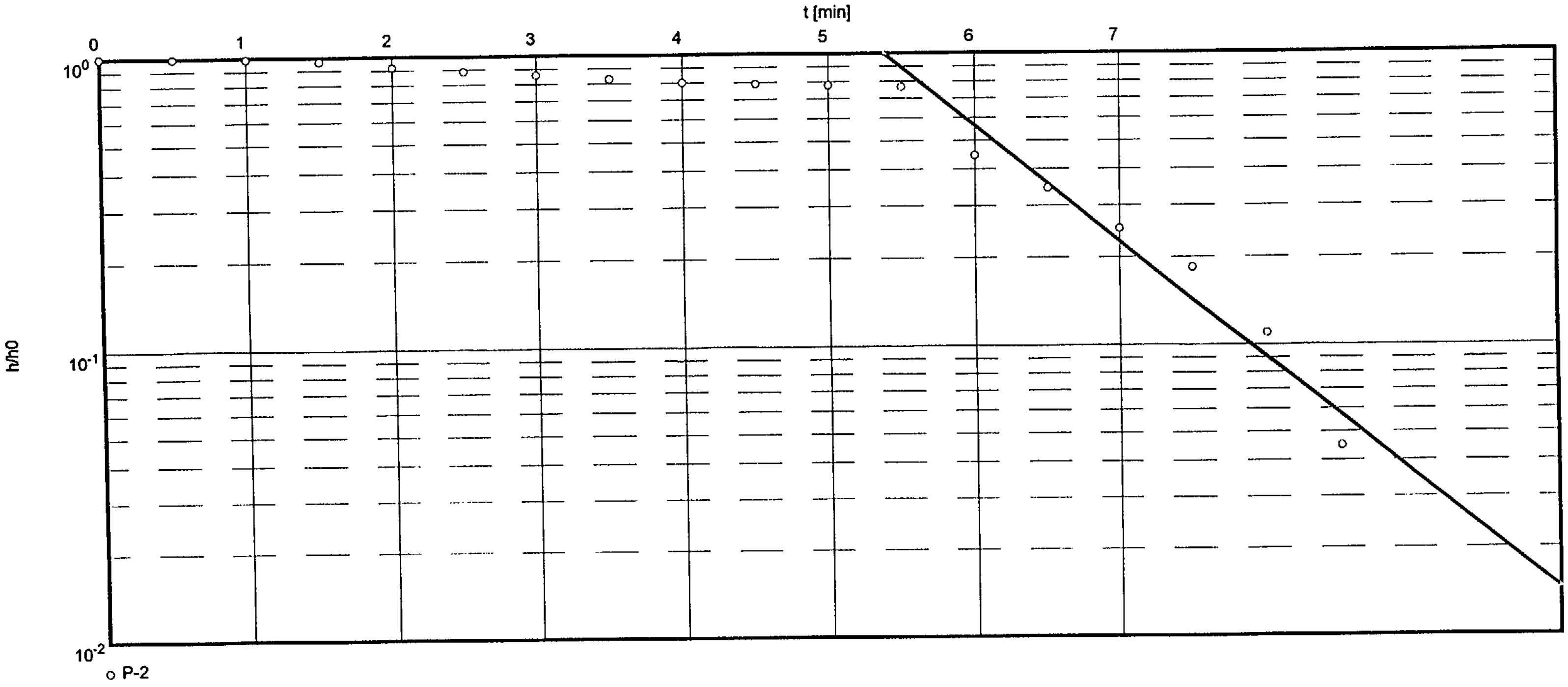
Hydraulic conductivity [ft/min]: 4.54 x $10^{-4}$

Hydraulic conductivity (cm\sec): 2.31 x 10-4 (S1)

Static Water Level Below TOC: 9.48 ft
Total Well Depth Below TOC: 31.54 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r(eff= 0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
| **A&[illegible]gineering**<br>10[illegible]6th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 1<br>Project: Kaiser, Tulsa, OK<br>Evaluated by: pls — Date: 24.04.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 4/27/97 |
| P-2 | |



Hydraulic conductivity [ft/min]: $1.08 \times 10^{-3}$

Hydraulic conductivity (cm\sec): 5.49 x 10-4 (S2)

Static Water Level Below TOC: 9.48 ft
Total Well Depth Below TOC: 31.54 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen Length = 10 ft
Porosity (filter pack) = 45 %

**A& gineering**
10 16th Street
Tulsa, OK
ph.(918) 665-6575

slug/bail test analysis
HVORSLEV's method

Project: Kaiser, Tulsa, OK

Evaluated by: pls

Date: 24.04.1999

Slug Test No. 1

Test conducted on: 4/27/97

P-2

P-2

Static water level: 9.48 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0.00 | 31.30 | 21.82 | |
| 2 | 0.50 | 31.12 | 21.64 | |
| 3 | 1.00 | 31.04 | 21.56 | |
| 4 | 1.50 | 30.57 | 21.09 | |
| 5 | 2.00 | 29.50 | 20.02 | |
| 6 | 2.50 | 28.81 | 19.33 | |
| 7 | 3.00 | 28.20 | 18.72 | |
| 8 | 3.50 | 27.56 | 18.08 | |
| 9 | 4.00 | 26.98 | 17.50 | |
| 10 | 4.50 | 26.70 | 17.22 | |
| 11 | 5.00 | 26.46 | 16.98 | |
| 12 | 5.50 | 26.20 | 16.72 | |
| 13 | 6.00 | 19.20 | 9.72 | |
| 14 | 6.50 | 17.00 | 7.52 | |
| 15 | 7.00 | 14.95 | 5.47 | |
| 16 | 7.50 | 13.50 | 4.02 | |
| 17 | 8.00 | 11.88 | 2.40 | |
| 18 | 8.50 | 10.46 | 0.98 | |
| 19 | 9.00 | 9.48 | 0.00 | |

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10 16th Street
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slug/bail test analysis
HVORSLEV's method

Page 1

Project: Kaiser, Tulsa, OK

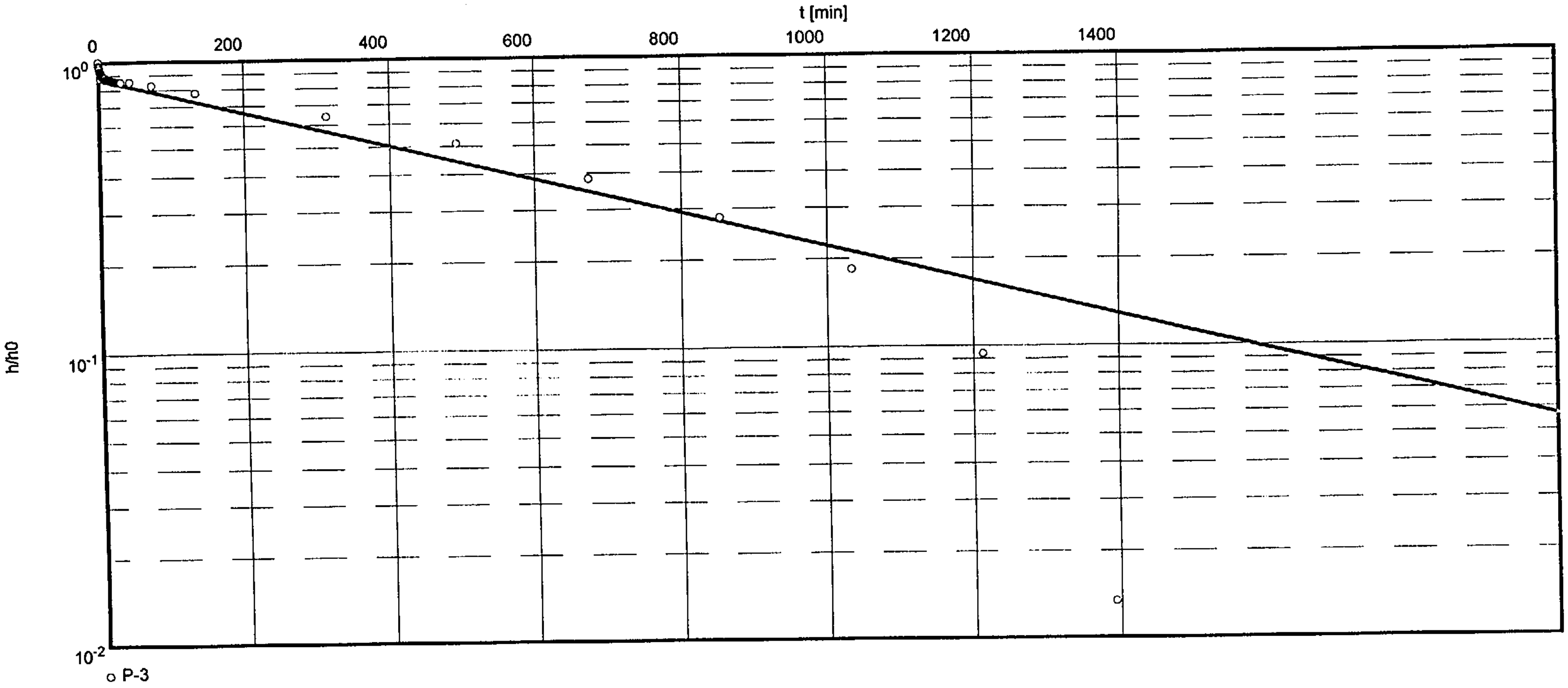
Evaluated by: pls

Date: 24.04.1999

Slug Test No. 1

Test conducted on: 4/17/97

P-3



Hydraulic conductivity [ft/min]: $8.20 \times 10^{-6}$

Hydraulic Conductivity (cm\sec): 4.17 x 10-6

Static Water Level Below TOC: 7.62 ft
Total Well Depth Below TOC: 16.30 ft
Casing Dia.: 2 in (r=.083 ft)
Boring Dia.: 6 in
(r)eff = 0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
| **A&M Engineering**<br>10 16th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 2<br>Project: Kaiser, Tulsa, OK<br>Evaluated by: pls — Date: 24.04.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 4/17/97 |
| P-3 | P-3 |

Static water level: 7.62 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0.00 | 15.10 | 7.48 |
| 2 | 0.50 | 14.90 | 7.28 |
| 3 | 1.00 | 14.80 | 7.18 |
| 4 | 1.50 | 14.70 | 7.08 |
| 5 | 2.00 | 14.58 | 6.96 |
| 6 | 2.50 | 14.55 | 6.93 |
| 7 | 3.00 | 14.49 | 6.87 |
| 8 | 3.50 | 14.45 | 6.83 |
| 9 | 4.00 | 14.42 | 6.80 |
| 10 | 4.50 | 14.39 | 6.77 |
| 11 | 5.00 | 14.36 | 6.74 |
| 12 | 5.50 | 14.33 | 6.71 |
| 13 | 6.00 | 14.29 | 6.67 |
| 14 | 6.50 | 14.29 | 6.67 |
| 15 | 7.00 | 14.29 | 6.67 |
| 16 | 7.50 | 14.26 | 6.64 |
| 17 | 8.00 | 14.23 | 6.61 |
| 18 | 8.50 | 14.23 | 6.61 |
| 19 | 9.00 | 14.23 | 6.61 |
| 20 | 9.50 | 14.23 | 6.61 |
| 21 | 10.00 | 14.13 | 6.51 |
| 22 | 10.50 | 14.16 | 6.54 |
| 23 | 11.00 | 14.13 | 6.51 |
| 24 | 11.50 | 14.13 | 6.51 |
| 25 | 12.00 | 14.13 | 6.51 |
| 26 | 12.50 | 14.13 | 6.51 |
| 27 | 13.00 | 14.13 | 6.51 |
| 28 | 13.50 | 14.13 | 6.51 |
| 29 | 14.00 | 14.13 | 6.51 |
| 30 | 14.50 | 14.13 | 6.51 |
| 31 | 15.00 | 14.13 | 6.51 |
| 32 | 15.50 | 14.10 | 6.48 |
| 33 | 16.00 | 14.10 | 6.48 |
| 34 | 16.50 | 14.10 | 6.48 |
| 35 | 17.00 | 14.10 | 6.48 |
| 36 | 17.50 | 14.07 | 6.45 |
| 37 | 18.00 | 14.07 | 6.45 |
| 38 | 18.50 | 14.07 | 6.45 |
| 39 | 19.00 | 14.07 | 6.45 |
| 40 | 20.00 | 14.07 | 6.45 |
| 41 | 20.50 | 14.07 | 6.45 |
| 42 | 21.00 | 14.07 | 6.45 |
| 43 | 21.50 | 14.07 | 6.45 |
| 44 | 22.00 | 14.03 | 6.41 |
| 45 | 22.50 | 14.03 | 6.41 |
| 46 | 23.00 | 14.03 | 6.41 |
| 47 | 23.50 | 14.03 | 6.41 |
| 48 | 24.00 | 14.00 | 6.38 |
| 49 | 24.50 | 14.03 | 6.41 |
| 50 | 25.00 | 14.00 | 6.38 |

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slug/bail test analysis
HVORSLEV's method

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Evaluated by: pls

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Slug Test No. 1

Test conducted on: 4/17/97

P-3

P-3

Static water level: 7.62 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 51 | 25.50 | 14.00 | 6.38 |
| 52 | 26.00 | 14.03 | 6.41 |
| 53 | 26.50 | 14.00 | 6.38 |
| 54 | 27.00 | 14.00 | 6.38 |
| 55 | 27.50 | 14.00 | 6.38 |
| 56 | 28.00 | 14.00 | 6.38 |
| 57 | 28.50 | 14.00 | 6.38 |
| 58 | 29.00 | 14.00 | 6.38 |
| 59 | 29.50 | 14.00 | 6.38 |
| 60 | 30.00 | 14.00 | 6.38 |
| 61 | 30.50 | 14.00 | 6.38 |
| 62 | 43.00 | 14.00 | 6.38 |
| 63 | 73.00 | 13.81 | 6.19 |
| 64 | 133.00 | 13.45 | 5.83 |
| 65 | 313.00 | 12.42 | 4.80 |
| 66 | 493.00 | 11.45 | 3.83 |
| 67 | 673.00 | 10.49 | 2.87 |
| 68 | 853.00 | 9.71 | 2.09 |
| 69 | 1033.00 | 9.00 | 1.38 |
| 70 | 1213.00 | 8.32 | 0.70 |
| 71 | 1393.00 | 7.72 | 0.10 |

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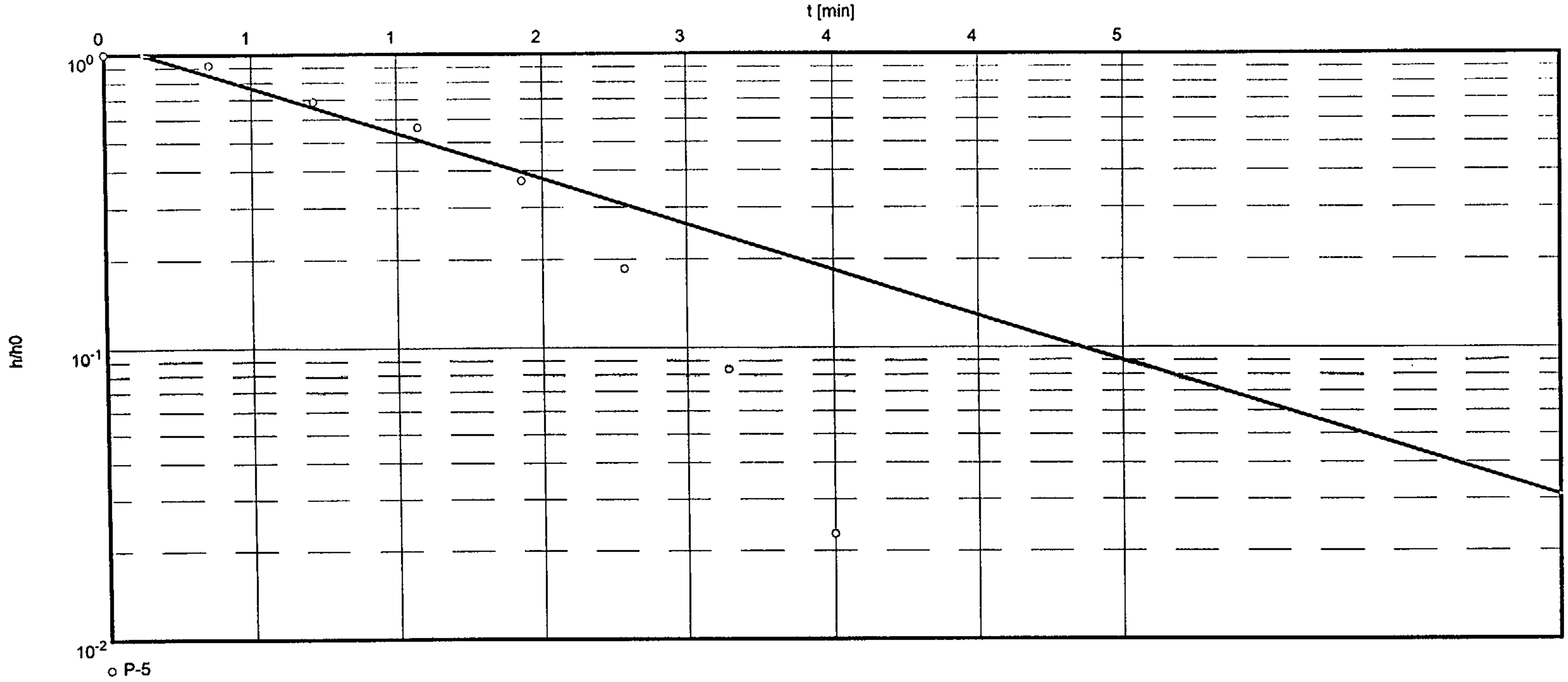
Slug Test No. 1

Test conducted on: 9/7/97

P-5



Hydraulic conductivity [ft/min]: $3.06 \times 10^{-3}$

Hydraulic conductivity (cm\sec):1.55x10-3 (S1)

Static Water Level Below TOC: 9.20 ft
Total Depth Below TOC: 23.06 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff=0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
| **A[illegible] Engineering**<br>[illegible] E. 16th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 2<br>Project: Kaiser, Tulsa, OK<br>Evaluated by: pls<br>Date: 24.04.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 9/7/97 |
| P-5 | P-5 |

Static water level: 9.20 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0.00 | 21.04 | 11.84 | |
| 2 | 0.50 | 20.08 | 10.88 | |
| 3 | 1.00 | 17.34 | 8.14 | |
| 4 | 1.50 | 15.86 | 6.66 | |
| 5 | 2.00 | 13.57 | 4.37 | |
| 6 | 2.50 | 11.40 | 2.20 | |
| 7 | 3.00 | 10.19 | 0.99 | |
| 8 | 3.50 | 9.47 | 0.27 | |
| 9 | 4.00 | 9.20 | 0.00 | |

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Slug Test No. 1

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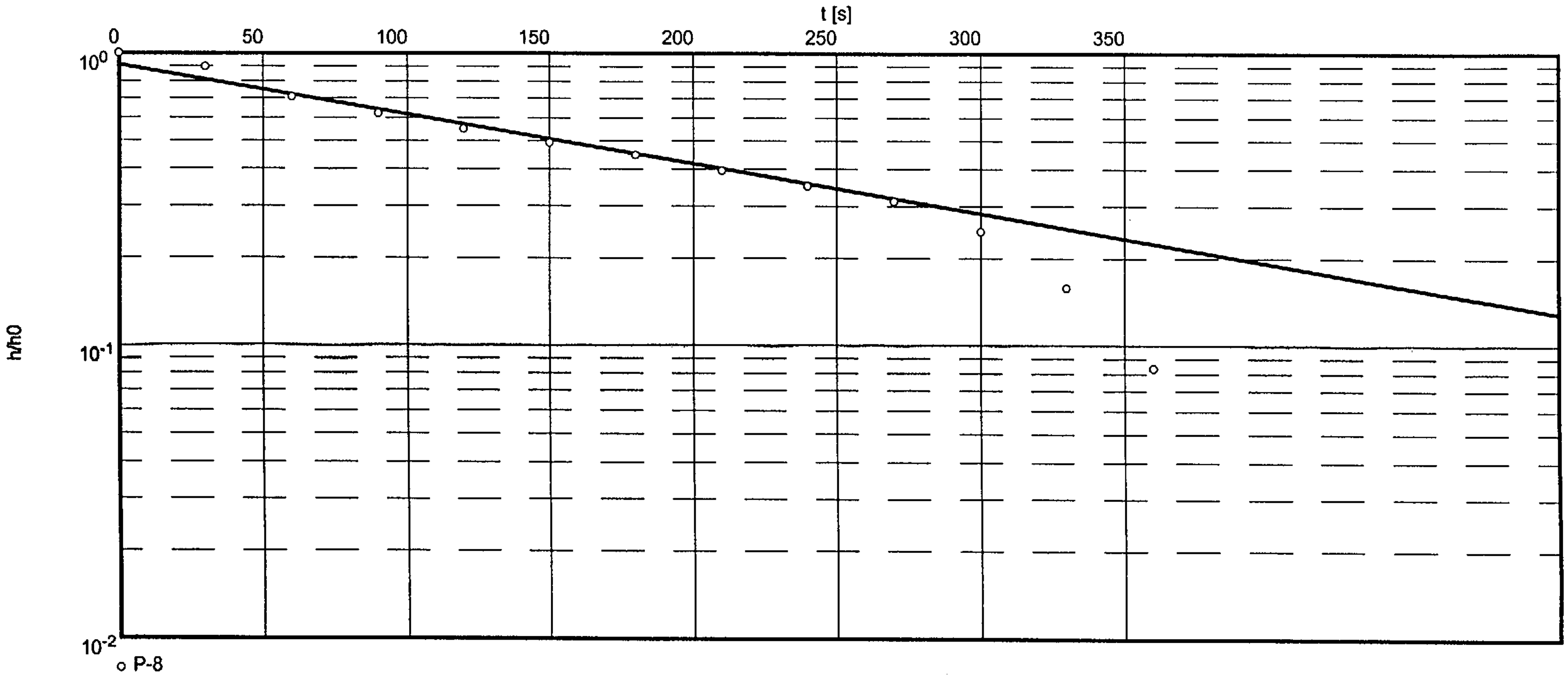
P-8



Hydraulic conductivity [ft/s]: $2.34 \times 10^{-5}$

Hydraulic conductivity (cm\sec): 7.13 x 10-4 (S1)

Static Water Depth Below TOC: 8.38 ft
Total Well Depth Below TOC: 26.67 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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P-8

P-8

Static water level: 8.38 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 26.58 | 18.20 |
| 2 | 30 | 24.72 | 16.34 |
| 3 | 60 | 21.24 | 12.86 |
| 4 | 90 | 19.69 | 11.31 |
| 5 | 120 | 18.37 | 9.99 |
| 6 | 150 | 17.35 | 8.97 |
| 7 | 180 | 16.51 | 8.13 |
| 8 | 210 | 15.58 | 7.20 |
| 9 | 240 | 14.76 | 6.38 |
| 10 | 270 | 14.05 | 5.67 |
| 11 | 300 | 12.86 | 4.48 |
| 12 | 330 | 11.27 | 2.89 |
| 13 | 360 | 9.90 | 1.52 |

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Slug Test No. 1

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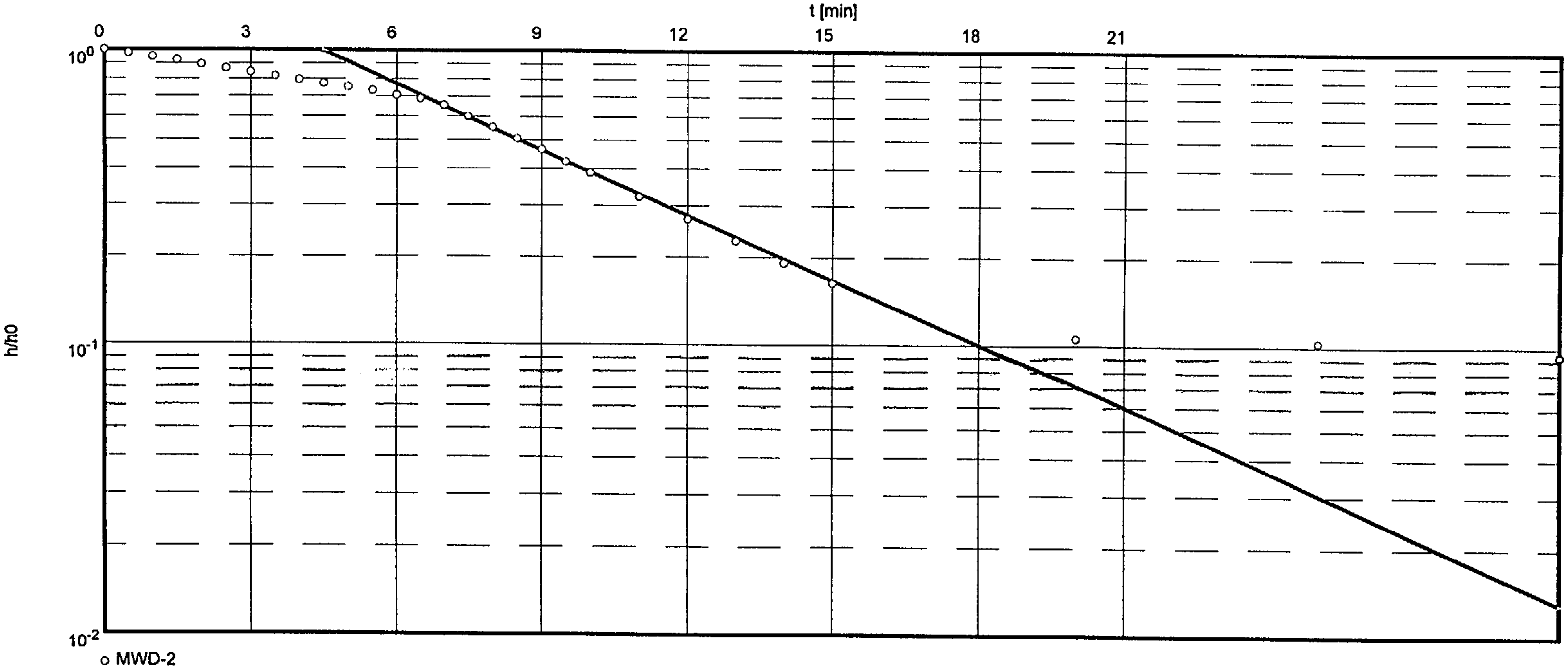
MWD-2



Hydraulic conductivity [ft/min]: $1.02 \times 10^{-3}$

Hydraulic conductivity (cm\sec): 5.18 x 10-4 (S1)

Static Water Level Below TOC: 7.37 ft
Total Depth below TOC : 18.88 ft
Casing Dia: 2 in (r=0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

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MWD-2

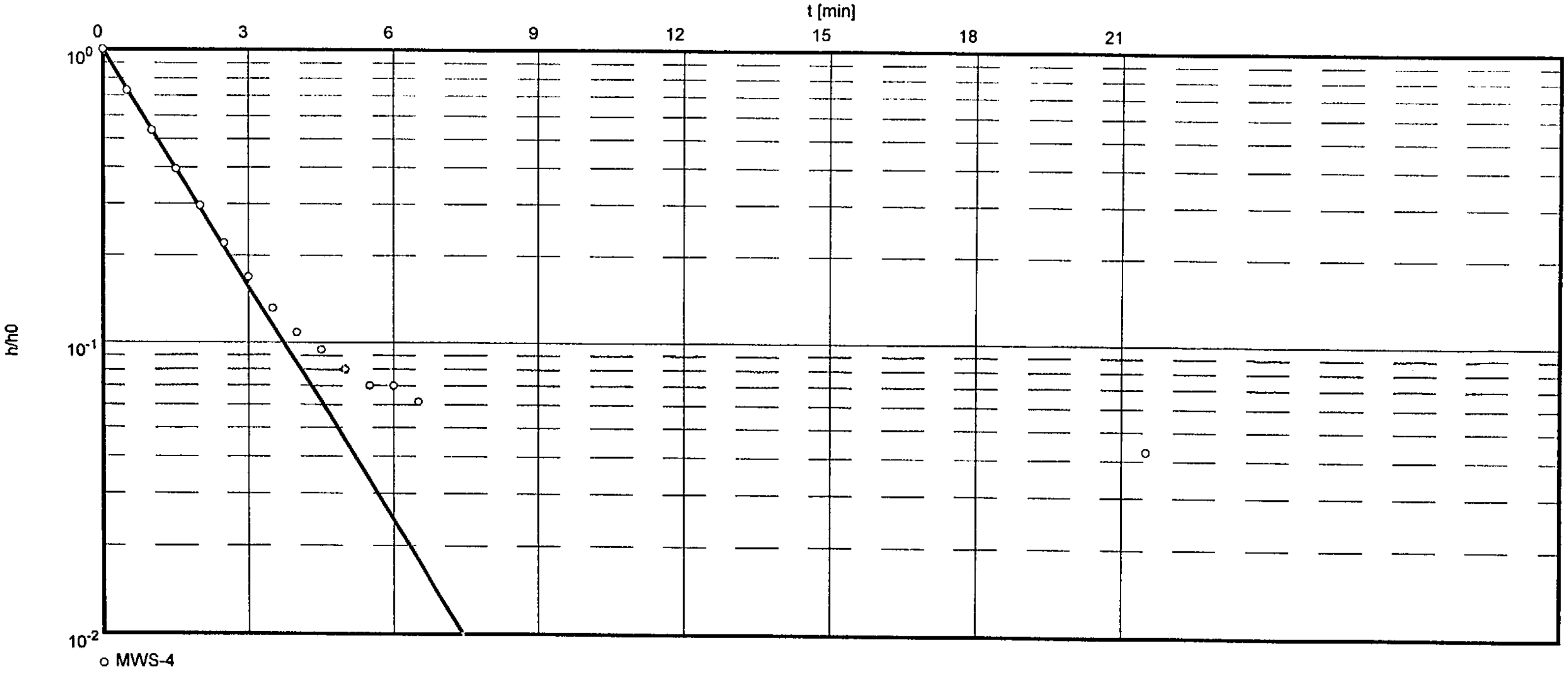
MWD-2

Static water level: 7.37 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0.00 | 18.49 | 11.12 |
| 2 | 0.50 | 18.18 | 10.81 |
| 3 | 1.00 | 17.90 | 10.53 |
| 4 | 1.50 | 17.62 | 10.25 |
| 5 | 2.00 | 17.31 | 9.94 |
| 6 | 2.50 | 17.02 | 9.65 |
| 7 | 3.00 | 16.74 | 9.37 |
| 8 | 3.50 | 16.46 | 9.09 |
| 9 | 4.00 | 16.21 | 8.84 |
| 10 | 4.50 | 15.97 | 8.60 |
| 11 | 5.00 | 15.75 | 8.38 |
| 12 | 5.50 | 15.51 | 8.14 |
| 13 | 6.00 | 15.24 | 7.87 |
| 14 | 6.50 | 15.02 | 7.65 |
| 15 | 7.00 | 14.65 | 7.28 |
| 16 | 7.50 | 14.06 | 6.69 |
| 17 | 8.00 | 13.52 | 6.15 |
| 18 | 8.50 | 13.00 | 5.63 |
| 19 | 9.00 | 12.54 | 5.17 |
| 20 | 9.50 | 12.08 | 4.71 |
| 21 | 10.00 | 11.69 | 4.32 |
| 22 | 11.00 | 10.95 | 3.58 |
| 23 | 12.00 | 10.37 | 3.00 |
| 24 | 13.00 | 9.90 | 2.53 |
| 25 | 14.00 | 9.50 | 2.13 |
| 26 | 15.00 | 9.19 | 1.82 |
| 27 | 20.00 | 8.55 | 1.18 |
| 28 | 25.00 | 8.52 | 1.15 |
| 29 | 30.00 | 8.41 | 1.04 |

| | | |
|---|---|---|
| **A&M Engineering**<br>1[illegible]E. 16th Street<br>T[illegible]<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 1<br>Project: Kaiser, Tulsa, OK<br>Evaluated by: PLS<br>Date: 24.04.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 4/27/97 |
| MWS-4 | |



Hydraulic conductivity [ft/min]: $6.03 \times 10^{-3}$

Hydraulic Conductivity (cm\sec): 3.06 x 10-3 (S1)

Static Water Level Below TOC: 5.64 ft
Total Depth Below TOC: 13.37 ft
Casing Diameter: 2 in (r=0.083)
Boring Diameter: 6 in
(r)eff= 0.18 ft
Screen Length = 5 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
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MWS-4

MWS-4

Static water level: 5.64 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0.00 | 12.63 | 6.99 |
| 2 | 0.50 | 10.73 | 5.09 |
| 3 | 1.00 | 9.38 | 3.74 |
| 4 | 1.50 | 8.40 | 2.76 |
| 5 | 2.00 | 7.71 | 2.07 |
| 6 | 2.50 | 7.18 | 1.54 |
| 7 | 3.00 | 6.82 | 1.18 |
| 8 | 3.50 | 6.56 | 0.92 |
| 9 | 4.00 | 6.40 | 0.76 |
| 10 | 4.50 | 6.30 | 0.66 |
| 11 | 5.00 | 6.20 | 0.56 |
| 12 | 5.50 | 6.13 | 0.49 |
| 13 | 6.00 | 6.13 | 0.49 |
| 14 | 6.50 | 6.07 | 0.43 |
| 15 | 21.50 | 5.94 | 0.30 |

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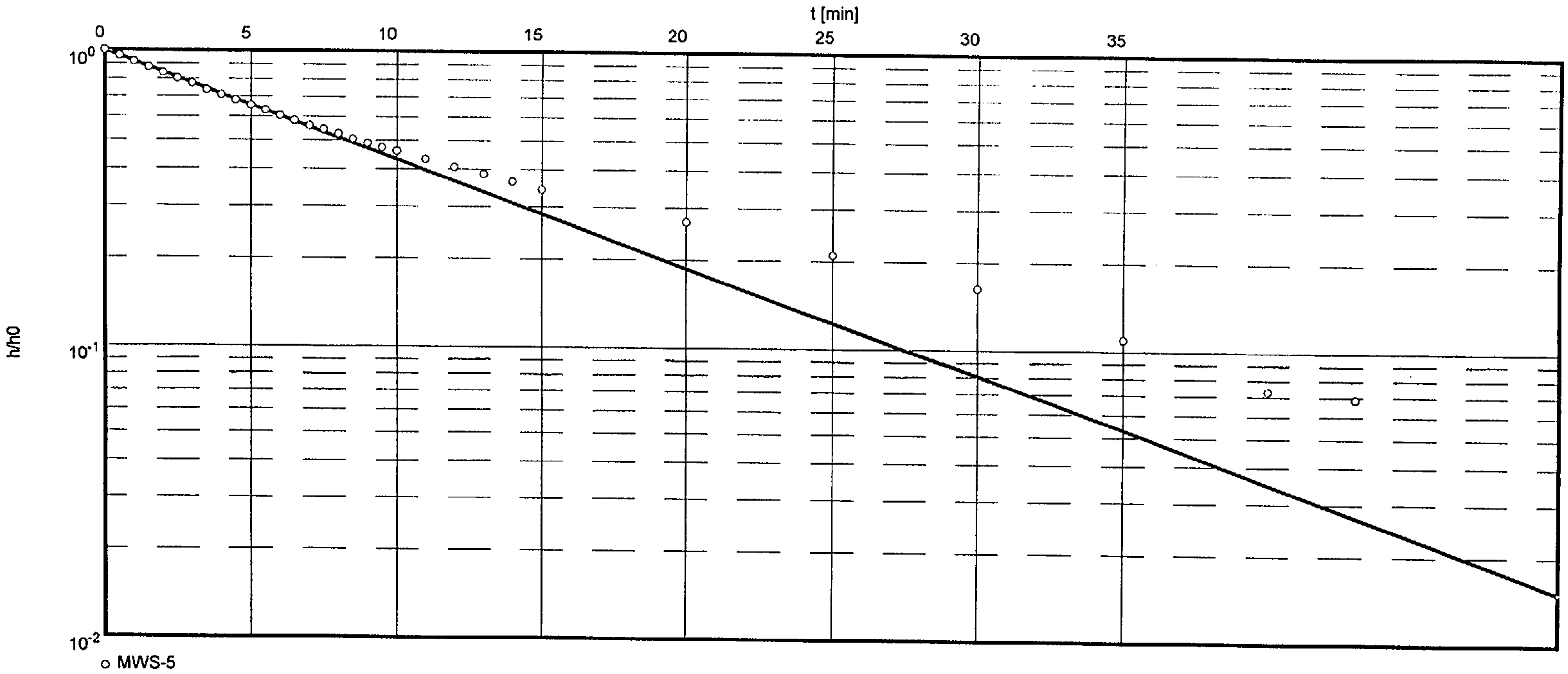
MWS-5



Hydraulic conductivity [ft/min]: $8.18 \times 10^{-4}$

Hydraulic conductivity (cm\sec): 4.16 x 10-4 (S1)

Static Water Depth Below TOC: 6.45 ft
Total Well Depth Below TOC: 16.21 ft
Casing Dia: 2 in (r= 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen Length = 5 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
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MWS-5

Static water level: 6.45 ft below datum

| | Pumping test duration<br>[min] | Water level<br>[ft] | Change in Waterlevel<br>[ft] |
|---|---|---|---|
| 1 | 0.00 | 15.90 | 9.45 |
| 2 | 0.50 | 15.51 | 9.06 |
| 3 | 1.00 | 15.11 | 8.66 |
| 4 | 1.50 | 14.74 | 8.29 |
| 5 | 2.00 | 14.37 | 7.92 |
| 6 | 2.50 | 14.05 | 7.60 |
| 7 | 3.00 | 13.76 | 7.31 |
| 8 | 3.50 | 13.41 | 6.96 |
| 9 | 4.00 | 13.16 | 6.71 |
| 10 | 4.50 | 12.89 | 6.44 |
| 11 | 5.00 | 12.64 | 6.19 |
| 12 | 5.50 | 12.41 | 5.96 |
| 13 | 6.00 | 12.17 | 5.72 |
| 14 | 6.50 | 11.96 | 5.51 |
| 15 | 7.00 | 11.75 | 5.30 |
| 16 | 7.50 | 11.60 | 5.15 |
| 17 | 8.00 | 11.42 | 4.97 |
| 18 | 8.50 | 11.23 | 4.78 |
| 19 | 9.00 | 11.07 | 4.62 |
| 20 | 9.50 | 10.92 | 4.47 |
| 21 | 10.00 | 10.80 | 4.35 |
| 22 | 11.00 | 10.54 | 4.09 |
| 23 | 12.00 | 10.30 | 3.85 |
| 24 | 13.00 | 10.09 | 3.64 |
| 25 | 14.00 | 9.90 | 3.45 |
| 26 | 15.00 | 9.69 | 3.24 |
| 27 | 20.00 | 8.99 | 2.54 |
| 28 | 25.00 | 8.43 | 1.98 |
| 29 | 30.00 | 7.99 | 1.54 |
| 30 | 35.00 | 7.49 | 1.04 |
| 31 | 40.00 | 7.14 | 0.69 |
| 32 | 43.00 | 7.10 | 0.65 |

| | | |
|---|---|---|
| **M Engineering**<br>I0 E. 16th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's methoc | Page 1<br>Project: Kaiser, Tulsa, OK<br>Evaluated by: pls — Date: 24.04.1999 |

Slug Test No. 1

Test conducted on: 4/27/97

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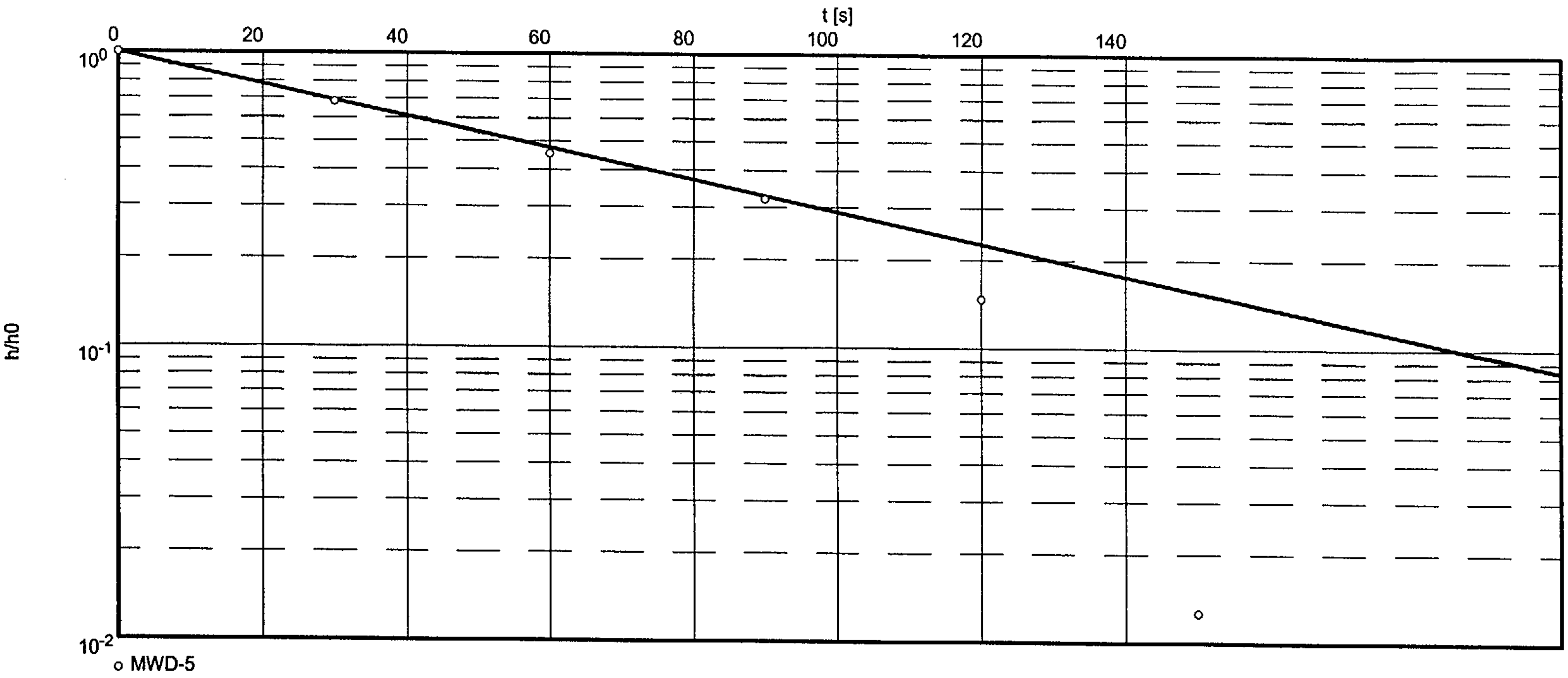

Hydraulic conductivity [ft/s]: $7.44 \times 10^{-5}$

Hydraulic conductivity (cm\sec): 2.27 x 10-3 (S1)

Static Water Level Below TOC: 11.37 ft
Total Depth Below TOC: 30.23 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
r(eff) = 0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

slug/bail test analysis
HVORSLEV's method

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MWD-5

Static water level: 11.37 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0.00 | 24.83 | 13.46 |
| 2 | 0.50 | 20.53 | 9.16 |
| 3 | 1.00 | 17.46 | 6.09 |
| 4 | 1.50 | 15.67 | 4.30 |
| 5 | 2.00 | 13.35 | 1.98 |
| 6 | 2.50 | 11.54 | 0.17 |
| 7 | 3.00 | 11.37 | 0.00 |

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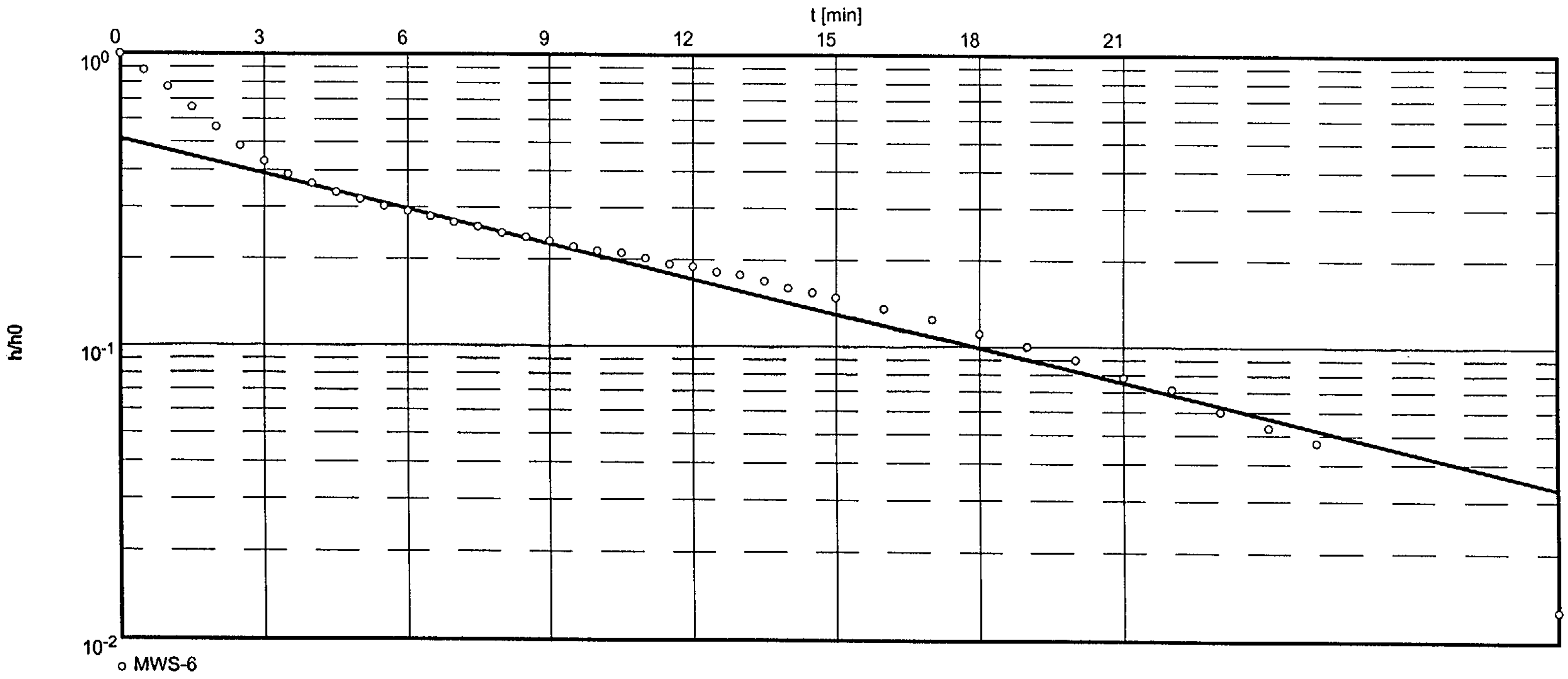
Slug Test No. 1
Test conducted on: 10/7/97
MWS-6



Hydraulic conductivity [ft/min]: $7.27 \times 10^{-4}$

Hydraulic conductivity (cm\sec): 3.69 x 10-4

Static Water Depth Below TOC: 8.36 ft
Total Depth Below TOC: 18.91 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen Length = 6.75 ft
Porosity (filter pack) = 45 %

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MWS-6

Static water level: 8.36 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0.00 | 17.03 | 8.67 | |
| 2 | 0.50 | 15.98 | 7.62 | |
| 3 | 1.00 | 15.05 | 6.69 | |
| 4 | 1.50 | 14.06 | 5.70 | |
| 5 | 2.00 | 13.24 | 4.88 | |
| 6 | 2.50 | 12.57 | 4.21 | |
| 7 | 3.00 | 12.08 | 3.72 | |
| 8 | 3.50 | 11.73 | 3.37 | |
| 9 | 4.00 | 11.49 | 3.13 | |
| 10 | 4.50 | 11.28 | 2.92 | |
| 11 | 5.00 | 11.13 | 2.77 | |
| 12 | 5.50 | 10.98 | 2.62 | |
| 13 | 6.00 | 10.88 | 2.52 | |
| 14 | 6.50 | 10.78 | 2.42 | |
| 15 | 7.00 | 10.67 | 2.31 | |
| 16 | 7.50 | 10.59 | 2.23 | |
| 17 | 8.00 | 10.49 | 2.13 | |
| 18 | 8.50 | 10.42 | 2.06 | |
| 19 | 9.00 | 10.36 | 2.00 | |
| 20 | 9.50 | 10.27 | 1.91 | |
| 21 | 10.00 | 10.21 | 1.85 | |
| 22 | 10.50 | 10.18 | 1.82 | |
| 23 | 11.00 | 10.11 | 1.75 | |
| 24 | 11.50 | 10.03 | 1.67 | |
| 25 | 12.00 | 10.00 | 1.64 | |
| 26 | 12.50 | 9.93 | 1.57 | |
| 27 | 13.00 | 9.90 | 1.54 | |
| 28 | 13.50 | 9.83 | 1.47 | |
| 29 | 14.00 | 9.75 | 1.39 | |
| 30 | 14.50 | 9.70 | 1.34 | |
| 31 | 15.00 | 9.65 | 1.29 | |
| 32 | 16.00 | 9.54 | 1.18 | |
| 33 | 17.00 | 9.44 | 1.08 | |
| 34 | 18.00 | 9.32 | 0.96 | |
| 35 | 19.00 | 9.23 | 0.87 | |
| 36 | 20.00 | 9.14 | 0.78 | |
| 37 | 21.00 | 9.04 | 0.68 | |
| 38 | 22.00 | 8.98 | 0.62 | |
| 39 | 23.00 | 8.88 | 0.52 | |
| 40 | 24.00 | 8.82 | 0.46 | |
| 41 | 25.00 | 8.77 | 0.41 | |
| 42 | 30.00 | 8.47 | 0.11 | |

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slug/bail test analysis
HVORSLEV's method

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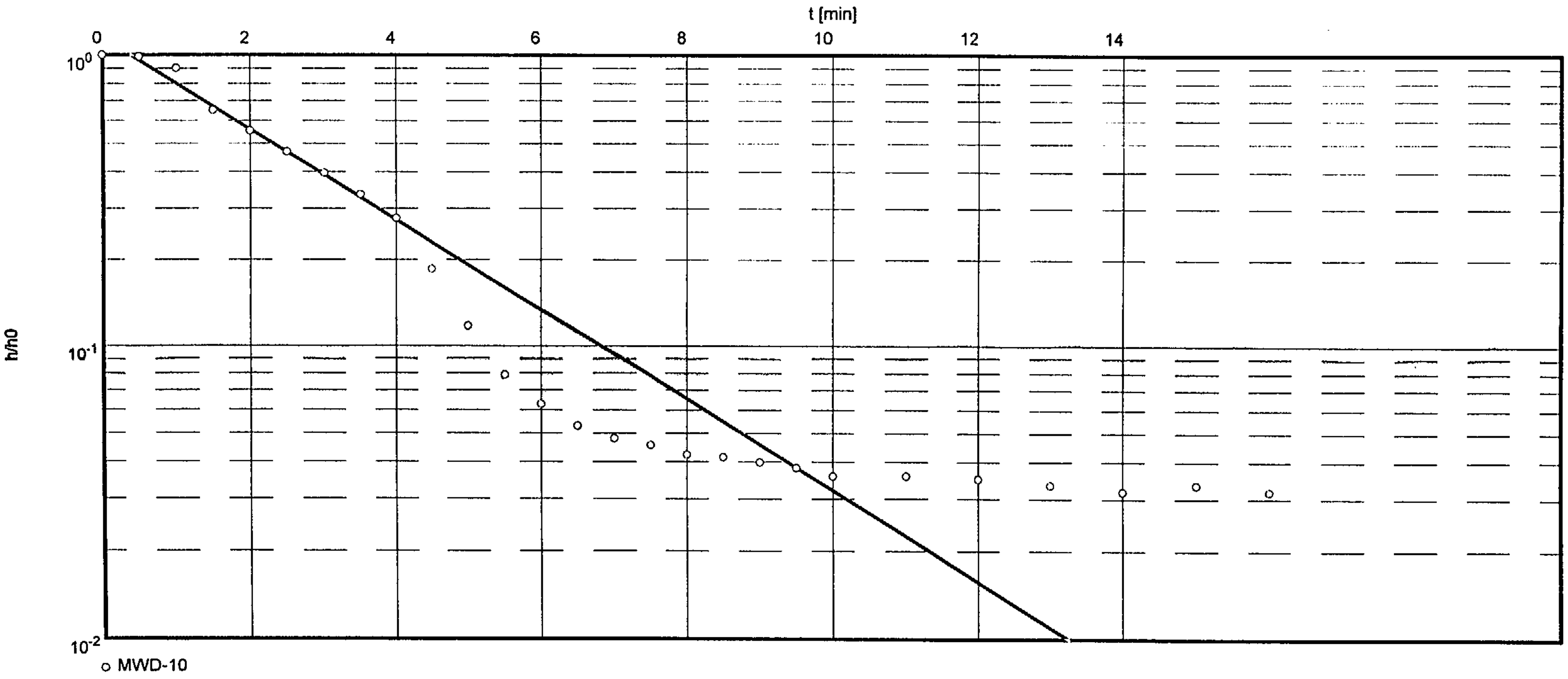
Evaluated by: pls

Date: 24.04.1999

Slug Test No. 1

Test conducted on: 7/9/97

MWD-10



Hydraulic conductivity [ft/min]: 2.15 x $10^{-3}$

Hydraulic conductivity (cm\sec): 1.09 x 10-3 (S1)

Static Water Depth Below TOC: 10.68 ft
Total Water Depth Below TOC: 23.80 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen Length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
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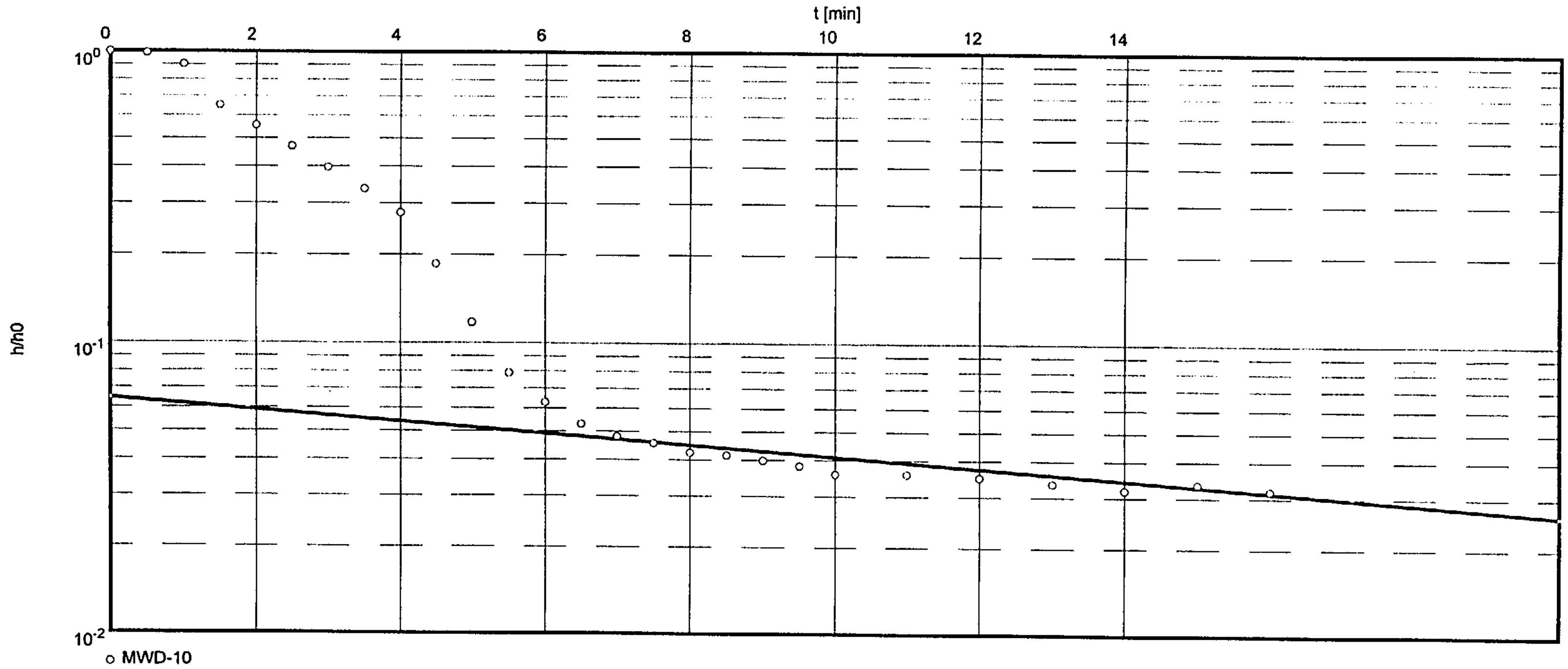
| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 7/9/97 |
| MWD-10 | |



Hydraulic conductivity [ft/min]: $5.38 \times 10^{-5}$

Hydraulic conductivity (cm\sec): 2.73 x 10-5 (S2)

Static Water Depth Below TOC: 10.68 ft
Total Water Depth Below TOC: 23.80 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen Length = 10 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
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Project: Kaiser, Tulsa, OK

Evaluated by: pls

Date: 24.04.1999

Slug Test No. 1

Test conducted on: 7/9/97

MWD-10

MWD-10

Static water level: 10.68 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0.00 | 22.95 | 12.27 |
| 2 | 0.50 | 22.80 | 12.12 |
| 3 | 1.00 | 21.75 | 11.07 |
| 4 | 1.50 | 18.68 | 8.00 |
| 5 | 2.00 | 17.48 | 6.80 |
| 6 | 2.50 | 16.45 | 5.77 |
| 7 | 3.00 | 15.55 | 4.87 |
| 8 | 3.50 | 14.80 | 4.12 |
| 9 | 4.00 | 14.09 | 3.41 |
| 10 | 4.50 | 12.96 | 2.28 |
| 11 | 5.00 | 12.12 | 1.44 |
| 12 | 5.50 | 11.65 | 0.97 |
| 13 | 6.00 | 11.45 | 0.77 |
| 14 | 6.50 | 11.33 | 0.65 |
| 15 | 7.00 | 11.27 | 0.59 |
| 16 | 7.50 | 11.24 | 0.56 |
| 17 | 8.00 | 11.20 | 0.52 |
| 18 | 8.50 | 11.19 | 0.51 |
| 19 | 9.00 | 11.17 | 0.49 |
| 20 | 9.50 | 11.15 | 0.47 |
| 21 | 10.00 | 11.12 | 0.44 |
| 22 | 11.00 | 11.12 | 0.44 |
| 23 | 12.00 | 11.11 | 0.43 |
| 24 | 13.00 | 11.09 | 0.41 |
| 25 | 14.00 | 11.07 | 0.39 |
| 26 | 15.00 | 11.09 | 0.41 |
| 27 | 16.00 | 11.07 | 0.39 |

# January 1998
# Slug Test Data

| | | |
|---|---|---|
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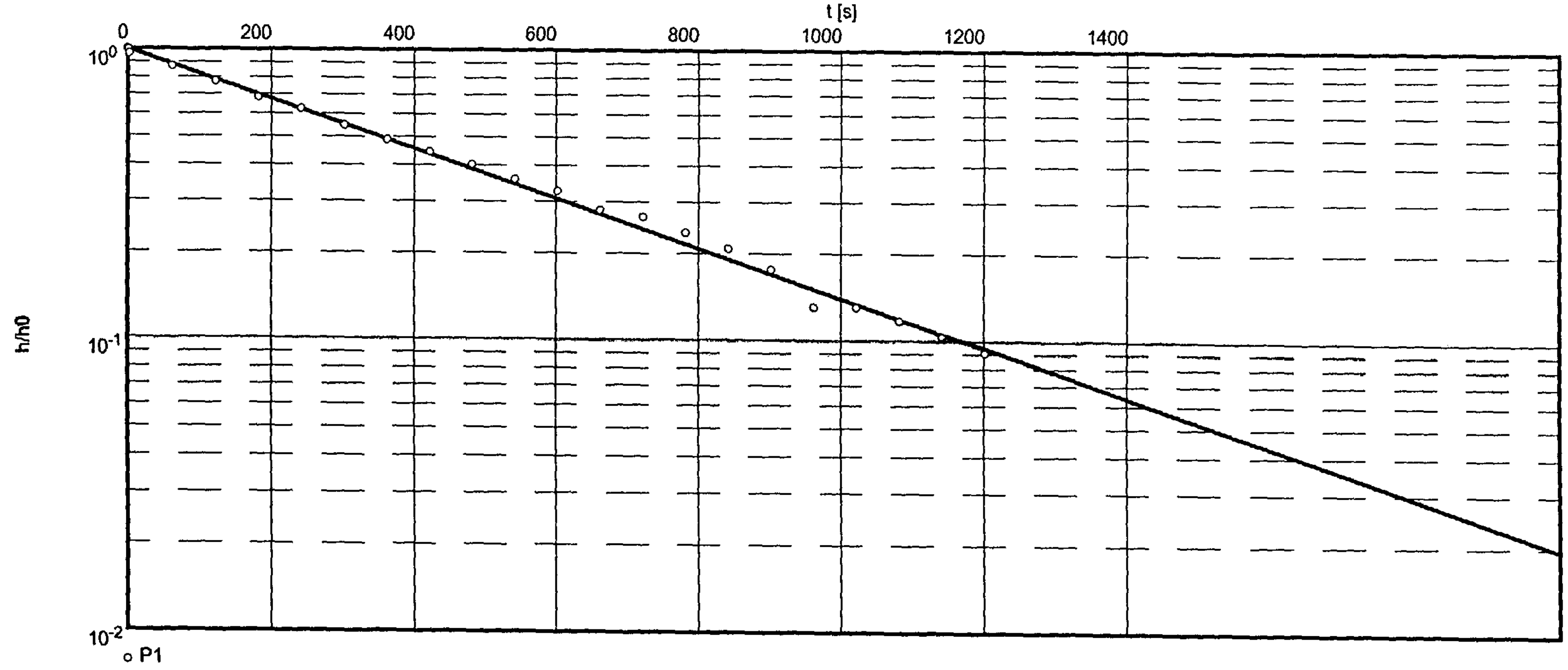
| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 19, 1998 |
| P1 | |



Hydraulic conductivity [ft/s]: 2.33 x $10^{-6}$

Hydraulic Conductivity: 7.1x10-5 cm/s

Static Water Depth Below TOC: 6.18 ft
Total Well Depth Below TOC: 23.51 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Poros [illegible] = 45 %

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Slug Test No.
P1

Test conducted on: Jan 19, 1998
P1

Static water level: 6.18 ft below datum

|  | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 3.97 | -2.21 |
| 2 | 1 | 3.98 | -2.20 |
| 3 | 2 | 4.05 | -2.13 |
| 4 | 62 | 4.25 | -1.93 |
| 5 | 122 | 4.47 | -1.71 |
| 6 | 182 | 4.67 | -1.51 |
| 7 | 242 | 4.80 | -1.38 |
| 8 | 302 | 4.97 | -1.21 |
| 9 | 362 | 5.10 | -1.08 |
| 10 | 422 | 5.20 | -0.98 |
| 11 | 482 | 5.29 | -0.89 |
| 12 | 542 | 5.39 | -0.79 |
| 13 | 602 | 5.46 | -0.72 |
| 14 | 662 | 5.56 | -0.62 |
| 15 | 722 | 5.59 | -0.59 |
| 16 | 782 | 5.66 | -0.52 |
| 17 | 842 | 5.72 | -0.46 |
| 18 | 902 | 5.79 | -0.39 |
| 19 | 962 | 5.89 | -0.29 |
| 20 | 1022 | 5.89 | -0.29 |
| 21 | 1082 | 5.92 | -0.26 |
| 22 | 1142 | 5.95 | -0.23 |
| 23 | 1202 | 5.98 | -0.20 |

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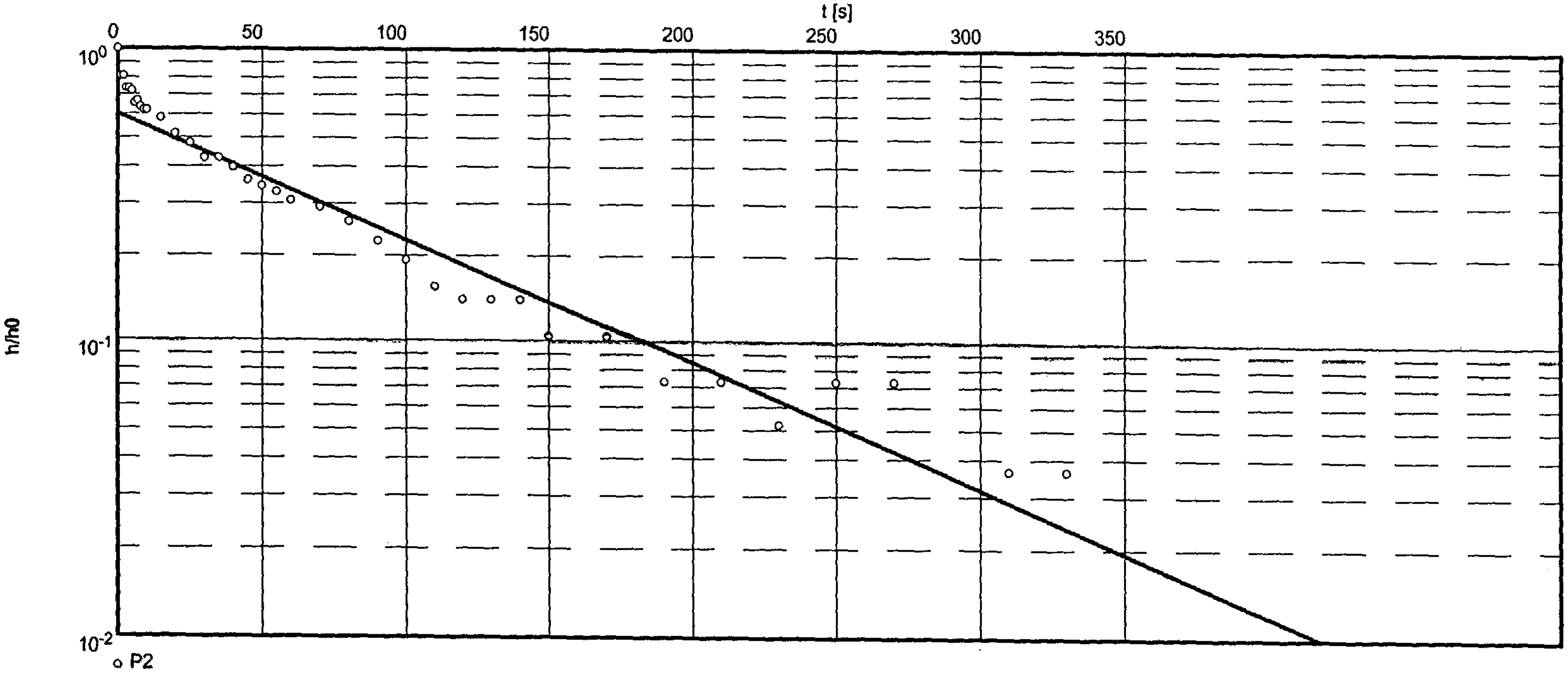
Slug Test No.

P2

Test conducted on: Jan 19, 1998



Hydraulic conductivity [ft/s]: 1.16 x $10^{-5}$

Hydraulic Conductivity: 3.54x10-4 cm/s

Static Water Depth Below TOC: 8.75 ft
Total Well Depth Below TOC: 31.87 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (f[illegible]) = 45 %

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Slug Test No.
P2

Test conducted on: Jan 19, 1998
P2

Static water level: 8.78 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 6.86 | -1.92 |
| 2 | 1 | 7.23 | -1.55 |
| 3 | 2 | 7.23 | -1.55 |
| 4 | 3 | 7.37 | -1.41 |
| 5 | 4 | 7.37 | -1.41 |
| 6 | 5 | 7.40 | -1.38 |
| 7 | 6 | 7.53 | -1.25 |
| 8 | 7 | 7.50 | -1.28 |
| 9 | 8 | 7.56 | -1.22 |
| 10 | 9 | 7.59 | -1.19 |
| 11 | 10 | 7.59 | -1.19 |
| 12 | 15 | 7.66 | -1.12 |
| 13 | 20 | 7.79 | -0.99 |
| 14 | 25 | 7.86 | -0.92 |
| 15 | 30 | 7.96 | -0.82 |
| 16 | 35 | 7.96 | -0.82 |
| 17 | 40 | 8.02 | -0.76 |
| 18 | 45 | 8.09 | -0.69 |
| 19 | 50 | 8.12 | -0.66 |
| 20 | 55 | 8.15 | -0.63 |
| 21 | 60 | 8.19 | -0.59 |
| 22 | 70 | 8.22 | -0.56 |
| 23 | 80 | 8.28 | -0.50 |
| 24 | 90 | 8.35 | -0.43 |
| 25 | 100 | 8.41 | -0.37 |
| 26 | 110 | 8.48 | -0.30 |
| 27 | 120 | 8.51 | -0.27 |
| 28 | 130 | 8.51 | -0.27 |
| 29 | 140 | 8.51 | -0.27 |
| 30 | 150 | 8.58 | -0.20 |
| 31 | 170 | 8.58 | -0.20 |
| 32 | 190 | 8.64 | -0.14 |
| 33 | 210 | 8.64 | -0.14 |
| 34 | 230 | 8.68 | -0.10 |
| 35 | 250 | 8.64 | -0.14 |
| 36 | 270 | 8.64 | -0.14 |
| 37 | 290 | 6.68 | -2.10 |
| 38 | 310 | 8.71 | -0.07 |
| 39 | 330 | 8.71 | -0.07 |

| | | |
|---|---|---|
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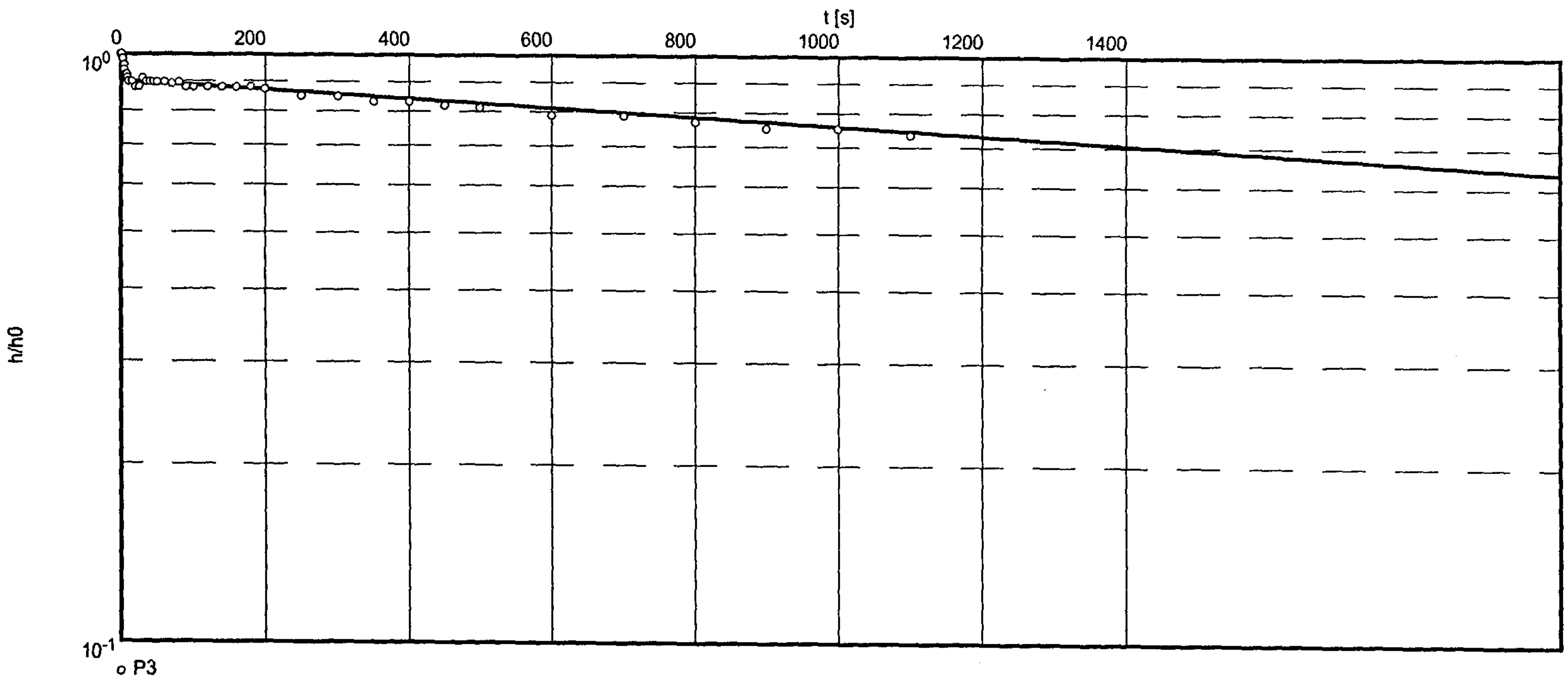
| Slug Test No. | Test conducted on: Jan 21, 1998 |
|---|---|
| P3 | |



Hydraulic conductivity [ft/s]: 2.06 x $10^{-7}$

Hydraulic Conductivity: 6.2x10-6 cm/s

Static Water Depth Below TOC: 7.23 ft
Total Well Depth Below TOC: 16.30 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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|---|---|
| P3 | P3 |

Static water level: 7.23 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 5.58 | -1.65 | |
| 2 | 1 | 5.58 | -1.65 | |
| 3 | 2 | 5.61 | -1.62 | |
| 4 | 3 | 5.65 | -1.58 | |
| 5 | 4 | 5.65 | -1.58 | |
| 6 | 5 | 5.68 | -1.55 | |
| 7 | 6 | 5.71 | -1.52 | |
| 8 | 7 | 5.71 | -1.52 | |
| 9 | 8 | 5.71 | -1.52 | |
| 10 | 9 | 5.73 | -1.50 | |
| 11 | 10 | 5.75 | -1.48 | |
| 12 | 15 | 5.75 | -1.48 | |
| 13 | 20 | 5.78 | -1.45 | |
| 14 | 25 | 5.78 | -1.45 | |
| 15 | 30 | 5.73 | -1.50 | |
| 16 | 35 | 5.75 | -1.48 | |
| 17 | 40 | 5.75 | -1.48 | |
| 18 | 45 | 5.75 | -1.48 | |
| 19 | 50 | 5.75 | -1.48 | |
| 20 | 60 | 5.75 | -1.48 | |
| 21 | 70 | 5.76 | -1.47 | |
| 22 | 80 | 5.75 | -1.48 | |
| 23 | 90 | 5.78 | -1.45 | |
| 24 | 100 | 5.78 | -1.45 | |
| 25 | 120 | 5.78 | -1.45 | |
| 26 | 140 | 5.78 | -1.45 | |
| 27 | 160 | 5.78 | -1.45 | |
| 28 | 180 | 5.78 | -1.45 | |
| 29 | 200 | 5.79 | -1.44 | |
| 30 | 250 | 5.83 | -1.40 | |
| 31 | 300 | 5.83 | -1.40 | |
| 32 | 350 | 5.86 | -1.37 | |
| 33 | 400 | 5.86 | -1.37 | |
| 34 | 450 | 5.88 | -1.35 | |
| 35 | 500 | 5.89 | -1.34 | |
| 36 | 600 | 5.93 | -1.30 | |
| 37 | 700 | 5.93 | -1.30 | |
| 38 | 800 | 5.96 | -1.27 | |
| 39 | 900 | 5.99 | -1.24 | |
| 40 | 1000 | 5.99 | -1.24 | |
| 41 | 1100 | 6.02 | -1.21 | |

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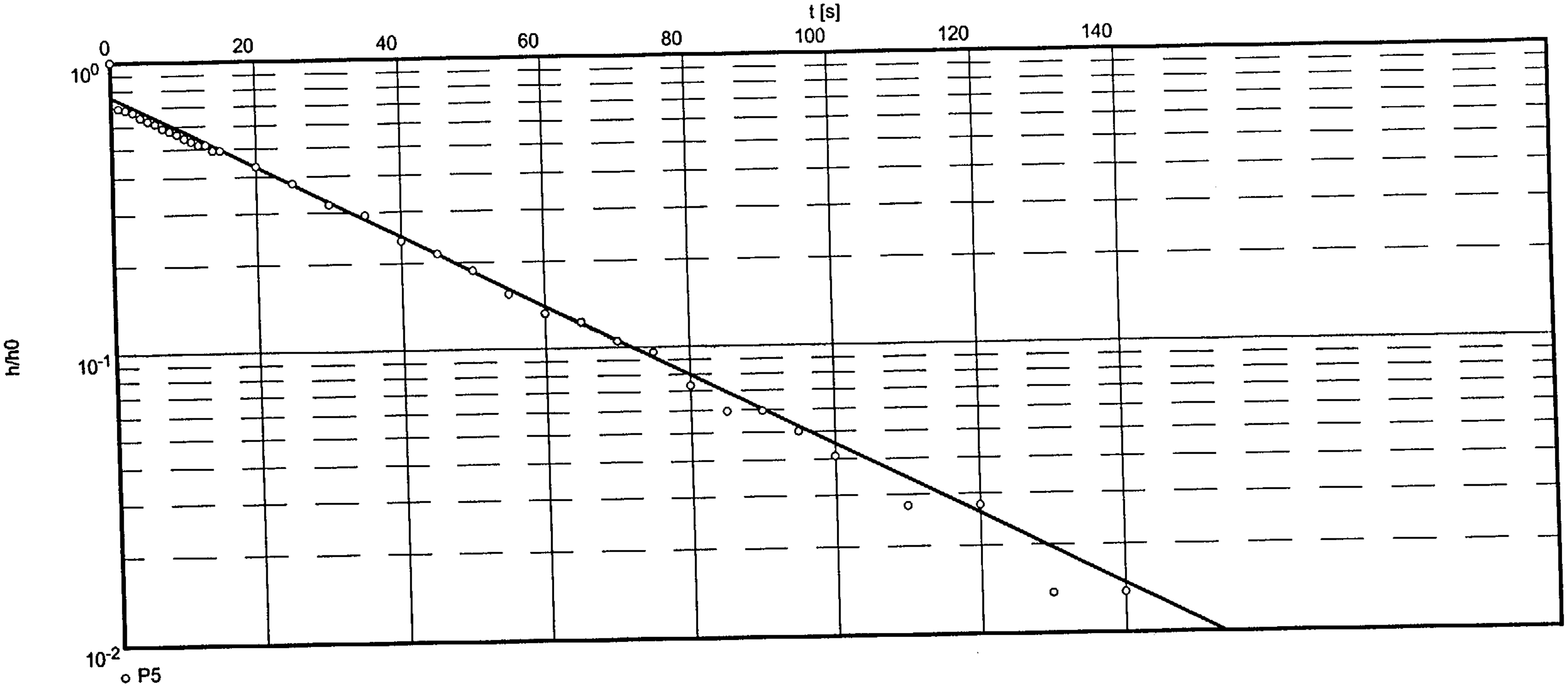
Slug Test No.

P5

Test conducted on: Jan 21, 1998



Hydraulic conductivity [ft/s]: $3.34 \times 10^{-5}$

Hydraulic Conductivity: 1.02x10-3 cm/s

Static Water Depth Below TOC: 9.76 ft
Total Well Depth Below TOC: 23.34 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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Slug Test No.
P5

Test conducted on: Jan 21, 1998
P5

Static water level: 9.76 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 7.57 | -2.19 | |
| 2 | 1 | 8.24 | -1.52 | |
| 3 | 2 | 8.26 | -1.50 | |
| 4 | 3 | 8.29 | -1.47 | |
| 5 | 4 | 8.35 | -1.41 | |
| 6 | 5 | 8.39 | -1.37 | |
| 7 | 6 | 8.42 | -1.34 | |
| 8 | 7 | 8.47 | -1.29 | |
| 9 | 8 | 8.50 | -1.26 | |
| 10 | 9 | 8.53 | -1.23 | |
| 11 | 10 | 8.57 | -1.19 | |
| 12 | 11 | 8.60 | -1.16 | |
| 13 | 12 | 8.63 | -1.13 | |
| 14 | 13 | 8.63 | -1.13 | |
| 15 | 14 | 8.68 | -1.08 | |
| 16 | 15 | 8.68 | -1.08 | |
| 17 | 20 | 8.81 | -0.95 | |
| 18 | 25 | 8.93 | -0.83 | |
| 19 | 30 | 9.06 | -0.70 | |
| 20 | 35 | 9.12 | -0.64 | |
| 21 | 40 | 9.24 | -0.52 | |
| 22 | 45 | 9.29 | -0.47 | |
| 23 | 50 | 9.35 | -0.41 | |
| 24 | 55 | 9.42 | -0.34 | |
| 25 | 60 | 9.47 | -0.29 | |
| 26 | 65 | 9.49 | -0.27 | |
| 27 | 70 | 9.53 | -0.23 | |
| 28 | 75 | 9.55 | -0.21 | |
| 29 | 80 | 9.60 | -0.16 | |
| 30 | 85 | 9.63 | -0.13 | |
| 31 | 90 | 9.63 | -0.13 | |
| 32 | 95 | 9.65 | -0.11 | |
| 33 | 100 | 9.67 | -0.09 | |
| 34 | 110 | 9.70 | -0.06 | |
| 35 | 120 | 9.70 | -0.06 | |
| 36 | 130 | 9.73 | -0.03 | |
| 37 | 140 | 9.73 | -0.03 | |

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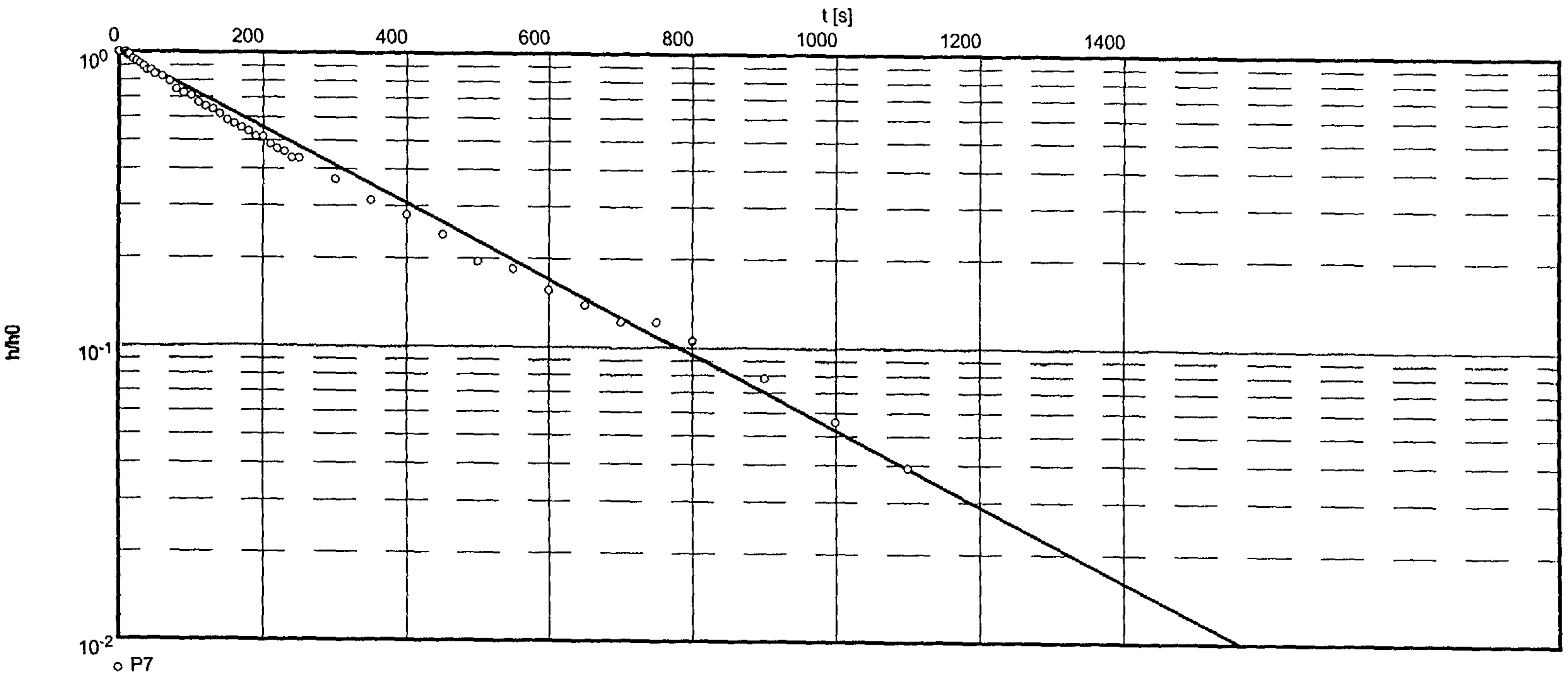
Slug Test No.
P7

Test conducted on: Jan 20, 1998



Hydraulic conductivity [ft/s]: $3.50 \times 10^{-6}$

Hydraulic Conductivity: 1.07x10-4 cm/s

Static Water Depth Below TOC: 12.50 ft
Total Well Depth Below TOC: 26.79 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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P7

Test conducted on: Jan 20, 1998

P7

Static water level: 12.50 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 10.71 | -1.79 |
| 2 | 1 | 10.71 | -1.79 |
| 3 | 2 | 10.59 | -1.91 |
| 4 | 3 | 10.56 | -1.94 |
| 5 | 4 | 10.66 | -1.84 |
| 6 | 5 | 10.66 | -1.84 |
| 7 | 6 | 10.66 | -1.84 |
| 8 | 7 | 10.67 | -1.83 |
| 9 | 8 | 10.71 | -1.79 |
| 10 | 9 | 10.72 | -1.78 |
| 11 | 10 | 10.71 | -1.79 |
| 12 | 11 | 10.74 | -1.76 |
| 13 | 12 | 10.74 | -1.76 |
| 14 | 13 | 10.76 | -1.74 |
| 15 | 14 | 10.76 | -1.74 |
| 16 | 15 | 10.74 | -1.76 |
| 17 | 20 | 10.81 | -1.69 |
| 18 | 25 | 10.84 | -1.66 |
| 19 | 30 | 10.87 | -1.63 |
| 20 | 35 | 10.90 | -1.60 |
| 21 | 40 | 10.95 | -1.55 |
| 22 | 45 | 10.95 | -1.55 |
| 23 | 50 | 11.00 | -1.50 |
| 24 | 60 | 11.02 | -1.48 |
| 25 | 70 | 11.08 | -1.42 |
| 26 | 80 | 11.17 | -1.33 |
| 27 | 90 | 11.20 | -1.30 |
| 28 | 100 | 11.23 | -1.27 |
| 29 | 110 | 11.30 | -1.20 |
| 30 | 120 | 11.33 | -1.17 |
| 31 | 130 | 11.36 | -1.14 |
| 32 | 140 | 11.40 | -1.10 |
| 33 | 150 | 11.45 | -1.05 |
| 34 | 160 | 11.48 | -1.02 |
| 35 | 170 | 11.51 | -0.99 |
| 36 | 180 | 11.54 | -0.96 |
| 37 | 190 | 11.58 | -0.92 |
| 38 | 200 | 11.58 | -0.92 |
| 39 | 210 | 11.63 | -0.87 |
| 40 | 220 | 11.66 | -0.84 |
| 41 | 230 | 11.68 | -0.82 |
| 42 | 240 | 11.72 | -0.78 |
| 43 | 250 | 11.72 | -0.78 |
| 44 | 300 | 11.84 | -0.66 |
| 45 | 350 | 11.94 | -0.56 |
| 46 | 400 | 12.00 | -0.50 |
| 47 | 450 | 12.07 | -0.43 |
| 48 | 500 | 12.15 | -0.35 |
| | | 12.17 | -0.33 |

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Slug Test No.
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Test conducted on: Jan 20, 1998
P7

Static water level: 12.50 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 650 | 12.25 | -0.25 | |
| 52 | 700 | 12.28 | -0.22 | |
| 53 | 750 | 12.28 | -0.22 | |
| 54 | 800 | 12.31 | -0.19 | |
| 55 | 900 | 12.36 | -0.14 | |
| 56 | 1000 | 12.40 | -0.10 | |
| 57 | 1100 | 12.43 | -0.07 | |

| | | |
|---|---|---|
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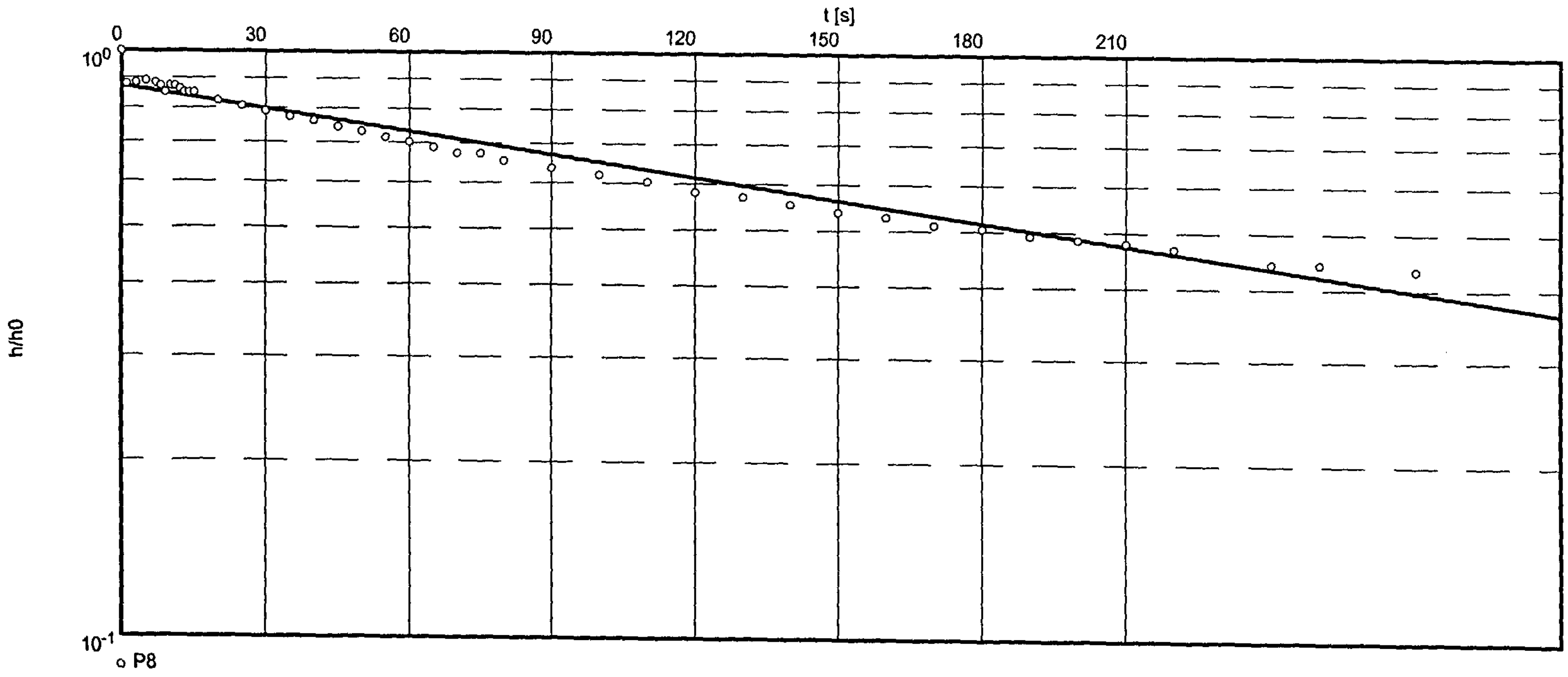
| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 20, 1998 |
| P8 | |



Hydraulic conductivity [ft/s]: $3.45 \times 10^{-6}$

Hydraulic Conductivity: 1.05x10-4 cm/s

Static Water Depth Below TOC: 9.98 ft
Total Well Depth Below TOC: 26.65 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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Slug Test No.
P8

Test conducted on: Jan 20, 1998
P8

Static water level: 9.98 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 6.93 | -3.05 |
| 2 | 1 | 7.30 | -2.68 |
| 3 | 3 | 7.29 | -2.69 |
| 4 | 5 | 7.27 | -2.71 |
| 5 | 7 | 7.29 | -2.69 |
| 6 | 8 | 7.32 | -2.66 |
| 7 | 9 | 7.39 | -2.59 |
| 8 | 10 | 7.32 | -2.66 |
| 9 | 11 | 7.32 | -2.66 |
| 10 | 12 | 7.35 | -2.63 |
| 11 | 13 | 7.39 | -2.59 |
| 12 | 14 | 7.39 | -2.59 |
| 13 | 15 | 7.39 | -2.59 |
| 14 | 20 | 7.47 | -2.51 |
| 15 | 25 | 7.52 | -2.46 |
| 16 | 30 | 7.57 | -2.41 |
| 17 | 35 | 7.62 | -2.36 |
| 18 | 40 | 7.66 | -2.32 |
| 19 | 45 | 7.71 | -2.27 |
| 20 | 50 | 7.75 | -2.23 |
| 21 | 55 | 7.80 | -2.18 |
| 22 | 60 | 7.84 | -2.14 |
| 23 | 65 | 7.88 | -2.10 |
| 24 | 70 | 7.93 | -2.05 |
| 25 | 75 | 7.93 | -2.05 |
| 26 | 80 | 7.99 | -1.99 |
| 27 | 90 | 8.04 | -1.94 |
| 28 | 100 | 8.09 | -1.89 |
| 29 | 110 | 8.14 | -1.84 |
| 30 | 120 | 8.21 | -1.77 |
| 31 | 130 | 8.24 | -1.74 |
| 32 | 140 | 8.29 | -1.69 |
| 33 | 150 | 8.34 | -1.64 |
| 34 | 160 | 8.37 | -1.61 |
| 35 | 170 | 8.42 | -1.56 |
| 36 | 180 | 8.44 | -1.54 |
| 37 | 190 | 8.48 | -1.50 |
| 38 | 200 | 8.50 | -1.48 |
| 39 | 210 | 8.52 | -1.46 |
| 40 | 220 | 8.55 | -1.43 |
| 41 | 240 | 8.63 | -1.35 |
| 42 | 250 | 8.63 | -1.35 |
| 43 | 270 | 8.66 | -1.32 |

| | | |
|---|---|---|
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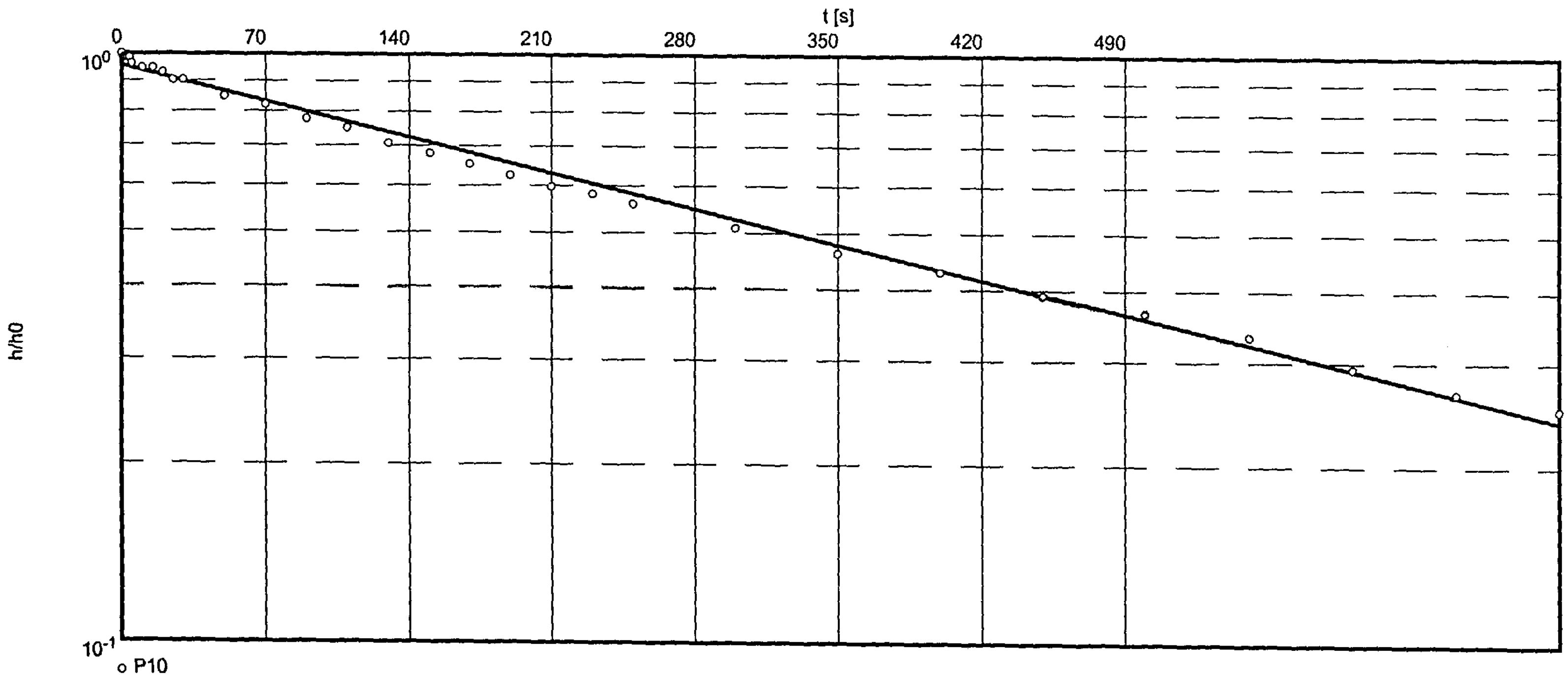
| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 20, 1998 |
| P10 | |



Hydraulic conductivity [ft/s]: $2.35 \times 10^{-6}$

Hydraulic Conductivity: 7.16x10-5 cm/s

Static Water Depth Below TOC: 8.43 ft
Total Well Depth Below TOC: 23.93 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft

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Slug Test No.

P10

Test conducted on: Jan 20, 1998

P10

Static water level: 8.43 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 6.59 | -1.84 |
| 2 | 1 | 6.62 | -1.81 |
| 3 | 2 | 6.62 | -1.81 |
| 4 | 3 | 6.62 | -1.81 |
| 5 | 4 | 6.62 | -1.81 |
| 6 | 5 | 6.66 | -1.77 |
| 7 | 10 | 6.69 | -1.74 |
| 8 | 15 | 6.69 | -1.74 |
| 9 | 20 | 6.72 | -1.71 |
| 10 | 25 | 6.77 | -1.66 |
| 11 | 30 | 6.77 | -1.66 |
| 12 | 50 | 6.87 | -1.56 |
| 13 | 70 | 6.92 | -1.51 |
| 14 | 90 | 7.00 | -1.43 |
| 15 | 110 | 7.05 | -1.38 |
| 16 | 130 | 7.13 | -1.30 |
| 17 | 150 | 7.18 | -1.25 |
| 18 | 170 | 7.23 | -1.20 |
| 19 | 190 | 7.28 | -1.15 |
| 20 | 210 | 7.33 | -1.10 |
| 21 | 230 | 7.36 | -1.07 |
| 22 | 250 | 7.40 | -1.03 |
| 23 | 300 | 7.49 | -0.94 |
| 24 | 350 | 7.58 | -0.85 |
| 25 | 400 | 7.64 | -0.79 |
| 26 | 450 | 7.71 | -0.72 |
| 27 | 500 | 7.76 | -0.67 |
| 28 | 550 | 7.82 | -0.61 |
| 29 | 600 | 7.89 | -0.54 |
| 30 | 650 | 7.94 | -0.49 |
| 31 | 700 | 7.97 | -0.46 |

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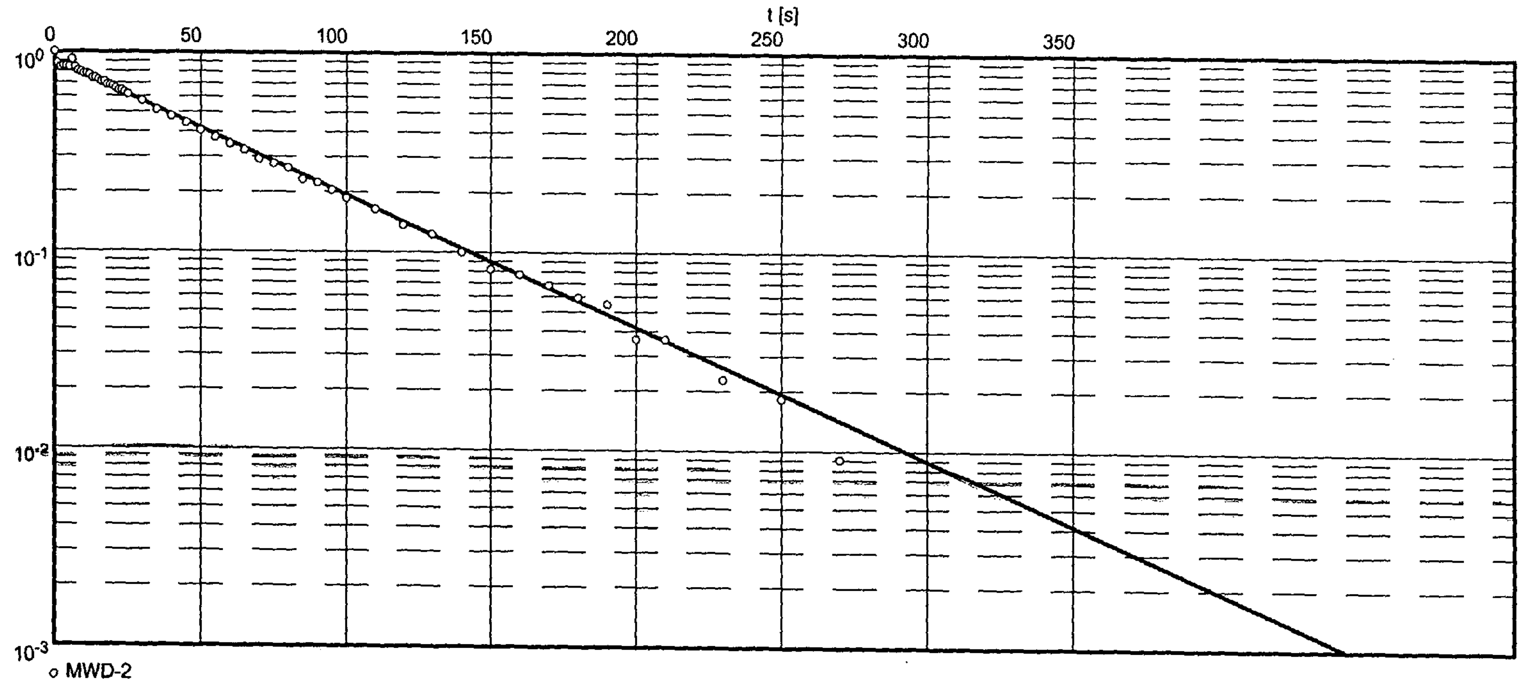
Slug Test No.
MWD-2

Test conducted on: Jan 20, 1998



Hydraulic conductivity [ft/s]: 1.82 x $10^{-5}$

Hydraulic Conductivity: 5.55x10-4 cm/s

Static Water Depth Below TOC: 7.51 ft
Total Well Depth Below TOC: 18.89 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) =

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Slug Test No.

MWD-2

Test conducted on: Jan 20, 1998

MWD-2

Static water level: 7.51 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 5.31 | -2.20 |
| 2 | 1 | 5.59 | -1.92 |
| 3 | 2 | 5.67 | -1.84 |
| 4 | 3 | 5.64 | -1.87 |
| 5 | 4 | 5.65 | -1.86 |
| 6 | 5 | 5.67 | -1.84 |
| 7 | 6 | 5.49 | -2.02 |
| 8 | 7 | 5.67 | -1.84 |
| 9 | 8 | 5.74 | -1.77 |
| 10 | 9 | 5.77 | -1.74 |
| 11 | 10 | 5.80 | -1.71 |
| 12 | 11 | 5.80 | -1.71 |
| 13 | 12 | 5.82 | -1.69 |
| 14 | 13 | 5.88 | -1.63 |
| 15 | 14 | 5.88 | -1.63 |
| 16 | 15 | 5.92 | -1.59 |
| 17 | 16 | 5.95 | -1.56 |
| 18 | 17 | 5.95 | -1.56 |
| 19 | 18 | 6.00 | -1.51 |
| 20 | 19 | 6.01 | -1.50 |
| 21 | 20 | 6.03 | -1.48 |
| 22 | 21 | 6.06 | -1.45 |
| 23 | 22 | 6.10 | -1.41 |
| 24 | 23 | 6.10 | -1.41 |
| 25 | 24 | 6.13 | -1.38 |
| 26 | 25 | 6.16 | -1.35 |
| 27 | 30 | 6.26 | -1.25 |
| 28 | 35 | 6.38 | -1.13 |
| 29 | 40 | 6.46 | -1.05 |
| 30 | 45 | 6.54 | -0.97 |
| 31 | 50 | 6.62 | -0.89 |
| 32 | 55 | 6.69 | -0.82 |
| 33 | 60 | 6.75 | -0.76 |
| 34 | 65 | 6.80 | -0.71 |
| 35 | 70 | 6.87 | -0.64 |
| 36 | 75 | 6.90 | -0.61 |
| 37 | 80 | 6.93 | -0.58 |
| 38 | 85 | 7.00 | -0.51 |
| 39 | 90 | 7.02 | -0.49 |
| 40 | 95 | 7.06 | -0.45 |
| 41 | 100 | 7.10 | -0.41 |
| 42 | 110 | 7.15 | -0.36 |
| 43 | 120 | 7.21 | -0.30 |
| 44 | 130 | 7.24 | -0.27 |
| 45 | 140 | 7.29 | -0.22 |
| 46 | 150 | 7.33 | -0.18 |
| 47 | 160 | 7.34 | -0.17 |
| | 170 | 7.36 | -0.15 |

| | | |
|---|---|---|
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| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 20, 1998 |
| MWD-2 | MWD-2 |

Static water level: 7.51 ft below datum

| | Pumping test duration<br>[s] | Water level<br>[ft] | Change in Waterlevel<br>[ft] | |
|---|---|---|---|---|
| 51 | 200 | 7.43 | -0.08 | |
| 52 | 210 | 7.43 | -0.08 | |
| 53 | 230 | 7.46 | -0.05 | |
| 54 | 250 | 7.47 | -0.04 | |
| 55 | 270 | 7.49 | -0.02 | |
| 56 | 290 | 7.51 | 0.00 | |
| 57 | 310 | 7.51 | 0.00 | |

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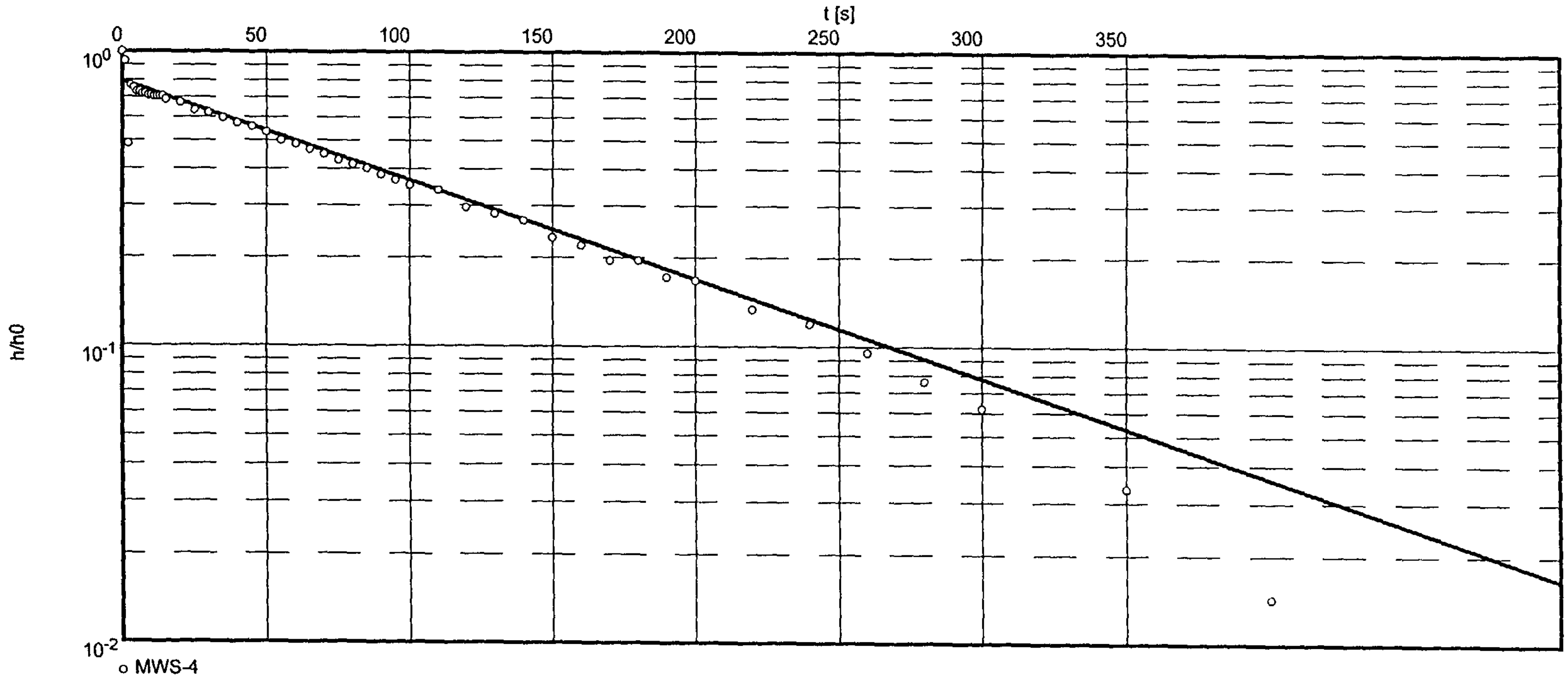
Slug Test No.

MWS-4

Test conducted on: Jan 21, 1998



Hydraulic conductivity [ft/s]: $1.49 \times 10^{-5}$

Hydraulic Conductivity: 4.54x10-4 cm/s

Static Water Depth Below TOC: 6.63 ft
Total Well Depth Below TOC: 13.36 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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Slug Test No.

MWS-4

Test conducted on: Jan 21, 1998

MWS-4

Static water level: 6.63 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 4.53 | -2.10 |
| 2 | 1 | 4.68 | -1.95 |
| 3 | 2 | 5.61 | -1.02 |
| 4 | 3 | 5.02 | -1.61 |
| 5 | 4 | 5.05 | -1.58 |
| 6 | 5 | 5.09 | -1.54 |
| 7 | 6 | 5.09 | -1.54 |
| 8 | 7 | 5.12 | -1.51 |
| 9 | 8 | 5.12 | -1.51 |
| 10 | 9 | 5.14 | -1.49 |
| 11 | 10 | 5.14 | -1.49 |
| 12 | 11 | 5.15 | -1.48 |
| 13 | 12 | 5.15 | -1.48 |
| 14 | 13 | 5.15 | -1.48 |
| 15 | 14 | 5.15 | -1.48 |
| 16 | 15 | 5.19 | -1.44 |
| 17 | 20 | 5.22 | -1.41 |
| 18 | 25 | 5.30 | -1.33 |
| 19 | 30 | 5.33 | -1.30 |
| 20 | 35 | 5.38 | -1.25 |
| 21 | 40 | 5.43 | -1.20 |
| 22 | 45 | 5.46 | -1.17 |
| 23 | 50 | 5.51 | -1.12 |
| 24 | 55 | 5.58 | -1.05 |
| 25 | 60 | 5.61 | -1.02 |
| 26 | 65 | 5.65 | -0.98 |
| 27 | 70 | 5.69 | -0.94 |
| 28 | 75 | 5.73 | -0.90 |
| 29 | 80 | 5.76 | -0.87 |
| 30 | 85 | 5.79 | -0.84 |
| 31 | 90 | 5.83 | -0.80 |
| 32 | 95 | 5.86 | -0.77 |
| 33 | 100 | 5.89 | -0.74 |
| 34 | 110 | 5.92 | -0.71 |
| 35 | 120 | 6.01 | -0.62 |
| 36 | 130 | 6.04 | -0.59 |
| 37 | 140 | 6.07 | -0.56 |
| 38 | 150 | 6.14 | -0.49 |
| 39 | 160 | 6.17 | -0.46 |
| 40 | 170 | 6.22 | -0.41 |
| 41 | 180 | 6.22 | -0.41 |
| 42 | 190 | 6.27 | -0.36 |
| 43 | 200 | 6.28 | -0.35 |
| 44 | 220 | 6.35 | -0.28 |
| 45 | 240 | 6.38 | -0.25 |
| 46 | 260 | 6.43 | -0.20 |
| 47 | 280 | 6.47 | -0.16 |
| 48 | 300 | 6.50 | -0.13 |
| 49 | 350 | 6.56 | -0.07 |

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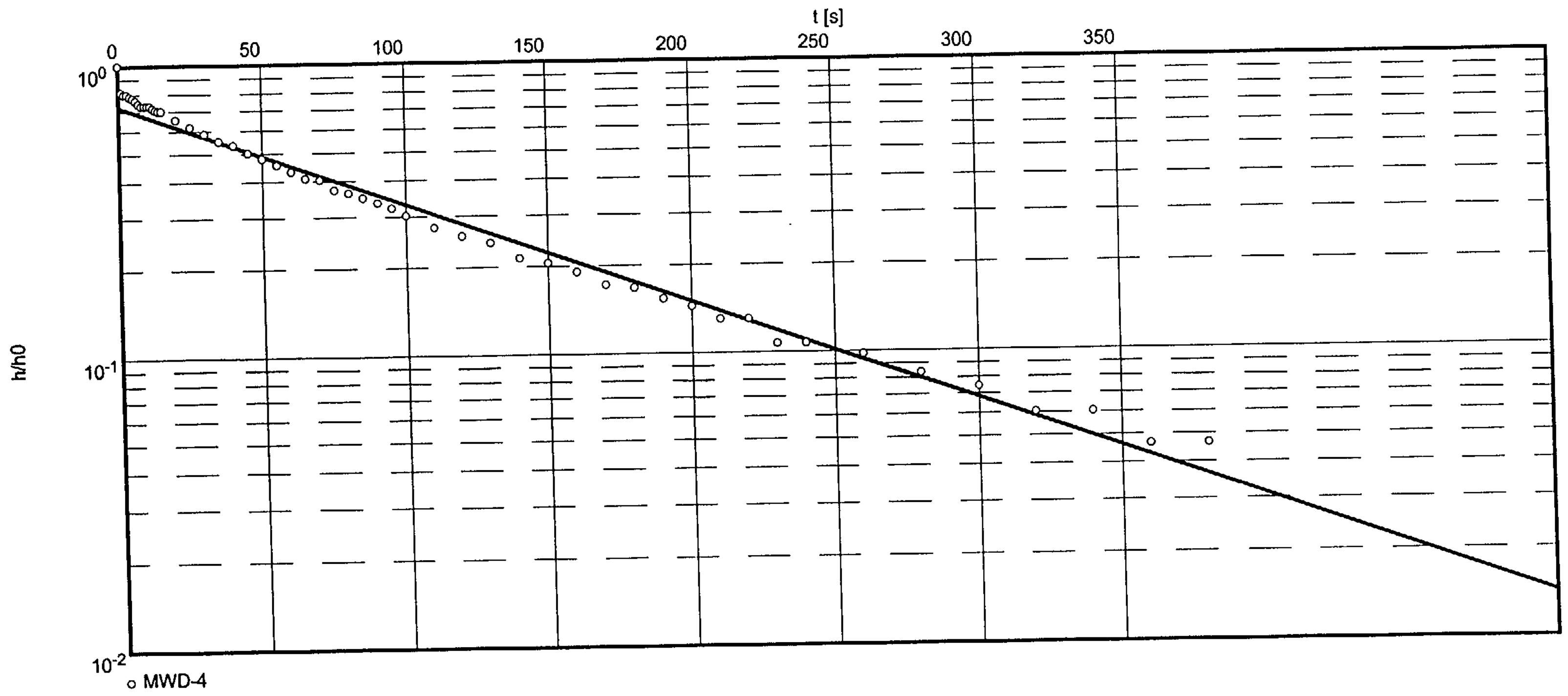
Slug Test No.

MWD-4

Test conducted on: Jan 21.1998



Hydraulic conductivity [ft/s]: $9.33 \times 10^{-6}$

Hydraulic Conductivity: 2.84x10-4 cm/s

Static Water Depth Below TOC: 8.29 ft
Total Well Depth Below TOC: 24.28 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
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| | |
|---|---|
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| MWD-4 | MWD-4 |

Static water level: 8.29 ft below datum

| | Pumping test duration<br>[s] | Water level<br>[ft] | Change in Waterlevel<br>[ft] | |
|---|---|---|---|---|
| 1 | 0 | 6.14 | -2.15 | |
| 2 | 1 | 6.54 | -1.75 | |
| 3 | 2 | 6.57 | -1.72 | |
| 4 | 3 | 6.57 | -1.72 | |
| 5 | 4 | 6.60 | -1.69 | |
| 6 | 5 | 6.62 | -1.67 | |
| 7 | 6 | 6.65 | -1.64 | |
| 8 | 7 | 6.69 | -1.60 | |
| 9 | 8 | 6.72 | -1.57 | |
| 10 | 9 | 6.72 | -1.57 | |
| 11 | 10 | 6.72 | -1.57 | |
| 12 | 11 | 6.72 | -1.57 | |
| 13 | 12 | 6.75 | -1.54 | |
| 14 | 13 | 6.77 | -1.52 | |
| 15 | 14 | 6.78 | -1.51 | |
| 16 | 15 | 6.78 | -1.51 | |
| 17 | 20 | 6.88 | -1.41 | |
| 18 | 25 | 6.96 | -1.33 | |
| 19 | 30 | 7.03 | -1.26 | |
| 20 | 35 | 7.10 | -1.19 | |
| 21 | 40 | 7.14 | -1.15 | |
| 22 | 45 | 7.21 | -1.08 | |
| 23 | 50 | 7.26 | -1.03 | |
| 24 | 55 | 7.31 | -0.98 | |
| 25 | 60 | 7.36 | -0.93 | |
| 26 | 65 | 7.41 | -0.88 | |
| 27 | 70 | 7.42 | -0.87 | |
| 28 | 75 | 7.49 | -0.80 | |
| 29 | 80 | 7.51 | -0.78 | |
| 30 | 85 | 7.54 | -0.75 | |
| 31 | 90 | 7.57 | -0.72 | |
| 32 | 95 | 7.60 | -0.69 | |
| 33 | 100 | 7.64 | -0.65 | |
| 34 | 110 | 7.70 | -0.59 | |
| 35 | 120 | 7.74 | -0.55 | |
| 36 | 130 | 7.77 | -0.52 | |
| 37 | 140 | 7.83 | -0.46 | |
| 38 | 150 | 7.85 | -0.44 | |
| 39 | 160 | 7.88 | -0.41 | |
| 40 | 170 | 7.92 | -0.37 | |
| 41 | 180 | 7.93 | -0.36 | |
| 42 | 190 | 7.96 | -0.33 | |
| 43 | 200 | 7.98 | -0.31 | |
| 44 | 210 | 8.01 | -0.28 | |
| 45 | 220 | 8.01 | -0.28 | |
| 46 | 230 | 8.06 | -0.23 | |
| 47 | 240 | 8.06 | -0.23 | |
| 48 | 260 | 8.08 | -0.21 | |
| 49 | 280 | 8.11 | -0.18 | |
| | | | 0.16 | |

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slug/bail test analysis
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Slug Test No.
MWD-4

Test conducted on: Jan 21.1998
MWD-4

Static water level: 8.29 ft below datum

| | Pumping test duration<br>[s] | Water level<br>[ft] | Change in Waterlevel<br>[ft] |
|---|---|---|---|
| 51 | 320 | 8.16 | -0.13 |
| 52 | 340 | 8.16 | -0.13 |
| 53 | 360 | 8.19 | -0.10 |
| 54 | 380 | 8.19 | -0.10 |

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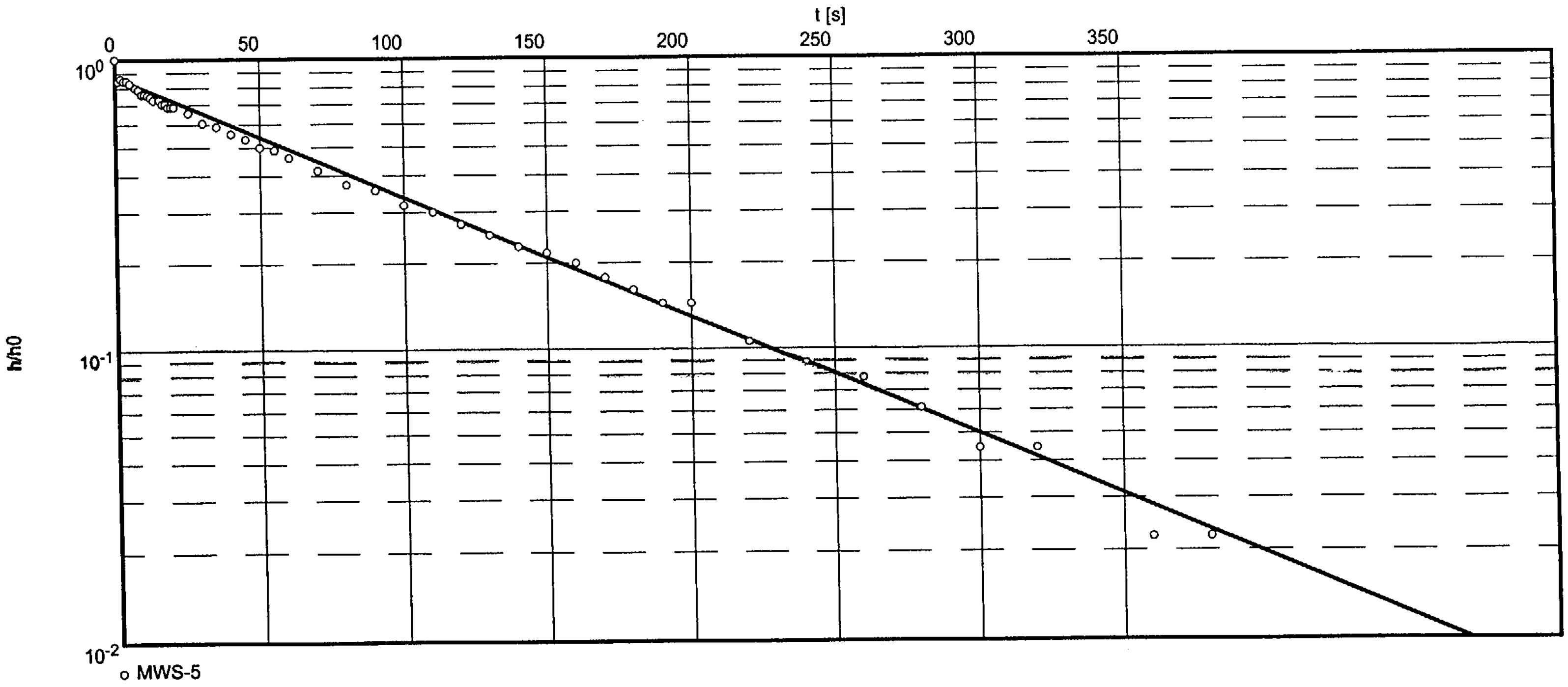
Slug Test No.

MWS-5

Test conducted on: Jan 20, 1998



Hydraulic conductivity [ft/s]: $1.12 \times 10^{-5}$

Hydraulic Conductivity: 3.41x10-4 cm/s

tatic Water Depth Below TOC: 7.78 ft
Total Well Depth Below TOC: 16.24 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 5 ft
Porosity (filter pack) = 45 %

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Slug Test No.

MWS-5

Test conducted on: Jan 20, 1998

MWS-5

Static water level: 7.78 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 5.98 | -1.80 |
| 2 | 1 | 6.26 | -1.52 |
| 3 | 2 | 6.23 | -1.55 |
| 4 | 3 | 6.26 | -1.52 |
| 5 | 4 | 6.26 | -1.52 |
| 6 | 5 | 6.29 | -1.49 |
| 7 | 7 | 6.34 | -1.44 |
| 8 | 8 | 6.36 | -1.42 |
| 9 | 9 | 6.41 | -1.37 |
| 10 | 10 | 6.41 | -1.37 |
| 11 | 11 | 6.42 | -1.36 |
| 12 | 12 | 6.44 | -1.34 |
| 13 | 13 | 6.47 | -1.31 |
| 14 | 15 | 6.47 | -1.31 |
| 15 | 16 | 6.51 | -1.27 |
| 16 | 17 | 6.51 | -1.27 |
| 17 | 18 | 6.54 | -1.24 |
| 18 | 19 | 6.54 | -1.24 |
| 19 | 20 | 6.54 | -1.24 |
| 20 | 25 | 6.60 | -1.18 |
| 21 | 30 | 6.69 | -1.09 |
| 22 | 35 | 6.72 | -1.06 |
| 23 | 40 | 6.78 | -1.00 |
| 24 | 45 | 6.82 | -0.96 |
| 25 | 50 | 6.88 | -0.90 |
| 26 | 55 | 6.90 | -0.88 |
| 27 | 60 | 6.95 | -0.83 |
| 28 | 70 | 7.03 | -0.75 |
| 29 | 80 | 7.11 | -0.67 |
| 30 | 90 | 7.14 | -0.64 |
| 31 | 100 | 7.21 | -0.57 |
| 32 | 110 | 7.24 | -0.54 |
| 33 | 120 | 7.29 | -0.49 |
| 34 | 130 | 7.33 | -0.45 |
| 35 | 140 | 7.37 | -0.41 |
| 36 | 150 | 7.39 | -0.39 |
| 37 | 160 | 7.42 | -0.36 |
| 38 | 170 | 7.46 | -0.32 |
| 39 | 180 | 7.49 | -0.29 |
| 40 | 190 | 7.52 | -0.26 |
| 41 | 200 | 7.52 | -0.26 |
| 42 | 220 | 7.59 | -0.19 |
| 43 | 240 | 7.62 | -0.16 |
| 44 | 260 | 7.64 | -0.14 |
| 45 | 280 | 7.67 | -0.11 |
| 46 | 300 | 7.70 | -0.08 |
| 47 | 320 | 7.70 | -0.08 |
| 48 | 360 | 7.74 | -0.04 |
| 49 | 380 | 7.74 | -0.04 |

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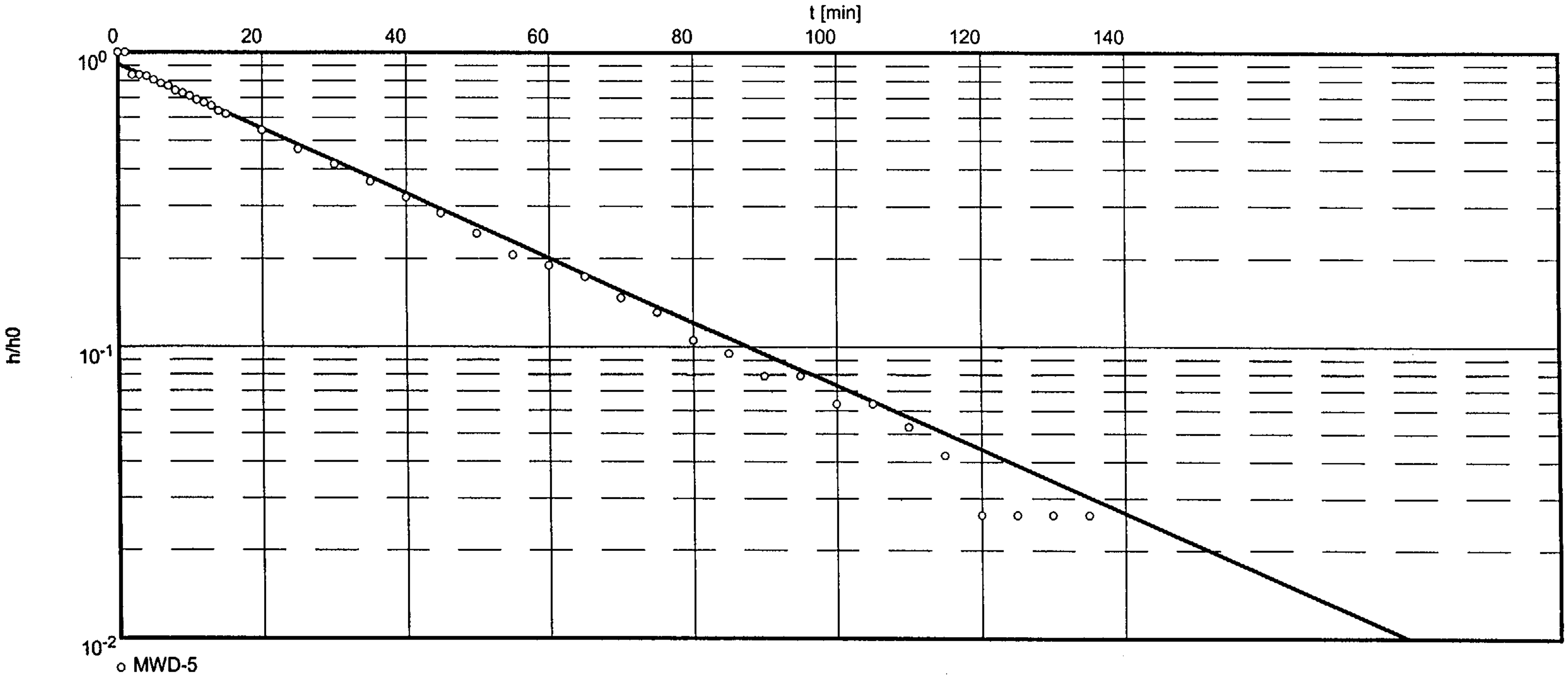
Slug Test No.

MWD-5

Test conducted on: Jan 20,1998



Hydraulic conductivity [ft/min]: $2.99 \times 10^{-5}$

Hydraulic Conductivity: 9.11x10-4 cm/s

Static Water Depth Below TOC: 11.52 ft
Total Well Depth Below TOC: 29.94 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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| Slug Test No. | Test conducted on: Jan 20,1998 |
|---|---|
| MWD-5 | MWD-5 |

Static water level: 11.52 ft below datum

| | Pumping test duration<br>[min] | Water level<br>[ft] | Change in Waterlevel<br>[ft] |
|---|---|---|---|
| 1 | 0.00 | 9.62 | -1.90 |
| 2 | 1.00 | 9.62 | -1.90 |
| 3 | 2.00 | 9.93 | -1.59 |
| 4 | 3.00 | 9.93 | -1.59 |
| 5 | 4.00 | 9.94 | -1.58 |
| 6 | 5.00 | 9.99 | -1.53 |
| 7 | 6.00 | 10.03 | -1.49 |
| 8 | 7.00 | 10.06 | -1.46 |
| 9 | 8.00 | 10.11 | -1.41 |
| 10 | 9.00 | 10.14 | -1.38 |
| 11 | 10.00 | 10.17 | -1.35 |
| 12 | 11.00 | 10.21 | -1.31 |
| 13 | 12.00 | 10.24 | -1.28 |
| 14 | 13.00 | 10.27 | -1.25 |
| 15 | 14.00 | 10.32 | -1.20 |
| 16 | 15.00 | 10.35 | -1.17 |
| 17 | 20.00 | 10.49 | -1.03 |
| 18 | 25.00 | 10.63 | -0.89 |
| 19 | 30.00 | 10.73 | -0.79 |
| 20 | 35.00 | 10.83 | -0.69 |
| 21 | 40.00 | 10.91 | -0.61 |
| 22 | 45.00 | 10.98 | -0.54 |
| 23 | 50.00 | 11.06 | -0.46 |
| 24 | 55.00 | 11.13 | -0.39 |
| 25 | 60.00 | 11.16 | -0.36 |
| 26 | 65.00 | 11.19 | -0.33 |
| 27 | 70.00 | 11.24 | -0.28 |
| 28 | 75.00 | 11.27 | -0.25 |
| 29 | 80.00 | 11.32 | -0.20 |
| 30 | 85.00 | 11.34 | -0.18 |
| 31 | 90.00 | 11.37 | -0.15 |
| 32 | 95.00 | 11.37 | -0.15 |
| 33 | 100.00 | 11.40 | -0.12 |
| 34 | 105.00 | 11.40 | -0.12 |
| 35 | 110.00 | 11.42 | -0.10 |
| 36 | 115.00 | 11.44 | -0.08 |
| 37 | 120.00 | 11.47 | -0.05 |
| 38 | 125.00 | 11.47 | -0.05 |
| 39 | 130.00 | 11.47 | -0.05 |
| 40 | 135.00 | 11.47 | -0.05 |
| 41 | 140.00 | 11.52 | 0.00 |
| 42 | 150.00 | 11.52 | 0.00 |

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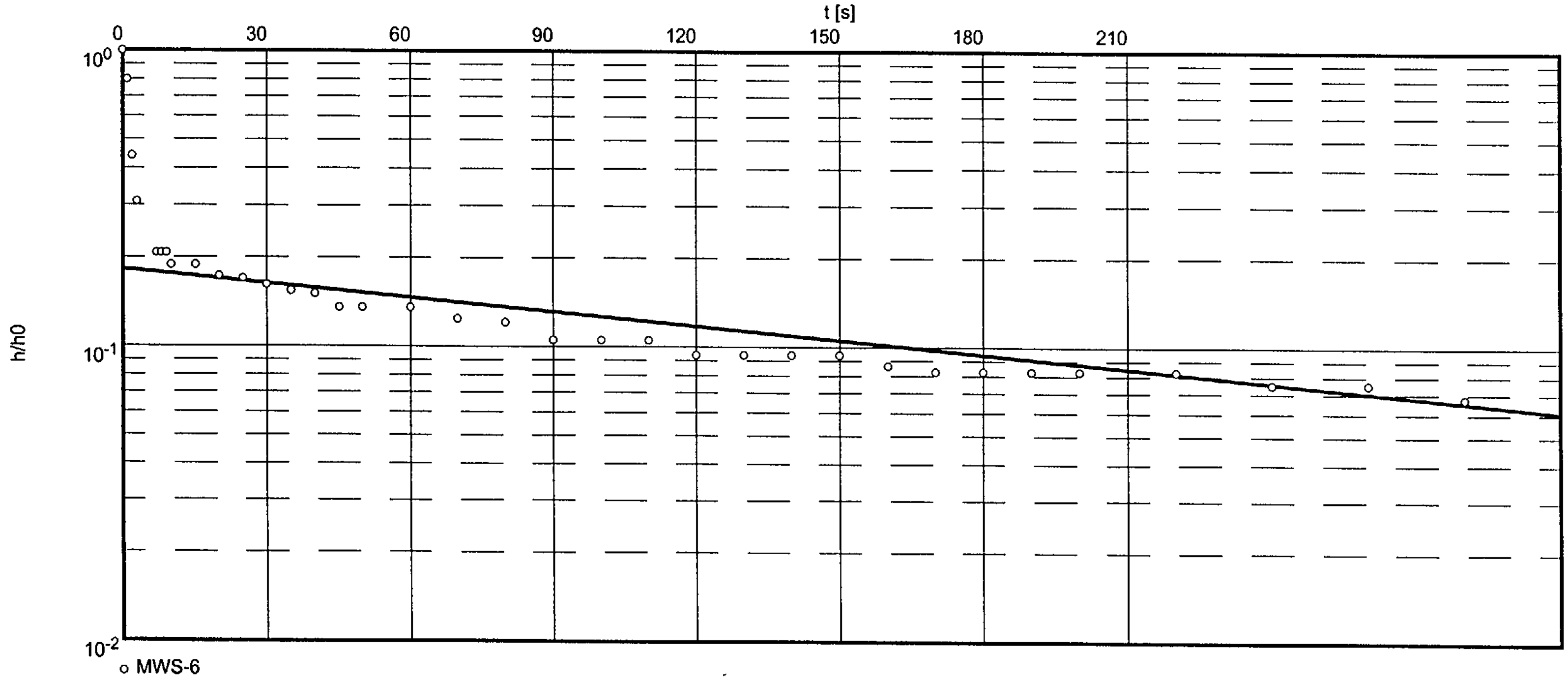
Slug Test No. | Test conducted on: Jan 20, 1998

MWS-6



Hydraulic conductivity [ft/s]: $5.74 \times 10^{-6}$

Hydraulic Conductivity: 1.75x10-4 cm/s

Static Water Depth Below TOC: 10.80 ft
Total Well Depth Below TOC: 18.93 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 6.75 ft
Porosity (filter pack) = 45 %

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Slug Test No.
MWS-6

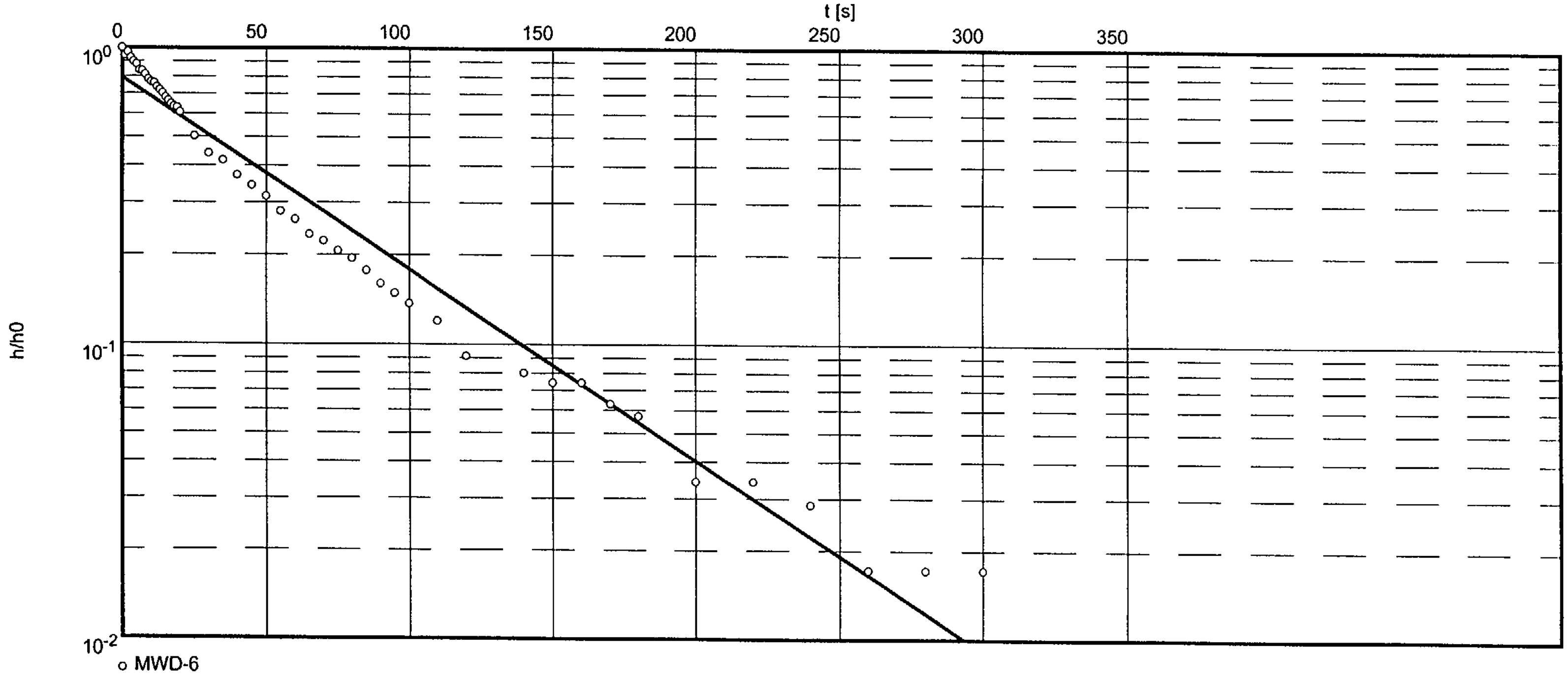
Test conducted on: Jan 20, 1998
MWS-6

Static water level: 10.80 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 8.14 | -2.66 | |
| 2 | 1 | 8.68 | -2.12 | |
| 3 | 2 | 9.63 | -1.17 | |
| 4 | 3 | 9.98 | -0.82 | |
| 5 | 7 | 10.25 | -0.55 | |
| 6 | 8 | 10.25 | -0.55 | |
| 7 | 9 | 10.25 | -0.55 | |
| 8 | 10 | 10.30 | -0.50 | |
| 9 | 15 | 10.30 | -0.50 | |
| 10 | 20 | 10.34 | -0.46 | |
| 11 | 25 | 10.35 | -0.45 | |
| 12 | 30 | 10.37 | -0.43 | |
| 13 | 35 | 10.39 | -0.41 | |
| 14 | 40 | 10.40 | -0.40 | |
| 15 | 45 | 10.44 | -0.36 | |
| 16 | 50 | 10.44 | -0.36 | |
| 17 | 60 | 10.44 | -0.36 | |
| 18 | 70 | 10.47 | -0.33 | |
| 19 | 80 | 10.48 | -0.32 | |
| 20 | 90 | 10.52 | -0.28 | |
| 21 | 100 | 10.52 | -0.28 | |
| 22 | 110 | 10.52 | -0.28 | |
| 23 | 120 | 10.55 | -0.25 | |
| 24 | 130 | 10.55 | -0.25 | |
| 25 | 140 | 10.55 | -0.25 | |
| 26 | 150 | 10.55 | -0.25 | |
| 27 | 160 | 10.57 | -0.23 | |
| 28 | 170 | 10.58 | -0.22 | |
| 29 | 180 | 10.58 | -0.22 | |
| 30 | 190 | 10.58 | -0.22 | |
| 31 | 200 | 10.58 | -0.22 | |
| 32 | 220 | 10.58 | -0.22 | |
| 33 | 240 | 10.60 | -0.20 | |
| 34 | 260 | 10.60 | -0.20 | |
| 35 | 280 | 10.62 | -0.18 | |

| | | |
|---|---|---|
| **A&M Engineering**<br>)10 E. 16th Street<br>sa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's meth | Page 1<br>Project: Kaiser<br>Evaluated by: pls — Date: 01.02.1998 |

| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 20, 1998 |
| MWD-6 | |



Hydraulic conductivity [ft/s]: $1.76 \times 10^{-5}$

Hydraulic Conductivity: 5.36x10-4 cm/s

Static Water Depth Below TOC: 11.04 ft
Total Well Depth Below TOC: 33.93 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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Slug Test No.

MWD-6

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MWD-6

Static water level: 11.04 ft below datum

| | Pumping test duration<br>[s] | Water level<br>[ft] | Change in Waterlevel<br>[ft] | |
|---|---|---|---|---|
| 1 | 0 | 9.29 | -1.75 | |
| 2 | 1 | 9.39 | -1.65 | |
| 3 | 2 | 9.35 | -1.69 | |
| 4 | 3 | 9.42 | -1.62 | |
| 5 | 4 | 9.47 | -1.57 | |
| 6 | 5 | 9.50 | -1.54 | |
| 7 | 6 | 9.57 | -1.47 | |
| 8 | 7 | 9.58 | -1.46 | |
| 9 | 8 | 9.62 | -1.42 | |
| 10 | 9 | 9.67 | -1.37 | |
| 11 | 10 | 9.70 | -1.34 | |
| 12 | 11 | 9.71 | -1.33 | |
| 13 | 12 | 9.75 | -1.29 | |
| 14 | 13 | 9.78 | -1.26 | |
| 15 | 14 | 9.81 | -1.23 | |
| 16 | 15 | 9.85 | -1.19 | |
| 17 | 16 | 9.88 | -1.16 | |
| 18 | 17 | 9.91 | -1.13 | |
| 19 | 18 | 9.93 | -1.11 | |
| 20 | 19 | 9.94 | -1.10 | |
| 21 | 20 | 9.98 | -1.06 | |
| 22 | 25 | 10.16 | -0.88 | |
| 23 | 30 | 10.27 | -0.77 | |
| 24 | 35 | 10.31 | -0.73 | |
| 25 | 40 | 10.39 | -0.65 | |
| 26 | 45 | 10.44 | -0.60 | |
| 27 | 50 | 10.49 | -0.55 | |
| 28 | 55 | 10.55 | -0.49 | |
| 29 | 60 | 10.58 | -0.46 | |
| 30 | 65 | 10.63 | -0.41 | |
| 31 | 70 | 10.65 | -0.39 | |
| 32 | 75 | 10.68 | -0.36 | |
| 33 | 80 | 10.70 | -0.34 | |
| 34 | 85 | 10.73 | -0.31 | |
| 35 | 90 | 10.76 | -0.28 | |
| 36 | 95 | 10.78 | -0.26 | |
| 37 | 100 | 10.80 | -0.24 | |
| 38 | 110 | 10.83 | -0.21 | |
| 39 | 120 | 10.88 | -0.16 | |
| 40 | 140 | 10.90 | -0.14 | |
| 41 | 150 | 10.91 | -0.13 | |
| 42 | 160 | 10.91 | -0.13 | |
| 43 | 170 | 10.93 | -0.11 | |
| 44 | 180 | 10.94 | -0.10 | |
| 45 | 200 | 10.98 | -0.06 | |
| 46 | 220 | 10.98 | -0.06 | |
| 47 | 240 | 10.99 | -0.05 | |
| 48 | 260 | 11.01 | -0.03 | |
| 49 | 280 | 11.01 | -0.03 | |
| 50 | 300 | 11.01 | -0.03 | |

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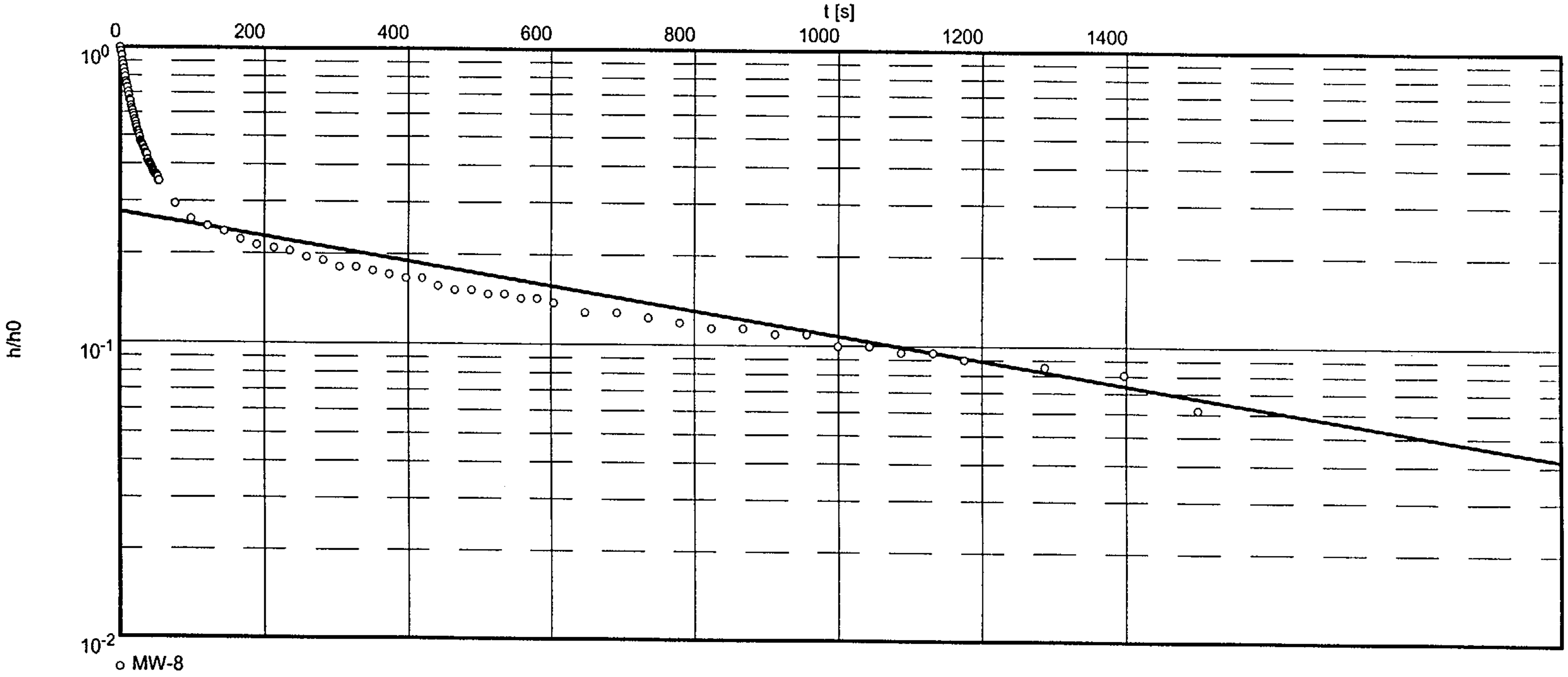
Slug Test No.
MWD-8

Test conducted on: Jan 20, 1998



Hydraulic conductivity [ft/s]: 1.11 x $10^{-6}$

Hydraulic Conductivity: 3.38x10-5 cm/s

Static Water Depth Below TOC: 5.21 ft
Total Well Depth Below TOC: 22.23 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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Slug Test No.
MWD-8

Test conducted on: Jan 20, 1998
MW-8

Static water level: 5.21 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 3.10 | -2.11 | |
| 2 | 1 | 3.16 | -2.05 | |
| 3 | 2 | 3.23 | -1.98 | |
| 4 | 3 | 3.32 | -1.89 | |
| 5 | 4 | 3.37 | -1.84 | |
| 6 | 5 | 3.43 | -1.78 | |
| 7 | 6 | 3.49 | -1.72 | |
| 8 | 7 | 3.54 | -1.67 | |
| 9 | 8 | 3.60 | -1.61 | |
| 10 | 9 | 3.63 | -1.58 | |
| 11 | 10 | 3.67 | -1.54 | |
| 12 | 11 | 3.73 | -1.48 | |
| 13 | 12 | 3.77 | -1.44 | |
| 14 | 13 | 3.81 | -1.40 | |
| 15 | 14 | 3.83 | -1.38 | |
| 16 | 15 | 3.88 | -1.33 | |
| 17 | 16 | 3.91 | -1.30 | |
| 18 | 17 | 3.93 | -1.28 | |
| 19 | 18 | 3.96 | -1.25 | |
| 20 | 19 | 3.99 | -1.22 | |
| 21 | 20 | 4.02 | -1.19 | |
| 22 | 21 | 4.04 | -1.17 | |
| 23 | 22 | 4.07 | -1.14 | |
| 24 | 23 | 4.09 | -1.12 | |
| 25 | 24 | 4.12 | -1.09 | |
| 26 | 25 | 4.13 | -1.08 | |
| 27 | 26 | 4.15 | -1.06 | |
| 28 | 27 | 4.17 | -1.04 | |
| 29 | 28 | 4.20 | -1.01 | |
| 30 | 29 | 4.21 | -1.00 | |
| 31 | 30 | 4.22 | -0.99 | |
| 32 | 31 | 4.23 | -0.98 | |
| 33 | 32 | 4.24 | -0.97 | |
| 34 | 33 | 4.26 | -0.95 | |
| 35 | 34 | 4.27 | -0.94 | |
| 36 | 35 | 4.29 | -0.92 | |
| 37 | 36 | 4.30 | -0.91 | |
| 38 | 37 | 4.30 | -0.91 | |
| 39 | 38 | 4.34 | -0.87 | |
| 40 | 39 | 4.34 | -0.87 | |
| 41 | 40 | 4.36 | -0.85 | |
| 42 | 41 | 4.36 | -0.85 | |
| 43 | 42 | 4.37 | -0.84 | |
| 44 | 43 | 4.38 | -0.83 | |
| 45 | 44 | 4.39 | -0.82 | |
| 46 | 45 | 4.40 | -0.81 | |
| 47 | 46 | 4.41 | -0.80 | |
| 48 | 47 | 4.42 | -0.79 | |
| 49 | 48 | 4.43 | -0.78 | |
| 50 | 49 | 4.43 | -0.78 | |

| | | |
|---|---|---|
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Slug Test No.

Test conducted on: Jan 20, 1998

MWD-8

MW-8

Static water level: 5.21 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 50 | 4.43 | -0.78 | |
| 52 | 51 | 4.44 | -0.77 | |
| 53 | 52 | 4.45 | -0.76 | |
| 54 | 53 | 4.47 | -0.74 | |
| 55 | 54 | 4.47 | -0.74 | |
| 56 | 76 | 4.59 | -0.62 | |
| 57 | 98 | 4.66 | -0.55 | |
| 58 | 121 | 4.69 | -0.52 | |
| 59 | 144 | 4.71 | -0.50 | |
| 60 | 167 | 4.74 | -0.47 | |
| 61 | 190 | 4.76 | -0.45 | |
| 62 | 213 | 4.77 | -0.44 | |
| 63 | 236 | 4.78 | -0.43 | |
| 64 | 259 | 4.80 | -0.41 | |
| 65 | 282 | 4.81 | -0.40 | |
| 66 | 305 | 4.83 | -0.38 | |
| 67 | 328 | 4.83 | -0.38 | |
| 68 | 351 | 4.84 | -0.37 | |
| 69 | 374 | 4.85 | -0.36 | |
| 70 | 397 | 4.86 | -0.35 | |
| 71 | 420 | 4.86 | -0.35 | |
| 72 | 443 | 4.88 | -0.33 | |
| 73 | 466 | 4.89 | -0.32 | |
| 74 | 489 | 4.89 | -0.32 | |
| 75 | 512 | 4.90 | -0.31 | |
| 76 | 535 | 4.90 | -0.31 | |
| 77 | 558 | 4.91 | -0.30 | |
| 78 | 581 | 4.91 | -0.30 | |
| 79 | 604 | 4.92 | -0.29 | |
| 80 | 648 | 4.94 | -0.27 | |
| 81 | 692 | 4.94 | -0.27 | |
| 82 | 736 | 4.95 | -0.26 | |
| 83 | 780 | 4.96 | -0.25 | |
| 84 | 824 | 4.97 | -0.24 | |
| 85 | 868 | 4.97 | -0.24 | |
| 86 | 912 | 4.98 | -0.23 | |
| 87 | 956 | 4.98 | -0.23 | |
| 88 | 1000 | 5.00 | -0.21 | |
| 89 | 1044 | 5.00 | -0.21 | |
| 90 | 1088 | 5.01 | -0.20 | |
| 91 | 1132 | 5.01 | -0.20 | |
| 92 | 1176 | 5.02 | -0.19 | |
| 93 | 1287 | 5.03 | -0.18 | |
| 94 | 1397 | 5.04 | -0.17 | |
| 95 | 1499 | 5.08 | -0.13 | |

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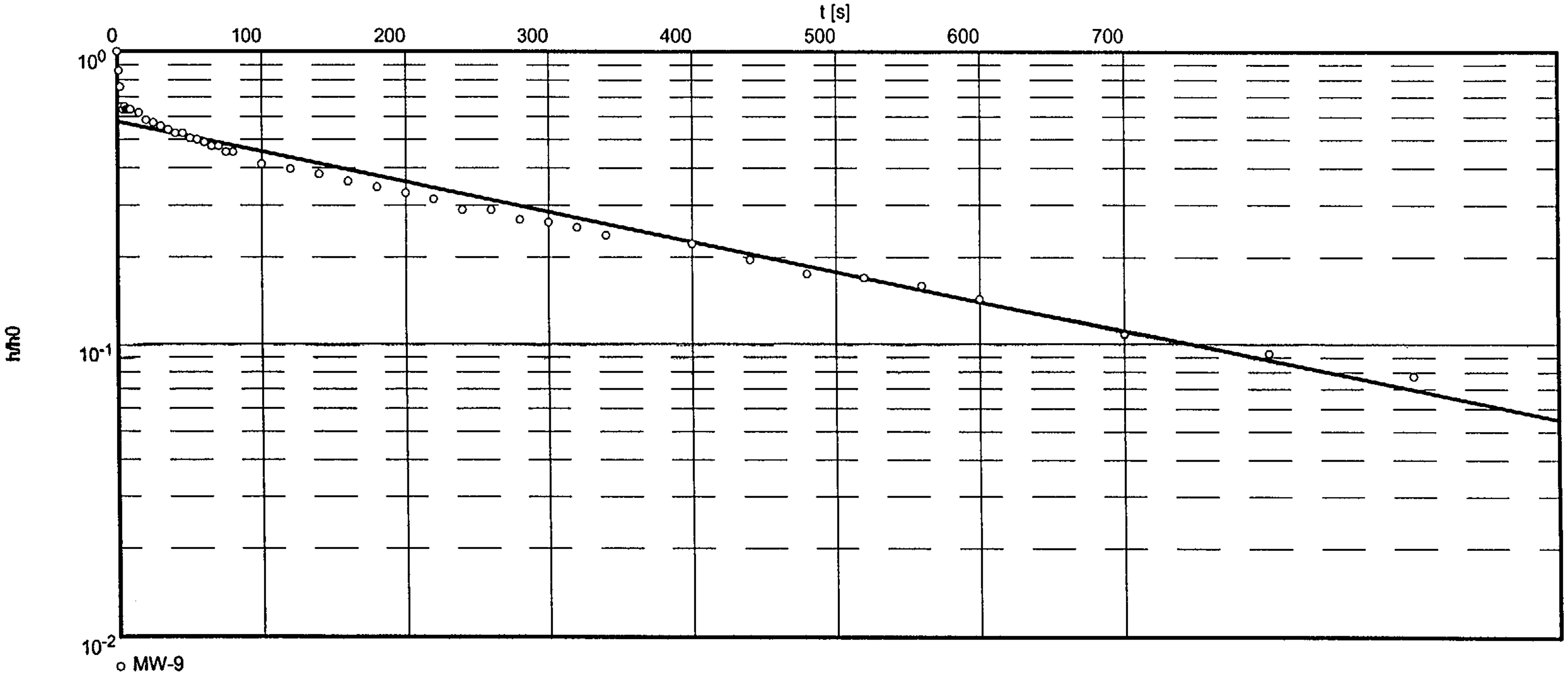
Slug Test No.
MWD-9

Test conducted on: Jan 21, 1998



Hydraulic conductivity [ft/s]: $2.78 \times 10^{-6}$

Hydraulic Conductivity: 8.47x10-5 cm/s

Static Water Depth Below TOC: 10.96 ft
Total Well Depth Below TOC: 24.00 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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| Slug Test No. | Test conducted on: Jan 21, 1998 |
|---|---|
| MWD-9 | MW-9 |

Static water level: 10.96 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 9.02 | -1.94 | |
| 2 | 1 | 9.29 | -1.67 | |
| 3 | 2 | 9.49 | -1.47 | |
| 4 | 3 | 9.70 | -1.26 | |
| 5 | 4 | 9.73 | -1.23 | |
| 6 | 5 | 9.70 | -1.26 | |
| 7 | 6 | 9.73 | -1.23 | |
| 8 | 7 | 9.73 | -1.23 | |
| 9 | 8 | 9.73 | -1.23 | |
| 10 | 9 | 9.73 | -1.23 | |
| 11 | 10 | 7.76 | -3.20 | |
| 12 | 15 | 9.76 | -1.20 | |
| 13 | 20 | 9.83 | -1.13 | |
| 14 | 25 | 9.85 | -1.11 | |
| 15 | 30 | 9.88 | -1.08 | |
| 16 | 35 | 9.91 | -1.05 | |
| 17 | 40 | 9.94 | -1.02 | |
| 18 | 45 | 9.94 | -1.02 | |
| 19 | 50 | 9.98 | -0.98 | |
| 20 | 55 | 9.99 | -0.97 | |
| 21 | 60 | 10.01 | -0.95 | |
| 22 | 65 | 10.04 | -0.92 | |
| 23 | 70 | 10.04 | -0.92 | |
| 24 | 75 | 10.08 | -0.88 | |
| 25 | 80 | 10.08 | -0.88 | |
| 26 | 100 | 10.16 | -0.80 | |
| 27 | 120 | 10.19 | -0.77 | |
| 28 | 140 | 10.22 | -0.74 | |
| 29 | 160 | 10.26 | -0.70 | |
| 30 | 180 | 10.29 | -0.67 | |
| 31 | 200 | 10.32 | -0.64 | |
| 32 | 220 | 10.35 | -0.61 | |
| 33 | 240 | 10.40 | -0.56 | |
| 34 | 260 | 10.40 | -0.56 | |
| 35 | 280 | 10.44 | -0.52 | |
| 36 | 300 | 10.45 | -0.51 | |
| 37 | 320 | 10.47 | -0.49 | |
| 38 | 340 | 10.50 | -0.46 | |
| 39 | 400 | 10.53 | -0.43 | |
| 40 | 440 | 10.58 | -0.38 | |
| 41 | 480 | 10.62 | -0.34 | |
| 42 | 520 | 10.63 | -0.33 | |
| 43 | 560 | 10.65 | -0.31 | |
| 44 | 600 | 10.68 | -0.28 | |
| 45 | 700 | 10.75 | -0.21 | |
| 46 | 800 | 10.78 | -0.18 | |
| 47 | 900 | 10.81 | -0.15 | |

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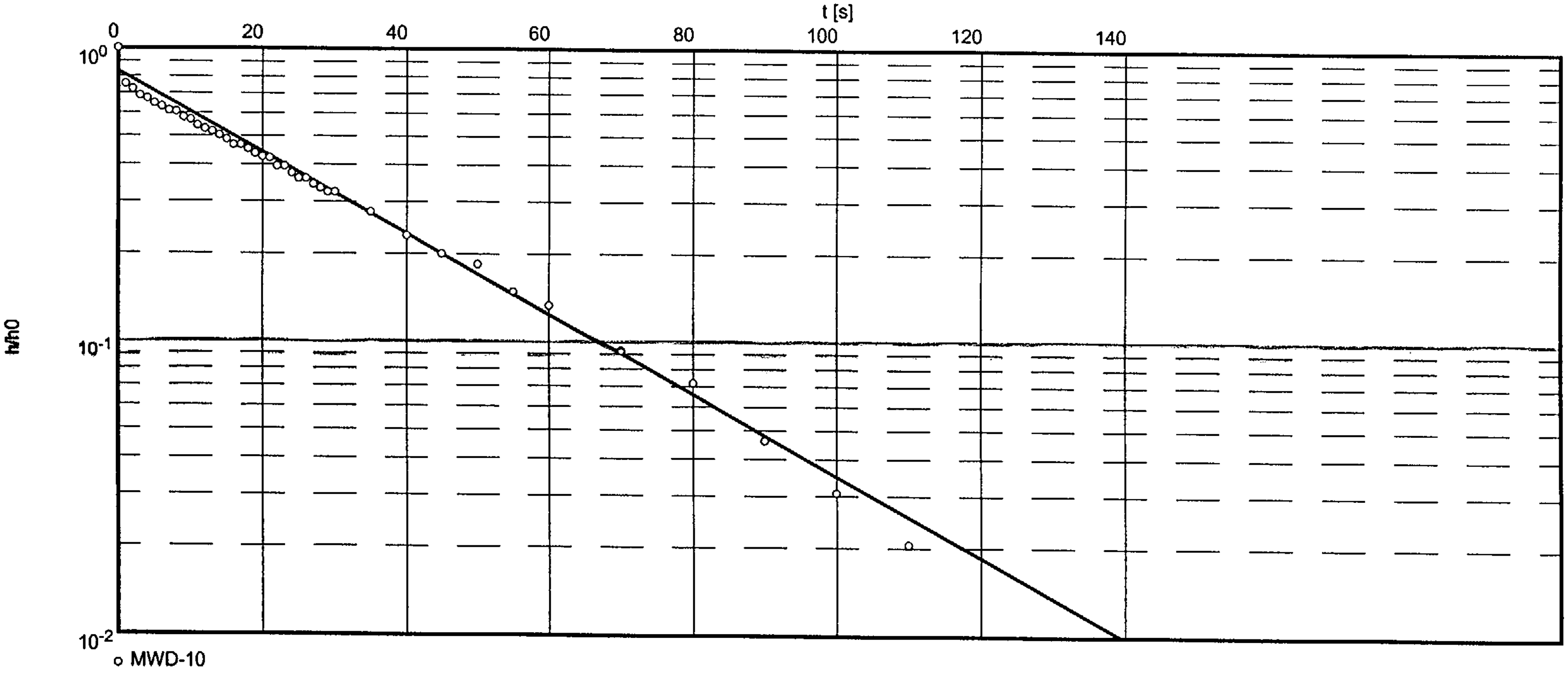
|---|---|---|---|

| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 20, 1998 |
| MWD-10 | |



Hydraulic conductivity [ft/s]: $3.76 \times 10^{-5}$

Hydraulic Conductivity: 1.15x10-3 cm/s

Static Water Depth Below TOC: 11.11 ft
Total Well Depth Below TOC: 23.87 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter pack) = 45 %

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| | |
|---|---|
| Slug Test No. | Test conducted on: Jan 20, 1998 |
| MWD-10 | MWD-10 |

Static water level: 11.11 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 9.16 | -1.95 |
| 2 | 1 | 9.64 | -1.47 |
| 3 | 2 | 9.70 | -1.41 |
| 4 | 3 | 9.77 | -1.34 |
| 5 | 4 | 9.80 | -1.31 |
| 6 | 5 | 9.85 | -1.26 |
| 7 | 6 | 9.88 | -1.23 |
| 8 | 7 | 9.92 | -1.19 |
| 9 | 8 | 9.93 | -1.18 |
| 10 | 9 | 9.98 | -1.13 |
| 11 | 10 | 10.00 | -1.11 |
| 12 | 11 | 10.05 | -1.06 |
| 13 | 12 | 10.08 | -1.03 |
| 14 | 13 | 10.10 | -1.01 |
| 15 | 14 | 10.13 | -0.98 |
| 16 | 15 | 10.16 | -0.95 |
| 17 | 16 | 10.20 | -0.91 |
| 18 | 17 | 10.20 | -0.91 |
| 19 | 18 | 10.23 | -0.88 |
| 20 | 19 | 10.26 | -0.85 |
| 21 | 20 | 10.28 | -0.83 |
| 22 | 21 | 10.29 | -0.82 |
| 23 | 22 | 10.34 | -0.77 |
| 24 | 23 | 10.34 | -0.77 |
| 25 | 24 | 10.38 | -0.73 |
| 26 | 25 | 10.41 | -0.70 |
| 27 | 26 | 10.41 | -0.70 |
| 28 | 27 | 10.44 | -0.67 |
| 29 | 28 | 10.46 | -0.65 |
| 30 | 29 | 10.48 | -0.63 |
| 31 | 30 | 10.48 | -0.63 |
| 32 | 35 | 10.57 | -0.54 |
| 33 | 40 | 10.66 | -0.45 |
| 34 | 45 | 10.72 | -0.39 |
| 35 | 50 | 10.75 | -0.36 |
| 36 | 55 | 10.82 | -0.29 |
| 37 | 60 | 10.85 | -0.26 |
| 38 | 70 | 10.93 | -0.18 |
| 39 | 80 | 10.97 | -0.14 |
| 40 | 90 | 11.02 | -0.09 |
| 41 | 100 | 11.05 | -0.06 |
| 42 | 110 | 11.07 | -0.04 |

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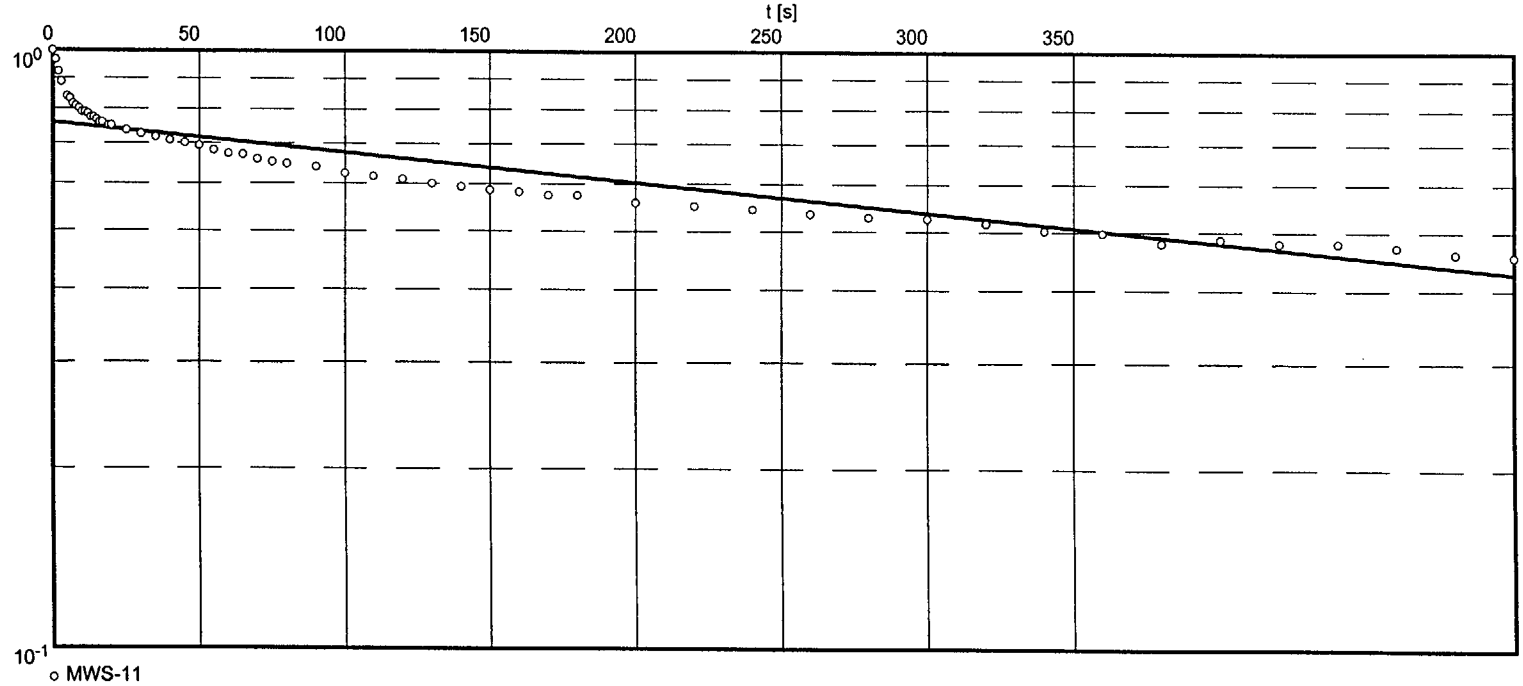
Slug Test No.

MWS11

Test conducted on: Jan 20, 1998



Hydraulic conductivity [ft/s]: $2.21 \times 10^{-6}$

Hydraulic Conductivity: 6.73x10-5 cm/s

Static Water Depth Below TOC: 12.59 ft
Total Well Depth Below TOC: 14.04 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 5 ft
Porosity (filter pack) = 45 %

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MWS-11

Static water level: 12.59 ft below datum

| | Pumping test duration<br>[s] | Water level<br>[ft] | Change in Waterlevel<br>[ft] | |
|---|---|---|---|---|
| 1 | 0 | 8.31 | -4.28 | |
| 2 | 1 | 8.46 | -4.13 | |
| 3 | 2 | 8.64 | -3.95 | |
| 4 | 3 | 8.79 | -3.80 | |
| 5 | 5 | 9.00 | -3.59 | |
| 6 | 6 | 9.03 | -3.56 | |
| 7 | 7 | 9.10 | -3.49 | |
| 8 | 8 | 9.13 | -3.46 | |
| 9 | 9 | 9.16 | -3.43 | |
| 10 | 10 | 9.21 | -3.38 | |
| 11 | 11 | 9.21 | -3.38 | |
| 12 | 12 | 9.23 | -3.36 | |
| 13 | 13 | 9.28 | -3.31 | |
| 14 | 14 | 9.28 | -3.31 | |
| 15 | 15 | 9.31 | -3.28 | |
| 16 | 16 | 9.34 | -3.25 | |
| 17 | 17 | 9.34 | -3.25 | |
| 18 | 19 | 9.38 | -3.21 | |
| 19 | 20 | 9.38 | -3.21 | |
| 20 | 25 | 9.44 | -3.15 | |
| 21 | 30 | 9.48 | -3.11 | |
| 22 | 35 | 9.52 | -3.07 | |
| 23 | 40 | 9.56 | -3.03 | |
| 24 | 45 | 9.59 | -3.00 | |
| 25 | 50 | 9.62 | -2.97 | |
| 26 | 55 | 9.67 | -2.92 | |
| 27 | 60 | 9.71 | -2.88 | |
| 28 | 65 | 9.72 | -2.87 | |
| 29 | 70 | 9.77 | -2.82 | |
| 30 | 75 | 9.80 | -2.79 | |
| 31 | 80 | 9.82 | -2.77 | |
| 32 | 90 | 9.85 | -2.74 | |
| 33 | 100 | 9.92 | -2.67 | |
| 34 | 110 | 9.95 | -2.64 | |
| 35 | 120 | 9.98 | -2.61 | |
| 36 | 130 | 10.02 | -2.57 | |
| 37 | 140 | 10.05 | -2.54 | |
| 38 | 150 | 10.08 | -2.51 | |
| 39 | 160 | 10.10 | -2.49 | |
| 40 | 170 | 10.13 | -2.46 | |
| 41 | 180 | 10.13 | -2.46 | |
| 42 | 200 | 10.20 | -2.39 | |
| 43 | 220 | 10.23 | -2.36 | |
| 44 | 240 | 10.26 | -2.33 | |
| 45 | 260 | 10.30 | -2.29 | |
| 46 | 280 | 10.33 | -2.26 | |
| 47 | 300 | 10.34 | -2.25 | |
| 48 | 320 | 10.38 | -2.21 | |
| 49 | 340 | 10.44 | -2.15 | |
| 50 | 360 | 10.46 | -2.13 | |

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HVORSLEV's meth

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Slug Test No.
MWS11

Test conducted on: Jan 20, 1998
MWS-11

Static water level: 12.59 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 380 | 10.54 | -2.05 | |
| 52 | 400 | 10.51 | -2.08 | |
| 53 | 420 | 10.54 | -2.05 | |
| 54 | 440 | 10.54 | -2.05 | |
| 55 | 460 | 10.57 | -2.02 | |
| 56 | 480 | 10.62 | -1.97 | |
| 57 | 500 | 10.64 | -1.95 | |

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Project: Kaiser

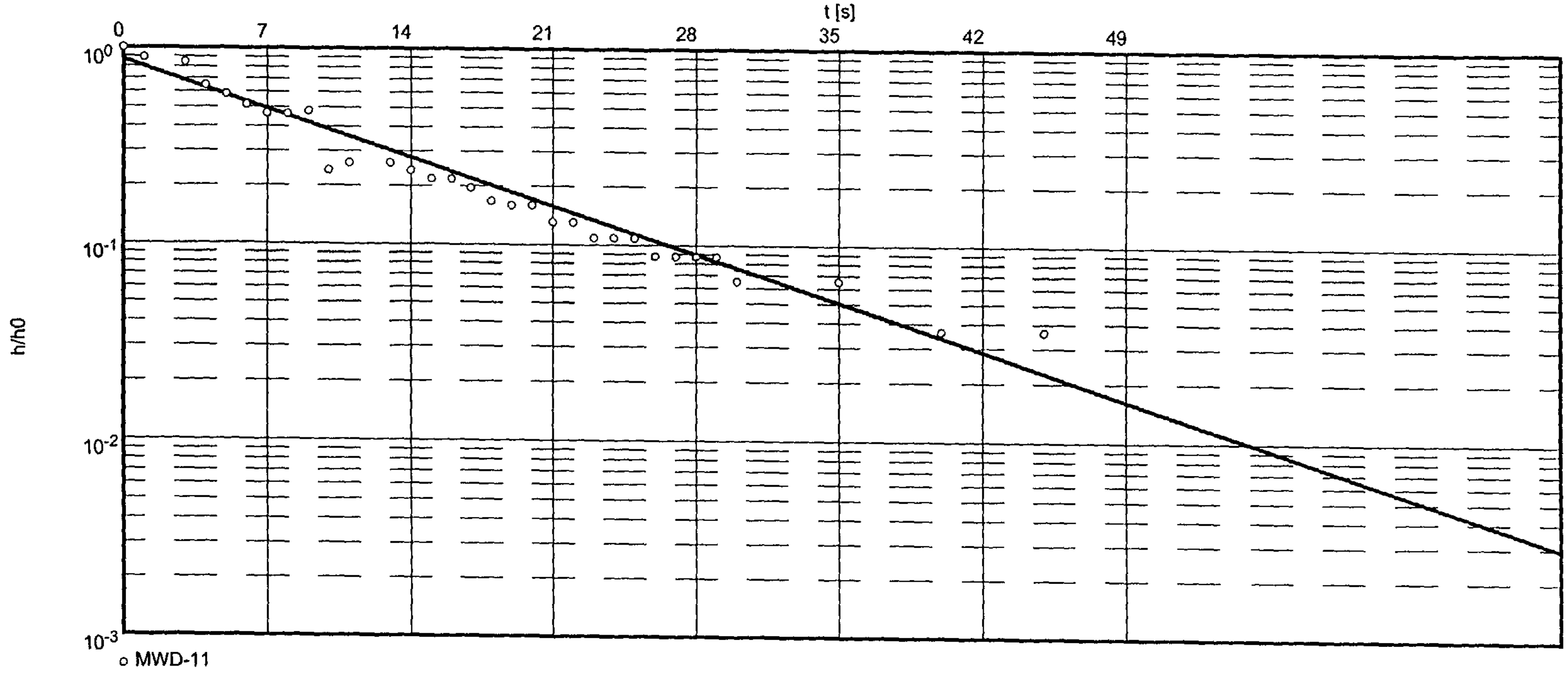
Evaluated by: pls

Date: 01.02.1998

Slug Test No.

MWD-11

Test conducted on: Jan 20, 1998



Hydraulic conductivity [ft/s]: $9.65 \times 10^{-5}$

Hydraulic Conductivity: 2.94x10-3 cm/s

Static Water Depth Below TOC: 13.29 ft
Total Well Depth Below TOC: 28.78 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in

Screen length = 10 ft
Porosity (filter ...) = 45 %

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slug/bail test analysis
HVORSLEV's method

Page 2

Project: Kaiser

Evaluated by: pls

Date: 01.02.1998

Slug Test No.

Test conducted on: Jan 20, 1998

MWD-11

MWD-11

Static water level: 13.29 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 11.91 | -1.38 |
| 2 | 1 | 12.06 | -1.23 |
| 3 | 3 | 12.12 | -1.17 |
| 4 | 4 | 12.40 | -0.89 |
| 5 | 5 | 12.48 | -0.81 |
| 6 | 6 | 12.58 | -0.71 |
| 7 | 7 | 12.65 | -0.64 |
| 8 | 8 | 12.65 | -0.64 |
| 9 | 9 | 12.63 | -0.66 |
| 10 | 10 | 12.96 | -0.33 |
| 11 | 11 | 12.93 | -0.36 |
| 12 | 13 | 12.93 | -0.36 |
| 13 | 14 | 12.96 | -0.33 |
| 14 | 15 | 12.99 | -0.30 |
| 15 | 16 | 12.99 | -0.30 |
| 16 | 17 | 13.02 | -0.27 |
| 17 | 18 | 13.06 | -0.23 |
| 18 | 19 | 13.07 | -0.22 |
| 19 | 20 | 13.07 | -0.22 |
| 20 | 21 | 13.11 | -0.18 |
| 21 | 22 | 13.11 | -0.18 |
| 22 | 23 | 13.14 | -0.15 |
| 23 | 24 | 13.14 | -0.15 |
| 24 | 25 | 13.14 | -0.15 |
| 25 | 26 | 13.17 | -0.12 |
| 26 | 27 | 13.17 | -0.12 |
| 27 | 28 | 13.17 | -0.12 |
| 28 | 29 | 13.17 | -0.12 |
| 29 | 30 | 13.20 | -0.09 |
| 30 | 35 | 13.20 | -0.09 |
| 31 | 40 | 13.24 | -0.05 |
| 32 | 45 | 13.24 | -0.05 |
| 33 | 50 | 13.29 | 0.00 |

# 1999
# Slug Test Data

| | | |
|---|---|---|
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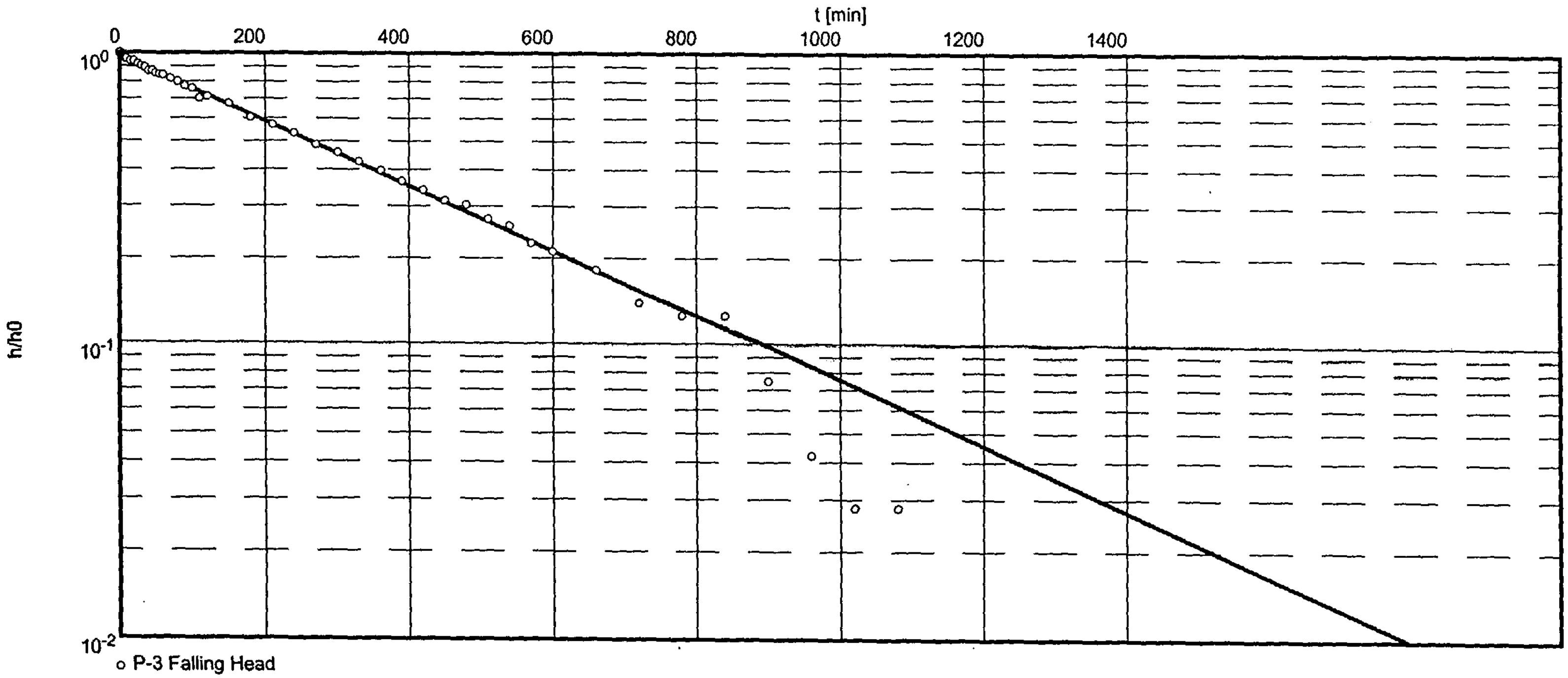
| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 5\24\99 |
| P-3 Falling Head | |



Hydraulic conductivity [ft/min]: $3.03 \times 10^{-6}$

Hydraulic Conductivity (cm\sec): 1.6 x 10-6

Static Water Depth Below TOC: 6.59 ft
Total Well Depth Below TOC: 16.31 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 10.06.1999

Slug Test No. 1

Test conducted on: 5\24\99

P-3 Falling Head

P-3 Falling Head

Static water level: 6.59 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0.00 | 4.45 | -2.14 |
| 2 | 1.00 | 4.45 | -2.14 |
| 3 | 2.00 | 4.48 | -2.11 |
| 4 | 3.00 | 4.50 | -2.09 |
| 5 | 4.00 | 4.51 | -2.08 |
| 6 | 5.00 | 4.51 | -2.08 |
| 7 | 6.00 | 4.51 | -2.08 |
| 8 | 7.00 | 4.53 | -2.06 |
| 9 | 8.00 | 4.55 | -2.04 |
| 10 | 9.00 | 4.55 | -2.04 |
| 11 | 10.00 | 4.55 | -2.04 |
| 12 | 15.00 | 4.58 | -2.01 |
| 13 | 20.00 | 4.58 | -2.01 |
| 14 | 25.00 | 4.63 | -1.96 |
| 15 | 30.00 | 4.66 | -1.93 |
| 16 | 35.00 | 4.68 | -1.91 |
| 17 | 40.00 | 4.73 | -1.86 |
| 18 | 45.00 | 4.73 | -1.86 |
| 19 | 50.00 | 4.77 | -1.82 |
| 20 | 55.00 | 4.78 | -1.81 |
| 21 | 60.00 | 4.79 | -1.80 |
| 22 | 70.00 | 4.84 | -1.75 |
| 23 | 80.00 | 4.88 | -1.71 |
| 24 | 90.00 | 4.94 | -1.65 |
| 25 | 100.00 | 4.97 | -1.62 |
| 26 | 110.00 | 5.09 | -1.50 |
| 27 | 120.00 | 5.07 | -1.52 |
| 28 | 150.00 | 5.15 | -1.44 |
| 29 | 180.00 | 5.30 | -1.29 |
| 30 | 210.00 | 5.37 | -1.22 |
| 31 | 240.00 | 5.45 | -1.14 |
| 32 | 270.00 | 5.55 | -1.04 |
| 33 | 300.00 | 5.61 | -0.98 |
| 34 | 330.00 | 5.68 | -0.91 |
| 35 | 360.00 | 5.74 | -0.85 |
| 36 | 390.00 | 5.81 | -0.78 |
| 37 | 420.00 | 5.86 | -0.73 |
| 38 | 450.00 | 5.92 | -0.67 |
| 39 | 480.00 | 5.94 | -0.65 |
| 40 | 510.00 | 6.01 | -0.58 |
| 41 | 540.00 | 6.04 | -0.55 |
| 42 | 570.00 | 6.11 | -0.48 |
| 43 | 600.00 | 6.14 | -0.45 |
| 44 | 660.00 | 6.20 | -0.39 |
| 45 | 720.00 | 6.29 | -0.30 |
| 46 | 780.00 | 6.32 | -0.27 |
| 47 | 840.00 | 6.32 | -0.27 |
| 48 | 900.00 | 6.43 | -0.16 |
| | | 6.50 | -0.09 |

| | | | |
|---|---|---|---|
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| | | Project: Kaiser Remediation Project | |
| | | Evaluated by: pls | Date: 10.06.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 5\24\99 |
| P-3 Falling Head | P-3 Falling Head |

Static water level: 6.59 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 1080.00 | 6.53 | -0.06 | |

| | | |
|---|---|---|
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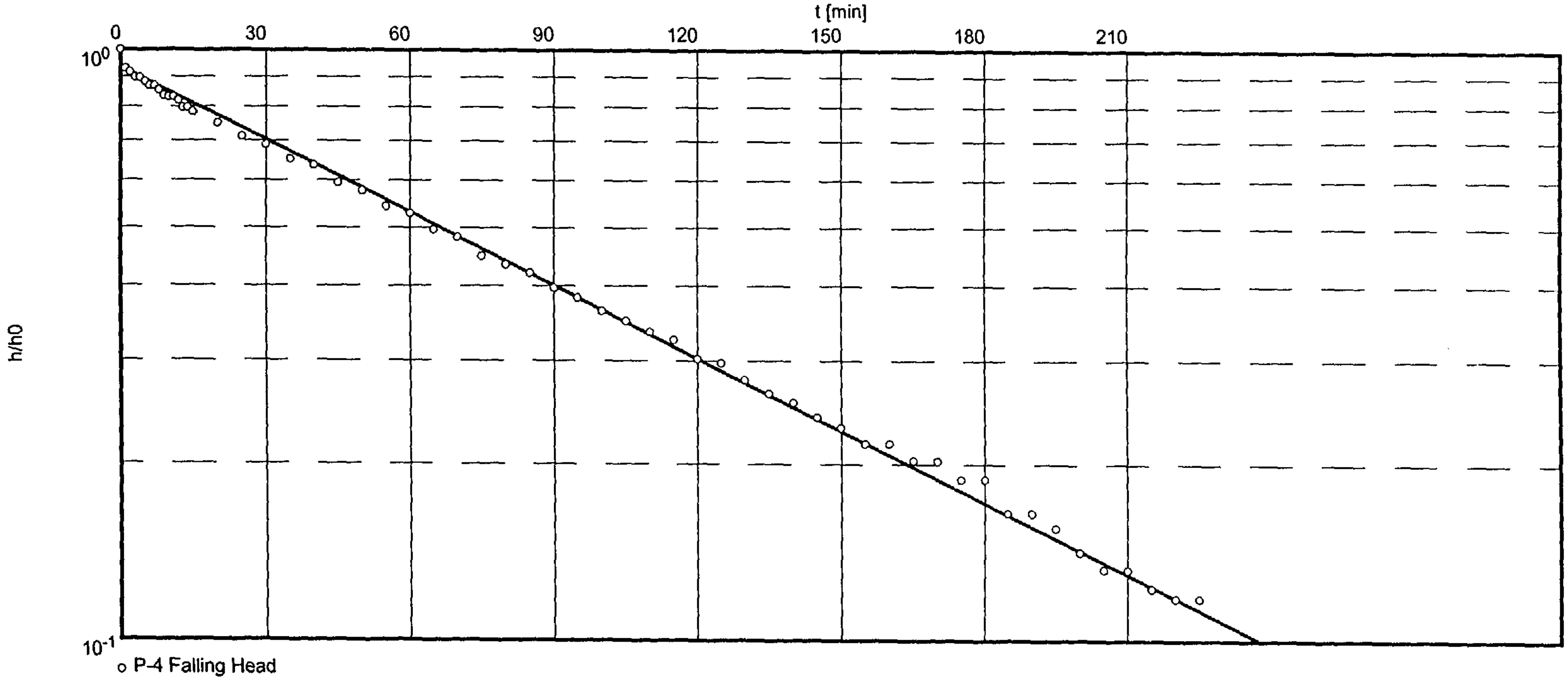
| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 5\25\99 |
| P-4 Falling Head | |



Hydraulic conductivity [ft/min]: $1.11 \times 10^{-5}$

Hydraulic Conductivity (cm\sec): 6.0 x 10-6

Static Water Depth Below TOC: 3.93 ft
Total Well Depth Below TOC: 21.32 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

Slug Test No. 1
Test conducted on: 5\25\99

P-4 Falling Head
P-4 Falling Head

Static water level: 3.93 ft below datum

| | Pumping test duration<br>[min] | Water level<br>[ft] | Change in Waterlevel<br>[ft] |
|---|---|---|---|
| 1 | 0.00 | 1.81 | -2.12 |
| 2 | 1.00 | 1.96 | -1.97 |
| 3 | 2.00 | 1.99 | -1.94 |
| 4 | 3.00 | 2.03 | -1.90 |
| 5 | 4.00 | 2.03 | -1.90 |
| 6 | 5.00 | 2.06 | -1.87 |
| 7 | 6.00 | 2.09 | -1.84 |
| 8 | 7.00 | 2.09 | -1.84 |
| 9 | 8.00 | 2.12 | -1.81 |
| 10 | 9.00 | 2.16 | -1.77 |
| 11 | 10.00 | 2.17 | -1.76 |
| 12 | 11.00 | 2.17 | -1.76 |
| 13 | 12.00 | 2.19 | -1.74 |
| 14 | 13.00 | 2.24 | -1.69 |
| 15 | 14.00 | 2.24 | -1.69 |
| 16 | 15.00 | 2.27 | -1.66 |
| 17 | 20.00 | 2.34 | -1.59 |
| 18 | 25.00 | 2.42 | -1.51 |
| 19 | 30.00 | 2.47 | -1.46 |
| 20 | 35.00 | 2.55 | -1.38 |
| 21 | 40.00 | 2.58 | -1.35 |
| 22 | 45.00 | 2.67 | -1.26 |
| 23 | 50.00 | 2.71 | -1.22 |
| 24 | 55.00 | 2.78 | -1.15 |
| 25 | 60.00 | 2.81 | -1.12 |
| 26 | 65.00 | 2.88 | -1.05 |
| 27 | 70.00 | 2.91 | -1.02 |
| 28 | 75.00 | 2.98 | -0.95 |
| 29 | 80.00 | 3.01 | -0.92 |
| 30 | 85.00 | 3.04 | -0.89 |
| 31 | 90.00 | 3.09 | -0.84 |
| 32 | 95.00 | 3.12 | -0.81 |
| 33 | 100.00 | 3.16 | -0.77 |
| 34 | 105.00 | 3.19 | -0.74 |
| 35 | 110.00 | 3.22 | -0.71 |
| 36 | 115.00 | 3.24 | -0.69 |
| 37 | 120.00 | 3.29 | -0.64 |
| 38 | 125.00 | 3.30 | -0.63 |
| 39 | 130.00 | 3.34 | -0.59 |
| 40 | 135.00 | 3.37 | -0.56 |
| 41 | 140.00 | 3.39 | -0.54 |
| 42 | 145.00 | 3.42 | -0.51 |
| 43 | 150.00 | 3.44 | -0.49 |
| 44 | 155.00 | 3.47 | -0.46 |
| 45 | 160.00 | 3.47 | -0.46 |
| 46 | 165.00 | 3.50 | -0.43 |
| 47 | 170.00 | 3.50 | -0.43 |
| 48 | 175.00 | 3.53 | -0.40 |
| | | 3.53 | -0.40 |

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slug/bail test analysis
HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 10.06.1999

Slug Test No. 1

Test conducted on: 5\25\99

P-4 Falling Head

P-4 Falling Head

Static water level: 3.93 ft below datum

| | Pumping test duration [min] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 190.00 | 3.58 | -0.35 | |
| 52 | 195.00 | 3.60 | -0.33 | |
| 53 | 200.00 | 3.63 | -0.30 | |
| 54 | 205.00 | 3.65 | -0.28 | |
| 55 | 210.00 | 3.65 | -0.28 | |
| 56 | 215.00 | 3.67 | -0.26 | |
| 57 | 220.00 | 3.68 | -0.25 | |
| 58 | 225.00 | 3.68 | -0.25 | |

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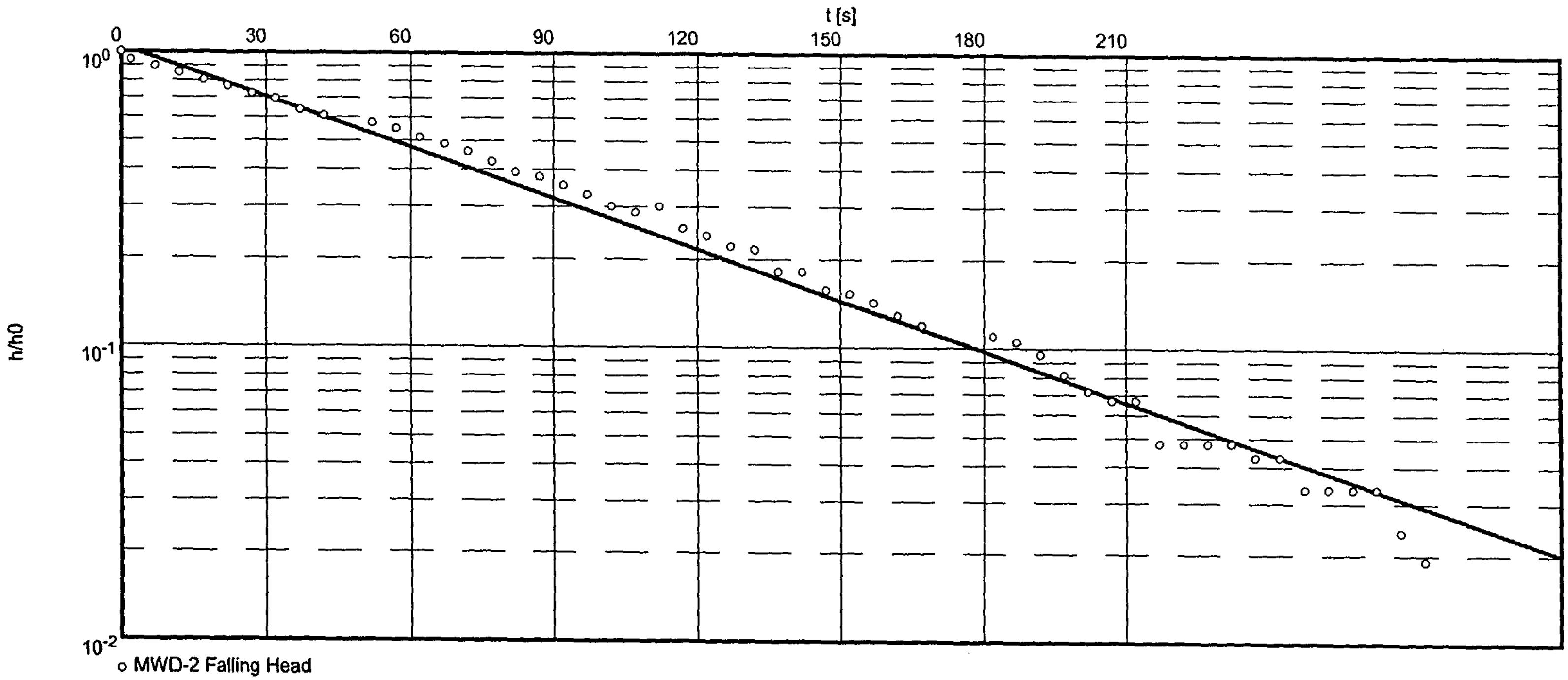
Project: Kaiser Remediation Project
Evaluated by: pls
Date: 09.06.1999

Slug Test No. 1
Test conducted on: 5\24\99

MWD-2 Falling Head



Hydraulic conductivity [ft/s]: $1.56 \times 10^{-5}$

Hydraulic Conductivity (cm\sec): 4.75 x 10-4

Static Water Depth Below TOC: 6.50 ft
Total Well Depth Below TOC: 18.92 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

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Slug Test No. 1

Test conducted on: 5\24\99

MWD-2 Falling Head

MWD-2 Falling Head

Static water level: 6.50 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 4.41 | -2.09 |
| 2 | 2 | 4.53 | -1.97 |
| 3 | 7 | 4.63 | -1.87 |
| 4 | 12 | 4.72 | -1.78 |
| 5 | 17 | 4.82 | -1.68 |
| 6 | 22 | 4.90 | -1.60 |
| 7 | 27 | 4.99 | -1.51 |
| 8 | 32 | 5.05 | -1.45 |
| 9 | 37 | 5.17 | -1.33 |
| 10 | 42 | 5.23 | -1.27 |
| 11 | 52 | 5.30 | -1.20 |
| 12 | 57 | 5.35 | -1.15 |
| 13 | 62 | 5.43 | -1.07 |
| 14 | 67 | 5.48 | -1.02 |
| 15 | 72 | 5.54 | -0.96 |
| 16 | 77 | 5.61 | -0.89 |
| 17 | 82 | 5.68 | -0.82 |
| 18 | 87 | 5.71 | -0.79 |
| 19 | 92 | 5.76 | -0.74 |
| 20 | 97 | 5.81 | -0.69 |
| 21 | 102 | 5.87 | -0.63 |
| 22 | 107 | 5.90 | -0.60 |
| 23 | 112 | 5.87 | -0.63 |
| 24 | 117 | 5.97 | -0.53 |
| 25 | 122 | 6.00 | -0.50 |
| 26 | 127 | 6.04 | -0.46 |
| 27 | 132 | 6.05 | -0.45 |
| 28 | 137 | 6.12 | -0.38 |
| 29 | 142 | 6.12 | -0.38 |
| 30 | 147 | 6.17 | -0.33 |
| 31 | 152 | 6.18 | -0.32 |
| 32 | 157 | 6.20 | -0.30 |
| 33 | 162 | 6.23 | -0.27 |
| 34 | 167 | 6.25 | -0.25 |
| 35 | 182 | 6.27 | -0.23 |
| 36 | 187 | 6.28 | -0.22 |
| 37 | 192 | 6.30 | -0.20 |
| 38 | 197 | 6.33 | -0.17 |
| 39 | 202 | 6.35 | -0.15 |
| 40 | 207 | 6.36 | -0.14 |
| 41 | 212 | 6.36 | -0.14 |
| 42 | 217 | 6.40 | -0.10 |
| 43 | 222 | 6.40 | -0.10 |
| 44 | 227 | 6.40 | -0.10 |
| 45 | 232 | 6.40 | -0.10 |
| 46 | 237 | 6.41 | -0.09 |
| 47 | 242 | 6.41 | -0.09 |
| | 247 | 6.43 | -0.07 |
| | | 6.43 | -0.07 |

|  |  |  |
|---|---|---|
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|  |  |
|---|---|
| Slug Test No. 1 | Test conducted on: 5\24\99 |
| MWD-2 Falling Head | MWD-2 Falling Head |

Static water level: 6.50 ft below datum

|  | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |  |
|---|---|---|---|---|
| 51 | 262 | 6.43 | -0.07 |  |
| 52 | 267 | 6.45 | -0.05 |  |
| 53 | 272 | 6.46 | -0.04 |  |

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HVORSLEV's method

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Project: Kaiser Remediation Project

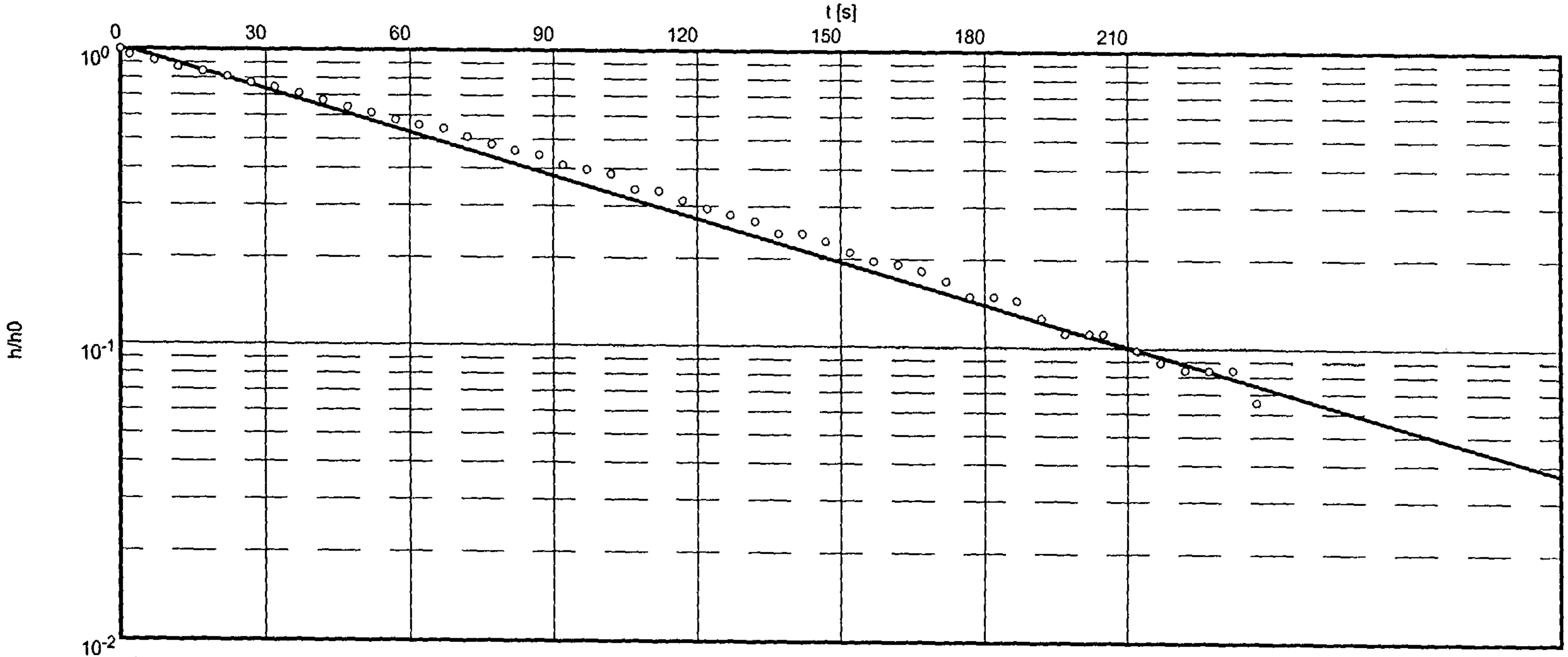
Evaluated by: pls

Date: 10.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWD-2 Rising Head



○ MWD-2 Rising Head

Hydraulic conductivity [ft/s]: 1.41 x $10^{-5}$

Hydraulic Conductivity (cm\sec): 4.29 x 10-4

Static Water Depth Below TOC: 6.50 ft
Total Well Depth Below TOC: 18.92 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 10.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWD-2 Rising Head

MWD-2 Rising Head

Static water level: 6.50 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 8.64 | 2.14 |
| 2 | 2 | 8.55 | 2.05 |
| 3 | 7 | 8.46 | 1.96 |
| 4 | 12 | 8.36 | 1.86 |
| 5 | 17 | 8.30 | 1.80 |
| 6 | 22 | 8.23 | 1.73 |
| 7 | 27 | 8.15 | 1.65 |
| 8 | 32 | 8.09 | 1.59 |
| 9 | 37 | 8.02 | 1.52 |
| 10 | 42 | 7.94 | 1.44 |
| 11 | 47 | 7.87 | 1.37 |
| 12 | 52 | 7.81 | 1.31 |
| 13 | 57 | 7.74 | 1.24 |
| 14 | 62 | 7.69 | 1.19 |
| 15 | 67 | 7.66 | 1.16 |
| 16 | 72 | 7.59 | 1.09 |
| 17 | 77 | 7.53 | 1.03 |
| 18 | 82 | 7.48 | 0.98 |
| 19 | 87 | 7.45 | 0.95 |
| 20 | 92 | 7.38 | 0.88 |
| 21 | 97 | 7.35 | 0.85 |
| 22 | 102 | 7.32 | 0.82 |
| 23 | 107 | 7.23 | 0.73 |
| 24 | 112 | 7.22 | 0.72 |
| 25 | 117 | 7.17 | 0.67 |
| 26 | 122 | 7.13 | 0.63 |
| 27 | 127 | 7.10 | 0.60 |
| 28 | 132 | 7.07 | 0.57 |
| 29 | 137 | 7.02 | 0.52 |
| 30 | 142 | 7.02 | 0.52 |
| 31 | 147 | 6.99 | 0.49 |
| 32 | 152 | 6.95 | 0.45 |
| 33 | 157 | 6.92 | 0.42 |
| 34 | 162 | 6.91 | 0.41 |
| 35 | 167 | 6.89 | 0.39 |
| 36 | 172 | 6.86 | 0.36 |
| 37 | 177 | 6.82 | 0.32 |
| 38 | 182 | 6.82 | 0.32 |
| 39 | 187 | 6.81 | 0.31 |
| 40 | 192 | 6.77 | 0.27 |
| 41 | 197 | 6.74 | 0.24 |
| 42 | 202 | 6.74 | 0.24 |
| 43 | 205 | 6.74 | 0.24 |
| 44 | 212 | 6.71 | 0.21 |
| 45 | 217 | 6.69 | 0.19 |
| 46 | 222 | 6.68 | 0.18 |
| 47 | 227 | 6.68 | 0.18 |
| 48 | 232 | 6.68 | 0.18 |
| | | 6.64 | 0.14 |

| | | |
|---|---|---|
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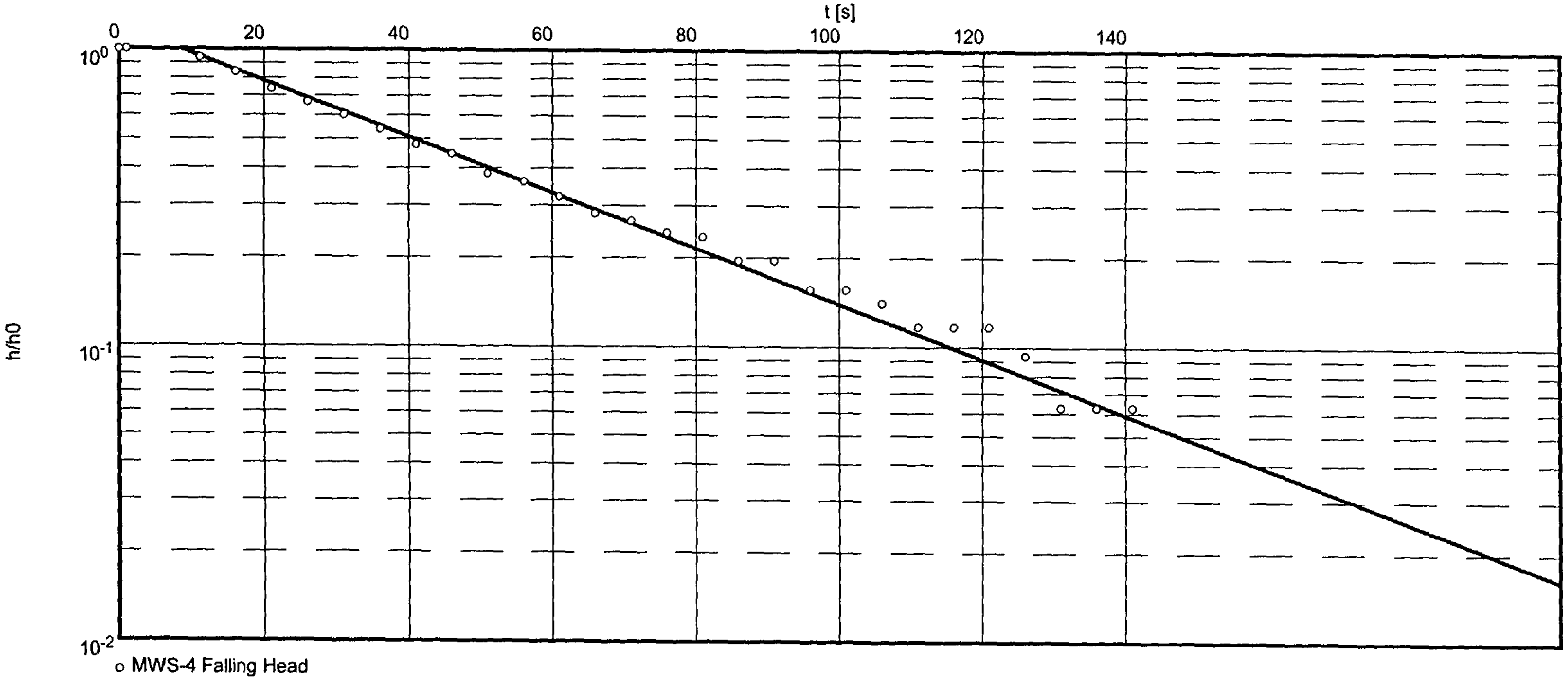
| Slug Test No. 1 | | Test conducted on: 5\26\99 |
| MWS-4 Falling Head | | |



Hydraulic conductivity [ft/s]: $4.15 \times 10^{-5}$

Hydraulic Conductivity (cm\sec): 1.37 x 10-3

Static Water Depth Below TOC: 6.09 ft
Total Well Depth Below TOC: 13.38 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 5 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5\26\99

MWS-4 Falling Head

MWS-4 Falling Head

Static water level: 6.09 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 4.81 | -1.28 | |
| 2 | 1 | 4.81 | -1.28 | |
| 3 | 6 | 4.63 | -1.46 | |
| 4 | 11 | 4.89 | -1.20 | |
| 5 | 16 | 5.02 | -1.07 | |
| 6 | 21 | 5.15 | -0.94 | |
| 7 | 26 | 5.24 | -0.85 | |
| 8 | 31 | 5.32 | -0.77 | |
| 9 | 36 | 5.40 | -0.69 | |
| 10 | 41 | 5.48 | -0.61 | |
| 11 | 46 | 5.52 | -0.57 | |
| 12 | 51 | 5.60 | -0.49 | |
| 13 | 56 | 5.63 | -0.46 | |
| 14 | 61 | 5.68 | -0.41 | |
| 15 | 66 | 5.73 | -0.36 | |
| 16 | 71 | 5.75 | -0.34 | |
| 17 | 76 | 5.78 | -0.31 | |
| 18 | 81 | 5.79 | -0.30 | |
| 19 | 86 | 5.84 | -0.25 | |
| 20 | 91 | 5.84 | -0.25 | |
| 21 | 96 | 5.89 | -0.20 | |
| 22 | 101 | 5.89 | -0.20 | |
| 23 | 106 | 5.91 | -0.18 | |
| 24 | 111 | 5.94 | -0.15 | |
| 25 | 116 | 5.94 | -0.15 | |
| 26 | 121 | 5.94 | -0.15 | |
| 27 | 126 | 5.97 | -0.12 | |
| 28 | 131 | 6.01 | -0.08 | |
| 29 | 136 | 6.01 | -0.08 | |
| 30 | 141 | 6.01 | -0.08 | |

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slug/bail test analysis
HVORSLEV's method

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Project: Kaiser Remediation Project

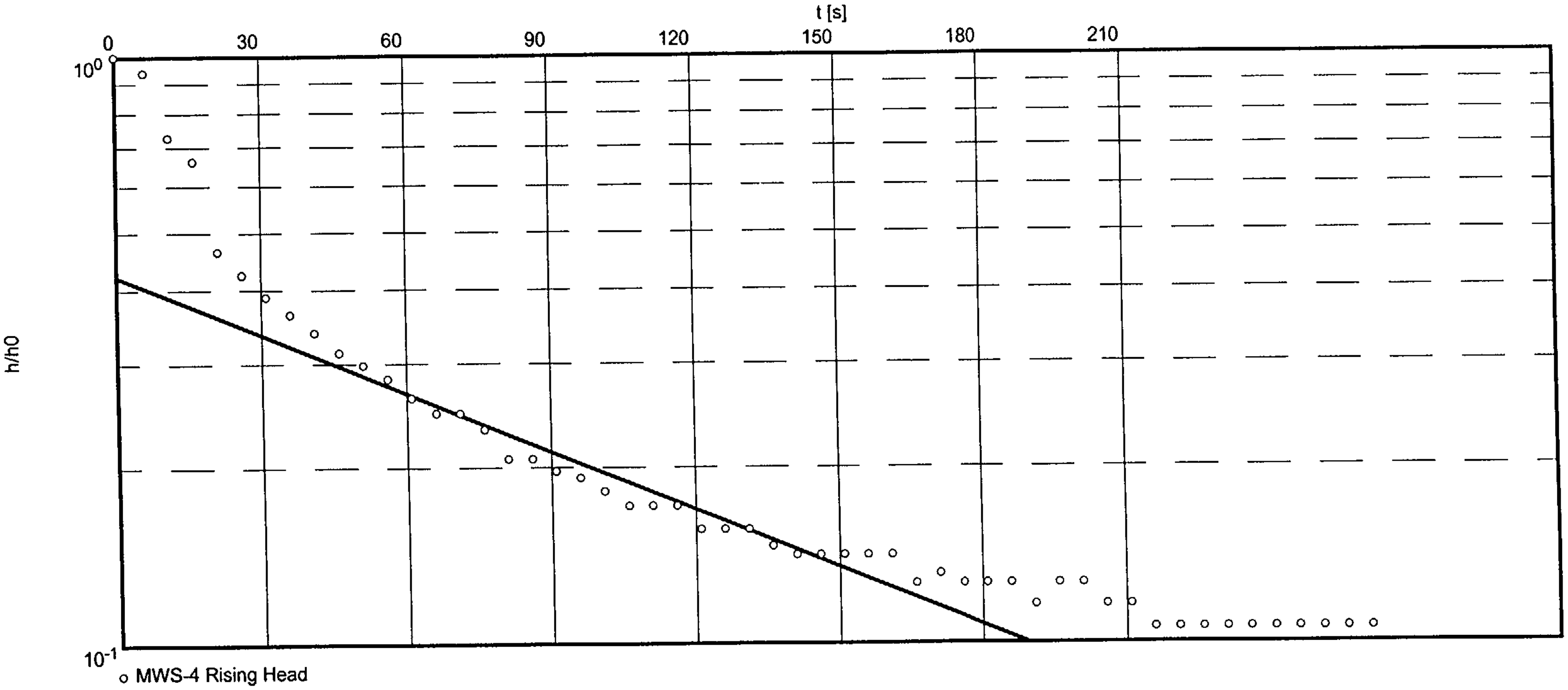
Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWS-4 Rising Head



Hydraulic conductivity [ft/s]: $7.41 \times 10^{-5}$

Hydraulic Conductivity (cm\sec): 2.26 x 10-3

Static Water Depth Below TOC: 6.09 ft
Total Well Depth Below TOC: 13.38 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 5 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
HVORSLEV's method

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Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWS-4 Rising Head

MWS-4 Rising Head

Static water level: 6.09 ft below datum

| | Pumping test duration<br>[s] | Water level<br>[ft] | Change in Waterlevel<br>[ft] |
|---|---|---|---|
| 1 | 0 | 8.07 | 1.98 |
| 2 | 6 | 7.95 | 1.86 |
| 3 | 11 | 7.53 | 1.44 |
| 4 | 16 | 7.40 | 1.31 |
| 5 | 21 | 7.01 | 0.92 |
| 6 | 26 | 6.93 | 0.84 |
| 7 | 31 | 6.86 | 0.77 |
| 8 | 36 | 6.81 | 0.72 |
| 9 | 41 | 6.76 | 0.67 |
| 10 | 46 | 6.71 | 0.62 |
| 11 | 51 | 6.68 | 0.59 |
| 12 | 56 | 6.65 | 0.56 |
| 13 | 61 | 6.61 | 0.52 |
| 14 | 66 | 6.58 | 0.49 |
| 15 | 71 | 6.58 | 0.49 |
| 16 | 76 | 6.55 | 0.46 |
| 17 | 81 | 6.50 | 0.41 |
| 18 | 86 | 6.50 | 0.41 |
| 19 | 91 | 6.48 | 0.39 |
| 20 | 96 | 6.47 | 0.38 |
| 21 | 101 | 6.45 | 0.36 |
| 22 | 106 | 6.43 | 0.34 |
| 23 | 111 | 6.43 | 0.34 |
| 24 | 116 | 6.43 | 0.34 |
| 25 | 121 | 6.40 | 0.31 |
| 26 | 126 | 6.40 | 0.31 |
| 27 | 131 | 6.40 | 0.31 |
| 28 | 136 | 6.38 | 0.29 |
| 29 | 141 | 6.37 | 0.28 |
| 30 | 146 | 6.37 | 0.28 |
| 31 | 151 | 6.37 | 0.28 |
| 32 | 156 | 6.37 | 0.28 |
| 33 | 161 | 6.37 | 0.28 |
| 34 | 166 | 6.34 | 0.25 |
| 35 | 171 | 6.35 | 0.26 |
| 36 | 176 | 6.34 | 0.25 |
| 37 | 181 | 6.34 | 0.25 |
| 38 | 186 | 6.34 | 0.25 |
| 39 | 191 | 6.32 | 0.23 |
| 40 | 196 | 6.34 | 0.25 |
| 41 | 201 | 6.34 | 0.25 |
| 42 | 206 | 6.32 | 0.23 |
| 43 | 211 | 6.32 | 0.23 |
| 44 | 216 | 6.30 | 0.21 |
| 45 | 221 | 6.30 | 0.21 |
| 46 | 226 | 6.30 | 0.21 |
| 47 | 231 | 6.30 | 0.21 |
| 48 | 236 | 6.30 | 0.21 |
| 49 | 241 | 6.30 | 0.21 |
| 50 | 246 | 6.30 | 0.21 |

Slug Test No. 2

Test conducted on: 5\26\99

MWS-4 Rising Head

MWS-4 Rising Head

Static water level: 6.09 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 251 | 6.30 | 0.21 | |
| 52 | 256 | 6.30 | 0.21 | |
| 53 | 261 | 6.30 | 0.21 | |

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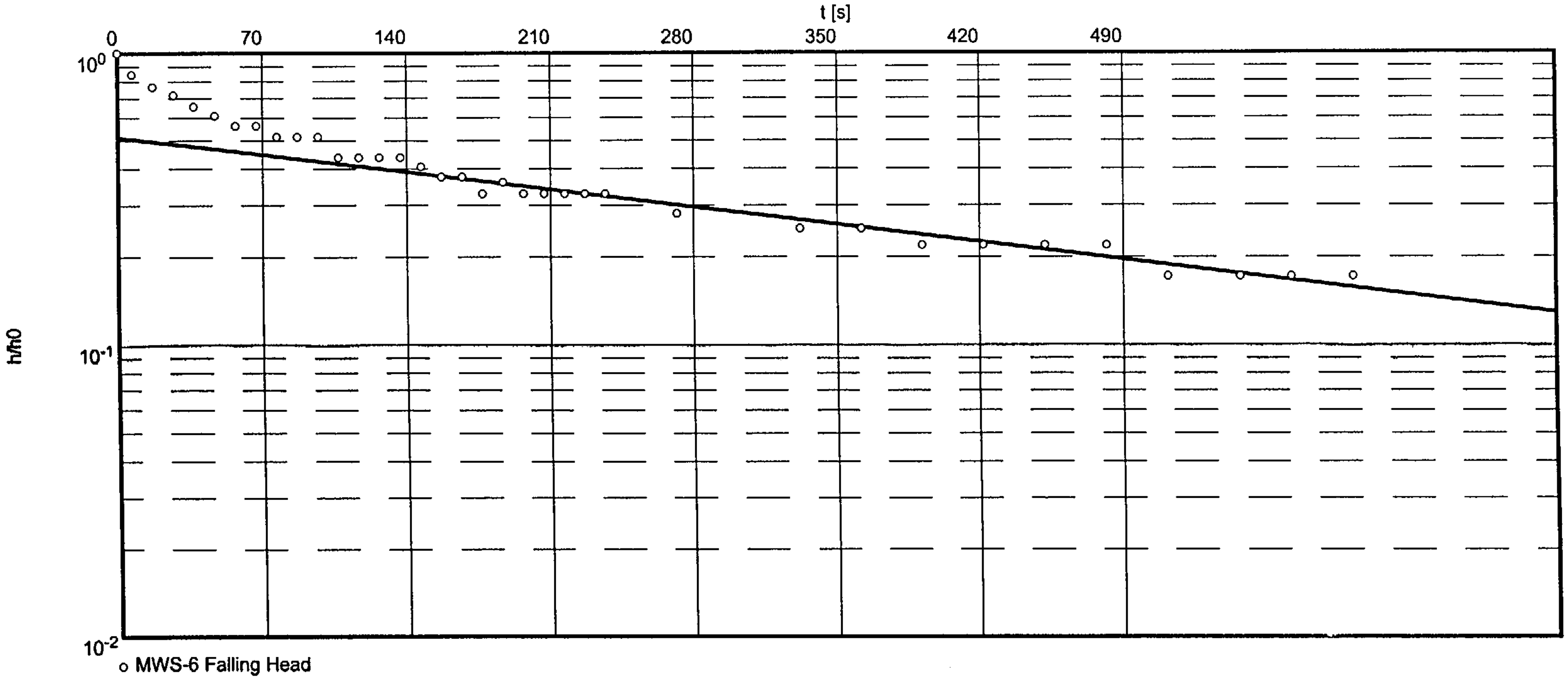
Project: Kaiser Remediation Project

Evaluated by: pls | Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5/26/99

MWS-6 Falling Head



Hydraulic conductivity [ft/s]: $1.55 \times 10^{-5}$

Hydraulic Conductivity (cm\sec): 4.72 x 10-4

Used r(eff)
Static Water Depth Below TOC: 9.71 ft
Total Well Depth Below TOC: 18.89 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 6.75 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5/26/99

MWS-6 Falling Head

MWS-6 Falling Head

Static water level: 9.71 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 9.07 | -0.64 | |
| 2 | 7 | 9.17 | -0.54 | |
| 3 | 17 | 9.22 | -0.49 | |
| 4 | 27 | 9.25 | -0.46 | |
| 5 | 37 | 9.29 | -0.42 | |
| 6 | 47 | 9.32 | -0.39 | |
| 7 | 57 | 9.35 | -0.36 | |
| 8 | 67 | 9.35 | -0.36 | |
| 9 | 77 | 9.38 | -0.33 | |
| 10 | 87 | 9.38 | -0.33 | |
| 11 | 97 | 9.38 | -0.33 | |
| 12 | 107 | 9.43 | -0.28 | |
| 13 | 117 | 9.43 | -0.28 | |
| 14 | 127 | 9.43 | -0.28 | |
| 15 | 137 | 9.43 | -0.28 | |
| 16 | 147 | 9.45 | -0.26 | |
| 17 | 157 | 9.47 | -0.24 | |
| 18 | 167 | 9.47 | -0.24 | |
| 19 | 177 | 9.50 | -0.21 | |
| 20 | 187 | 9.48 | -0.23 | |
| 21 | 197 | 9.50 | -0.21 | |
| 22 | 207 | 9.50 | -0.21 | |
| 23 | 217 | 9.50 | -0.21 | |
| 24 | 227 | 9.50 | -0.21 | |
| 25 | 237 | 9.50 | -0.21 | |
| 26 | 272 | 9.53 | -0.18 | |
| 27 | 332 | 9.55 | -0.16 | |
| 28 | 362 | 9.55 | -0.16 | |
| 29 | 392 | 9.57 | -0.14 | |
| 30 | 422 | 9.57 | -0.14 | |
| 31 | 452 | 9.57 | -0.14 | |
| 32 | 482 | 9.57 | -0.14 | |
| 33 | 512 | 9.60 | -0.11 | |
| 34 | 547 | 9.60 | -0.11 | |
| 35 | 572 | 9.60 | -0.11 | |
| 36 | 602 | 9.60 | -0.11 | |

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Project: Kaiser Remediation Project

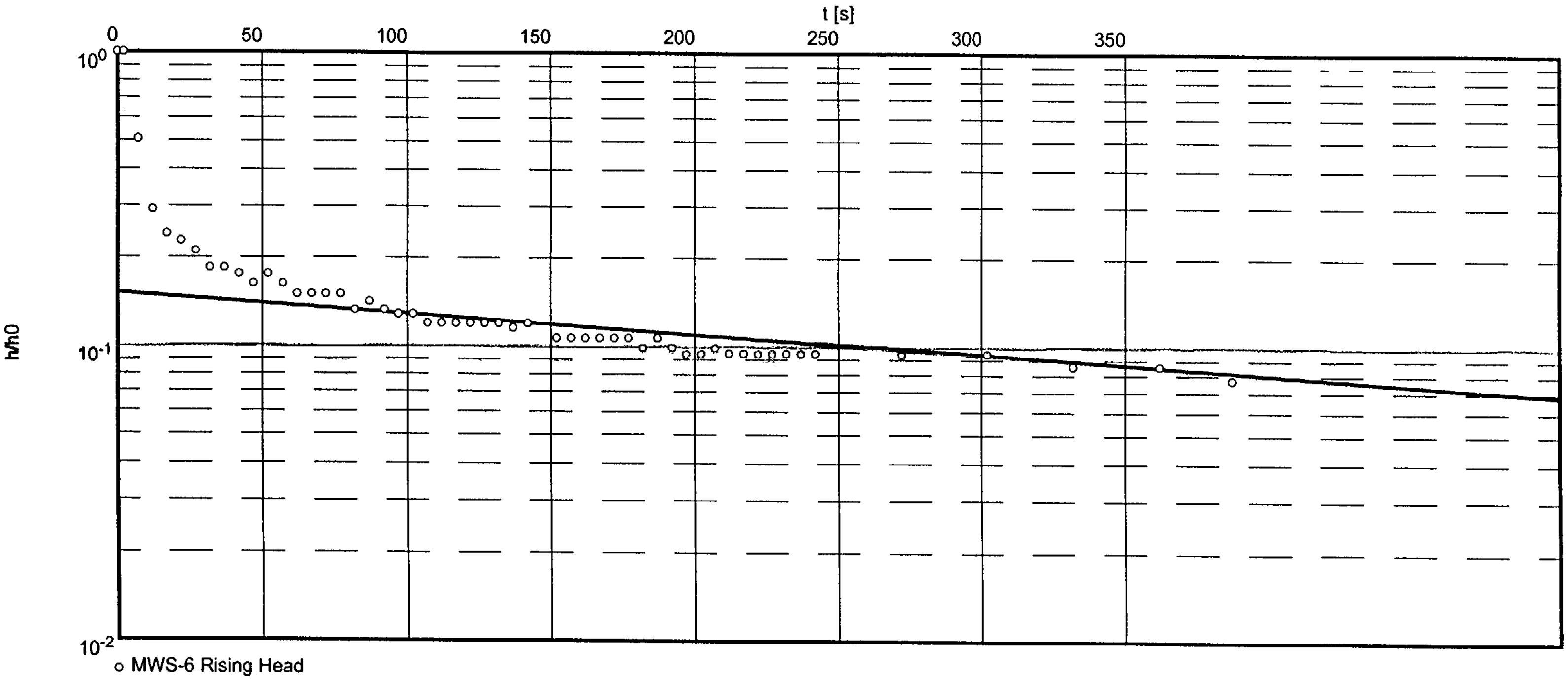
Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWS-6 Rising Head



Hydraulic conductivity [ft/s]: $1.26 \times 10^{-5}$

Hydraulic Conductivity (cm\sec): 3.84 x 10-4

Used r(eff)
Static Water Depth Below TOC: 9.71 ft
Total Well Depth Below TOC: 18.89 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 6.75 ft
Porosity (filter pack) = 45 %

Project: Kaiser Remediation Project

Evaluated by: pls | Date: 09.06.1999

Slug Test No. 2 | Test conducted on: 5\26\99

MWS-6 Rising Head | MWS-6 Rising Head

Static water level: 9.71 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 12.04 | 2.33 | |
| 2 | 2 | 12.04 | 2.33 | |
| 3 | 7 | 10.89 | 1.18 | |
| 4 | 12 | 10.39 | 0.68 | |
| 5 | 17 | 10.27 | 0.56 | |
| 6 | 22 | 10.24 | 0.53 | |
| 7 | 27 | 10.20 | 0.49 | |
| 8 | 32 | 10.14 | 0.43 | |
| 9 | 37 | 10.14 | 0.43 | |
| 10 | 42 | 10.12 | 0.41 | |
| 11 | 47 | 10.09 | 0.38 | |
| 12 | 52 | 10.12 | 0.41 | |
| 13 | 57 | 10.09 | 0.38 | |
| 14 | 62 | 10.06 | 0.35 | |
| 15 | 67 | 10.06 | 0.35 | |
| 16 | 72 | 10.06 | 0.35 | |
| 17 | 77 | 10.06 | 0.35 | |
| 18 | 82 | 10.02 | 0.31 | |
| 19 | 87 | 10.04 | 0.33 | |
| 20 | 92 | 10.02 | 0.31 | |
| 21 | 97 | 10.01 | 0.30 | |
| 22 | 102 | 10.01 | 0.30 | |
| 23 | 107 | 9.99 | 0.28 | |
| 24 | 112 | 9.99 | 0.28 | |
| 25 | 117 | 9.99 | 0.28 | |
| 26 | 122 | 9.99 | 0.28 | |
| 27 | 127 | 9.99 | 0.28 | |
| 28 | 132 | 9.99 | 0.28 | |
| 29 | 137 | 9.98 | 0.27 | |
| 30 | 142 | 9.99 | 0.28 | |
| 31 | 152 | 9.96 | 0.25 | |
| 32 | 157 | 9.96 | 0.25 | |
| 33 | 162 | 9.96 | 0.25 | |
| 34 | 167 | 9.96 | 0.25 | |
| 35 | 172 | 9.96 | 0.25 | |
| 36 | 177 | 9.96 | 0.25 | |
| 37 | 182 | 9.94 | 0.23 | |
| 38 | 187 | 9.96 | 0.25 | |
| 39 | 192 | 9.94 | 0.23 | |
| 40 | 197 | 9.93 | 0.22 | |
| 41 | 202 | 9.93 | 0.22 | |
| 42 | 207 | 9.94 | 0.23 | |
| 43 | 212 | 9.93 | 0.22 | |
| 44 | 217 | 9.93 | 0.22 | |
| 45 | 222 | 9.93 | 0.22 | |
| 46 | 227 | 9.93 | 0.22 | |
| 47 | 232 | 9.93 | 0.22 | |
| 48 | 237 | 9.93 | 0.22 | |
| 49 | 242 | 9.93 | 0.22 | |
| 50 | 272 | 9.93 | 0.22 | |

| | | | |
|---|---|---|---|
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| | |
|---|---|
| Slug Test No. 2 | Test conducted on: 5\26\99 |
| MWS-6 Rising Head | MWS-6 Rising Head |

Static water level: 9.71 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 302 | 9.93 | 0.22 | |
| 52 | 332 | 9.91 | 0.20 | |
| 53 | 362 | 9.91 | 0.20 | |
| 54 | 387 | 9.89 | 0.18 | |

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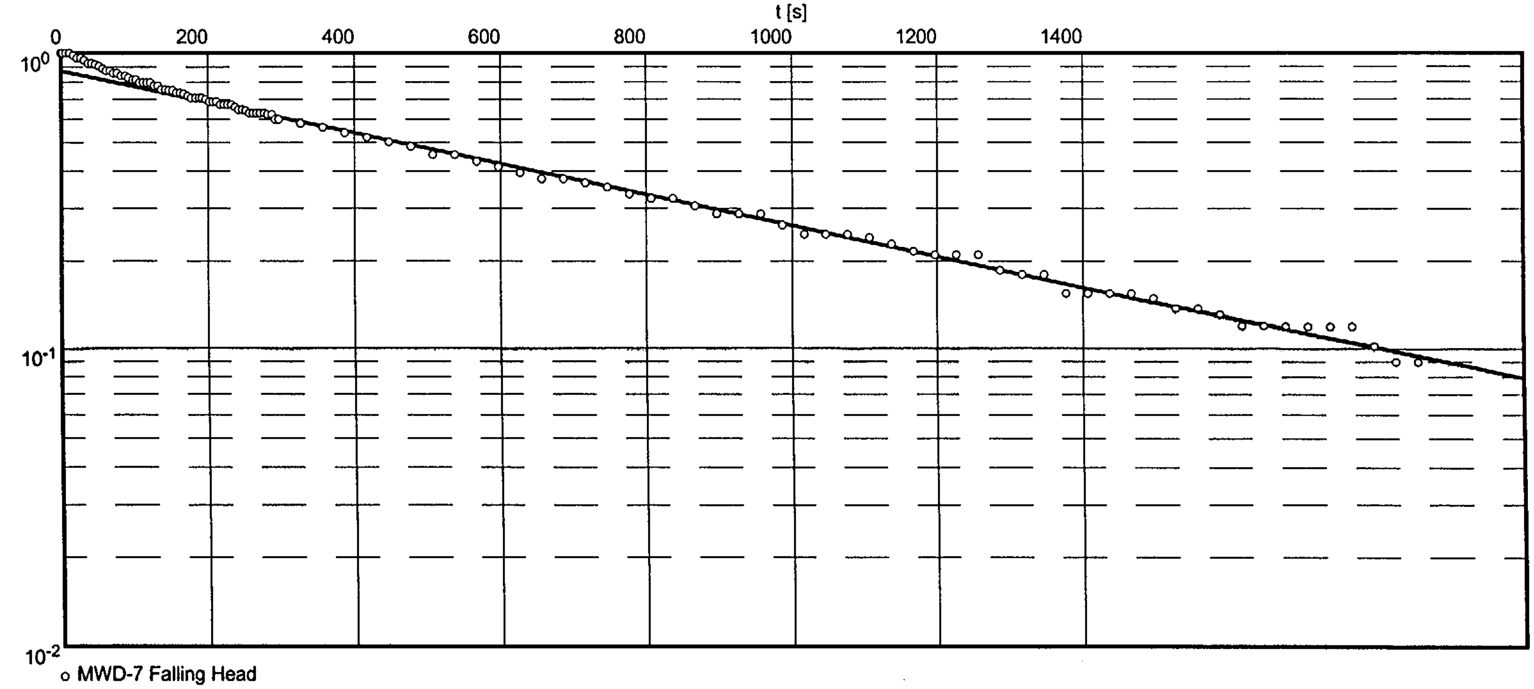
Project: Kaiser Remediation Project
Evaluated by: pls
Date: 09.06.1999

Slug Test No. 1
Test conducted on: 5/26/99
MWD-7 Falling Head



Hydraulic conductivity [ft/s]: $1.42 \times 10^{-6}$

Hydraulic Conductivity (cm\sec): 4.63 x 10-5

Static Water Depth Below TOC: 8.25 ft
Total Well Depth Below TOC: 24.05 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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HVORSLEV's method

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Project: Kaiser Remediation Project

Evaluated by: pls | Date: 09.06.1999

Slug Test No. 1 | Test conducted on: 5/26/99

MWD-7 Falling Head | MWD-7 Falling Head

Static water level: 8.25 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 6.58 | -1.67 | |
| 2 | 2 | 6.58 | -1.67 | |
| 3 | 7 | 6.58 | -1.67 | |
| 4 | 12 | 6.58 | -1.67 | |
| 5 | 17 | 6.61 | -1.64 | |
| 6 | 22 | 6.64 | -1.61 | |
| 7 | 27 | 6.64 | -1.61 | |
| 8 | 32 | 6.67 | -1.58 | |
| 9 | 37 | 6.71 | -1.54 | |
| 10 | 42 | 6.71 | -1.54 | |
| 11 | 47 | 6.72 | -1.53 | |
| 12 | 52 | 6.74 | -1.51 | |
| 13 | 57 | 6.77 | -1.48 | |
| 14 | 62 | 6.79 | -1.46 | |
| 15 | 67 | 6.79 | -1.46 | |
| 16 | 72 | 6.82 | -1.43 | |
| 17 | 77 | 6.82 | -1.43 | |
| 18 | 82 | 6.85 | -1.40 | |
| 19 | 88 | 6.85 | -1.40 | |
| 20 | 92 | 6.87 | -1.38 | |
| 21 | 98 | 6.89 | -1.36 | |
| 22 | 102 | 6.89 | -1.36 | |
| 23 | 107 | 6.92 | -1.33 | |
| 24 | 112 | 6.92 | -1.33 | |
| 25 | 117 | 6.92 | -1.33 | |
| 26 | 122 | 6.92 | -1.33 | |
| 27 | 127 | 6.95 | -1.30 | |
| 28 | 132 | 6.95 | -1.30 | |
| 29 | 137 | 6.99 | -1.26 | |
| 30 | 142 | 6.99 | -1.26 | |
| 31 | 147 | 7.00 | -1.25 | |
| 32 | 152 | 7.00 | -1.25 | |
| 33 | 157 | 7.02 | -1.23 | |
| 34 | 162 | 7.02 | -1.23 | |
| 35 | 167 | 7.03 | -1.22 | |
| 36 | 172 | 7.05 | -1.20 | |
| 37 | 177 | 7.07 | -1.18 | |
| 38 | 183 | 7.07 | -1.18 | |
| 39 | 188 | 7.07 | -1.18 | |
| 40 | 192 | 7.07 | -1.18 | |
| 41 | 197 | 7.08 | -1.17 | |
| 42 | 202 | 7.10 | -1.15 | |
| 43 | 207 | 7.10 | -1.15 | |
| 44 | 212 | 7.10 | -1.15 | |
| 45 | 217 | 7.13 | -1.12 | |
| 46 | 222 | 7.13 | -1.12 | |
| 47 | 227 | 7.13 | -1.12 | |
| 48 | 232 | 7.13 | -1.12 | |
| 49 | 237 | 7.15 | -1.10 | |
| 50 | 242 | 7.17 | -1.08 | |

slug/bail test analysis
HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5/26/99

MWD-7 Falling Head

MWD-7 Falling Head

Static water level: 8.25 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 247 | 7.17 | -1.08 | |
| 52 | 252 | 7.18 | -1.07 | |
| 53 | 257 | 7.20 | -1.05 | |
| 54 | 262 | 7.20 | -1.05 | |
| 55 | 267 | 7.20 | -1.05 | |
| 56 | 272 | 7.20 | -1.05 | |
| 57 | 277 | 7.20 | -1.05 | |
| 58 | 282 | 7.21 | -1.04 | |
| 59 | 288 | 7.21 | -1.04 | |
| 60 | 292 | 7.25 | -1.00 | |
| 61 | 297 | 7.25 | -1.00 | |
| 62 | 327 | 7.28 | -0.97 | |
| 63 | 357 | 7.31 | -0.94 | |
| 64 | 387 | 7.35 | -0.90 | |
| 65 | 417 | 7.38 | -0.87 | |
| 66 | 447 | 7.41 | -0.84 | |
| 67 | 477 | 7.44 | -0.81 | |
| 68 | 507 | 7.49 | -0.76 | |
| 69 | 537 | 7.49 | -0.76 | |
| 70 | 567 | 7.53 | -0.72 | |
| 71 | 597 | 7.56 | -0.69 | |
| 72 | 627 | 7.59 | -0.66 | |
| 73 | 657 | 7.62 | -0.63 | |
| 74 | 687 | 7.62 | -0.63 | |
| 75 | 717 | 7.64 | -0.61 | |
| 76 | 747 | 7.66 | -0.59 | |
| 77 | 777 | 7.69 | -0.56 | |
| 78 | 807 | 7.71 | -0.54 | |
| 79 | 837 | 7.71 | -0.54 | |
| 80 | 867 | 7.74 | -0.51 | |
| 81 | 897 | 7.77 | -0.48 | |
| 82 | 927 | 7.77 | -0.48 | |
| 83 | 957 | 7.77 | -0.48 | |
| 84 | 987 | 7.81 | -0.44 | |
| 85 | 1017 | 7.84 | -0.41 | |
| 86 | 1047 | 7.84 | -0.41 | |
| 87 | 1077 | 7.84 | -0.41 | |
| 88 | 1107 | 7.85 | -0.40 | |
| 89 | 1137 | 7.87 | -0.38 | |
| 90 | 1167 | 7.89 | -0.36 | |
| 91 | 1197 | 7.90 | -0.35 | |
| 92 | 1227 | 7.90 | -0.35 | |
| 93 | 1257 | 7.90 | -0.35 | |
| 94 | 1287 | 7.94 | -0.31 | |
| 95 | 1317 | 7.95 | -0.30 | |
| 96 | 1347 | 7.95 | -0.30 | |
| 97 | 1377 | 7.99 | -0.26 | |
| 98 | 1407 | 7.99 | -0.26 | |
| 99 | 1437 | 7.99 | -0.26 | |
| 100 | 1467 | 7.99 | -0.26 | |

slug/bail test analysis
HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5/26/99

MWD-7 Falling Head

MWD-7 Falling Head

Static water level: 8.25 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 101 | 1497 | 8.00 | -0.25 | |
| 102 | 1527 | 8.02 | -0.23 | |
| 103 | 1557 | 8.02 | -0.23 | |
| 104 | 1587 | 8.03 | -0.22 | |
| 105 | 1617 | 8.05 | -0.20 | |
| 106 | 1647 | 8.05 | -0.20 | |
| 107 | 1677 | 8.05 | -0.20 | |
| 108 | 1707 | 8.05 | -0.20 | |
| 109 | 1737 | 8.05 | -0.20 | |
| 110 | 1767 | 8.05 | -0.20 | |
| 111 | 1797 | 8.08 | -0.17 | |
| 112 | 1827 | 8.10 | -0.15 | |
| 113 | 1857 | 8.10 | -0.15 | |

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slug/bail test analysis
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Project: Kaiser Remediation Project

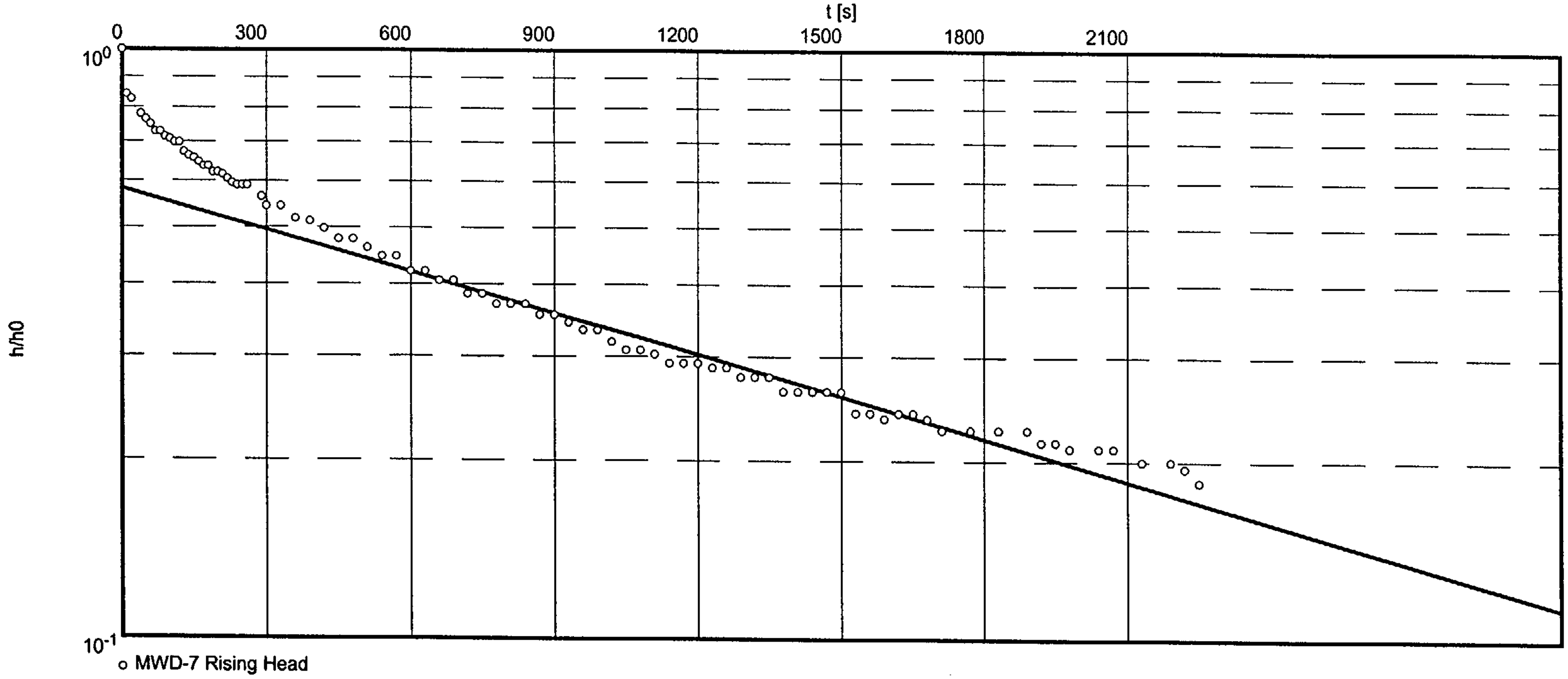
Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWD-7 Rising Head



Hydraulic conductivity [ft/s]: 6.47 x $10^{-7}$

Hydraulic Conductivity (cm\sec): 2.12 x 10-5

Static Water Depth Below TOC: 8.25 ft
Total Well Depth Below TOC: 24.05 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

Slug Test No. 2

Test conducted on: 5\26\99

MWD-7 Rising Head

MWD-7 Rising Head

Static water level: 8.25 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 10.20 | 1.95 |
| 2 | 10 | 9.89 | 1.64 |
| 3 | 20 | 9.86 | 1.61 |
| 4 | 40 | 9.77 | 1.52 |
| 5 | 50 | 9.74 | 1.49 |
| 6 | 60 | 9.71 | 1.46 |
| 7 | 70 | 9.67 | 1.42 |
| 8 | 80 | 9.67 | 1.42 |
| 9 | 90 | 9.64 | 1.39 |
| 10 | 100 | 9.63 | 1.38 |
| 11 | 110 | 9.61 | 1.36 |
| 12 | 120 | 9.61 | 1.36 |
| 13 | 130 | 9.56 | 1.31 |
| 14 | 140 | 9.54 | 1.29 |
| 15 | 150 | 9.53 | 1.28 |
| 16 | 160 | 9.51 | 1.26 |
| 17 | 170 | 9.49 | 1.24 |
| 18 | 180 | 9.49 | 1.24 |
| 19 | 190 | 9.46 | 1.21 |
| 20 | 200 | 9.46 | 1.21 |
| 21 | 210 | 9.45 | 1.20 |
| 22 | 220 | 9.43 | 1.18 |
| 23 | 230 | 9.41 | 1.16 |
| 24 | 240 | 9.40 | 1.15 |
| 25 | 250 | 9.40 | 1.15 |
| 26 | 260 | 9.40 | 1.15 |
| 27 | 270 | 3.36 | -4.89 |
| 28 | 280 | 3.36 | -4.89 |
| 29 | 290 | 9.35 | 1.10 |
| 30 | 300 | 9.31 | 1.06 |
| 31 | 330 | 9.31 | 1.06 |
| 32 | 360 | 9.26 | 1.01 |
| 33 | 390 | 9.25 | 1.00 |
| 34 | 420 | 9.22 | 0.97 |
| 35 | 450 | 9.18 | 0.93 |
| 36 | 480 | 9.18 | 0.93 |
| 37 | 510 | 9.15 | 0.90 |
| 38 | 540 | 9.12 | 0.87 |
| 39 | 570 | 9.12 | 0.87 |
| 40 | 600 | 9.07 | 0.82 |
| 41 | 630 | 9.07 | 0.82 |
| 42 | 660 | 9.04 | 0.79 |
| 43 | 690 | 9.04 | 0.79 |
| 44 | 720 | 9.00 | 0.75 |
| 45 | 750 | 9.00 | 0.75 |
| 46 | 780 | 8.97 | 0.72 |
| 47 | 810 | 8.97 | 0.72 |
| 48 | 840 | 8.97 | 0.72 |
| 49 | 870 | 8.94 | 0.69 |
| 50 | 900 | 8.94 | 0.69 |

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slug/bail test analysis
HVORSLEV's method

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Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWD-7 Rising Head

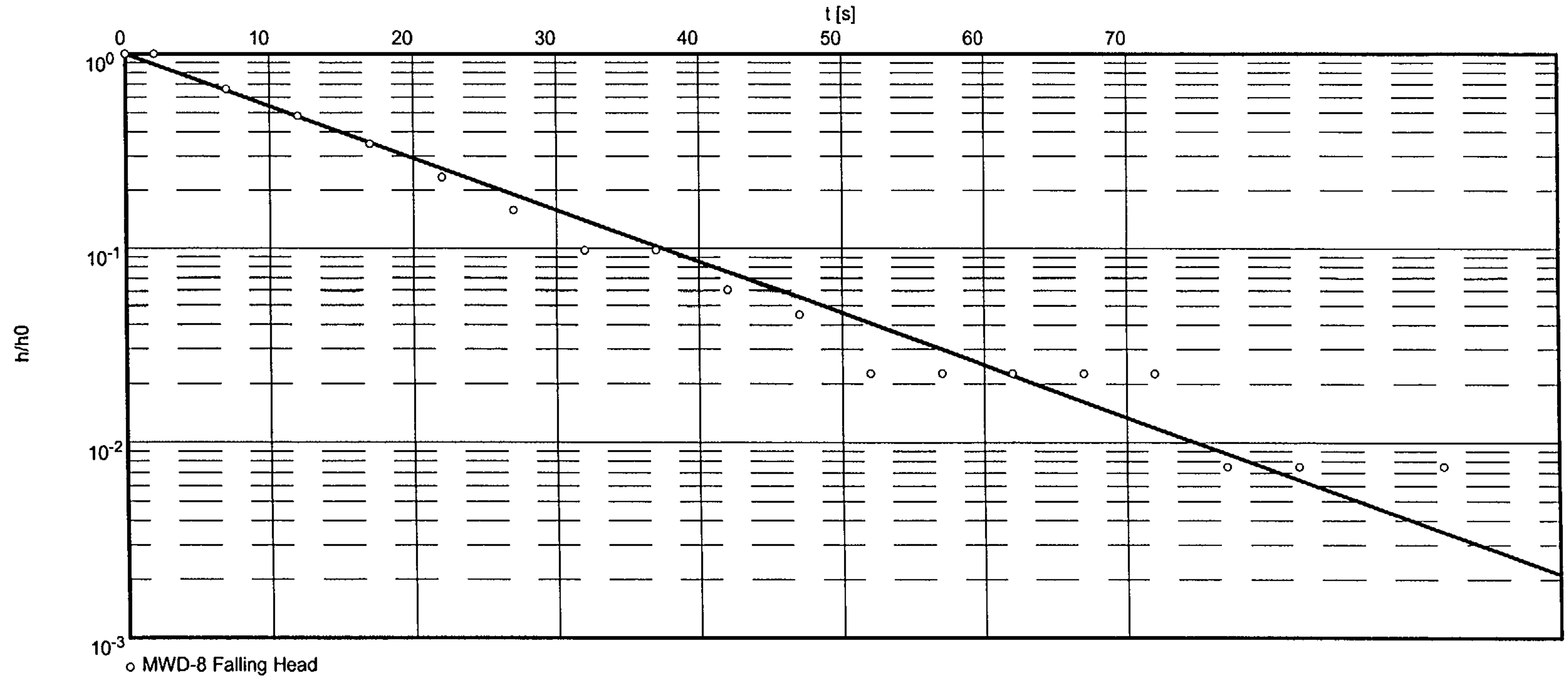
MWD-7 Rising Head

Static water level: 8.25 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 930 | 8.92 | 0.67 | |
| 52 | 960 | 8.90 | 0.65 | |
| 53 | 990 | 8.90 | 0.65 | |
| 54 | 1020 | 8.87 | 0.62 | |
| 55 | 1050 | 8.85 | 0.60 | |
| 56 | 1080 | 8.85 | 0.60 | |
| 57 | 1110 | 8.84 | 0.59 | |
| 58 | 1140 | 8.82 | 0.57 | |
| 59 | 1170 | 8.82 | 0.57 | |
| 60 | 1200 | 8.82 | 0.57 | |
| 61 | 1230 | 8.81 | 0.56 | |
| 62 | 1260 | 8.81 | 0.56 | |
| 63 | 1290 | 8.79 | 0.54 | |
| 64 | 1320 | 8.79 | 0.54 | |
| 65 | 1350 | 8.79 | 0.54 | |
| 66 | 1380 | 8.76 | 0.51 | |
| 67 | 1410 | 8.76 | 0.51 | |
| 68 | 1440 | 8.76 | 0.51 | |
| 69 | 1470 | 8.76 | 0.51 | |
| 70 | 1500 | 8.76 | 0.51 | |
| 71 | 1530 | 8.72 | 0.47 | |
| 72 | 1560 | 8.72 | 0.47 | |
| 73 | 1590 | 8.71 | 0.46 | |
| 74 | 1620 | 8.72 | 0.47 | |
| 75 | 1650 | 8.72 | 0.47 | |
| 76 | 1680 | 8.71 | 0.46 | |
| 77 | 1710 | 8.69 | 0.44 | |
| 78 | 1770 | 8.69 | 0.44 | |
| 79 | 1830 | 8.69 | 0.44 | |
| 80 | 1890 | 8.69 | 0.44 | |
| 81 | 1920 | 8.67 | 0.42 | |
| 82 | 1950 | 8.67 | 0.42 | |
| 83 | 1980 | 8.66 | 0.41 | |
| 84 | 2040 | 8.66 | 0.41 | |
| 85 | 2070 | 8.66 | 0.41 | |
| 86 | 2130 | 8.64 | 0.39 | |
| 87 | 2190 | 8.64 | 0.39 | |
| 88 | 2220 | 8.63 | 0.38 | |
| 89 | 2250 | 8.61 | 0.36 | |

| | | |
|---|---|---|
| **Engineering**<br>E. 16th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 1<br>Project: Kaiser Remediation Project<br>Evaluated by: pls — Date: 09.06.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 5\26\99 |
| MWD-8 Falling Head | |



Hydraulic conductivity [ft/s]: 7.86 x $10^{-5}$

Hydraulic Conductivity (cm\sec): 2.40 x 10-3

Static Water Depth Below TOC: 5.28 ft
Total Well Depth Below TOC: 22.22 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
HVORSLEV's methoc

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5\26\99

MWD-8 Falling Head

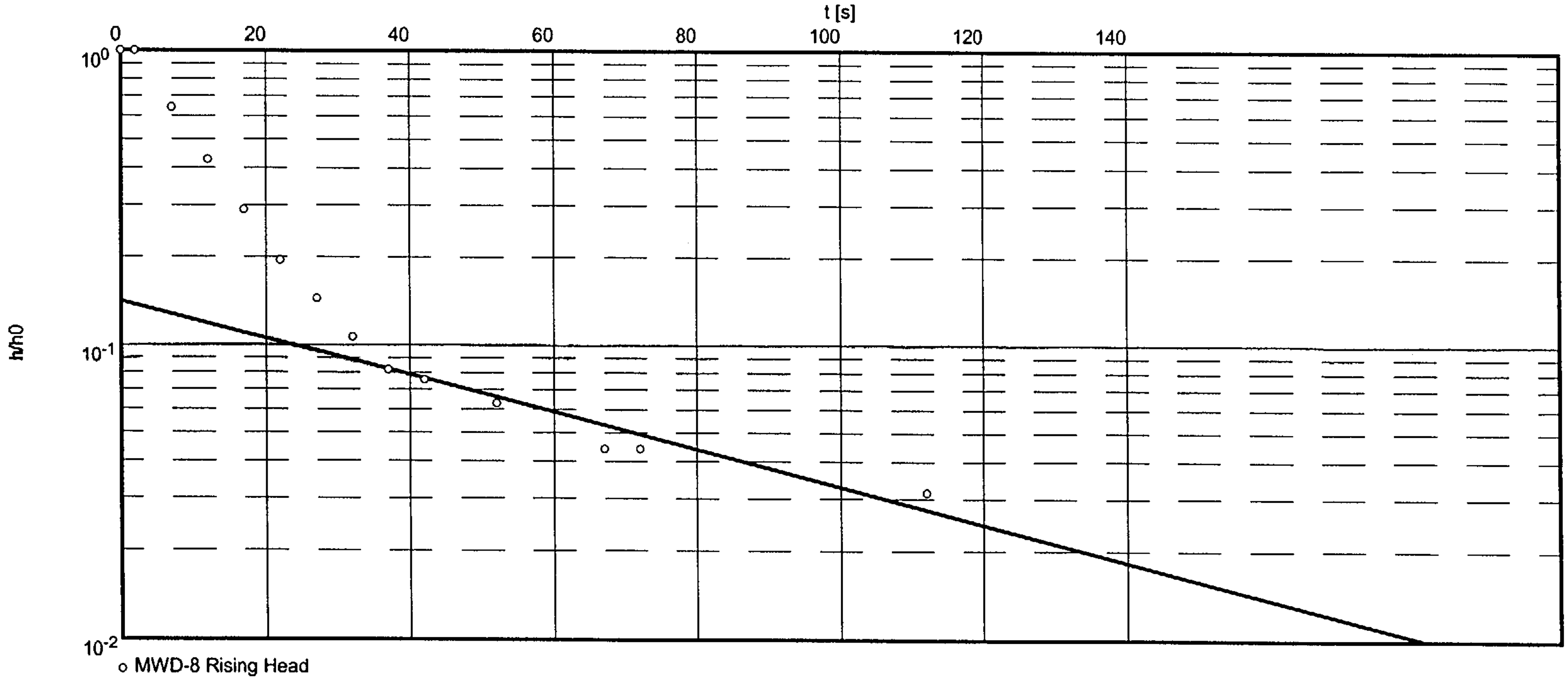
MWD-8 Falling Head

Static water level: 5.28 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 3.95 | -1.33 |
| 2 | 2 | 3.95 | -1.33 |
| 3 | 7 | 4.40 | -0.88 |
| 4 | 12 | 4.64 | -0.64 |
| 5 | 17 | 4.82 | -0.46 |
| 6 | 22 | 4.97 | -0.31 |
| 7 | 27 | 5.07 | -0.21 |
| 8 | 32 | 5.15 | -0.13 |
| 9 | 37 | 5.15 | -0.13 |
| 10 | 42 | 5.20 | -0.08 |
| 11 | 47 | 5.22 | -0.06 |
| 12 | 52 | 5.25 | -0.03 |
| 13 | 57 | 5.25 | -0.03 |
| 14 | 62 | 5.25 | -0.03 |
| 15 | 67 | 5.25 | -0.03 |
| 16 | 72 | 5.25 | -0.03 |
| 17 | 77 | 5.27 | -0.01 |
| 18 | 82 | 5.27 | -0.01 |
| 19 | 87 | 5.28 | 0.00 |
| 20 | 92 | 5.27 | -0.01 |
| 21 | 97 | 5.28 | 0.00 |

| | | |
|---|---|---|
| **A&M Engineering**<br>0 E. 16th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 1<br>Project: Kaiser Remediation Project<br>Evaluated by: pls — Date: 09.06.1999 |

| | |
|---|---|
| Slug Test No. 2 | Test conducted on: 5\26\99 |
| MWD-8 Rising Head | |



Hydraulic conductivity [ft/s]: 1.86 x $10^{-5}$

Hydraulic Conductivity (cm\sec): 5.67 x 10-4

Static Water Depth Below TOC: 5.28 ft
Total Well Depth Below TOC: 22.22 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

slug/bail test analysis
HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5\26\99

MWD-8 Rising Head

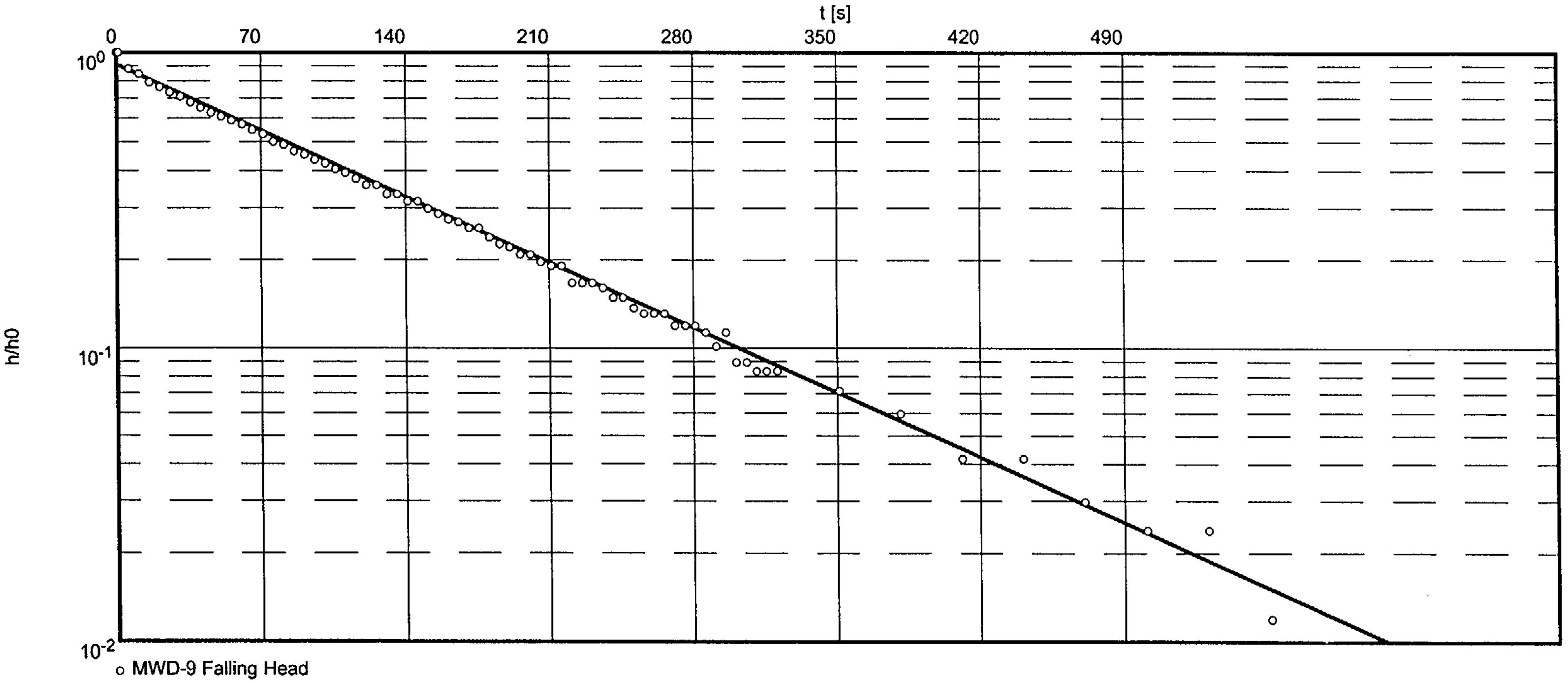
MWD-8 Rising Head

Static water level: 5.28 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 6.87 | 1.59 |
| 2 | 2 | 6.87 | 1.59 |
| 3 | 7 | 6.30 | 1.02 |
| 4 | 12 | 5.96 | 0.68 |
| 5 | 17 | 5.74 | 0.46 |
| 6 | 22 | 5.59 | 0.31 |
| 7 | 27 | 5.51 | 0.23 |
| 8 | 32 | 5.45 | 0.17 |
| 9 | 37 | 5.41 | 0.13 |
| 10 | 42 | 5.40 | 0.12 |
| 11 | 52 | 5.38 | 0.10 |
| 12 | 67 | 5.35 | 0.07 |
| 13 | 72 | 5.35 | 0.07 |
| 14 | 112 | 5.33 | 0.05 |

| | | | |
|---|---|---|---|
| **A M Engineering**<br>E. 16th Street<br>Tulsa, OK<br>ph.(918) 665-6575 | slug/bail test analysis<br>HVORSLEV's method | Page 1<br>Project: Kaiser Remediation Project | |
| | | Evaluated by: PLS | Date: 09.06.1999 |

| | |
|---|---|
| Slug Test No. 1 | Test conducted on: 5/27/99 |
| MWD-9 Falling Head | |
| | |



Hydraulic conductivity [ft/s]: $9.34 \times 10^{-6}$

Hydraulic Conductivity (cm/s): 2.85 x 10-4

Static Water Depth Below TOC: 10.55 ft
Total Well Depth Below TOC: 24.00 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
HVORSLEV's method

Page 2

Project: Kaiser Remediation Project

Evaluated by: PLS

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5/27/99

MWD-9 Falling Head

MWD-9 Falling Head

Static water level: 10.55 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 8.87 | -1.68 |
| 2 | 1 | 8.87 | -1.68 |
| 3 | 6 | 9.07 | -1.48 |
| 4 | 11 | 9.13 | -1.42 |
| 5 | 16 | 9.22 | -1.33 |
| 6 | 21 | 9.27 | -1.28 |
| 7 | 26 | 9.32 | -1.23 |
| 8 | 31 | 9.36 | -1.19 |
| 9 | 36 | 9.41 | -1.14 |
| 10 | 41 | 9.46 | -1.09 |
| 11 | 46 | 9.50 | -1.05 |
| 12 | 51 | 9.53 | -1.02 |
| 13 | 56 | 9.56 | -0.99 |
| 14 | 61 | 9.59 | -0.96 |
| 15 | 66 | 9.63 | -0.92 |
| 16 | 71 | 9.66 | -0.89 |
| 17 | 76 | 9.71 | -0.84 |
| 18 | 81 | 9.73 | -0.82 |
| 19 | 86 | 9.77 | -0.78 |
| 20 | 91 | 9.79 | -0.76 |
| 21 | 96 | 9.82 | -0.73 |
| 22 | 101 | 9.84 | -0.71 |
| 23 | 106 | 9.87 | -0.68 |
| 24 | 111 | 9.89 | -0.66 |
| 25 | 116 | 9.92 | -0.63 |
| 26 | 121 | 9.95 | -0.60 |
| 27 | 126 | 9.95 | -0.60 |
| 28 | 131 | 9.99 | -0.56 |
| 29 | 136 | 9.99 | -0.56 |
| 30 | 141 | 10.02 | -0.53 |
| 31 | 146 | 10.02 | -0.53 |
| 32 | 151 | 10.05 | -0.50 |
| 33 | 156 | 10.07 | -0.48 |
| 34 | 161 | 10.09 | -0.46 |
| 35 | 166 | 10.10 | -0.45 |
| 36 | 171 | 10.12 | -0.43 |
| 37 | 176 | 10.12 | -0.43 |
| 38 | 181 | 10.15 | -0.40 |
| 39 | 186 | 10.17 | -0.38 |
| 40 | 191 | 10.18 | -0.37 |
| 41 | 196 | 10.20 | -0.35 |
| 42 | 201 | 10.20 | -0.35 |
| 43 | 206 | 10.22 | -0.33 |
| 44 | 211 | 10.23 | -0.32 |
| 45 | 216 | 10.23 | -0.32 |
| 46 | 221 | 10.27 | -0.28 |
| 47 | 226 | 10.27 | -0.28 |
| 48 | 231 | 10.27 | -0.28 |
| 49 | 236 | 10.28 | -0.27 |
| 50 | 241 | 10.30 | -0.25 |

slug/bail test analysis
HVORSLEV's method

Project: Kaiser Remediation Project

Evaluated by: PLS

Date: 09.06.1999

Slug Test No. 1

Test conducted on: 5/27/99

MWD-9 Falling Head

MWD-9 Falling Head

Static water level: 10.55 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 51 | 246 | 10.30 | -0.25 |
| 52 | 251 | 10.32 | -0.23 |
| 53 | 256 | 10.33 | -0.22 |
| 54 | 261 | 10.33 | -0.22 |
| 55 | 266 | 10.33 | -0.22 |
| 56 | 271 | 10.35 | -0.20 |
| 57 | 276 | 10.35 | -0.20 |
| 58 | 281 | 10.35 | -0.20 |
| 59 | 286 | 10.36 | -0.19 |
| 60 | 291 | 10.38 | -0.17 |
| 61 | 296 | 10.36 | -0.19 |
| 62 | 301 | 10.40 | -0.15 |
| 63 | 306 | 10.40 | -0.15 |
| 64 | 311 | 10.41 | -0.14 |
| 65 | 316 | 10.41 | -0.14 |
| 66 | 321 | 10.41 | -0.14 |
| 67 | 351 | 10.43 | -0.12 |
| 68 | 381 | 10.45 | -0.10 |
| 69 | 411 | 10.48 | -0.07 |
| 70 | 441 | 10.48 | -0.07 |
| 71 | 471 | 10.50 | -0.05 |
| 72 | 501 | 10.51 | -0.04 |
| 73 | 531 | 10.51 | -0.04 |
| 74 | 561 | 10.53 | -0.02 |

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slug/bail test analysis
HVORSLEV's method

Page 1

Project: Kaiser Remediation Project

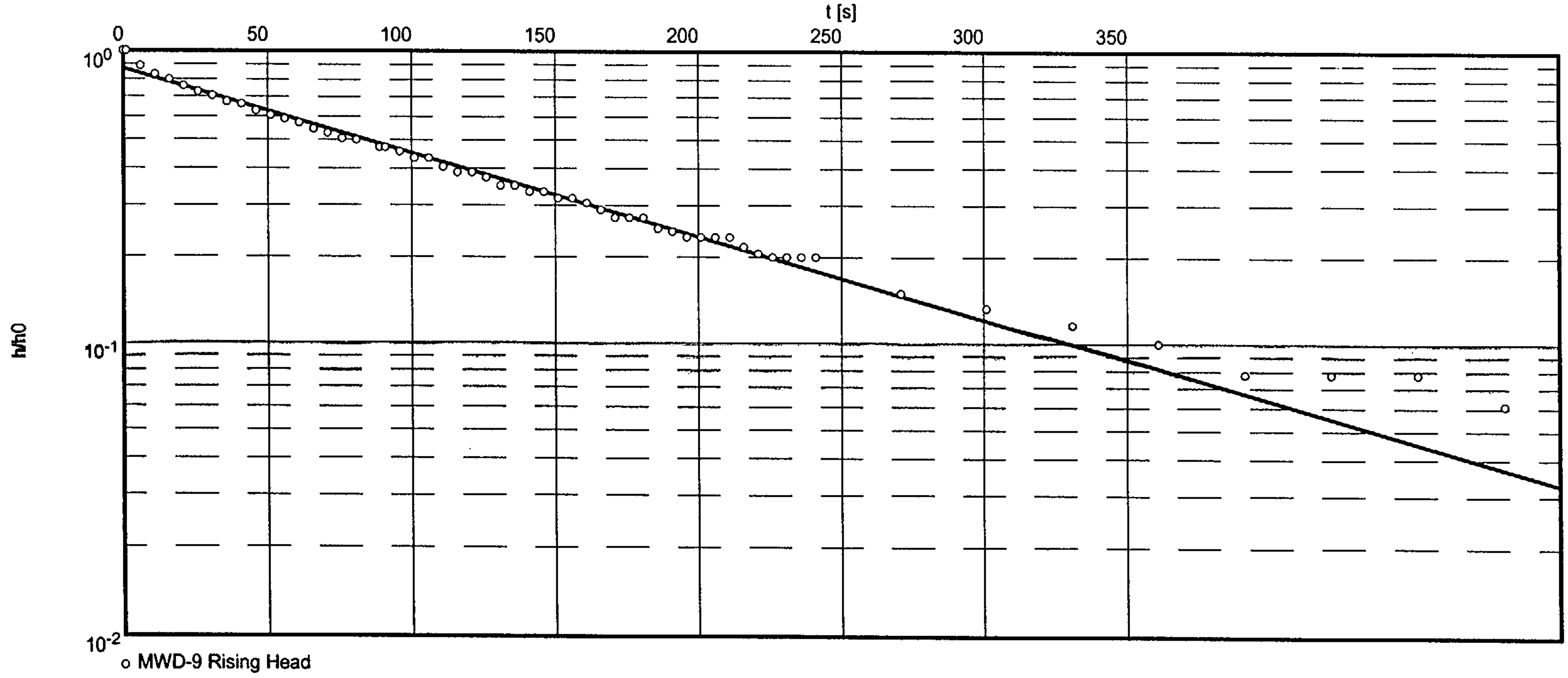
Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5/24/99

MWD-9 Rising Head



Hydraulic conductivity [ft/s]: $7.79 \times 10^{-6}$

Hydraulic Conductivity (cm\sec): 2.5 x 10-4

Static Water Depth Below TOC: 10.55 ft
Total Well Depth Below TOC: 24.00 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

| | | |
|---|---|---|
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| | |
|---|---|
| Slug Test No. 2 | Test conducted on: 5/24/99 |
| MWD-9 Rising Head | MWD-9 Rising Head |

Static water level: 10.55 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 12.35 | 1.80 |
| 2 | 1 | 12.35 | 1.80 |
| 3 | 6 | 12.15 | 1.60 |
| 4 | 11 | 12.05 | 1.50 |
| 5 | 16 | 11.99 | 1.44 |
| 6 | 21 | 11.92 | 1.37 |
| 7 | 26 | 11.86 | 1.31 |
| 8 | 31 | 11.82 | 1.27 |
| 9 | 36 | 11.76 | 1.21 |
| 10 | 41 | 11.74 | 1.19 |
| 11 | 46 | 11.68 | 1.13 |
| 12 | 51 | 11.64 | 1.09 |
| 13 | 56 | 11.61 | 1.06 |
| 14 | 61 | 11.58 | 1.03 |
| 15 | 66 | 11.53 | 0.98 |
| 16 | 71 | 11.50 | 0.95 |
| 17 | 76 | 11.46 | 0.91 |
| 18 | 81 | 11.45 | 0.90 |
| 19 | 89 | 11.40 | 0.85 |
| 20 | 91 | 11.40 | 0.85 |
| 21 | 96 | 11.37 | 0.82 |
| 22 | 101 | 11.33 | 0.78 |
| 23 | 106 | 11.33 | 0.78 |
| 24 | 111 | 11.28 | 0.73 |
| 25 | 116 | 11.25 | 0.70 |
| 26 | 121 | 11.25 | 0.70 |
| 27 | 126 | 11.22 | 0.67 |
| 28 | 131 | 11.18 | 0.63 |
| 29 | 136 | 11.18 | 0.63 |
| 30 | 141 | 11.15 | 0.60 |
| 31 | 146 | 11.15 | 0.60 |
| 32 | 151 | 11.12 | 0.57 |
| 33 | 156 | 11.12 | 0.57 |
| 34 | 161 | 11.10 | 0.55 |
| 35 | 166 | 11.07 | 0.52 |
| 36 | 171 | 11.04 | 0.49 |
| 37 | 176 | 11.04 | 0.49 |
| 38 | 181 | 11.04 | 0.49 |
| 39 | 186 | 11.00 | 0.45 |
| 40 | 191 | 10.99 | 0.44 |
| 41 | 196 | 10.97 | 0.42 |
| 42 | 201 | 10.97 | 0.42 |
| 43 | 206 | 10.97 | 0.42 |
| 44 | 211 | 10.97 | 0.42 |
| 45 | 216 | 10.94 | 0.39 |
| 46 | 221 | 10.92 | 0.37 |
| 47 | 226 | 10.91 | 0.36 |
| 48 | 231 | 10.91 | 0.36 |
| 49 | 236 | 10.91 | 0.36 |
| 50 | 241 | 10.91 | 0.36 |

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slug/bail test analysis
HVORSLEV's method

Page 3

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 09.06.1999

Slug Test No. 2

Test conducted on: 5/24/99

MWD-9 Rising Head

MWD-9 Rising Head

Static water level: 10.55 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 51 | 271 | 10.82 | 0.27 | |
| 52 | 301 | 10.79 | 0.24 | |
| 53 | 331 | 10.76 | 0.21 | |
| 54 | 361 | 10.73 | 0.18 | |
| 55 | 391 | 10.69 | 0.14 | |
| 56 | 421 | 10.69 | 0.14 | |
| 57 | 451 | 10.69 | 0.14 | |
| 58 | 481 | 10.66 | 0.11 | |

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HVORSLEV's method

Page 1

Project: Kaiser Remediation Project

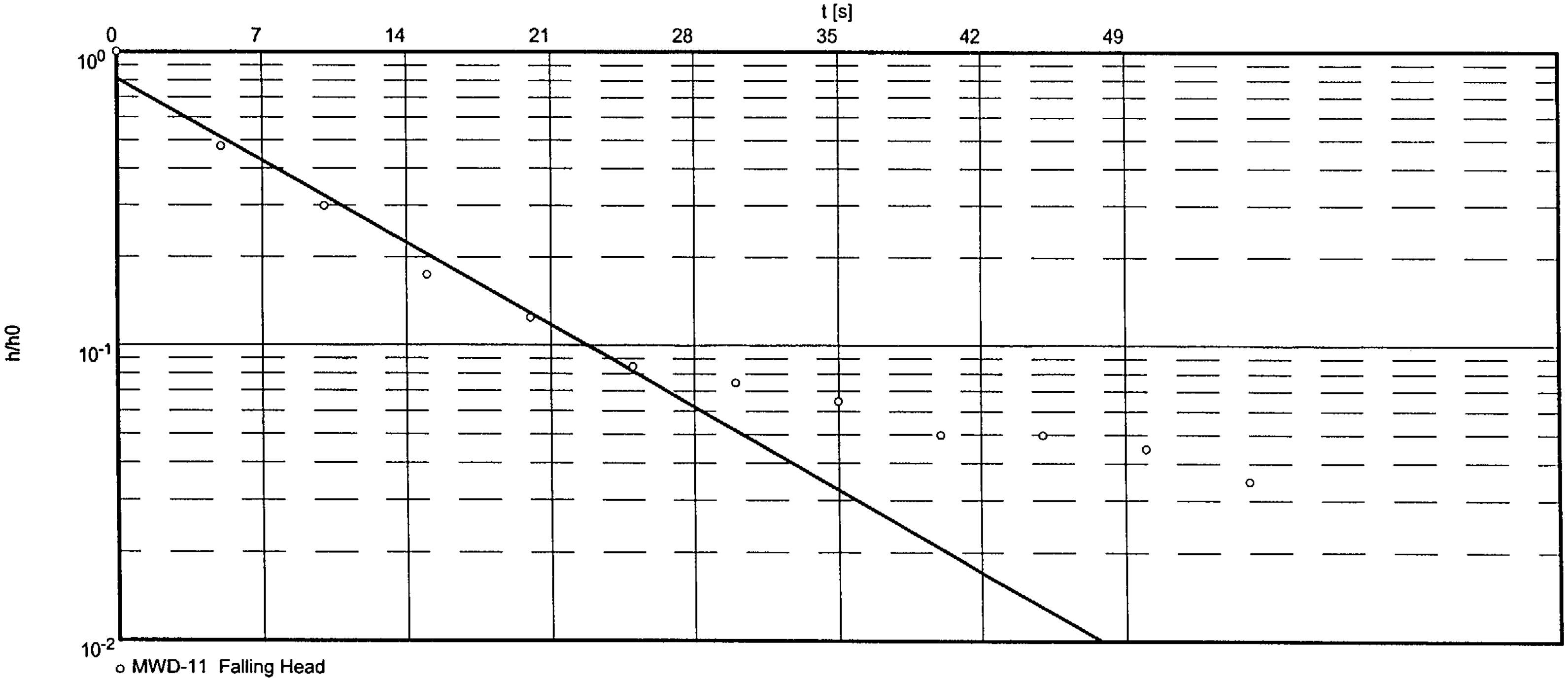
Evaluated by: pls

Date: 14.07.1999

Slug Test No. 1

Test conducted on: 5/26/99

MWD-11 Falling Head



Hydraulic conductivity [ft/s]: 1.09 x $10^{-4}$

Hydraulic Conductivity (cm\sec): 3.32 x 10-3

Static Water Depth Below TOC: 12.5 ft
Total Well Depth Below TOC: 28.75 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

slug/bail test analysis
HVORSLEV's methoc

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 14.07.1999

Slug Test No. 1

Test conducted on: 5/26/99

MWD-11 Falling Head

MWD-11 Falling Head

Static water level: 12.50 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] | |
|---|---|---|---|---|
| 1 | 0 | 10.49 | -2.01 | |
| 2 | 5 | 11.54 | -0.96 | |
| 3 | 10 | 11.90 | -0.60 | |
| 4 | 15 | 12.15 | -0.35 | |
| 5 | 20 | 12.25 | -0.25 | |
| 6 | 25 | 12.33 | -0.17 | |
| 7 | 30 | 12.35 | -0.15 | |
| 8 | 35 | 12.37 | -0.13 | |
| 9 | 40 | 12.40 | -0.10 | |
| 10 | 45 | 12.40 | -0.10 | |
| 11 | 50 | 12.41 | -0.09 | |
| 12 | 55 | 12.43 | -0.07 | |

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slug/bail test analysis
HVORSLEV's method

Page 1

Project: Kaiser Remediation Project

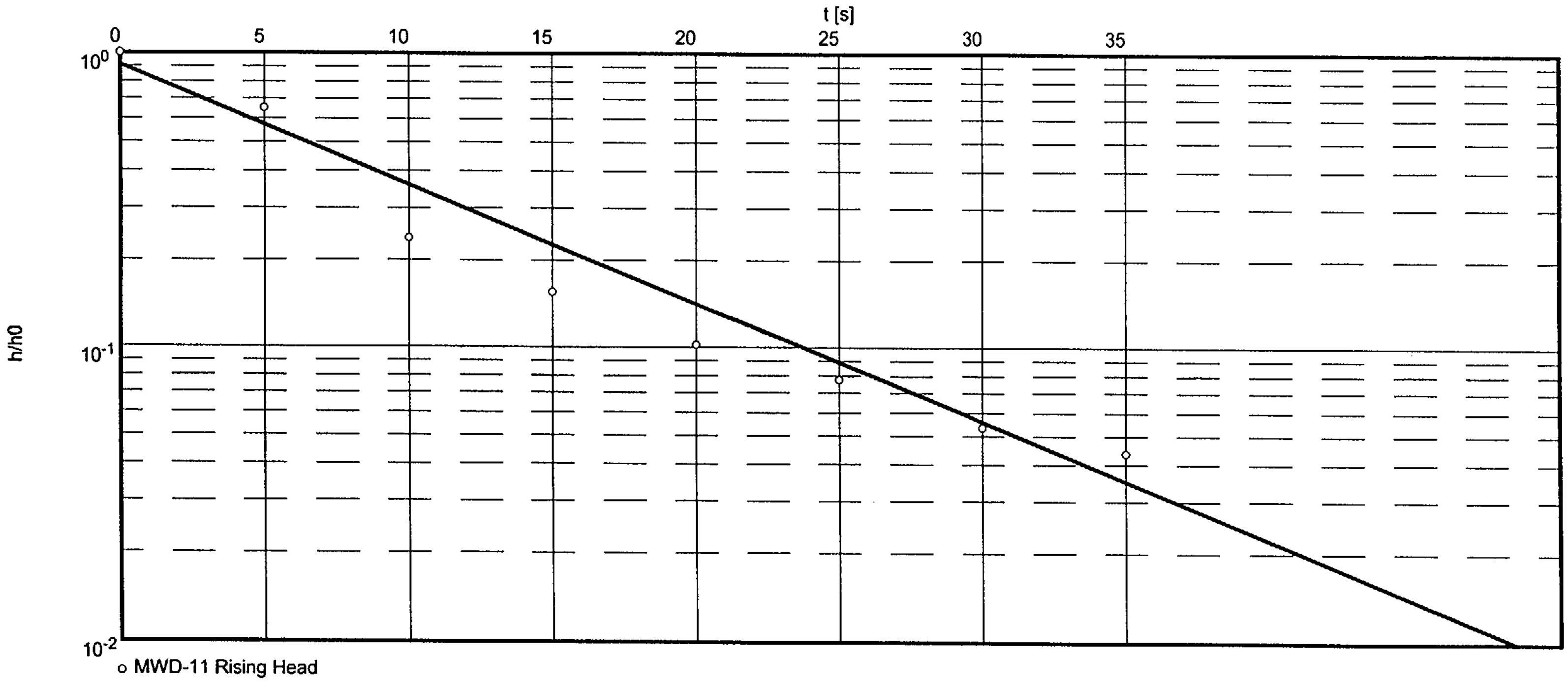
Evaluated by: pls

Date: 10.06.1999

Slug Test No. 2

Test conducted on: 5/26/99

MWD-11 Rising Head



Hydraulic conductivity [ft/s]: 1.18 x $10^{-4}$

Hydraulic Conductivity (cm\sec): 3.6x 10-3

Static Water Depth Below TOC: 12.50 ft
Total Well Depth Below TOC: 28.75 ft
Casing Dia: 2 in (r = 0.083 ft)
Boring Dia: 6 in
(r)eff = 0.18 ft
Screen length = 10 ft
Porosity (filter pack) = 45 %

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slug/bail test analysis
HVORSLEV's method

Page 2

Project: Kaiser Remediation Project

Evaluated by: pls

Date: 10.06.1999

Slug Test No. 2

Test conducted on: 5/26/99

MWD-11 Rising Head

MWD-11 Rising Head

Static water level: 12.50 ft below datum

| | Pumping test duration [s] | Water level [ft] | Change in Waterlevel [ft] |
|---|---|---|---|
| 1 | 0 | 14.56 | 2.06 |
| 2 | 5 | 13.84 | 1.34 |
| 3 | 10 | 12.99 | 0.49 |
| 4 | 15 | 12.82 | 0.32 |
| 5 | 20 | 12.71 | 0.21 |
| 6 | 25 | 12.66 | 0.16 |
| 7 | 30 | 12.61 | 0.11 |
| 8 | 35 | 12.59 | 0.09 |

# APPENDIX E

# HYDRAULIC CONDUCTIVITY OF BEDROCK

**AA Engineering**

**Environmental Services, Inc.**

ENGINEERING • ENVIRONMENTAL
CONSTRUCTION

3840 S. 103rd E. Ave.
Tulsa, OK 74146
(918) 665-6575

SHEET NO. 1 OF 4

PROJECT TITLE KAISER

CALCULATED BY MRM DATE 3/31/97

SUBJECT PACKER TEST JOB NO. 1556

BOREHOLE PRESSURE TESTING

FORMULA USED:

$$k\,(ft/min) = \frac{Q\,(ft^3/min)}{2\pi\, L(ft)\, H(ft)} \log_e \frac{L\,(ft)}{r\,(ft)}$$

WHERE: $k$ = permeability

$Q$ = constant rate of flow into hole

$L$ = length of hole tested

$H$ = column head + gage head − friction loss

$r$ = hole radius

ST-3

50' to 66'

$Q$ = 4.3 gallons/min = 0.57 $ft^3$/min gage 21psi

$L$ = 17.3 ft (66 − 48.7 (top of packer)

$H = 3.5^{\circ} + 50 + 48 - (.38 \times 48.7)$

$H$ = 83.2 feet

$r$ = 6" = 0.5 ft

Therefore $k = \frac{0.57}{6.28 \times 17.3 \times 83.2} \times \log_e \frac{17.3}{0.5}$

$k = 2.2 \times 10^{-4}$ ft/min $= 1.1 \times 10^{-4}$ cm/sec

Test Hole ST-3
Packer Testing
Total Depth 66.2 ft.
Radius of Hole 8" from 0 to 20 ft.
Test Interval 50 to 66.2 ft.

| | **Test #1** | | | **Test #2** | |
|---|---|---|---|---|---|
| Time (min.) | Flow (gal.) | Pressure (psi.) | Time (min.) | Flow (gal.) | Pressure (psi.) |
| 1 | 0.7 | 21.0 | 1 | 10.2 | 20.5 |
| 2 | 1.3 | 21.0 | 2 | 20.2 | 20.5 |
| 3 | 2.1 | 21.5 | 3 | 30.0 | 21.0 |
| 4 | 2.8 | 22.0 | 4 | 40.2 | 21.0 |
| 5 | 3.5 | 22.0 | 5 | 50.1 | 21.0 |
| 6 | 4.3 | 20.0 | 6 | 60.1 | 21.5 |
| 7 | 4.3 | 21.0 | 7 | 69.9 | 21.5 |
| 8 | 4.3 | 21.0 | 8 | 80.0 | 21.5 |
| 9 | 4.3 | 21.0 | 9 | 89.9 | 21.5 |
| 10 | 4.3 | 21.0 | 10 | 99.8 | 21.5 |
| 12 | 4.3 | 21.0 | 12 | 119.7 | 21.5 |
| 15 | 4.3 | 21.0 | 15 | 149.6 | 22.0 |
| 20 | 4.3 | 21.0 | 20 | 198.8 | 22.0 |
| 25 | 4.3 | 21.0 | 25 | | |
| 30 | 4.3 | 21.0 | 30 | | |

SHEET NO. 2 OF 4
PROJECT TITLE ____
CALCULATED BY ____ DATE ____
SUBJECT ____ JOB NO. ____

TEST

ST-1 INTERVAL TESTED 160 to 173

$K = \frac{Q}{2\pi L H} \log_e \frac{L}{r}$ $\log_e \frac{L}{r} = 2.9$

$L = 13'$ , $Q = 6.6 \times 10^{-3}$ ft$^3$/min

$H = 4.1 + 48 + 160 - 60.8 = 151.3'$

$Q = \underline{6.6 \times 10^{-3}}$

$K = 1.54 \times 10^{-6}$ ft/min $= 7.8 \times 10^{-7}$ cm/sec

Interval 83 to 100 no water take

24 to 67 no water take

**Engineering**

**& Environmental Services, Inc.**

ENGINEERING • ENVIRONMENTAL
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Tulsa, OK 74146
(918) 665-6575

SHEET NO. 3 OF 4
PROJECT TITLE KAISER
CALCULATED BY MRM DATE 4/2/97
SUBJECT Packer Test JOB NO. 1556

ST-2 INTERVAL 35' to 60'

$K = \frac{Q}{2\pi L H} \log_e \frac{L}{r}$ $\log_e \frac{L}{r} = 3.9$

$Q = 0.17$ gpm $= 0.023$ ft$^3$/min

$L = 25'$, $H = 2.58$ (gage ht) $+ 52.9$ (pressure head) $- 13.3$ (friction loss) $+ 35$ ft $=$

$H = 77.1$

$K = \frac{0.023}{6.28 \times 25 \times 77.1} \times 3.9$

$K = 7.4 \times 10^{-6}$ ft/min $= 3.7 \times 10^{-6}$ cm/sec

INTERVAL 50' to 60' $\log_e \frac{L}{r} = 2.9$

$Q = .026$ gpm $= 3.4 \times 10^{-3}$ ft$^3$/min

$L = 10'$, $H = 2.58 + 50 + 48.3 - 19 = 82.1$

$K = \frac{.0034}{6.28 \times 10 \times 82.1} \times 2.9$

$K = 1.9 \times 10^{-6}$ ft/min $= 9.7 \times 10^{-7}$ cm/sec

Test Hole ST-2
Packer Testing
Total Depth 59.4 ft.
Radius of Hole 6"
Test Interval 50 to 59.4 ft.

|  | **Test #1** |  |
|---|---|---|
| Time<br>(min.) | Flow<br>(gal.) | Pressure<br>(psi.) |
| 1 | 0.0 | 21.0 |
| 2 | 0.0 | 21.0 |
| 3 | 0.1 | 23.0 |
| 4 | 0.1 | 23.0 |
| 5 | 0.1 | 23.0 |
| 6 | 0.1 | 23.0 |
| 7 | 0.1 | 23.0 |
| 8 | 0.1 | 23.0 |
| 9 | - | - |
| 10 | 0.1 | 23.0 |
| 15 | 0.3 | 23.0 |
| 20 | 0.4 | 23.0 |
| 25 | 0.6 | 23.0 |
| 30 | 0.8 | 23.0 |

AA Engineering
& Environmental Services, Inc.
ENGINEERING • ENVIRONMENTAL
CONSTRUCTION

3840 S. 103rd E. Ave.
Tulsa. OK 74146
(918) 665-6575

SHEET NO. 4 OF 4
PROJECT TITLE KAISER
CALCULATED BY MRM DATE 3/31/97
SUBJECT PACKER TEST JOB NO. 1556

TEST 2

ST-3 INTERVAL 34' to 66'

$$K = \frac{Q}{2\pi L H} \log_e \frac{L}{r}$$

gage 22 psi

$Q = 9.94 \text{ gpm} = 1.32 \text{ ft}^3/\text{min}$

$L = 32 \text{ ft}$

$r = 0.5 \text{ ft}$

$L_e \frac{L}{r} = 4.15$

$H = 3.58 \text{ ft} + 34 + 48.3 - 11.4 = 74.5 \text{ ft}$

$K = 3.6 \times 10^{-4} \text{ ft/min} = 1.8 \times 10^{-4} \text{ cm/sec}$

TEST 3

ST-3 INTERVAL 20' to 66'

gage 11.5 psi

$Q = 1.08 \text{ gpm} = 0.14 \text{ ft}^3/\text{min}$

$\log_e \frac{L}{r} = \frac{46}{.5} = 4.52$

$L = 46 \text{ ft}$

$r = 0.5 \text{ ft}$

$H = 3.58 + 20 + 26.4 - 7.6 = 42.3$

$K = 5.2 \times 10^{-5} \text{ ft/min} = 2.6 \times 10^{-5} \text{ cm/sec}$

Test Hole ST-2
Packer Testing
Total Depth 59.4 ft.
Radius of Hole 6"
Test Interval 35 to 59.4 ft.

**Test #1**

| Time (min.) | Flow (gal.) | Pressure (psi.) |
|---|---|---|
| 1 | 0.0 | 22.0 |
| 2 | 0.0 | 22.0 |
| 3 | 0.0 | 22.0 |
| 4 | 0.0 | 22.0 |
| 5 | - | - |
| 6 | 0.0 | 22.0 |
| 7 | - | - |
| 8 | - | - |
| 9 | 0.0 | 22.0 |
| 10 | | |
| 15 | | |
| 20 | | |
| 25 | | |
| 30 | | |

**Test #2**

| Time (min.) | Flow (gal.) | Pressure (psi.) |
|---|---|---|
| 1 | 0.9 | 25.0 |
| 2 | 1.6 | 23.0 |
| 3 | 2.2 | 21.0 |
| 4 | 2.7 | 20.0 |
| 5 | 3.0 | 23.0 |
| 6 | 3.2 | 21.0 |
| 7 | 3.4 | 20.0 |
| 8 | 3.6 | 23.0 |
| 9 | 3.8 | 21.0 |
| 10 | 3.9 | 21.0 |
| 12 | 4.1 | 21.0 |
| 15 | 4.4 | 22.0 |
| 20 | - | 21.0 |
| 25 | 5.2 | 22.0 |
| 30 | 5.2 | 21.0 |

Test Hole ST-3
Packer Testing
Total Depth 66.2 ft.
Radius of Hole 8" from 0 to 20 ft.
Test Interval 20 to 66.2 ft.

| | **Test #1** | |
|---|---|---|
| Time<br>(min.) | Flow<br>(gal.) | Pressure<br>(psi.) |
| 1 | 2.0 | 10.0 |
| 2 | 3.5 | 10.0 |
| 3 | 4.9 | 11.5 |
| 4 | 6.3 | 11.5 |
| 5 | - | - |
| 6 | 8.9 | 11.0 |
| 7 | 10.3 | 11.0 |
| 8 | 11.5 | 11.0 |
| 9 | 12.7 | 11.0 |
| 10 | 13.7 | 11.0 |
| 12 | 16.0 | 11.0 |
| 15 | 19.2 | 11.0 |
| 20 | 24.0 | 11.0 |
| 25 | 28.6 | 11.0 |
| 30 | 32.5 | 11.0 |

# FRACTURED ROCK ASSESSMENTS

## 6.11.6 "Normal" Hydraulic Conductivity Test Methods - Packer Permeability Tests

"Normally" permeable fractured rocks is a subjective decision to be made by the investigative staff. However, if the hydraulic conductivity of the bedrock fracture system is expected to range between 10-3 and 10-6 cm/sec the "normal" packer permeability tests can provide reliable values for in-situ hydraulic conductivity. Hydraulic conductivity above and below these values may cause system limitations that necessitate evaluations using aquifer pump tests (highly permeable environments) or special low volume shut-in packer testing (sparingly permeable environments).

The U.S. Bureau of Reclamation (1960) developed one of the most useful methods (U.S.B.R. Method E-18) for the determination of in-situ hydraulic conductivity through the use of packers to segregate portions of a drilled hole. CASECO (1964), Dames & Moore (1974) and Harza (1972) have made use of the packer technique for many large scale geotechnical site investigations in both consolidated soil and rock. Figure 6-57 gives the arrangement for the performance of hydraulic conductivity tests in holes that will remain open without casing.

Hydraulic conductivity are calculated by the formula:

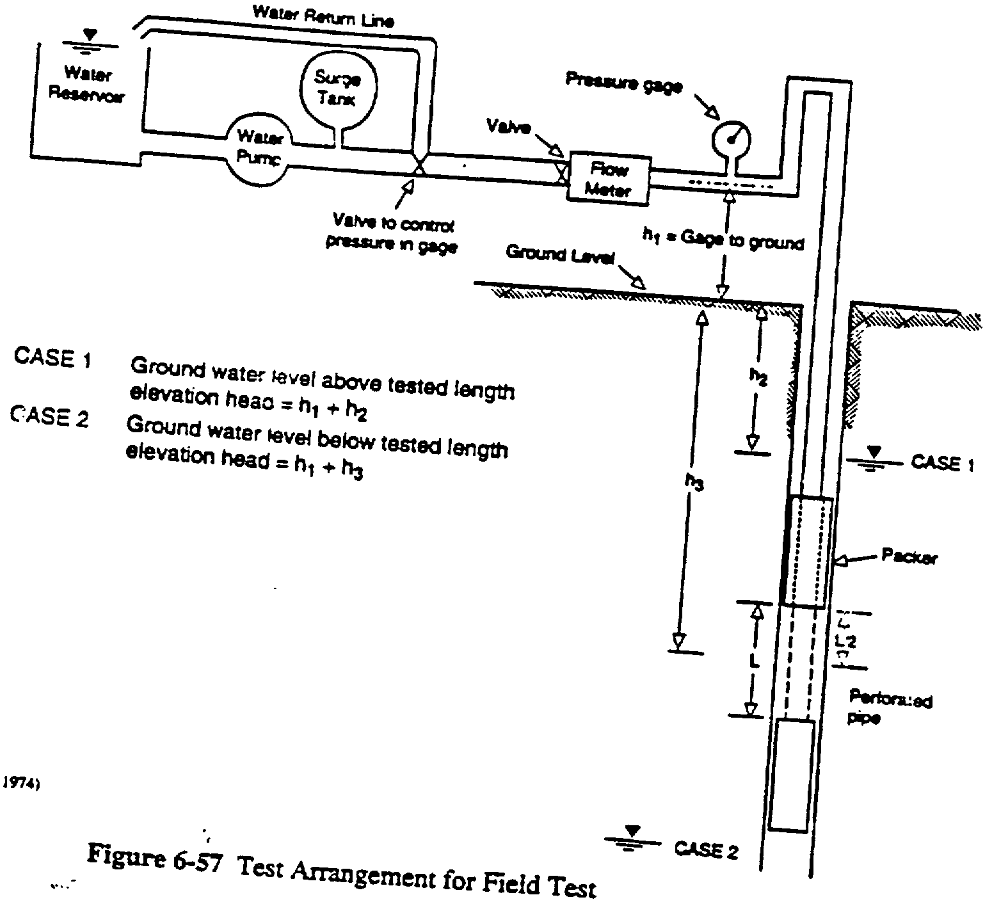
$$K = \frac{q}{2Lh} \log_e \frac{L}{r} \qquad \text{where } L \geq 10r$$

**Equation 6-12a,b**

$$K = \frac{q}{2Lh} Sinh^{-1} \frac{L}{2r} \qquad \text{where } 10r > L \geq r$$

r = radius of the hole tested
L = length of the section of the hole being tested
q = the constant rate of flow into the hole
$\log_e$ = natural logarithm
$\sin h^{-1}$ = arc hyperbolic sine

In the above equation any consistent units may be used in calculating the hydraulic conductivity. Figure 6-58 taken from Lambe and Whitman (1969) can be used to convert numbers into the various hydraulic conductivity units. These formulas have best validity when the thickness of the stratum tested is as least 5L, and they are considered by Dames Br Moore (1974) to be more accurate for tests below ground-water table than above it. The following sections will review in some detail important considerations in borehole pressure testing that were not considered or quantified by the original Earth Manual U.S.B.R. (1960) test description. In addition, a general procedure for borehole pressure testing common to several references is given in the following text.



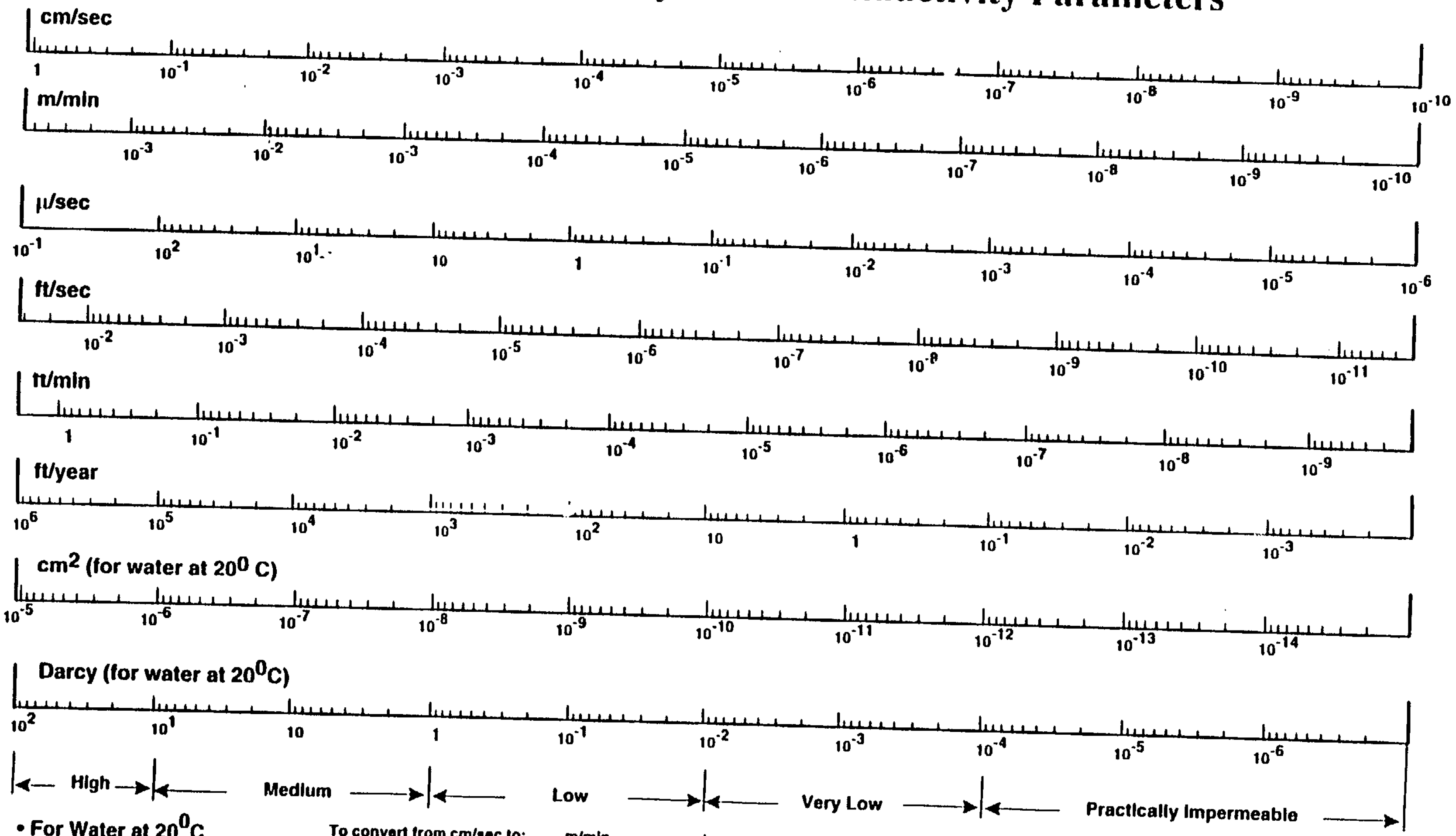
CASE 1 Ground water level above tested length elevation head = $h_1 + h_2$

CASE 2 Ground water level below tested length elevation head = $h_1 + h_3$

Source: Modified from Dames and Moore (1974)

Figure 6-57 Test Arrangement for Field Test

# Conversion Chart for Hydraulic Conductivity Parameters



- For Water at 20⁰C

| To convert from cm/sec to: | m/min | m/sec | ft/sec | ft/min | ft/yr | cm2* | Darcy* |
|---|---|---|---|---|---|---|---|
| Multiply by: | 0.600 | $10^{4}$ | 0.0328 | 1.968 | $1.034 \times 10^{6}$ | $1.031 \times 10^{-5}$ | $1.045 \times 10^{3}$ |

Figure 6-58 Hydraulic Conductivity Conversions

## Net Pressure

An important consideration in borehole pressure tests is the water pressure applied between the packers (or under one packer) which is referred to as the net pressure. The net pressure applied to a section of borehole is the algebraic sum of the following three pressure terms as shown:

Net Pressure = gauge pressure + column pressure - friction losses.

All pressure terms are expressed in units of feet of water. Column pressure is measured directly in feet. Friction losses due to the flow of water through the test pipe are calculated in feet. However, gauge pressure is usually measured in pounds per square inch (psi) and must be converted to feet of water by the following factor:

Gauge Pressure (psi)/0.433 = feet of water **Equ. 6-13**

## Gauge Pressure

The gauge pressure is the water pressure measured on a gauge at the ground surface (or other reference point such as the top of casing). Since a pressure difference of' a few psi is equivalent to several feet of water, the gauge pressure must be measured very precisely. A high quality gauge that is accurate to +1 psi should be used for packer permeability tests is recommended by both Harts (1972) and Dames & Moore(1976).

A common problem noted by Dames & Moore (1974) was the type of pump used in the test. If a reciprocating pump is supplied by the drilling contractor, the pressure gauges may exhibit so much vibration that they become unreadable. To eliminate this problem, it was recommended that the contractor should install one or more surge chambers in series between the pump and the pressure gauge to dampen this vibration. If this does not eliminate the pressure change problem, a new system is required using a different pumping setup.

## Column Pressure

The column pressure is the static pressure due to the weight of water in the test pipe above the water table. Column pressure is therefore equal to either the depth to the upper packer or the depth to ground water, whichever is smaller.

Above the water table, the column pressure is equal to the distance between the bottom of the upper packer and the surface reference point (where the pressure gauge is situated). This distance is measured to the nearest foot. Sometimes the lower reference point is chosen as the center of the tested interval, rather than the depth of the upper packer. However, the difference has a negligible effect on the calculations for a packer spacing of less than 10 feet.

Below the water table, the column pressure is always equal to the depth of the water table with respect to the surface reference point. The depth to ground water should be measured to the nearest foot immediately before lowering the packer string into the hole.

## Friction Loss

The head loss from friction of the pipe causes a back pressure that is recorded on the pressure gauge, but is not applied to the formation. Friction loss is a function of the flow rate and the length of pipe between the pressure gauge and the packer. Both Harza (1972) and Dames & Moore (1974/ note the importance of calculation of friction losses that were not considered by Lowe & Zaccheo (1975), Cedergren (1967) and U.S.B.R. (1960).

Two methods may be used to determine friction loss during a particular test. The first method is to use handbook values for head loss for a given pipe diameter and roughness condition. Figure 6-59 shows an example of a theoretical flow rate Vs head loss relationship for ¾- inch rough iron pipe. For example, if a flow rate of 5 gpm and 125 feet of pipe are given for a particular test, the friction loss is estimated as follows:

Friction loss = 0.43 feet/foot (at 5 gpm on graph) X 125 feet of pipe = 54 feet (of water) **Equ. 6-13**

Friction losses at high flow rates can have a dominating effect in the calculation of net pressure. Conversely, friction losses at very low flow rates (less than 1 gpm) are insignificant and can be disregarded. The second method of determining friction loss is to perform a calibration test in the field. Flow rate versus head loss is plotted on log-log paper, and the resulting relationship is used in the same manner as the handbook curve. Figure 6-60 shows a layout for this purpose. A record of values of P = Fl - P2 for a given flow Q is made. The graph shows the head loss per 100 feet of pipe for different discharges. For different lengths of pipe, the head loss is assumed to be linear.

## Test Water Quality

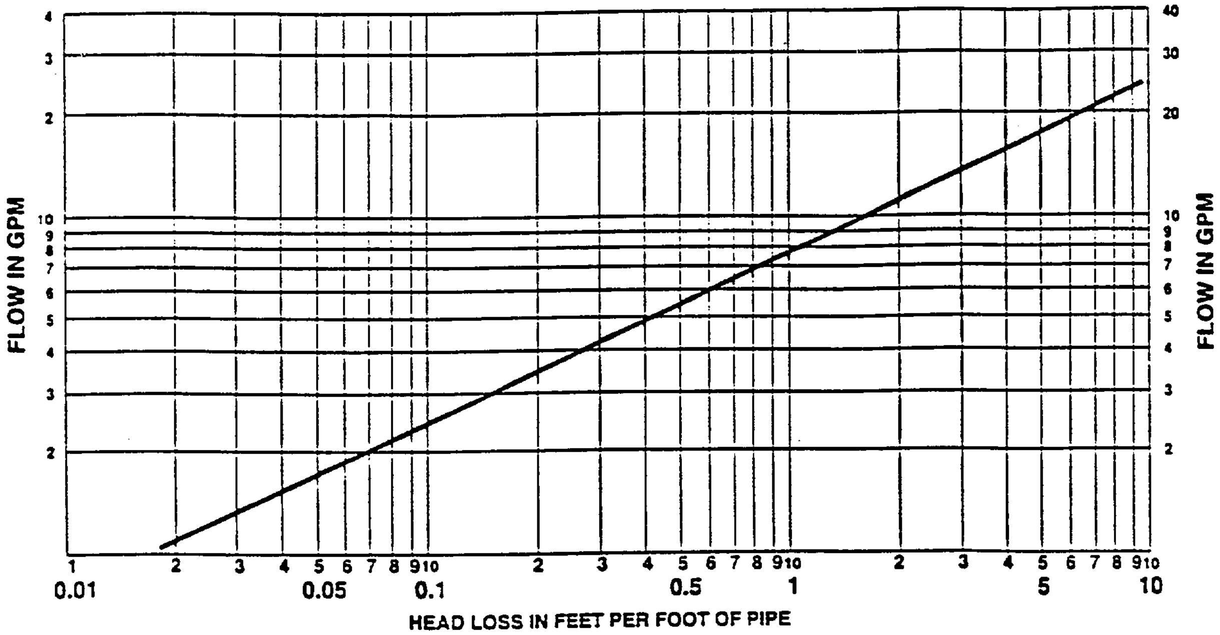
The water used for pressure testing must meet nominal specifications to maintain a valid test result. Generally, fine grained, low permeability rocks are more sensitive to water quality than are rocks of high hydraulic conductivity (Dames & Moore 1974).

Most studies of field measurement of hydraulic conductivity recognize one of the first considerations of the test is turbidity in the test water. Water containing visible suspended solids will tend to plug any formation fine-grained enough to filter out the solid material. This includes many soils and rocks that have hydraulic conductivity < $10^{-3}$ cm/sec. Therefore, clean water must always be used for pressure testing. The second consideration brought out by CASECO (1964) and Dames & Moore (1974) is test water temperature. Test water temperature should be as close to natural ground-water temperature, as possible. Water supplies for pressure testing may range from near freezing to temperatures over 80°F. The kinematic viscosity of water ranges from about 0.009 to 0.018 Stokes between these limits. Since hydraulic conductivity values obtained from pressure tests are controlled partially by viscosity of the fluid, an error is possible if "warm" or "cold" water is used. The maximum likely range of this error is a factor of about 2 for waters between 32°F and 80°F. For test water within 10 degrees of natural formation temperature, this error is very small. If one must use test water of differing temperature than formation water, then it is better to use test water slightly warmer than the formation temperature. Cold water may contain more dissolved gas than warm water. If gas-saturated cold water is pumped into the ground and becomes warmed, gas will come out of solution which will reduce the apparent hydraulic conductivity of the formation. This effect is most significant in fine-grained rocks where porosity can be blocked by the presence of gas bubbles.

## Measurement Procedures - Preliminary Setup

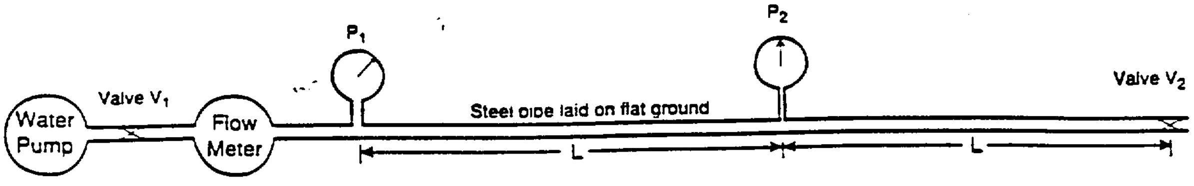
The following steps are conducted prior to testing each interval in a boring:

1. The depth to ground water is measured with water level indicator;
2. The distance between the pressure gauge and ground is measured and recorded at the location of top of the hole;
3. Equipment is set up as shown in Figure 6-57. The exact distance between packers is measured and recorded; and,
4. All tests should be: conducted from top to bottom of hole unless advised otherwise. The top of the bottom packer is used as reference point for depth measurements.



Source: Modified from Dames and Moore (1974)

Figure 6-59 Friction Loss Estimates



Source: Modified from Dames and Moore (1974)

Figure 6-60 Test Arrangement for Friction Loss Test

## Testing

The following steps recommended by both Harza (1972) and Dames & Moore (1974) are used during the testing of each interval:

1. The packer is lowered to interval to be tested.
2. Air pressure is increased slowly to seal the packers.
3. The water-return valve is opened fully. Then, the operator is instructed to start the water pump at low speed.
4. The maximum gage pressure is recommended as 1 psi per foot of rock depth except as noted below. This pressure should not exceeded, since hydrofracturing of the rock is likely to occur during test. The minimum recommended pressure for testing is 20 psi.

   Pressure of 1 psi per foot of rock depth can open joints of bedding planes and increase hydraulic conductivity in the following cases:

   - Shallow rock up to a depth of approximately 50 feet. This depth varies with the quality of the rock;
   - The rock is low strength, highly jointed or thin bedded,
   - The test is done near a valley as in the case of many boreholes along a dam axis.

In the above cases the maximum gage pressure should be ¾ psi per foot of rock depth or less. The maximum pressure used is a judgment decision based on the quality of rock.

5. The gauge pressure is built-up by partially closing the return valve until the desired pressure is obtained. If the return valve is fully closed and the desired pressure is not obtained, the valve is opened and the operator instructed to increase the pump speed.
6. When the desired pressure is reached, the flow meter reading is recorded and timing with the stopwatch begins. The flow meter readings are then recorded.
7. Flow meter readings are taken at the end of the first, second and third minutes. After the third minute, readings every 2,3 or 5 minutes are considered adequate.
8. During step no. 7, a constant watch is kept on the gauge pressure which is adjusted if necessary. In most instances, it starts decreasing or increasing due to variations in pump speed, or loosening of material in the rock.
9. The tests are finished when a constant rate of loss is obtained. In most instances, 10 minutes is an adequate time to obtain a constant flow and adequate data.
10. Subsequently, the same section is tested using a somewhat higher allowable pressure.(but not exceeding maximum recommended). Typically test pressures of ½ maximum allowed, full pressure allowed, and again ½ full pressure is used in testing rock formations. Steps 5 to 9 are repeated. However, for shallow depths only one test may be possible, due to the 1 psi per foot of rock depth maximum, and 20 psi minimum.
11. When all tests are completed at an interval, the pump speed is reduced or shut off, the return valve opened fully, the flow meter valve closed and the air valve to release the air from the packer is opened. These operations must be done in the sequence explained above.
12. Steps 5 through 11 are repeated for each interval tested.
13. The last 10 feet of depth of the borehole are not tested.

Loose rock and sediment commonly accumulate at the bottom of the hole and the packer systems can get stuck down the hole.

## Data Requirements

The importance of detailed data recording was stressed by CASECO (1964), Harza (1972) and Dames & Moore (1974), which includes the following information:

1. Depth of hole at time of each test;
2. depth to bottom of top packer;
3. depth to top of bottom packer;
4. depth to water level in borehole at frequent intervals;
5. elevation of piezometric level;
6. length of test section;
7. radius of hole;
8. length of packer;
9. height of pressure gauge above ground surface;
10. height of water swivel above ground surface; and
11. description of material tested.

The formulas for calculation of hydraulic conductivity with packer tests give only an approximate value of K since they are based on several simplifying assumptions. They do, however, give values of the correct magnitude and as suitable for most geotechnical and hydrogeologic investigations. A graphical solution of Equation 6-12 is given in Figure 6-61 from Davis & Sorensen (1969). The test procedure used depends upon the condition of the rock. In rock which is not subject to cave-in, the following method is in general use. After the borehole has been completed, it is filled with clear water, surged, and washed out. The test apparatus is then inserted into the hole until the top packer is at the top of the rock. Both packers are then expanded and water under pressure is introduced into the hole, first between the packers and then below the lower packer. Observations of the elapsed time and the volume of water pumped at different pressures are recorded as detailed in the section on pumping below. Upon completion of the test, the apparatus is lowered a distance equal to the space between the packers and the test is repeated. This procedure is continued until the entire length of the hole has been tested or until there is no measurable loss of water in the hole below the lower packer. If the rock in which the hole is being drilled is subject to cave-in, the pressure test is conducted after each advance of the hole for a length equal to the maximum permissible unsupported length o.' hole or the distance between the packers, whichever is less. In this case, the test is limited, of course, to the zone between the packers. Regardless of which procedure is used, a minimum of three pressures should be used for each section tested. The magnitude of these pressures are commonly 15, 30, and 45 psi above the natural piezometric level. However, in no case should the excess pressure above the natural piezometric level be greater than 1 psi per foot of soil and rock overburden above the upper packer. This limitation is imposed to insure against possible heaving and damage to the base grade foundation rock and obtaining falsely high values for hydraulic conductivity. In general, each of the above pressures should be maintained for 10 minutes or until a uniform rate of flow is attained, whichever is longer. If a uniform rate of flow is not reached in a reasonable time, the engineer must use his discretion in terminating the test. The quantity of flow for each pressure should be recorded at 1, 2, and 5 minutes and for each 5 minute interval thereafter. Upon completion of the tests at 15, 30, and 45 psi, the pressure should be reduced to 30 and 15 psi, respectively, and the rate of flow and elapsed time should once more be recorded in a Similar manner. Observation of the water take with increasing and decreasing pressure permits evaluation of the nature of the openings in the rock. For example, a linear variation of flow with pressure indicates an opening which neither increases or decreases in size. If the curve of flow versus pressure is concave upward. it indicates the openings are enlarging; if convex, the openings are becoming plugged. Item (4) is important since a rise in water level in the borehole may indicate leakage from the test section.

## 6.11.7 "Low" Hydraulic Conductivity Test Methods

Low hydraulic conductivity bedrock provides the site assessment professional with many obstacles beginning with difficult conceptual movement of ground water to complex equipment requirements necessary to perform the evaluation.

The equipment used in testing low hydraulic conductivity fractured rock environments require sensitive and highly accurate instruments to evaluate the in-situ hydraulic conductivity (see Figure 6-62). Equipment calibrations and the procedures used in the various field testing methods become extremely important in obtaining accurate data. In general these 'low' hydraulic conductivity environments would range between 10-6 to below 10-9 cm/sec, and in most hydrostratigraphic environments these units would be considered as confining units or aquitards. Evaluation of these low hydraulic conductivity environments can be extremely important for confirming unit containment of hazardous waste or the evaluation of separation of aquifers from contaminated zones. The equipment for testing low hydraulic conductivity fractured rocks can be divided into, surface equipment, down-the-hole system and the data acquisition system.

### Surface Equipment

Surface equipment includes the pumps, flow meters, and control systems necessarily to conduct the test program. Due to the difficulties of monitoring constant pump pressures, pressure tanks are used to run the constant pressure tests. Tanks should be insulated or otherwise protected from temperature fluctuations. Additional flow meters (e.g., turbine flow meters) may be used in combination with bubble tube flow meters in parallel with higher volume meters. If a pressure transducer is used in the surface instrumentation to monitor injection pressure, it should be located downstream of the flow meter and any other parts of fittings that may have high pressure losses.

### The Down-hole System

A down-hole testing system for low hydraulic conductivity rock includes the packers, down-hole valving, down-hole instrumentation, tubing from the surface to the test zone, and pressurization lines for down-hole equipment in a field set up as shown in Figure 6-63. Packers used in fractured rock assessments should be inflatable and capable of withstanding a differential pressure of about 5 MPa. The packers can be either water or nitrogen inflated.

An essential for conduct of the tests in these fractured rock environments is the down-hole valving of the main flow line. The down-hole valve must be easily operable from the surface in a period of a few seconds. The speed of opening the valve controls the early build-up rate of pressure for instantaneous tests and also affects the duration of the pressure pulse in pulse tests. Down-hole measuring instruments used in the test include pressure transducers and temperature sensors. Pressure transducers are used to measure hydraulic or pressure heads in the test zone, the packers, and, if possible, above and below the packers in the hole. A thermal sensor should be placed to provide an accurate reading of the test zone temperature conditions. The pressure transducers should be set for rapid data acquisition rates through computer based data storage.

## Data Acquisition

Down-hole hydraulic testing in fractured rock is an extremely costly and exacting technique. Thus, efforts should be directed toward insuring that data necessary for interpretation and analysis of the results are not lost. Therefore, the digital system should be backed by an analog recording system, such as a set of strip chart recorders.

Data acquisition systems for low hydraulic conductivity fractured rock environments should contain both digital and analog filtering and recording capabilities for multiple data channels. The data acquisition system should be capable to recording at high rates, as fast as 1-2 readings per second during the early time of the test.

# APPENDIX F

# MONITOR WELL AND SURFACE SAMPLING AND ANALYSIS PLAN

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## LIST OF FIGURES

## LIST OF TABLES

## LIST OF ATTACHMENTS

Attachment 1: Resumes of Sampling Personnel
Attachment 2: Laboratory QC/QA Program

## PURPOSE

The purpose of the groundwater sampling is to ascertain the geochemistry of groundwater upgradient and downgradient of the Kaiser Aluminium Plant, refered to as the "Site". Samples will be taken for inorganic parameter determination as well as radiological evaluation.

## QUALIFICATIONS OF SAMPLING PERSONNEL

The sampling will be directed by:

A & M Engineering And Environmental Services, Inc.
3840 South 103rd East Avenue, Suite 227
Tulsa, Oklahoma 74146
918-665-6575

Sampling personnel will consist of a Technician, Project Geologist, Health and Safety Officer and Project Manager. All on-site personnel, experienced in safety procedures and sampling of hazardous and non-hazardous materials, are trained under criteria set by 29 CFR 1910.120. This program instructs employees on general health and safety principles, proper operation of monitoring instruments, and the use of Personal Protective Equipment (PPE). Each employee also receives an eight hour annual update. The team consists of the personnel listed in Table 1.

**Table 1 : Field Sampling Personnel**

| NAME | AFFILIATION | TITLE |
|---|---|---|
| Murray R. McComas, PhD, CPG | A & M Engineering | Project Manager / Geologist |
| Irfan Taner CPG | A & M Engineering | Project Geologist |
| Peter L. Schultze | A & M Engineering | Geologist |
| Randal Beeson | A & M Engineering | Project Health & Safety Officer |
| Jeff Elbert | A & M Engineering | Project Technician |
| Scott McReynolds | A & M Engineering | Project Technician |

Resumes are included in Attachment 1.

## *PARAMETERS*

### Table 2 : List of Parameters and Analytical Methods

| PARAMETER | ANALYTICAL METHOD | PRACTICAL QUANTITATION LIMIT (PQL)(mg/l) |
|---|---|---|
| Antimony | SW-846 6010 | 0.06 |
| Arsenic | SW-846 6010 | 0.01 |
| Beryllium | SW-846 6010 | 0.005 |
| Barium | SW-846 6010 | 0.01 |
| Cadmium | SW-846 6010 | 0.005 |
| Chromium | SW-846 6010 | 0.01 |
| Cobalt | SW-846 6010 | 0.02 |
| Copper | SW-846 6010 | 0.025 |
| Lead | SW-846 6010 | 0.003 |
| Mercury | SW-846 7471 | 0.0005 |
| Nickel | SW-846 6010 | 0.035 |
| Selenium | SW-846 6010 | 0.005 |
| Silver | SW-846 6010 | 0.005 |
| Thallium | SW-846 6010 | 0.01 |
| Tin | SW-846 6010 | 0.1 |
| Vanadium | SW-846 6010 | 0.02 |
| Zinc | SW-846 6010 | 0.02 |
| Hexavalent Chromium ($Cr^{+6}$) | SW-846 7196 | 0.05 |
| | | |
| Bicarbonate | Std. Methods 403 | 20 |
| Carbonate | Std. Methods 403 | 20 |
| Calcium | SW-846 6010 | 0.5 |
| Potassium | SW-846 6010 | 5 |
| Phosphorus (P) | EPA 365.2 | 0.01 |
| Magnesium | SW-846 6010 | 0.25 |
| Chloride | EPA 300 | 0.2 |
| Fluoride | EPA 300 | 0.2 |
| Iron | SW-846 6010 | 0.1 |
| Manganese | SW-846 6010 | 0.01 |
| Sodium | SW-846 6010 | 0.5 |
| Sulfate | EPA 300 | 0.2 |
| Nitrate (as $NO_3$) | EPA 300 | 0.2 |
| Silica (Si) | EPA 370.1 | 0.2 |
| | | |
| Total Dissolved Solids | EPA 160.1 | 10 |
| Total Suspended Solids | EPA 160.2 | 10 |

| PARAMETER | ANALYTICAL METHOD | PRACTICAL QUANTITATION LIMIT (PQL)(mg/l) |
|---|---|---|
| Hardness | EPA 130.2 | 1 |
| Alkalinity | EPA 310.1 | 20 |
| Specific Conductivity | EPA 120.1 | N/A |
| pH | EPA 150.1 | N/A |
|  |  |  |

## ORDER OF WELL VISITATION

To avoid cross contamination, well measurements will be taken starting with those wells with the least potential for contamination and proceeding to those wells with the highest potential for contamination. Well measurements will be taken at upgradient well MW 5-1 first, then downgradient wells.

## RECORDKEEPING

The Field Sampling Team will maintain a two-volume groundwater sampling logbook. The first volume is a compendium of all Field Data Sheets. The Field Data Sheets shown in Figure 1 provide a permanent record of information about monitoring activities at each sample point..

After entering the general information The team recordkeeper will note the condition of the well, including whether or not the lock was in place, any evidence of tampering, if there is any water standing near the well, and the condition of the concrete well pad.

Upon arrival at each well on the schedule, the team recordkeeper will record the following on the Field Data Sheets in Field Book Volume I:

- Date and time of water level measurements, temperature and weather data
- Persons present
- Well ID and condition of well
- Depth to water and technique used to measure
- Presence of immiscible layer and detection method
- Total Well depth
- Time well purged
- Well evacuation procedure/equipment, if different from plan
- Purge volume
- Time well sampled
- Sample withdrawal procedure/equipment, if different from plan
- Sampling sequence
- Parameters to be analyzed

# FIELD WATER QUALITY SAMPLING AND ANALYSIS DATA SHEET

PROJECT NAME ______________________________ PROJECT NUMBER ____________

SAMPLER NAME ____________________ PERSON PRESENT ______________________

WEATHER ______________ AMBIENT AIR TEMPERATURE ______ F DAYS SINCE LAST PRECIPITATION ______

<table>
<tr><td>LOCATION (STATION NO.)</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>CONDITION OF WELL</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>WATER SOURCES</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>DATE AND TIME WATER LEVEL MEASURED</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>DATE AND TIME PURGED</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>DATE AND TIME SAMPLED</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>SAMPLING METHOD(BAILER,PUMP..)</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>TOTAL WELL DEPTH (TWD)</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>WATER DEPTH "TOC" (WD)</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>THICKNESS OF NAPL/DNAPL</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>VOLUME TO EVACUATE*</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>PUMP RATE WHILE PURGING</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>SUBSTANCE ON WATER</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">SAMPLING TEMPERATURE</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">SAMPLING pH<br>(INST NAME )</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">SAMPLING SPECIFIC<br>CONDUCTANCE(INST )</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>COLOR</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>ODOR</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>SEDIMENT</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>FIELD TREATRMENT PRESERVATION</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>PURGING/SAMPLINING PLAN AND PROCEDURES FOLLOWED?</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

*VOL EVACUATION EQUA.- [[(TWD-WD) x .163 gal/ft] x 3] + 3.5 gal.

FIGURE 1

- Preservatives used (if any)
- Field observations

The Field Book Volume II will contain space for additional observations or calculations along with the following logistical information:

- Order/sequence of wells sampled
- Type of sample containers used and ID numbers [include ID number of field blank(s)]
- Documentation of container cleanliness
- Calibration logs for various meters used; recalibrations recorded between wells
- Laboratories used for sample analyses
- Chain-of-custody records, and copies of special instructions (if any)
- Shippers' airbill
- Analysis request sheets
- Well depths and recharge rates
- Copy of laboratory QA/QC program including methods and detection limits

## *FIELD ACTIVITIES*

### Procedural Outline For Sampling

1) Decontaminate all field sampling equipment
2) Arrive on location, Prepare well location for sampling
3) Measure water level
4) Measure total well depth
5) Purge three well volumes testing pH and Specific Conductance
6) Collect samples at rate of 100 ml/min testing pH and Specific Conductance
7) Collect field blank and equipment blank samples
8) Preserve and label samples
9) Prepare chain-of-custody
10) Transport or ship to laboratory
11) Decontaminate all equipment
12) Sign chain-of-custody with laboratory
13) Complete laboratory logbook

### Decontamination

With the exception of disposable polyethylene bailers, all equipment used to collect groundwater samples, whether new or previously used, is assumed to be contaminated and undergoes the level of decontamination appropriate to its intended use and construction.

Equipment used for metals and inorganic samples will be decontaminated as follows:

1. Wash thoroughly with non-phosphate detergent in hot water.
2. Rinse once with 1:1 nitric acid.
3. Rinse several times with tap water.
4. Rinse once with 1:1 hydrochloric acid.
5. Rinse several times with tap water.
6. Rinse several times with deionized water.
7. Invert and air dry in dust free environment.
8. Cap after drying.

Once equipment has been allowed to dry, package the equipment to protect it from dust. Plastic bags are appropriate for larger items such as bailers and bladder pumps; aluminum foil is preferred for glasswater openings. Once packaged, a label stating the level of decontamination, date of decontamination, and initials of individual certifying decontamination should be affixed to the protective package so that the label must be torn to unpack it. In the field, use a piece of equipment if this seal is broken.

The analytical laboratory will provide pre-cleaned containers for monitor well groundwater samples.

Disposable polyethylene bailers, factory decontaminated and sealed in plastic, will be used for sample collection.

## Prevention of Contamination Release

To avoid a release of potentially contaminated groundwater, a protective layer of 6 mil polyethylene sheeting will be spread around the monitor well to collect any spillage during purging and sampling. Five gallon capacity plastic buckets will be used to collect rinse and decontamination water during field measurement and sampling. At each groundwater monitoring well, a 55 gallon capacity steel drum meeting the DOT 17-H specifications will be placed to store rinse water, decontamination water and purge water from the well. Purge water and excess sampled water will be disposed in the retention pond.

## Water Level and Total Depth Readings

Water level and total depth readings for each well will be taken at each sampling event. The designated team member will put on clean latex gloves and proceed as follows:

a. Grasp the monitor well cap with both hands and gently remove. Care must be taken to not let the lid (cap) touch anything while being placed on a clean sheet of polyethylene out of the sampler's work area.

b. The team leader will rinse the cable and probe of the depth meter with de-ionized (DI) water supplied from the laboratory and collect the rinse water in a five gallon plastic bucket. Slowly the team leader will lower the depth indicator probe into the well until the meter indicates that water has been reached. Using the permanent measuring point designated on the casing, the depth at which the water was encountered will be mentally noted (the meter will be read to the nearest 0.01 ft.). Raise the probe until it is no longer in the water and lower the probe again until the meter indicates that water has been reached and mentally note the second value. If the values do not agree within 0.01 ft., repeat the steps as above until the two readings agree within 0.01 ft.. Once a stable depth to water reading has been confirmed, the depth-to-water value will be recorded in the field logbook

c. Slowly lower the depth sounder into the well until it hits the bottom of the well. Read and mentally note the depth when tension in the cable is relieved as the weighted end touches the bottom of the well. Raise the probe above the bottom and then lower it again to the bottom to take an independent reading. If both readings are the same, record the value; if not, take an additional reading. Readings will be recorded to the nearest 0.01 ft. as measured from the permanent measuring point designated on the casing.

d. Slowly remove the probe from the well and decontaminate using a triple rinse with the DI water as it is removed. If organic contamination is suspected in the monitor well, decontamination of the water level indicator will include thorough washing with an Alconox soap solution before rinsing with DI water. During decontamination, the sampler will be careful to collect all rinsate water while not to allowing any rinse water to run down the well. The sampling team whould be absolutely sure the wire or probe never touches the ground or anything other than the water in the well.

e. Prior to covering the well, the well lid (cap) should be rinsed with distilled water. Then place the cap securely back onto the well stem.

f. Secure the locking protective well cover and proceed to the next monitor well in the circuit.

g. Transfer rinse water from the five gallon buckets to the 55 gallon drum for storage until analyses are completed.

## Purging

Three well volumes of water will be pumped from each well prior to sampling. The designated well pump is a Grundfos BMI / MP-1-115V. One well volume is equal to the amount of water held in the well bore and in the filter pack. A 10-foot filter pack will contain approximately 3.0 gallons of water (considering 20 percent specific yield of filter pack). The factor for 2-inch diameter pipe is 0.163 gallons per foot of water in the well. The amount of water in the filter pack is added to the amount of water in three times the casing volume for total amount of purgate.

The purge volume will be calculated in the field for each well by the following method:

Measure depth to water (static water level - SWL)
Measure depth to bottom of hole (total depth - TD)
[(TD-SWL) X 0.163 gal/foot X 3] + gravel pack $H_2O$ = purge volume

Purging the well will be accomplished using a pump or bailer for removing the required quantity of water. Groundwater purged from the well prior to sampling will be placed in a 55 gallon drum which meets the DOT 17-H specifications. Once the analyses are complete, stored purge and decontamination water will be properly disposed based upon the chemical characteristics identified in each discrete groundwater monitoring well.

## Field Testing

Field analyses consisting of Temperature, Specific Conductance and pH will be conducted before the well is purged and at intervals (at least 3 times) during purging to ensure the water to be sampled is represenative of the formation water and not impacted by static conditions in the well casing or gravel pack. Regardless of the number of well volumes removed, the purging will continue until field analyses are stable, or the well is "pumped dry". All field measurements will be recorded in the field logbook.

After purging, as soon as the water level in the well has returned to static levels, field measurements of temperature, pH and Specific Conductance will be made. Then as laboratory samples are collected, additional replicate samples willl be collected and tested temperature, pH and Specific Conductivity. A total of four replicate field measurements will be made at the surface during laboratory sample collection Replicates will be tested in glass containers which are rinsed thoroughly between replicate tests.

## Sample Collection

Groundwater samples will be collected using disposable polyethylene bailers and disposable nylon cord. Two field technicians will be reponsible for sample collection and a third will complete the recordkeeping and labelling requirements. The two samplers will don clean latex examaination gloves before removing the bailer from the protective plastic bag. The top of the bag will be opened to allow attachment of the disposable nylon cord to the bailer. Once the cord is securely attached the bailer will be removed from it's protective cover and slowly lowered into the well casing. As the bailer slowly contacts the water surface, it will be lowered very slowly approximatley twelve inches and then withdrawn from the well casing. The water column in the bailer will be checked for indications of an immiscible layer of light non-aqueous phase liquid (LNAPL) on the water surface.

If LNAPL's are indicated, the bailer will be carefully discharged into a 40 ml Volatile Organics and Aromatics (VOA) vial with a teflon septum designed for collection of volatile organic samples in water. The VOA vial would then be immediately labeled and place in the pre-chilled ice chest to be delivered to the analytical laboratory.

If there is no indication of LNAPL's, the contents of the bailer would be used for the first replicate sample for field Measurement of Temperature, pH and Specific Conductivity. Following bailer discharge, the bailer would then be lowered slowly down into the well casing to the water surface. The bailer will be very slowly lowered into the water completely to the bottom of the well casing. once on the bottom of the well, the bailer will be slowly withdrawn and the water column checked for indications of a dense non-aqueous phase liquid (DNAPL) which would accumulate on the bottom of the water table just above the aquifer confining bed or zone.

If DNAPL's are indicated, the bailer will be carefully discharged into a 40 ml Volatile Organics and Aromatics (VOA) vial with a teflon septum designed for collection of volatile organic samples in water. The VOA vial would then be immediately labeled and place in the pre-chilled ice chest to be delivered to the analytical laboratory.

If there is no indication of DNAPL's, the contents of the bailer would be used for the second replicate sample for fieid Measurement of Temperature, pH and Specific Conductivity. Following bailer discharge, the bailer will then be lowered down into the well casing and filled with water for laboratory samples.

The samples from each well will be collected in the following order and quantity:

## Table 3 : Order of Sample Collection

| Parameter | Container | Quantity |
|---|---|---|
| Total Suspended Solids | Plastic | 500 ml |
| Total Dissolved Solids | Glass | 500 ml |
| pH and Specific Conductance (lab sample & 3rd field replicate) | Plastic | 500 ml |
| Appendix IX Metals | Plastic | 500 ml |
| Hexavalent Chromium | Glass | 500 ml |
| Cations | Plastic | 500 ml |
| Anions | Plastic | 500 ml |
| Hardness, Alkalinity | Plastic | 500 ml |
| Radiological | Glass | 2 liters |

Note: At least one field blank and one equipment blank per sampling day will be included with the samples.

In accordance with the above, eight separate containers will be used for each well. At the conclusion of taking the designated samples for the laboratory, the fourth and final replicate pH, temperature and Specific Conductance will again be run at the well.

### Sample Preservation

Containers designed for each group of parameters to be analyzed will be provided by the analytical laboratory. These containers will have the appropriate preservative already in the container, and labeled with the type of preservative used.

### Sample Custody Documentation

The chain-of-custody requirements for groundwater sampling are outlined in the following sections. These sections include a description of the minimum information requirements for:

- Sample labels
- Sample seals
- Chain-of-custody record
- Sample shipping
- Sample analysis request sheets, and
- Laboratory logbook.

### Sample Labels

The primary function of the sample label is to prevent misidentification of samples. The sample label will be completed using a waterproof ink marker. It will be firmly affixed to the sample container. Even if the label has a self-adhesive back, it is recommended that transparent cellophane tape be applied over the label to ensure it is not dislodged during shipping and handling.

### Sample Seal

If a common carrier will be used to transport samples to the contract laboratory, seals will be used to ensure that samples have not been disturbed during transportation. Two-inch nylon reinforced packing tape will be used to seal individual sample containers. As a further precaution, a custody seal, signed and dated by the designated recordkeeper, must be affixed over the tape and/or to the sealed ice chest.

### Chain-of-Custody Record

All samples must be accompanied by chain-of-custody forms. The chain-of-custody record provides the necessary documentation to track sample possession from time of collection through analysis. Figure - 2 illustrates the chain-of-custody form to be utilized by the field sampling team.

## A & M ENGINEERING
## AND
## ENVIRONMENTAL SERVICES, INC.

TULSA, OKLAHOMA

ENGINEERING - ENVIRONMENTAL - CONSTRUCTION

3840 SOUTH 103rd EAST AVENUE - TULSA, OKLAHOMA 74146
TEL (918)665-6575 FAX (918)665-6576

| | | |
|---|---|---|
| SAMPLING FIRM | CLIENT CONTACT | PHONE NUMBER |
| PROJECT NUMBER | PROJECT NAME | |

SAMPLERS: *(Signature)*

FIGURE 2

| STA. NO | DATE | TIME | COMP | GRAB | STATION LOCATION | MATRIX | NO. OF CONTAINERS | RUSH ? | | ANALYTICAL TESTS REQUIRED | | | | | | | | | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | YES | NO | | | | | | | | | | | | |
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| RELINQUISHED BY: *(Signature)* | DATE | TIME | RECEIVED BY: *(Signature)* |
|---|---|---|---|
| RELINQUISHED BY: *(Signature)* | DATE | TIME | RECEIVED BY: *(Signature)* |
| RELINQUISHED BY: *(Signature)* | DATE | TIME | RECEIVED BY: *(Signature)* |

| RELINQUISHED BY: *(Signature)* | DATE | TIME | RECEIVED BY: *(Signature)* |
|---|---|---|---|
| RELINQUISHED BY: *(Signature)* | DATE | TIME | RECEIVED BY: *(Signature)* |

REMARKS:

The chain-of-custody documentation will include, at a minimum, the date, time and conditions under which the samples were collected along with the preservation techniques and the shipping data. The original chain-of-custody record will be sealed in a watertight pouch and placed in one of the sample coolers just before it is closed and sealed. A copy of the chain-of-custody report will be placed in the sampling logbook.

### Sample Transportation

After collection of groundwater samples, the sample containers will be packed into plastic coolers lined with plastic bags. Sample bottles will be suitably packed in styrofoam to avoid breakage. The temperature in each cooler will be maintained at 4 degrees C by two large, frozen "blue ice" packs. After packing, the shipping coolers shall be secured closed with 2" wide nylon fiber reinforced packing tape and sealed with custody seals. The groundwater samples shall be delivered the day of collection to Southwest Laboratory of Oklahoma (SWLO) for analysis.

### Sample Analysis Request Sheets

The chain-of-custody form used includes information on required analyses.

### Laboratory Logbook

Once the sample has been received in the laboratory, the sample custodian and/or laboratory personnel should clearly document in a logbook the processing steps that ar applied to the sample. All sample preparation techniques (e.g., extraction) and instrumental methods must be identified in the laboratory logbook. Experimental conditions, such as the use of specific reagents (e.g., solvents, acids), temperatures, reaction times and instrument settings should be noted. The results of the analysis of all quality control samples should be identified specific to each batch of groundwater samples analyzed. The laboratory logbook should include the time, data and name of the person who performed each processing step.

## QUALITY ASSURANCE/QUALITY CONTROL

### Field and Sampling

The field quality control program is the responsibility of the sampling company and the laboratory. The laboratory will supply a sufficient number of containers for each group of parameters to be analyzed. One bottle of each type (glass and polyethylene) will be filled with reagent grade deionized water and transported to the field sampling location and returned to the laboratory in a manner identical to field handling procedures for other samples. These samples referred to a "trip blanks" will be subjected to the same analysis as groundwater.

If contaminants are detected and are within the range of one order of magnitude when compared to field sample results, the well will be resampled. One trip blank per sampling event will be used.

The field equipment, such as pH meter and Specific Conductance meter, will be calibrated prior to transport to the field, and once in the field, instruments will be calibrated between each well. The pH meter is calibrated with prepared solutions as is the Specific Conductance meter. The date of laboratory calibration will be shown on the field sample collection data sheet. An equipment blank will be collected to ensure that any non-dedicated sampling equipment has been cleaned. To collect, run reagent-grade water through all equipment and transfer water to sample bottles. Samples will be subjected to same analyses as well samples.

## Laboratory QA/QC Procedures

The laboratory has the responsibility of providing quality control within the laboratory. The laboratory has presented a QA/QC program prior to initiation of implementation of sampling and analysis. The plan provides for the use of standard, laboratory blanks, duplicates and spiked samples for calibration and identification of potential matrix interferences.

Laboratory control requirements for this project will include:

1) System performance checks
2) Continuing calibration checks
3) Method blank analysis
4) Interval standard area and retention time monitoring
5) Matrix spike/duplicates
6) Surrogate spikes
7) Criteria for qualitative identification

Specifically, the above are described by Fisk (1986) in ASTM STO 925. Data form QC samples will be used as a measure of performance and as an indicator of possible cross-contamination.

# ATTACHMENT 1

# RESUMES OF SAMPLING PERSONNEL

Professional Qualifications of

# Irfan Taner, C. P. G.

Geologist/Hydrogeologist

## Education

B. S., Geology/Geophysics, University of Istanbul - 1973
M. S., Geology, University of Istanbul - 1974,
Graduate Studies (Geology), University of Tulsa - 1980 - 1981

## Areas of Expertise and Experience

Mr. Taner has over 21 years professional experience in earth sciences. He has developed expertise in field and subsurface mapping, hydrogeology, environmental geology, stratigraphy, structural geology/tectonics, petroleum geology and engineering geology. His experience in hydrogeology - environmental geology includes hazardous and non-hazardous site characterization, evaluation, and remedial design; groundwater monitor well design, construction and sampling; deep injection well design, permitting, construction and operation; landfill permitting design and construction; groundwater characterization and modeling. He has used many different data sets in different disciplines and, from this experience, has developed the expertise to integrate them and evaluate very complex projects.

Mr. Taner has also served as an expert in several civil litigations involving environmental cases.

| | |
|---|---|
| 1988-Pres. | Chief Geologist, A & M Engineering and Environmental Services, Inc. |
| 1983-1988 | Consulting Geologist, A. A. Meyerhoff and Associates, Tulsa, Oklahoma |
| 1981-1983 | Geologist/Geophysicist, Borehole Exploration Co., Tulsa, Oklahoma |
| 1980-1981 | Geologist, Cities Service Technology Center, Tulsa, Oklahoma |
| 1976-1980 | Geologist, Turkish Petroleum, Ankara, Turkey |
| 1975-1976 | Geologist, Turkish Army, Ankara, Turkey |

## Publications

Mr. Taner has published 20 papers in refereed journals and co-authored two books, China - Stratigraphy, Paleogeography & Tectonics, a comprehensive treatment of the geology of China, and Tectonics: A New Hypothesis of Global Geodynamics, both published by Kluwer Academic Publishers.

## Associations

Association of Engineering Geologists
American Association of Petroleum Geologists
Association of Groundwater Scientists and Engineers
AAPG Division of Environmental Geosciences
(Charter Member)
Tulsa Geological Society

## Registrations and Certifications

Certified Professional Geologist: American Institute of Professional Geologists
Registered Professional Geologist: Tennessee, Kentucky
Licensed UST Tank Consultant - Oklahoma
Licensed Geotechnical Well Driller - Oklahoma
Certified Hazardous Waste Operator

## Representative Project Experience (Partial List)

**Farmland Industries, Inc., Coffeyville, Kansas.**
Conducted survey and site characterization of hazardous refinery sludge ponds. Prepared groundwater evaluation for pond closures and onsite landfill construction. Designed and installed groundwater monitoring system for lagoons and landfill.

**IMCO Recycling Inc., Sapulpa, Oklahoma.**
Investigated the shallow and deep groundwater aquifers in relation to onsite Class I industrial deep injection well, retention pond and landfill. Assisted in management and disposal of aluminum salt cake, magnesium salt cake, and baghouse dust from an aluminum and magnesium recycling operation.

**IMCO Recycling Inc., Morgantown, Kentucky.**
Project Manager for design, permit application preparation, and construction of Class I industrial deep injection well. Conducted hydrogeological surveys of plant area for onsite landfills, retention ponds and plant structures and developed three dimensional models for the site. Installed surface and groundwater monitoring systems and oversee operation of the systems.

**McDonnell Douglas Corp., Tulsa, Oklahoma.**
Project Manager for process areas characterization for soil and groundwater contamination, remedial design, and remediation. Machine pits contamination investigation, remediation and closure. Hydrogeological investigation and groundwater modeling for onsite hazardous waste lagoons and landfill.

**Duralast (Unarco Industries, Inc.), Tulsa, Oklahoma.**
Site characterization, groundwater and surface water investigation, remedial design for soil and groundwater, and site remediation.

**Browning Ferris Industries, Tulsa, Oklahoma.**
Groundwater investigation, permitting, and evaluation of groundwater monitoring system.

**Valero Energy, San Antonio, Texas.**
Conducted hydrogeological survey and investigated soil and groundwater contamination. Prepared remediation design.

# Professional Qualifications of

# Peter L. Schultze, R. P. G.

Geologist

## Education

B.S., Geology, University of Oklahoma - 1989
Post Graduate Studies toward M. S., Civil Engineering, University of Oklahoma - (Present)
Post Graduate (3 CEU), University of Texas at Austin - 1993

## Areas of Expertise and Experience

Since 1989, Mr. Schultze has served as a Geotechnical Scientist for A & M in the areas of Geotechnical Engineering, Monitor Well Installation and Development, Soil Mechanics, Environmental Site Assessments, Low Level Radiation Surveys, PSD permit applications, and Liner Installation Supervisor for municipal Subtitle D landfills.

Mr. Schultze is A & M's Radiation Safety Officer and is certified to use a nuclear dosimeter. He has completed radiation safety courses for operation of a nuclear moisture/density gauge, extended radiation safety training as well as the 40-hour SARA Operation Training Course.

Mr. Schultze also manages A & M's Geotechnical Soil Laboratory. This laboratory performs grain size analysis, density, plasticity, permeability, and other characteristic analyses of soil and gravel. The laboratory also maintains and uses a nuclear density gauge for field in-situ moisture and density measurements.

Among his duties as Radiation Safety Officer, Mr. Schultze conducts yearly refresher courses for nuclear density gauge operators and reviews documentation for Nuclear Regulatory Commission permit compliance.

## Registrations and Certifications

Registered Professional Geologist, Missouri
Licensed Geotechnical Well Driller, Oklahoma
Certified Radiation Safety Officer (NRC 10 CFR Part 30)
Certified Troxler Nuclear Density Gauge Operator
Certified Hazardous Waste Operator and Supervisor

## Associations

Association of Engineering Geologists
National Water Well Association
Tulsa Geological Society

## Representative Project Experience (Partial List)

**Browning Ferris Industries, Inc., Red Bird, Broken Arrow, and Oklahoma City, Oklahoma.**
Project Manager for clay and geosynthetic liner inspection and certification reports for landfill facilities at each of the above sites. Includes moisture and compaction analyses using a nuclear density gauge.

**UNR Industries, Inc. (Duralast Rubber Facility), Tulsa, Oklahoma.**
Conducted radiation survey of facility to determine radiation levels at the site. Materials stored on site were suspected to be radioactive, and the survey was conducted to determine the radiation levels and potential health risk. No health risk was discovered.

**Waste Management, Inc., Tulsa and Muskogee, Oklahoma.**
Conducted radiation survey of landfills to determine if radioactive material was being placed in active landfills. Equipment, dump trucks, and refuse being placed in the landfills were all surveyed and recorded.

**IMCO Recycling Inc., Morgantown, Kentucky.**
Site Geologist during completion of boring plan for a Subtitle C industrial landfill. Interpreted boring cores, installed monitor wells, and performed hydraulic evaluation of site.

**Farmland Industries, Inc., Coffeyville, Kansas.**
Project Supervisor for ditch remediaton and cleanup. Removed petroleum hydrocarbon contaminated soil from surface ditches, treated the contaminated soil and disposed in an on-site RCRA vault. Conducted QA/QC sampling and supervised construction work.

**National Cooperative Refinery Association, McPherson, Kansas.**
Adaptation of computer models for a PSD permit application for a major refinery modification.

**McDonnell Douglas Corp., Tulsa, Oklahoma.**
Prepared proposal and submitted documents to the Nuclear Regulatory Commission to remove and dispose low level radioactive material from Air Force Plant No. 3. Included coordination with the NRC in determining quantities of material to be removed.

**Phase I and Phase II Environmental Site Assessments.**
Conducted nearly 100 Environmental Site Assessments for industrial and commercial properties.

# APPENDIX G

# CHEMICAL ANALYSES OF GROUND AND SURFACE WATER

**A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.**
TULSA, OKLAHOMA
ENGINEERING - ENVIRONMENTAL - CONSTRUCTION
3840 SOUTH 103rd EAST AVENUE - TULSA, OKLAHOMA 74146
TEL (918)665-6575 FAX (918)665-6578

SAMPLING FIRM: A&M
CLIENT CONTACT: Murray Mclomas
PHONE NUMBER: 665-6575
PROJECT NUMBER: 1556
PROJECT NAME: KAISER ALUM

SAMPLERS: (Signature)

| STA. NO | DATE | TIME | COMP. | GRAB | STATION LOCATION | MATRIX | NO. OF CONTAINERS | RUSH ? YES | RUSH ? NO | Brine Analysis | Total Phosphate | Barium | Sulfide | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5/13/97 | | | ✓ | MWS-5 | WATER | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | 5/13/97 | 12:00 | | ✓ | P-1 | WATER | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | 5/13/97 | | | ✓ | ST-3 | WATER | 1 | | | | ✓ | | | |
| | 5/13/97 | | | ✓ | EQUIP BLANK | WATER | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | 5/13/97 | | | ✓ | FIELD BLANK | WATER | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | 5/13/97 | | | ✓ | DUPLICATE | WATER | 4 | | | ✓ | ✓ | ✓ | ✓ | |

ANALYTICAL TESTS REQUIRED

| RELINQUISHED BY: (Signature) | DATE | TIME | RECEIVED BY: (Signature) |
|---|---|---|---|
| | 5/13/97 | 4:40 | |
| | | | |
| | | | |

| RELINQUISHED BY: (Signature) | DATE | TIME | RECEIVED BY: (Signature) |
|---|---|---|---|
| | | | |
| | | | |

REMARKS:

# A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

TULSA, OKLAHOMA

ENGINEERING - ENVIRONMENTAL - CONSTRUCTION

3840 SOUTH 103rd EAST AVENUE - TULSA, OKLAHOMA 74146
TEL (918)665-6575 FAX (918)665-6576

SAMPLING FIRM: A&M Engineering
CLIENT CONTACT: Murray McLomas
PHONE NUMBER: 665-6575
PROJECT NUMBER: 1556
PROJECT NAME: KAISER ALUM

SAMPLERS: (Signature)

ANALYTICAL TESTS REQUIRED

| STA. NO | DATE | TIME | COMP | GRAB | STATION LOCATION | MATRIX | NO. OF CONTAINERS | RUSH ? YES | RUSH ? NO | Brine Analysis | Total Phosphate | Barium | Sulfide | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5/12/97 | 3:37 | | | P-2 | WATER | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | | 10:51 | | | P-8 | | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | | 12:39 | | | MWD-5 | | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | | 11:42 | | | P-5 | | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | | 12:12 | | | MW-8 | | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | | 2:33 | | | ST-3 | | 4 | | | ✓ | ✓ | ✓ | ✓ | |
| | | | | | ~~EQUIPBLANK~~ | | 1 | | | ✓ | ✓ | ✓ | ✓ | Canceled Per Client |
| | | | | | ~~FIELD BLANK~~ | | 1 | | | ✓ | ✓ | ✓ | ✓ | " " " |
| | | | | | ~~DUPLICITE~~ | | 1 | | | ✓ | ✓ | ✓ | ✓ | " " " |
| | 5/12 | 12:48 | | | Retention Pond | | 4 | | | ✓ | ✓ | ✓ | ✓ | Added Per Client |
| | 5/12 | 11:28 | | | Fresh Water Pond | | 4 | | | ✓ | ✓ | ✓ | ✓ | " " " |
| | | | | | | | ~~4~~ MUR | | | | | | | MUB |
| | | | | | | | 5/13/97 | | | | | | | 5/13/97 |

| RELINQUISHED BY: (Signature) | DATE | TIME | RECEIVED BY: (Signature) | RELINQUISHED BY: (Signature) | DATE | TIME | RECEIVED BY: (Signature) |
|---|---|---|---|---|---|---|---|
| | 5/12/97 | 5:15 | | | | | |
| | | | | | 5/12/97 | 1715 | |
| | | | | REMARKS: | | | |

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: P-8 Project ID: KAISER AL SITE

SWLO ID: 29326.02 Report: 29326.02 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1

Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | | *** INORGANICS *** | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 154 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 23.5 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 13.8 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 12.60 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 2.06 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 213 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 481 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 40 | mg/l | 840 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 268 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 4.4 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | 0.10 | S.U. | 7.24 | 05/14/97 | | ** |
| Spec. Conductance | | 0.10 | umho/cm | 1250 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/16/97 | SW 9030 | |
| | | | *** METALS *** | | | | |
| BARIUM | | 2 | ug/l | 3650 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985
SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

**SOUTHWEST LABORATORY OF OKLAHOMA, INC.**
1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: MWD-5 Project ID: KAISER AL SITE
SWLO ID: 29326.03 Report: 29326.03 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | *** INORGANICS *** | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 122 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 42.1 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 48.7 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 0.266 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 232 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | 23.8 | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 12.1 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 478 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 1150 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 636 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 11.5 | 05/16/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/16/97 | | ** |
| pH | | 0.10 | S.U. | 9.15 | 05/14/97 | | ** |
| Spec. Conductance | | 0.10 | umho/cm | 2240 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | *** METALS *** | | | | | |
| BARIUM | | 2 | ug/l | 7670 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: P-5
Project ID: KAISER AL SITE
SWLO ID: 29326.04
Report: 29326.04 -M

Collected: 05/12/1997
Report Date: 06/03/1997
Page: 1
Received: 05/13/1997
Last Modified: 06/03/1997
Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| *** INORGANICS *** | | | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 123 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 81.2 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 60.6 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | ND | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 357 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 254 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 640 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 1730 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 981 | 05/16/97 | | ** |
| Sulfate | | 2 | mg/l | 7.9 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | 0.1 | S.U. | 7.37 | 05/14/97 | | ** |
| Spec. Conductance | | 0.1 | umho/cm | 3290 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| *** METALS *** | | | | | | | |
| BARIUM | | 2 | ug/l | 8530 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

**SOUTHWEST LABORATORY OF OKLAHOMA, INC.**
1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

| | | | |
|---|---|---|---|
| Client ID: | MW-8 | Project ID: | KAISER AL SITE |
| SWLO ID: | 29326.05 | Report: | 29326.05 -M |

| | | | | | |
|---|---|---|---|---|---|
| Collected: | 05/12/1997 | Report Date: | 06/03/1997 | Page: | 1 |
| Received: | 05/13/1997 | Last Modified: | 06/03/1997 | Matrix: | Water-Rad |

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | *** INORGANICS *** | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 47.8 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 98.7 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 25.3 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 1.87 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 194 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 228 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 524 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 1130 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 517 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 4.6 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/07 | | ** |
| pH | | .1 | S.U. | 7.91 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 2160 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | *** METALS *** | | | | | |
| BARIUM | | 2 | ug/l | 12300 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

**SOUTHWEST LABORATORY OF OKLAHOMA, INC.**
1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: ST-3
Project ID: KAISER AL SITE
SWLO ID: 29326.06
Report: 29326.06 -M

Collected: 05/12/1997
Received: 05/13/1997
Report Date: 06/03/1997
Last Modified: 06/03/1997
Page: 1
Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| *** INORGANICS *** | | | | | | | |
| BRINE PACKAGE | | | | | | | ** |
| Calcium | | .25 | mg/l | 159 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 58.4 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 1020 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | .384 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 10.4 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 139 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 637 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 13500 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 6720 | 05/16/97 | | ** |
| Sulfate | | 2 | mg/l | 11.2 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | .1 | s.u. | 7.72 | 05/14/97 | | ** |
| Spec. Conductance | | -1 | umho/cm | 6280 | 05/27/97 | | |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| *** METALS *** | | | | | | | |
| BARIUM | | 2 | ug/l | 3710 | 05/22/97 | SW 6010 | |

ND - NOT DETECTED ABOVE QUANTITATION LIMIT
B - ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I - UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM - STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* - SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D - SURROGATES DILUTED OUT
J - ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW - EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

**SOUTHWEST LABORATORY OF OKLAHOMA, INC.**
1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: RETENTION POND
Project ID: KAISER AL SITE
SWLO ID: 29326.07
Report: 29326.07 -M

Collected: 05/12/1997
Received: 05/13/1997
Report Date: 06/03/1997
Last Modified: 06/03/1997
Page: 1
Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | | *** INORGANICS *** | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 16.5 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 49.4 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 24.5 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | ND | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 10.3 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | 69.7 | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 112 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 244 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 360 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 57.6 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 40.1 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | .1 | s.u. | 9.53 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 585 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | | *** METALS *** | | | | |
| BARIUM | | 2 | ug/l | 765 | 05/22/97 | SW 6010 | |

ND - NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA - NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: FRESH WATER POND
Project ID: KAISER AL SITE
SWLO ID: 29326.08
Report: 29326.08 -M

Collected: 05/12/1997
Received: 05/13/1997
Report Date: 06/03/1997
Last Modified: 06/03/1997
Page: 1
Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | | *** INORGANICS *** | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 40.2 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 7.01 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 21.8 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 1.18 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 2.74 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 113 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 129 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 208 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 13.9 | 05/16/97 | | ** |
| Sulfate | | 2 | mg/l | 38.7 | 05/16/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/16/97 | | ** |
| pH | | .1 | S.U. | 8.13 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 352 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | | *** METALS *** | | | | |
| BARIUM | | 2 | ug/l | 110 | 05/22/97 | SW 6010 | |

ND - NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I - UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA - NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

**Client Name:** A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

**Client ID:** MWS-5 **Project ID:** KAISER AL SITE

**SWLO ID:** 29344.01 **Report:** 29344.01 -M

**Collected:** 05/13/1997 **Report Date:** 06/03/1997 **Page:** 1

**Received:** 05/14/1997 **Last Modified:** 06/03/1997 **Matrix:** Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | | *** INORGANICS *** | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 14.7 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 69.3 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 29.0 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | .8 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 11.6 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | 20.5 | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 128 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 321 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 343 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 197 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 10 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | .1 | S.U. | 9.84 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 705 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | | *** METALS *** | | | | |
| BARIUM | | 2 | ug/l | 1260 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

**SOUTHWEST LABORATORY OF OKLAHOMA, INC.**

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

**Client Name:** A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

**Client ID:** P-1 **Project ID:** KAISER AL SITE

**SWLO ID:** 29344.02 **Report:** 29344.02 -M

**Collected:** 05/13/1997 **Report Date:** 06/03/1997 **Page:** 1
**Received:** 05/14/1997 **Last Modified:** 06/03/1997 **Matrix:** Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | *** INORGANICS *** | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 159 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 9.49 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 19.4 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 2.56 | 06/22/97 | | ** |
| Potassium | | .3 | mg/l | 1.57 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 414 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 436 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 511 | 06/23/97 | | ** |
| Chloride | | 2 | mg/l | 20.8 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 35.6 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | .1 | S.U. | 7.07 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 866 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | *** METALS *** | | | | | |
| BARIUM | | 2 | ug/l | 288 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: ST-3
Project ID: KAISER AL SITE
SWLO ID: 29344.03
Report: 29344.03

Collected: 05/13/1997
Report Date: 06/03/1997
Page: 1
Received: 05/14/1997
Last Modified:
Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE |
|---|---|---|---|---|---|---|
| | | *** INORGANICS *** | | | | |
| TOTAL PHOS. | | 0.10 | mg/1 | ND | 05/22/97 | EPA 365.2 |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: Equip Blank
Project ID: KAISER AL SITE
SWLO ID: 29344.04
Report: 29344.04 -M

Collected: 05/13/1997
Report Date: 06/03/1997
Page: 1
Received: 05/14/1997
Last Modified: 06/03/1997
Matrix: Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | *** INORGANICS *** | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | ND | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | ND | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | ND | 05/22/97 | | ** |
| Iron | | .1 | mg/l | ND | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | ND | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | ND | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | ND | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | ND | 05/21/97 | | ** |
| Chloride | | 2 | mg/l | ND | 05/16/97 | | ** |
| Sulfate | | 2 | mg/l | ND | 05/16/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/16/97 | | ** |
| pH | | .1 | S.U. | 5.75 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 2.6 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | *** METALS *** | | | | | |
| BARIUM | | 2 | ug/l | ND | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW - EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

| | | | |
|---|---|---|---|
| Client ID: | Field Blank | Project ID: | KAISER AL SITE |
| SWLO ID: | 29344.05 | Report: | 29344.05 -M |

| | | | | | |
|---|---|---|---|---|---|
| Collected: | 05/13/1997 | Report Date: | 06/03/1997 | Page: | 1 |
| Received: | 05/14/1997 | Last Modified: | 06/03/1997 | Matrix: | Water-Rad |

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | *** INORGANICS *** | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | ND | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | ND | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | ND | 05/22/97 | | ** |
| Iron | | .1 | mg/l | .144 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | ND | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | ND | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | ND | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | ND | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | ND | 05/16/97 | | ** |
| Sulfate | | 2 | mg/l | ND | 05/16/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/16/97 | | ** |
| pH | | .1 | S.U. | 5.88 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 1.4 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | *** METALS *** | | | | | |
| BARIUM | | 2 | ug/l | ND | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

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D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

**Client Name:** A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

**Client ID:** Duplicate P-1
**Project ID:** KAISER AL SITE
**SWLO ID:** 29344.06
**Report:** 29344.06 -M

**Collected:** 05/13/1997
**Received:** 05/14/1997
**Report Date:** 06/03/1997
**Last Modified:** 06/03/1997
**Page:** 1
**Matrix:** Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| | | | *** INORGANICS *** | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 161 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 9.58 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 19.5 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 2.23 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 1.41 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 414 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 442 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 10 | mg/l | 515 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 20.9 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 35.9 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | .1 | S.U. | 7.07 | 05/14/97 | | ** |
| Spec. Conductance | | .1 | umho/cm | 866 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | ND | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| | | | *** METALS *** | | | | |
| BARIUM | | 2 | ug/l | 288 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

**Client Name:** A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

**Client ID:** P-2 **Project ID:** KAISER AL SITE

**SWLO ID:** 29326.01 **Report:** 29326.01 -M

**Collected:** 05/12/1997 **Report Date:** 06/03/1997 **Page:** 1
**Received:** 05/13/1997 **Last Modified:** 06/03/1997 **Matrix:** Water-Rad

| TEST | DATE EXTRACTED | DETECTION LIMIT | UNITS | RESULTS | DATE ANALYZED | METHOD REFERENCE | |
|---|---|---|---|---|---|---|---|
| *** INORGANICS *** | | | | | | | |
| BRINE PACKAGE | | | | | | | |
| Calcium | | .25 | mg/l | 180 | 05/22/97 | | ** |
| Magnesium | | .25 | mg/l | 20 | 05/22/97 | | ** |
| Sodium | | .15 | mg/l | 32 | 05/22/97 | | ** |
| Iron | | .1 | mg/l | 54.8 | 05/22/97 | | ** |
| Potassium | | .3 | mg/l | 8.2 | 05/22/97 | | ** |
| Carbonate Alkalinity | | 1 | mg/l | ND | 05/23/97 | | ** |
| Bi-Carb. Alkalinity | | 20 | mg/l | 533 | 05/23/97 | | ** |
| T. Hardness as CaCO3 | | | mg/l | 542 | 05/29/97 | | ** |
| Total Dissolved Sol. | | 100 | mg/l | 630 | 05/23/97 | | ** |
| Chloride | | 2 | mg/l | 24.8 | 05/19/97 | | ** |
| Sulfate | | 2 | mg/l | 11.8 | 05/19/97 | | ** |
| Nitrate | | 2 | mg/l | ND | 05/19/97 | | ** |
| pH | | 0.10 | S.U. | 7.2 | 05/14/97 | | ** |
| Spec. Conductance | | 0.1 | umho/cm | 990 | 05/27/97 | | ** |
| TOTAL PHOS. | | 0.10 | mg/l | 0.21 | 05/22/97 | EPA 365.2 | |
| TOTAL SULFIDE | | 1.0 | mg/l | ND | 05/18/97 | SW 9030 | |
| *** METALS *** | | | | | | | |
| BARIUM | | 2 | ug/l | 1820 | 05/22/97 | SW 6010 | |

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION
SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

## TRACE ICP
## INORGANICS QUALITY CONTROL DATA SHEET
## LCS/LCSD

MATRIX **WATER**

EPISODE 29344
CLIENT AMEES

UNITS ug/l
BATCHID 970521I6

SAMPLE # METHOD BLANK
SPIKE # LCS
DUPLICATE # LCSD

| PARAMETER | TEST CODE | METHOD BLANK | | LCS | | | | | | LCS DUPLICATE | | | RPD | | | DATE | ANALYST | INSTR. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AMT. FOUND | DET. LIMIT | KNOWN CONC. | AMT. FOUND | % REC | %REC. LIMITS | | FLAG | AMT. FOUND | %REC. | FLAG | RPD | LIMIT | FLAG | ANALYZED | INITIALS | |
| Barium | MT063 | <2.0 | 2.0 | 2000 | 1970 | 99 | 80 | 120 | | 1910 | 96 | | 3.1 | 20 | | 22-May-97 | JLW | TJA#1 |
| Calcium | MT143 | <250 | 250 | 20000 | 19500 | 98 | 80 | 120 | | 19100 | 96 | | 2.1 | 20 | | 22-May-97 | JLW | TJA#1 |
| Iron | MT223 | <100 | 100 | 1000 | 1040 | 104 | 80 | 120 | | 1090 | 109 | | 4.7 | 20 | | 22-May-97 | JLW | TJA#1 |
| Magnesium | MT263 | <250 | 250 | 20000 | 19600 | 98 | 80 | 120 | | 19100 | 96 | | 2.6 | 20 | | 22-May-97 | JLW | TJA#1 |
| Potassium | MT363 | <300 | 300 | 20000 | 18000 | 90 | 80 | 120 | | 17800 | 89 | | 1.1 | 20 | | 22-May-97 | JLW | TJA#1 |
| Sodium | MT423 | <150 | 150 | 20000 | 20300 | 102 | 80 | 120 | | 19900 | 100 | | 2.0 | 20 | | 22-May-97 | JLW | TJA#1 |

**NARRATIVE:**
* = OUTSIDE QC LIMITS

29344
/TRACELCW REV 4.2
02-Jun-97

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

## ANIONS
## INORGANICS QUALITY CONTROL DATA SHEET
## LCS/LCSD

MATRIX **WATER**

EPISODE 29344
CLIENT AMEES

UNITS mg/l

SAMPLE # METHOD BLANK
SPIKE # LCS
DUPLICATE # LCSD

| PARAMETER | TEST CODE | METHOD BLANK | | LCS | | | | | | LCS DUPLICATE | | | RPD | | | | DATE | ANALYST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | AMT. FOUND | DET. LIMIT | KNOWN CONC. | AMT. FOUND | % REC | LIMITS | | FLAG | AMT. FOUND | %REC. | FLAG | RPD | LIMIT | FLAG | BATCH ID | ANALYZED | INITIALS |
| Chloride | IN055 | <2 | 2.0 | 50.0 | 49.5 | 99 | 80 | 120 | | 47.8 | 96 | | 3.5 | 20 | | 970516IC1 | 16-May-97 | LAB |
| Nitrate | IN185 | <2 | 2.0 | 25.0 | 24 | 96 | 80 | 120 | | 23.3 | 93 | | 3.0 | 20 | | 970516IC1 | 16-May-97 | LAB |
| Sulfate | IN295 | <2 | 2.0 | 50.0 | 48.1 | 96 | 80 | 120 | | 46.4 | 93 | | 3.6 | 20 | | 970516IC1 | 16-May-97 | LAB |
| Sulfate | IN295 | <2 | 2.0 | 50.0 | 49.1 | 98 | 80 | 120 | | 47.2 | 94 | | 3.9 | 20 | | 970519IC1 | 19-May-97 | LAB |
| Chloride | IN055 | <2 | 2 | 50 | 50.9 | 102 | 80 | 120 | | 48.7 | 97 | | 4.4 | 20 | | 970519IC1 | 19-May-97 | LAB |
| Nitrate | IN135 | <2 | 2 | 25 | 24.7 | 99 | 80 | 120 | | 23.7 | 95 | | 4.1 | 20 | | 970519IC1 | 19-May-97 | LAB |

**NARRATIVE:**

* = OUTSIDE QC LIMITS

29344
/ALCSW
02-Jun-97

REV 4.2

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

## GENERAL CHEMISTRY
## INORGANICS QUALITY CONTROL DATA SHEET
## LCS/LCSD

MATRIX **WATER**

EPISODE 29344
CLIENT AMEES

| PARAMETER | TEST CODE | UNITS | METHOD BLANK | | LCS | | | | | | LCS DUPLICATE | | | RPD | | | BATCHID | DATE | ANA-LYST |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | AMT. FOUND | DET. LIMIT | KNOWN CONC. | AMT. FOUND | % REC | %REC LIMITS | | FLAG | AMT. FOUND | %REC. | FLAG | RPD | LIMIT | FLAG | | ANALYZED | INI. |
| Total Phosphorus | IN240 | mg/l | <0.10 | 0.10 | 1.000 | 1.080 | 108 | 80 | 120 | | 1.060 | 106 | | 1.9 | 20 | | 9705222401 | 22-May-97 | TGG |
| TDS | IN270 | mg/l | <10 | 10 | 263.0 | 264.0 | 100 | 80 | 120 | | NA | | | | | | 9705232702 | 23-May-97 | KAL |
| Total Sulfide | IN300 | mg/l | <1.0 | 1.0 | 26.7 | 27.7 | 104 | 80 | 120 | | 25.6 | 96 | | 7.9 | 20 | | 9705183001 | 18-May-97 | TGG |
| Alkalinity | IN010 | mg/l | <20 | 20 | 100.0 | 95.3 | 95 | 80 | 120 | | 96.4 | 96 | | 1.1 | 20 | | 9705230101 | 23-May-97 | LAB |

NARRATIVE:

* = OUTSIDE QC LIMITS

# SOUTHWEST LABORATORY OF OKLAHOMA, INC.

## GENERAL CHEMISTRY
## INORGANICS QUALITY CONTROL DATA SHEET
## LABORATORY CONTROL SAMPLE

MATRIX **WATER**

EPISODE 29344
CLIENT AMEES

| PARAMETER | TEST CODE | UNITS | STANDARD READING | LCS READING | % DIFF. | LIMIT | FLAG | BATCHID | DATE ANALYZED | ANA-LYST |
|---|---|---|---|---|---|---|---|---|---|---|
| Conductance | IN080 | umhos/cm | 142 | 149 | 4.9 | 5 | | 9705270801 | 27-May-97 | KAL |
| pH | IN220 | su | 7.00 | 7.00 | 0.0 | 1 | | 9705142201 | 14-May-97 | KAL |

NARRATIVE:
* = OUTSIDE QC LIMITS

29344
/GWCOND\PH REV 4.2
02-Jun-97

# APPENDIX H

## Storm Flow Calculations

# SAMPLE CALCULATION OF PEAK FLOW DISCHARGES

Soil Conservation Service techniques for predicting flows in Fulton Creek were used to predict peak flow in response to rainfall events. The RSA (1996) classified the 297-acre watershed as predominantly commercial and light industrial. The soil types are grouped into the hydrologic soil group of C of moderate to high runoff (Tulsa County Soils, SCS).

The volume of runoff (Q) depends on the volume of precipitation (P) and the volume of storage available for retention. The actual retention (F) is the difference between the volumes of precipitation and runoff. A certain volume of the precipitation at the beginning of the storm, which is called the initial abstraction ($I_a$), will not appear as runoff. The SCS assumed the following rainfall-runoff retention, shown in Figure H-1.

Where:

$$\frac{F}{S} = \frac{Q}{P - I_a}$$

in which S is potential maximum retention.

An empirical analysis was performed for the development of the SCS rainfall-runoff relations. This relationship is illustrated in Figure H-1.

Where: $I_a = 0.2S$

Studies further indicate that S can be estimated by:

$$S = \frac{1000}{CN} - 10$$

in which CN = runoff curve number. The CN is a function of land use, antecedent soil moisture and other factors which affect runoff and retention. Table H.1, taken from Sheaffer et al (1982), presents the data from which CN 91 for the upper watershed was chosen. For calculation, the CN 90 is used.

Antecedent soil moisture has an effect on volume and rate of runoff. For example, if the Fresh Water Pond is full, storm water passes through with no retention. The SCS developed three antecedent moisture conditions (AMC) labelled I, II, and III.

| | |
|---|---|
| AMC I | Soils are dry, satisfactory cultivation |
| AMC II | Average conditions |
| AMC III | Heavy rainfall, or light rainfall and low temperatures have occurred within the last 5 days; saturated soil. |

Rainfall limits over the past 5 days for the three antecedent moisture conditions are:

| AMC | Dormant Season (inches) | Growing Season (inches) |
|---|---|---|
| I | Less than 0.5 | Less than 1.4 |
| II | 0.5 to 1.1 | 1.4 to 2.1 |
| III | Over 1.1 | Over 2.1 |

Given a CN of 90 for Condition II, the corresponding CN for Condition I is 78 and for Condition III is 98. This illustrates the large range between dry and wet conditions.

Using the SCS set of curves, the peak discharge and volume of water discharge at Fulton Creek can be accurately estimated. For example, to determine Runoff Volume from 5-inch rainfall for AMC II, Figure H-1 is used. The 5-inch rainfall produces 4.2 inches of direct runoff. Over the 297-acre watershed, the volume is 103.9 acre-feet of water. As the Kaiser facility is only 25 acres of the 297 or 8 percent, modifications of the existing topography at

Kaiser will be minor for the overall hydrologic regime. A sample computation of runoff and peak flow is included as Table H.2.

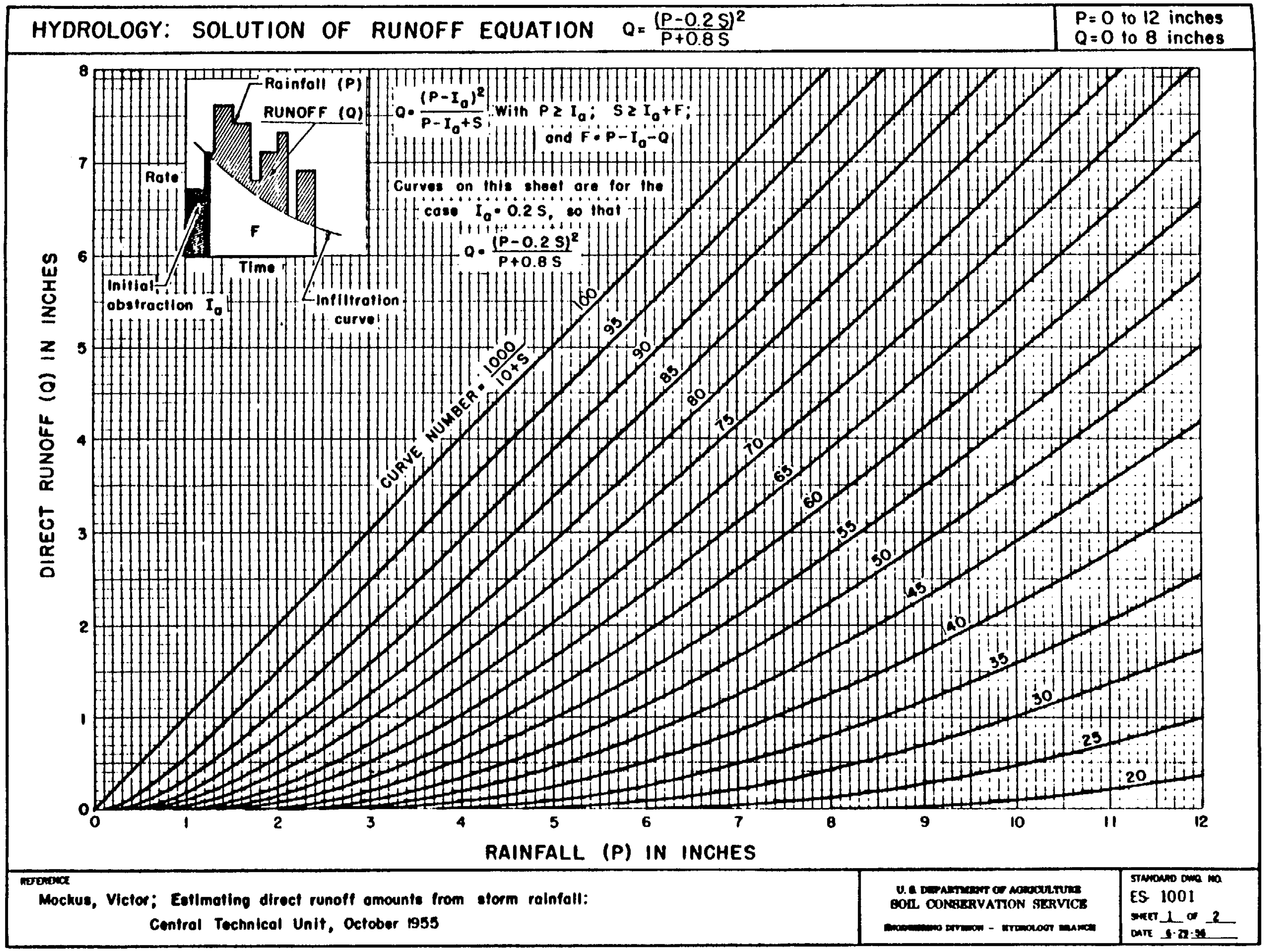
The 25-year return period storm for the Tulsa area is 7 inches (SCS, 1972). For AMC II, the curve number of 90 indicates a Direct Runoff (DRO) of 5.8 inches (Figure H-1). This DRO is an approximate volume of 5.8 inches over the 297-acre watershed. This is a volume of approximately 143 acre-feet.

To calculate the peak flow, the velocity method is used. The steps for this calculation, shown on Table H.2 are the following:

- Use Table H.4 to determine land use factor. For Kaiser site, use adjustment of 0.2 for percentage of swampy area. For storm frequency of Tr-25, adjustment factor is 0.96.
- Use Table H.5 to determine slope effect. The slope is approximately 3 percent over 297 acres. The slope factor is, therefore, 90.
- Use Figure H-2 to estimate hydraulic length and drainage area relationship. The 297 acre watershed has an approximate watershed length of 6000 feet.
- Use Figure H-3 to estimate velocity based on slope and land use. For a 3 percent slope over paved area with small gullies, the estimated velocity is 2.5 fps. Calculate $T_c$ per Table H.2.
- Use Figure H-4 to estimate Peak Flow for $T_r$-25. For $T_c = 0.66$, peak flow will be 420 cfs/mi$^2$/inch or 1130 cfs.

The data indicate that closure of the shallow Fresh Water Pond will only impact the runoff under AMC I conditions. The Pond, when full, passes water through as if it were a channel. The main difference is the time to peak flow which would be a function of the condition of the pond at the time of runoff. Without the Pond, peak flow will occur earlier and decline sooner.

The peak flow for AMC II conditions is calculated from SCS curves as shown in Table H.4. The sample calculation indicates a projected discharge of 1130 cfs is for a 25-year storm. The calculation indicates that the Peak Flow velocity will be 2.5 feet per second with a discharge of 143 acre-feet. As the discharge is above the V notch weir, the peak height can be estimated by employing the upper part of the weir which is a Broad Crested Weir. The calculation is shown on Table H.5. The discharge will raise the water level at the weir approximately 10.7 feet. This will be at an elevation of about 690 feet. The 690 elevation will put water on the slopes of the closed Reserve Pond with a velocity of 2.5 feet per second. Any final covering or cap on the Reserve Pond or on a closed Retention Pond would be designed to withstand surface water encroachment with a velocity of about 2.5 feet per second.



REFERENCE

Mockus, Victor; Estimating direct runoff amounts from storm rainfall: Central Technical Unit, October 1955

**Figure H-1** Graphical Solution of Rainfall-Runoff Equation

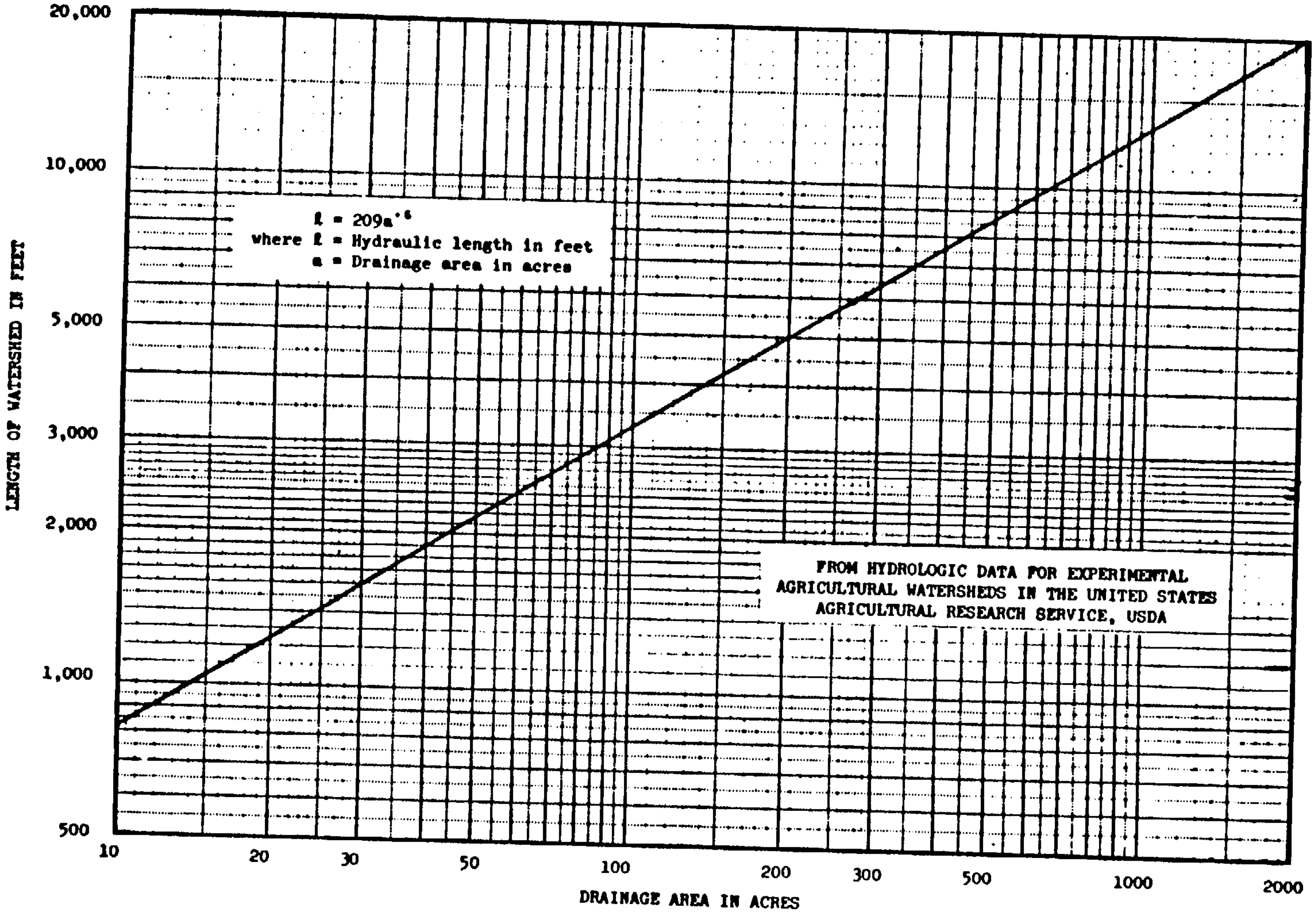


Figure H-2 --Hydraulic length and drainage area relationship.

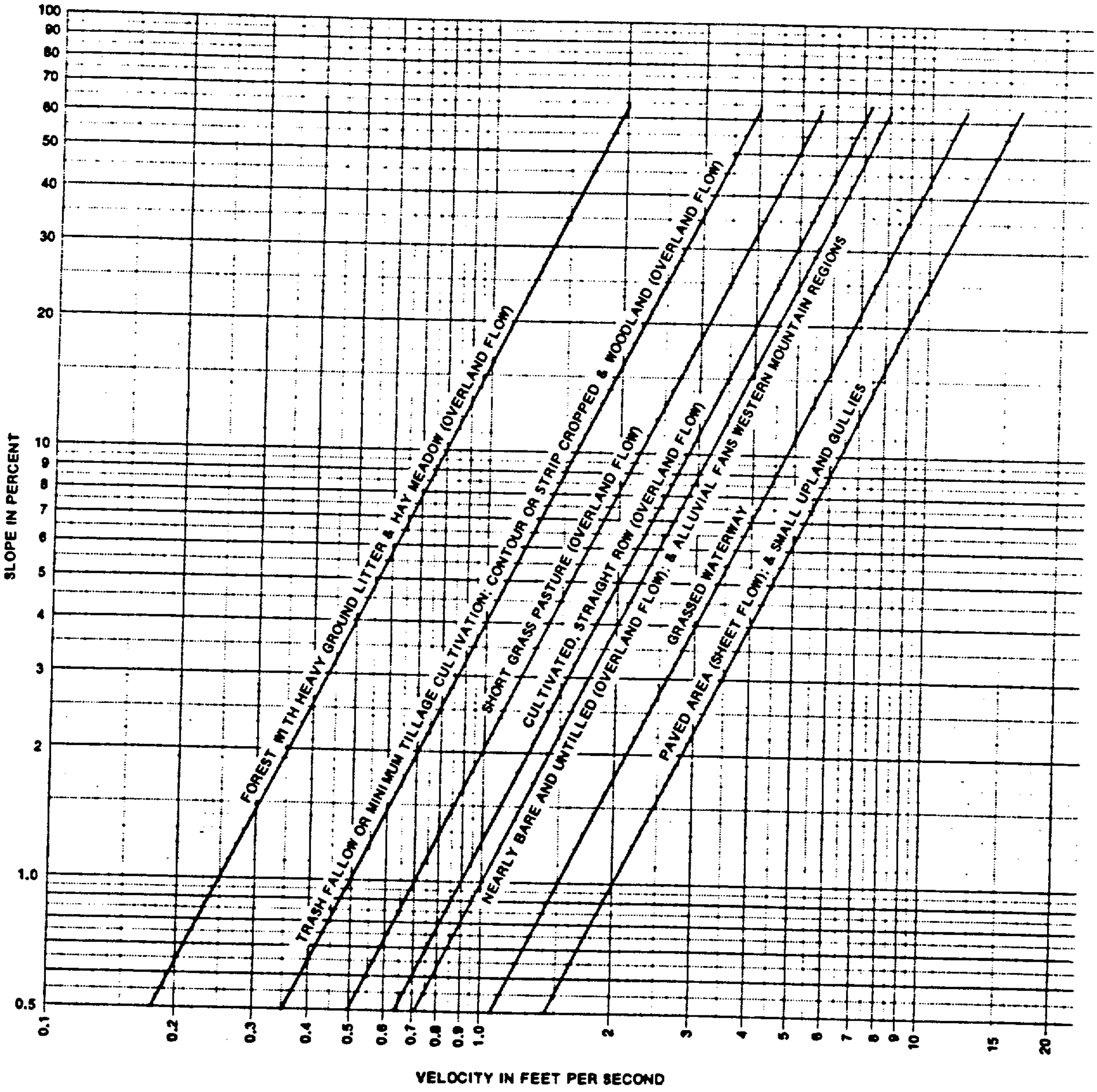


Figure H-3 Velocities for upland method of estimating $T_c$

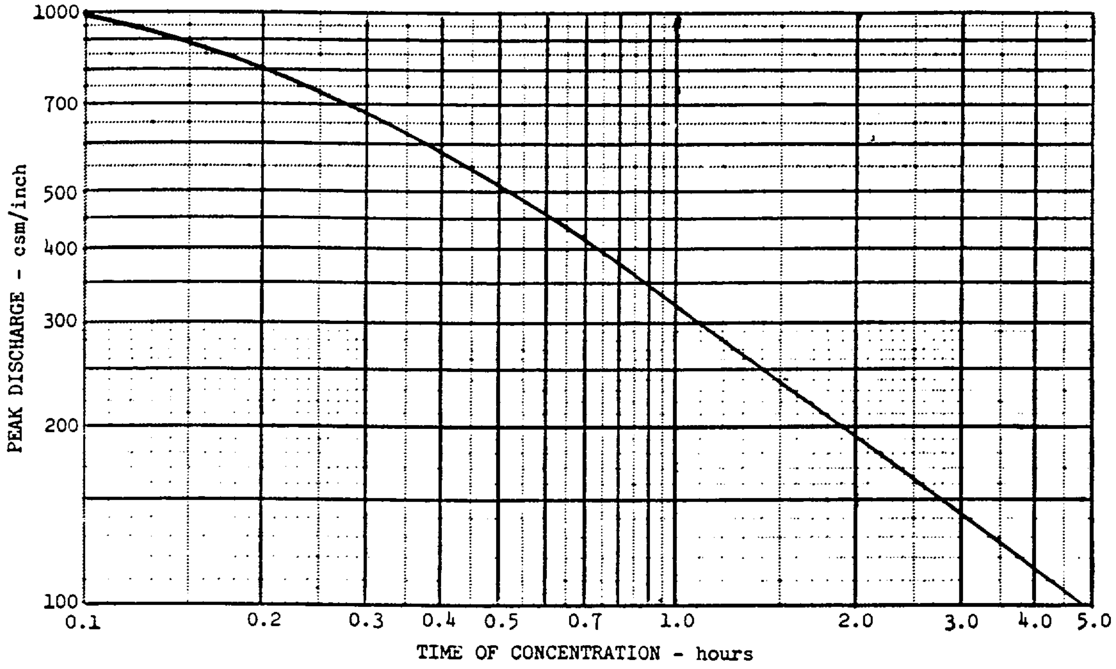


**Figure H-4** Peak discharge in csm per inch of runoff versus time of concentration ($T_c$) for 24-hour, type-II storm distribution.

To further define limitations on the graphical method the results of numerous TR-20 runs were compared with estimates of peak discharge made with the graphical method. The runs were made for ranges of the time of concentration (hours), the precipitation volume (inches), and the curve number of 0.5 to 5.0 hours, 1.0 to 10.0 inches, and 50 to 95 curve number units, respectively. The results indicate that the graphical method is a valid approximation of TR-20 as long as the initial abstraction is less than 25 percent of the total 24-hour rainfall; this constraint is easily assessed using the following tabular representation of the constraint, which relates the curve number (CN) and the minimum precipitation:

| CN | minimum precipitation |
|---|---|
| 50 | 8.00 inches |
| 60 | 5.33 |
| 70 | 3.42 |
| 80 | 2.00 |
| 90 | 0.88 |
| 95 | 0.42 |

Table Runoff Curve Numbers for Selected Agricultural, Suburban, Urban Land Use (Antecedent Moisture Condition II, and $I_a$ 25)

## Table H.1

| Land use description | | Hydrologic soil group | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| Cultivated land:[a] | | | | | |
| Without conservation treatment | | 72 | 81 | 88 | 91 |
| With conservation treatment | | 62 | 71 | 78 | 81 |
| Pasture or range land: | | | | | |
| Poor condition | | 68 | 79 | 86 | 89 |
| Good condition | | 39 | 61 | 74 | 80 |
| Meadow: good condition | | 30 | 58 | 71 | 78 |
| Wood or forest land: | | | | | |
| Thin stand, poor cover, no mulch | | 45 | 66 | 77 | 83 |
| Good cover[b] | | 25 | 55 | 70 | 77 |
| Open spaces, lawns, parks, golf courses, cemeteries, etc.: | | | | | |
| Good condition: grass cover on 75% or more of the area | | 39 | 61 | 74 | 80 |
| Fair condition: grass cover on 50% to 75% of the area | | 49 | 69 | 79 | 84 |
| Commercial and business areas (85% impervious) | | 89 | 92 | 94 | 95 |
| Industrial districts (72% impervious) | | 81 | 88 | 91 | 93 |
| Residential:[c] | | | | | |
| Average lot size | Average % Impervious[d] | | | | |
| 0.05 hectare (1/8 acre) or less | 65 | 77 | 85 | 90 | 92 |
| 0.10 hectare (1/4 acre) | 38 | 61 | 75 | 83 | 87 |
| 0.13 hectare (1/3 acre) | 30 | 57 | 72 | 81 | 86 |
| 0.20 hectare (1/2 acre) | 25 | 54 | 70 | 80 | 85 |
| 0.90 hectare (1 acre) | 20 | 51 | 68 | 79 | 84 |
| Paved parking lots, roofs, driveways, etc.[e] | | 98 | 98 | 98 | 98 |
| Streets and roads: | | | | | |
| Paved with curbs and storm sewers[e] | | 98 | 98 | 98 | 98 |
| Gravel | | 76 | 85 | 89 | 91 |
| Dirt | | 72 | 82 | 87 | 89 |

---

[a] For a more detailed description of agricultural land use curve numbers refer to Ref. 9, Chap. 9.

[b] Good cover is protected from grazing and litter and brush cover soil.

[c] Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.

[d] The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.

[e] In some warmer climates of the country a curve number of 95 may be used.

*Source*: U.S. Department of Agriculture, Soil Conservation Service [9].

## Table H.2

## COMPUTATION SHEET: TR-55 GRAPH METHOD

1. Estimate the volume of runoff

*a. T = Tr 25 (years): return period for design

*b. P = 7 (inches): 24-hr, T-year precipitation volume (i.e., depth)

*c. CN = 90 AMC II: runoff curve number

d. Q = 5.8 (inches): runoff volume obtained from : or Fig. 4-6

2. Drainage Area: A = 0.464 (Square miles)

3. Estimate Time-of-Concentration (use either the lag method or the velocity method)

LAG METHOD

*a. CN = ________

*b. Slope = ________ (%)

*c. hydraulic length = ________ (ft)

d. L = ________ (hours): from Fig.

e. $t_c$ = ________ (hours) $= \frac{5}{3} L$

VELOCITY METHOD

*a. land use 0.96

*b. slope = 3 (%)

*c. hydraulic length (HL) = 6000 (ft)

d. velocity (V) = 3.5 (fps): from Fig. 4-8

e. $t_c = \frac{HL}{3600V}$ 0.47 (hours)

4. Estimate unit peak discharge ($q'_p$) = 530 ($cfs/mi^2/in$): use Fig. 4-9

5. Estimate peak discharge $q_p = q'_p AQ$ = 1696 (cfs)

---

*indicates required input

## Table H.3

Adjustment factors where ponding and swampy areas occur at the design point

| Ratio of drainage area to ponding and swampy area | Percentage of ponding and swampy area | Storm frequency (years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 25 | 50 | 100 |
| 500 | 0.2 | 0.92 | 0.94 | 0.95 | 0.96 | 0.97 | 0.98 |
| 200 | .5 | .86 | .87 | .88 | .90 | .92 | .93 |
| 100 | 1.0 | .80 | .81 | .83 | .85 | .87 | .89 |
| 50 | 2.0 | .74 | .75 | .76 | .79 | .82 | .86 |
| 40 | 2.5 | .69 | .70 | .72 | .75 | .78 | .82 |
| 30 | 3.3 | .64 | .65 | .67 | .71 | .75 | .78 |
| 20 | 5.0 | .59 | .61 | .63 | .67 | .71 | .75 |
| 15 | 6.7 | .57 | .58 | .60 | .64 | .67 | .71 |
| 10 | 10.0 | .53 | .54 | .56 | .60 | .63 | .68 |
| 5 | 20.0 | .48 | .49 | .51 | .55 | .59 | .64 |

Adjustment factors where ponding and swampy areas are spread throughout the watershed or occur in central parts of the watershed

| Ratio of drainage area to ponding and swampy area | Percentage of ponding and swampy area | Storm frequency (years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 25 | 50 | 100 |
| 500 | 0.2 | 0.94 | 0.95 | 0.96 | 0.97 | 0.98 | 0.99 |
| 200 | .5 | .88 | .89 | .90 | .91 | .92 | .94 |
| 100 | 1.0 | .83 | .84 | .86 | .87 | .88 | .90 |
| 50 | 2.0 | .78 | .79 | .81 | .83 | .85 | .87 |
| 40 | 2.5 | .73 | .74 | .76 | .78 | .81 | .84 |
| 30 | 3.3 | .69 | .70 | .71 | .74 | .77 | .81 |
| 20 | 5.0 | .65 | .66 | .68 | .72 | .75 | .78 |
| 15 | 6.7 | .62 | .63 | .65 | .69 | .72 | .75 |
| 10 | 10.0 | .58 | .59 | .61 | .65 | .68 | .71 |
| 5 | 20.0 | .53 | .54 | .56 | .60 | .63 | .68 |
| 4 | 25.0 | .50 | .51 | .53 | .57 | .61 | .66 |

Adjustment factors where ponding and swampy areas are located only in upper reaches of the watershed

| Ratio of drainage area to ponding and swampy area | Percentage of ponding and swampy area | Storm frequency (years) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2 | 5 | 10 | 25 | 50 | 100 |
| 500 | 0.2 | 0.96 | 0.97 | 0.98 | 0.98 | 0.99 | 0.99 |
| 200 | .5 | .93 | .94 | .94 | .95 | .96 | .97 |
| 100 | 1.0 | .90 | .91 | .92 | .93 | .94 | .95 |
| 50 | 2.0 | .87 | .88 | .88 | .90 | .91 | .93 |
| 40 | 2.5 | .85 | .85 | .86 | .88 | .89 | .91 |
| 30 | 3.3 | .82 | .83 | .84 | .86 | .88 | .89 |
| 20 | 5.0 | .80 | .81 | .82 | .84 | .86 | .88 |
| 15 | 6.7 | .78 | .79 | .80 | .82 | .84 | .86 |
| 10 | 10.0 | .77 | .77 | .78 | .80 | .82 | .84 |
| 5 | 20.0 | .74 | .75 | .76 | .78 | .80 | .82 |

Table H.4

## Slope adjustment factors by drainage areas

| Slope (percent) | 10 acres | 20 acres | 50 acres | 100 acres | 200 acres | 500 acres | 1,000 acres | 2,000 acres |
|---|---|---|---|---|---|---|---|---|
| FLAT SLOPES | | | | | | | | |
| 0.1 | 0.49 | 0.47 | 0.44 | 0.43 | 0.42 | 0.41 | 0.41 | 0.40 |
| 0.2 | .61 | .59 | .56 | .55 | .54 | .53 | .53 | .52 |
| 0.3 | .69 | .67 | .65 | .64 | .63 | .62 | .62 | .61 |
| 0.4 | .76 | .74 | .72 | .71 | .70 | .69 | .69 | .69 |
| 0.5 | .82 | .80 | .78 | .77 | .77 | .76 | .76 | .76 |
| 0.7 | .90 | .89 | .88 | .87 | .87 | .87 | .87 | .87 |
| 1.0 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 1.5 | 1.13 | 1.14 | 1.14 | 1.15 | 1.16 | 1.17 | 1.17 | 1.17 |
| 2.0 | 1.21 | 1.24 | 1.26 | 1.28 | 1.29 | 1.30 | 1.31 | 1.31 |
| MODERATE SLOPES | | | | | | | | |
| 3 | .93 | .92 | .91 | .90 | .90 | .90 | .89 | .89 |
| 4 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 5 | 1.04 | 1.05 | 1.07 | 1.08 | 1.08 | 1.08 | 1.09 | 1.09 |
| 6 | 1.07 | 1.10 | 1.12 | 1.14 | 1.15 | 1.16 | 1.17 | 1.17 |
| 7 | 1.09 | 1.13 | 1.18 | 1.21 | 1.22 | 1.23 | 1.23 | 1.24 |
| STEEP SLOPES | | | | | | | | |
| 8 | .92 | .88 | .84 | .81 | .80 | .78 | .78 | .77 |
| 9 | .94 | .90 | .86 | .84 | .83 | .82 | .81 | .81 |
| 10 | .96 | .92 | .88 | .87 | .86 | .85 | .84 | .84 |
| 11 | .96 | .94 | .91 | .90 | .89 | .88 | .87 | .87 |
| 12 | .97 | .95 | .93 | .92 | .91 | .90 | .90 | .90 |
| 13 | .97 | .97 | .95 | .94 | .94 | .93 | .93 | .92 |
| 14 | .98 | .98 | .97 | .96 | .96 | .96 | .95 | .95 |
| 15 | .99 | .99 | .99 | .98 | .98 | .98 | .98 | .98 |
| 16 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| 20 | 1.03 | 1.04 | 1.05 | 1.06 | 1.07 | 1.08 | 1.09 | 1.10 |
| 25 | 1.06 | 1.08 | 1.12 | 1.14 | 1.15 | 1.16 | 1.17 | 1.19 |
| 30 | 1.09 | 1.11 | 1.14 | 1.17 | 1.20 | 1.22 | 1.23 | 1.24 |
| 40 | 1.12 | 1.16 | 1.20 | 1.24 | 1.29 | 1.31 | 1.33 | 1.35 |
| 50 | 1.17 | 1.21 | 1.25 | 1.29 | 1.34 | 1.37 | 1.40 | 1.43 |

## Table H.5

## STREAM HEIGHT FOR 25 YEAR RETURN PEAK FLOW

Discharge at Peak Flow 1130.3 cfs

Total Discharge for v notch portion of weir at H - 5.5 ft = 136.4 cfs

Total Discharge for broad crested portion for 2 ft head and 18.9 foot length

$Q = 3.33\ H^{3/2}\ (L-0.2H)$

$= 9.4 \times (18.9-0.4)$

$= 173.9$ cfs

So: Weir full discharge is 136.4 cfs + 173.9 cfs = 310.3 cfs

For: Elevation at 686.8 weir is full

For: Elevation 690 use width of 100 ft V = 2.5 cfs  H = 3.2 ft

$Q = VA = 2.5 \times 320 = 800$ cfs

And: 310.3 cfs (weir full) + 800 cfs = 1110.3 cfs

Elevation at 1110.3 cfs is approximately 3.2 + 5.5 + 2 = 10.7 ft

Bottom channel = 679.36 + 10.7 = 690.06 ft

For elevation 695 (top of berm) Q = 100x2.5x8.2 =2050 cfs

Therefore, since 2200 cfs >1499 cfs, 100 year storm will not exceed 695 ft elevation

Reference: Equation for broad crested weir

Ackers, P., W.R. White, J.A. Perkins and A.J.M. Harrison, 1978, Weirs and Flumes for Flow Measurement,

# APPENDIX I

## LIST OF FULL-SIZE FIGURES

### FIGURES

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 3-1,

## TULSA REMEDIATION PROJECT LOCATION OF BORINGS, PEZOMETERS AND MONITORING WELLS

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 3-1

**NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.**

D-1

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-1,

## TULSA REMEDIATION PROJECT SURFACE TOPOGRAPHY OF SITE

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-1

**NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.**

D-2

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-17, TULSA REMEDIATION PROJECT TOP OF BEDROCK ELEVATION CONTOURS

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-17

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D-3

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-18, TULSA REMEDIATION PROJECT CROSS-SECTION LOCATIONS

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-18

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D-4

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-19, TULSA REMEDIATION PROJECT GEOLOGIC CROSS-SECTIONS A-A' , B-B'

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-19

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D-5

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

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## FIGURE 4-20,

## TULSA REMEDIATION PROJECT GEOLOGIC CROSS-SECTIONS C-C' , D-D'

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-20

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D-6

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-21, TULSA REMEDIATION PROJECT GEOLOGIC CROSS-SECTIONS E-E'

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-21

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D-7

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-22,

## TULSA REMEDIATION PROJECT GEOLOGIC CROSS-SECTIONS F-F'

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D-8

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-23, TULSA REMEDIATION PROJECT ISOPACH OF UNIT 1 (CLAYEY SAND)

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-23

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D-9

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-24,

## TULSA REMEDIATION PROJECT ISOPACH OF UNIT 2 (CLAY)

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-24

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D-10

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-25,

## TULSA REMEDIATION PROJECT TOP OF CLAY CONTOUR MAP

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-25

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D-11

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-27,
## TULSA REMEDIATION PROJECT DEEP OVERBURDEN POTENTIOMETER CONTOUR MAP APRIL 1997

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-27

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D-12

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-28, TULSA REMEDIATION PROJECT DEEP OVERBURDEN POTENTIOMETER CONTOUR MAP SEPTEMBER 1998

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-28

**NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.**

D-13

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-29,

## TULSA REMEDIATION PROJECT DEEP OVERBURDEN POTENTIOMETER CONTOUR MAP MARCH 1999

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-29

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D-14

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-30,

## TULSA REMEDIATION PROJECT SHALLOW OVERBURDEN POTENTIOMETER CONTOUR MAP APRIL 1997

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-30

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D-15

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:
## FIGURE 4-31,
## TULSA REMEDIATION PROJECT SHALLOW OVERBURDEN POTENTIOMETER CONTOUR MAP SEPTEMBER 1998

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-31

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D-26

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE 4-32, TULSA REMEDIATION PROJECT SHALLOW OVERBURDEN POTENTIOMETER CONTOUR MAP MARCH 1999

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-32

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D-17

# THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

## THAT CAN BE VIEWED AT THE RECORD TITLED:

## FIGURE 4-38,

## TULSA REMEDIATION PROJECT FULTON CREEK PROFILE AND PROJECTED MONITOR WELLS AND WATER LEVELS

## WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DOCUMENT/REPORT NUMBER: FIGURE 4-38

**NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.**

D-18