70-925
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CIMARRON CORPORATION

P.O. BOX 25861 • OKLAHOMA CITY, OKLAHOMA 73125

October 18, 1989

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CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Mr. Davis Hurt
U.S. Nuclear Regulatory Commission
Uranium Fuel Licensing Branch
Division of Fuel Cycle & Material Safety
Office of Nuclear Material Safety & Safeguards (NMSS)
Washington, D.C. 20555

RE: License SNM-928; Docket 70-925
Amendment Request: On-site Disposition of
Uranium Containing Soils Meeting NRC
Branch Technical Position Option 2 Criteria

Dear Mr. Hurt:

Attached are four (4) additional copies of Cimarron Corporation's October 9, 1989, submittal relating to the above referenced amendment request.

Sincerely,

S. C. Munson

for John C. Stauter, Director
Environmental Affairs

JCS:gw

Enclosures

A SUBSIDIARY OF KERR-McGEE CORPORATION

JAN 16 1990

Docket No. 70-925

Cimarron Corporation
ATTN: J. C. Stauter, Director
Nuclear Licensing and Regulation
P. O. Box 25861
Kerr-McGee Center
Oklahoma City, OK 73125

Dear Dr. Stauter:

Enclosed for your information is a staff memorandum describing our meeting of December 1, 1989, concerning the Cimarron and Cushing sites.

Sincerely,

Original Signed by

Glen L. Sjoblom, Deputy Director
Division of Industrial and
Medical Nuclear Safety
Office of Nuclear Material Safety
and Safeguards

Enclosure: Memorandum of December 28, 1989
from R. D. Hurt to G. L. Sjoblom

cc: Dale McHard
Oklahoma State
Department of Health

Distribution: w/o enclosure

NRC File Center	Docket No. 70-925	PDR
NMSS R/F	IMSB R/F	IMAF R/F
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(DH/CIMARRON CORPORATION)

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JAN 23 1990

CIMARRON CORPORATION
P.O. BOX 25861 • OKLAHOMA CITY, OKLAHOMA 73125

October 9, 1989

FEDERAL EXPRESS

Mr. A. Bert Davis
U.S. Nuclear Regulatory Commission
Region III
799 Roosevelt Road
Glen Ellyn, IL 60137

Re: License SNM-928; Docket 70-925
Amendment Request: Onsite Disposition of Uranium Containing Soils Meeting NRC Branch Technical Position Option 2 Criteria

Dear Mr. Davis:

Cimarron Corporation submitted on June 29, 1988, a request for the onsite disposition of uranium contaminated soils at the Cimarron Facility. A letter dated February 3, 1989, from Jerry J. Swift of the NMSS office, requested additional information based on NRC's and State of Oklahoma's review of our request. Cimarron Corporation responds to each of the NRC and State comments in Attachments A and B to this letter. Questions related to regional and site geology/hydrology are answered in the detailed "Site Investigation Report" by James L. Grant and Associates (Attachment C) and demonstrates that the soils to be left on site as proposed under NRC's Branch Technical Position do not pose any environmental concerns.

Cimarron requests your prompt review and authorization of the proposed site program. Please contact me at your convenience should you have any questions related to these materials.

Sincerely,

J. C. Stauter, Director
Environmental Affairs

JCS:wpc

Attachment

cc: Mr. Leland C. Rouse, NRC-NMSS
Mr. Dale McHard, OSDH

0008s

ATTACHMENT A

CIMARRON CORPORATION

RESPONSE TO NRC COMMENTS
PROVIDED BY LETTER DATED FEBRUARY 3, 1989

NRC Comment 1.a.: Please provide a map showing existing pipelines and routes of old pipelines.

Cimarron Corp. Response: Exhibits I and II respectively are maps showing the Underground Piping Systems and Facilities as they existed during operations and after decommissioning. During excavation of piping, soils were analyzed and any contaminated materials removed.

NRC Comment 1.b.: Please identify, preferably on a map similar to Exhibit 1A (the borehole map) of the March 21, 1988 Request for Amendment, the areas and depths of possible soil contamination. It is not clear to us at present how the 400,000 and 3,000,000 ft^3 estimates of Table 1 in your submittal were derived.

Cimarron Corp. Response: Material volume estimates were derived from gamma logging of boreholes drilled in potentially contaminated areas at the Cimarron Facility. The borehole gamma logging results were compared to data derived from logging test drums of known concentration. Cimarron Corporation stresses that this estimation technique was used to identify those areas where contamination existed and is believed to be conservative. We are confident, however, that the borehole logging method delineated suspect areas which require evaluation and excavation.

The borehole program was undertaken to provide the bounds of volume and activity information required by NRC for evaluation of Cimarron Corporation's request for onsite disposal of uranium and thorium contaminated soils in accordance with the Branch Technical Position. The borehole program encompassed the area surrounding the uranium facility and the potentially impacted buried pipeline routes to obtain the best information to make these impacted area estimates. Approximately 300 boreholes were drilled on gridded 50 foot centers and gamma logged with reference to known standards. Approximately 7,500 gamma logging measurements were obtained by measuring at one foot intervals in each borehole.

Based upon computer interpolation of the gamma data between boreholes, the greater than Option #1 and less than Option #2 concentration soil volume was estimated at 400,000 and 3,000,000 ft^3 for material located within four feet of the surface and deeper than four feet, respectively. No material was identified as being above Option 2 concentration criteria deeper than four feet.

Probes used for gamma logging were calibrated daily using a series of specially prepared 55 gallon drums containing known uniform concentrations of uranium and/or thorium. A three inch diameter PVC access pipe was installed down the center of each drum to provide a portal for the probe. The sodium iodide (Na I) probe was placed in the center of each drum standard and the count rate recorded. In addition, soil samples were collected from randomly selected depths of several boreholes and analyzed for U-238, U-235, U-234, Th-232 and Th-228 to provide additional reference data.

The soil sample isotopic results were compared with the counting results to enhance the accuracy of the estimated in-situ concentrations. Although a strong linear statistical correlation was not demonstrated over a large count rate versus concentration range, the logging data and soil isotopic analyses support the gamma logging technique as adequate for use as a screening tool in identifying Option 1 and 2 concentration materials. Additional information concerning the logging data evaluation is included in the attached Site Investigation Report performed by James L. Grant and Associates.

The approximately 7,500 gamma logging count rate measurements were entered into a computer database[1/], analyzed and an estimate of the location and volume of soil requiring removal generated. Cimarron Corporation believes the 3,000,000 ft^3 volume estimate for material proposed to be left in-situ below at least 4 feet of soil in accordance with Option No. 2 of the Branch Technical Position is conservative. The actual volume is believed to be less because of the computer model bounds used to generate the volume estimate and the distribution of the contaminated soil. The computer model calculates volumes using the assumption that concentrations are uniform and increase/decrease uniformly in all directions between the logging point grid and the next nearest grid location.

* 1/ CPS-3 by Radian Corporation, 8501 MoPac Blvd., Austin, Texas, 78720-1088 (Volumetric Algorithm in CPS-3 software)

The count rate which represents the cut-off between Option No. 1 and Option No. 2 concentrations is also conservative. The range of values obtained from the drum source calibration program and the count rate reflecting a known sample concentration equivalent to the Option 1 cutoff criterion was identified, this value was near 26,000 cpm.

In summary, the borehole gamma logging program properly identifies suspect areas, but is not intended to provide an accurate or detailed isotopic concentration to individual borehole depth and areal locations. The volume estimates derived for soil which exceed Option No. 1 concentrations but are less than Option No. 2 levels are, therefore, conservative upper bound type estimates.

NRC Comment 1.c.:

Please translate the borehole logging data of Exhibit 2A of your March 21 submittal into picrocuries of uranium or thorium per gram of soil, at least for the potentially contaminated areas.

Cimarron Corp. Response:

Borehole gamma logging was used to identify areas which could contain materials greater than Branch Technical Position Option No. 1 uranium equivalent concentration criteria of 30 pCi/g. The technique provides a screening method for identification of areas suspected to exceed the criteria only and is not intended to provide detailed radionuclide concentration data. The borehole program identified areas which meet the applicable concentration criteria, i.e. at or below the established concentration.

Areas which have been identified to contain Option 2 concentrations of uranium by gamma borehole logging will be evaluated as required when an area is being excavated to demonstrate that the appropriate release criteria have been met. Both gamma logging and sample collection for gamma pulse height analysis will be used as methods to evaluate soil concentrations at that time.

Gamma logging will continue to be used as a screening tool to define the extent of impacted soil. In addition, samples will be collected from each area and analyzed by gamma pulse height analysis to determine the uranium activity. Soil samples collected will be placed into 500 ml bottles and analyzed. The analytical accuracy for samples analyzed using the Cimarron Facility NaI detector based gamma pulse height system has been verified by ORAU. Discussion of analysis comparison results with Mr. Davis Hurt of NRC-NMSS indicates that Cimarron Corporation's analysis system is acceptable.

Each excavated area, when decontamination is believed to be complete, will be gridded and probed at 2 meter intervals and a representative number of the grid intervals sampled for gamma spec. analysis. In unexcavated areas, the 10 meter grid and sampling program will be maintained. The analysis results for each sample will be compared to the Option 1 or Option 2 criteria. If the concentration exceeds the applicable action criterion the area will be re-excavated and resampled at locations specified by the Cimarron Facility Manager. Cimarron Corporation will maintain these sample results to demonstrate that all required contaminated soil removal is complete.

Gamma logging will also be used to probe at depths below the surface as material is excavated to identify contaminated soil below the surface which may exceed the Option 1 or Option 2 criteria, as appropriate. Excavated material will be sorted by inserting a NaI gamma logging probe into each bucket of soil at three locations and obtaining a count rate at each location. The count rate results will be used to determine into which pile the material should be placed (e.g. material stored for future placement into the designated area). Newly stockpiled material will be sampled by obtaining representative samples of the material placed in each pile and using these samples to prepare a composite sample for that pile. Composite samples will be analyzed using the Cimarron Facility gamma pulse height system.

All sample and gamma logging locations will be identified using a standard coordinate system so that locations can be easily referenced. As a quality assurance measure, randomly selected samples will be sent to the Kerr-McGee Technical Center for independent alpha pulse height analysis.

NRC Comment 2.: On page 3 of your June 29, 1988 submittal, you state that the uranium in the soil can be assumed to be 3 percent soluble. In the attachment to the June 29 submittal that addresses previous NRC questions you refer (p.2) to Exhibit 2 for solubility data on the uranium found in soil samples. The only solubility data we can find is in Exhibit 3 of your March 21 submittal. The Exhibit 3 data show solubilities ranging from 6 percent to 42 percent. Please clarify this inconsistency.

Cimarron Corp. Response: The statement on page 3 of the Cimarron Corporation June 29, 1988 submittal refers to 3 percent enrichment in U-235, <u>not</u> 3 percent solubility. The solubility data are provided in Exhibit 3 of that submittal.

NRC Comment 3.: Ground Water Issue

Cimarron Corp. Response: The ground water issues related to this comment have been comprehensively addressed by James L. Grant and Associates in their report titled "Site Investigation Report for the Cimarron Corporation Facility, Logan County, Oklahoma." A copy of this report is attached as part of this submittal. Briefly:

Consideration of the site geological and hydrological features, the characteristics of the source, the climatology and other pertinent factors shows both the material to be removed to the designated burial area and that to be left in-situ beneath at least four feet of clean soil will not represent a real or potential threat to groundwater or surface-water use in the surrounding area. Model simulations, based on site-specific data, show the potential for uranium to leach and reach the water table is very low and that if such occurs, the period required would be many tens to hundreds of thousands of years.

The old burial trenches, which have been excavated and are awaiting back filling, were located at the base of the bluff overlooking the Cimarron River flood plain and water depth in that location is strongly influenced by the river's flood plain. The designated burial area and the in-situ areas are at much higher elevations and are not influenced by the flood plain status. The wells installed clearly show the depth to water in these latter areas is greater than 20 feet.

Based on the existing ground water quality, the ready availability of supplied water and the area developmental potentials, Cimarron is not aware of any likely potential ground water uses within a mile of the site that would be hydrologically influenced by the site. The surface water potential use is similarly unlikely for the same reasons.

ATTACHMENT A

EXHIBIT I

THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED
AT THE RECORD TITLED:
"BOREHOLE & UNDERGROUND
PIPING MAP
EXHIBIT I"
DRAWING NO. ATP-C-11

WITHIN THIS PACKAGE... OR
BY SEARCHING USING THE
DOCUMENT/REPORT NO.

D-01

ATTACHMENT A

EXHIBIT II

THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

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"FACILITIES AFTER DECOMMISSIONING EXHIBIT II"
DRAWING NO. ATO-C-11
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D-02

ATTACHMENT B

CIMARRON CORPORATION

RESPONSE TO STATE OF OKLAHOMA COMMENTS
ATTACHED TO LETTER DATED FEBRUARY 3, 1989

State Comment 1.(a):	In regard to burial of the relocated wastes, SFC should specify the dust suppression methods to be used. Water spraying, if contemplated for dust suppression, could exacerbate the groundwater contamination issue by speeding leaching of contaminants from the wastes.
Cimarron Corp. Response:	Water spraying will be used to control dust emissions. The amount of water used for dust control will not be sufficient to generate leachate or result in the leaching of contaminants from the soil. Water seepage into the soil from a typical rain event will exceed the amount of water used for dust control by many orders of magnitude. Operations would be conducted in a quagmire if anything close to generation of leachate occurred from application of water spray for dust suppression. Further, the detailed site investigation demonstrates the negligible leaching potential.
State Comment 1.(b):	SFC should specify the final grade slopes proposed for the relocation burial area, preferably supported with a detailed final grade topographic map of the burial site. The Permian sediments (and the soils derived from them) in the area of the Facility are subject to severe erosion. Oklahoma requires that municipal waste landfills, for example, be graded so that final cover slopes are no steeper than 25 to 1 (horizontal or vertical).
Cimarron Corp. Response:	The final grade of the material relocation area will match the natural grade of the area existing prior to excavation. The final slope of the cover will be no greater than 25H to 1V after backfilling and site closure is complete. A vegetative cover will be established to control erosion. Surrounding areas of the property are gently rolling and routinely farmed without any evidence of gullying. Cimarron, as part of the final decommissioning closeout, will provide survey information as to location and elevation of the relocation burial area.

State Comment 1.(c): SFC should provide complete details on the methodology used to measure activity of the radioisotopes placed in the calibration drums, and how the calibration drums can be related to the measurement of isotopes in place in the soil. The correlation between calibration drums and natural soil measurement is not fully demonstrated. The relationship of known isotope mixes in the drums to gross gamma count detected by the probes does not appear to be dependably quantifiable.

Cimarron Corp. Response: The instrumentation used for the gamma logging was calibrated using a series of specially prepared 55 gallon drums containing known uniform concentrations of uranium and/or thorium. A three inch diameter PVC access pipe was installed down through the center of each drum to provide a portal for the probe. Calibration of the system was accomplished by inserting the center of the probe into the PVC pipe so the probe was also located at the center of each drum. The count rate obtained at this position was recorded for each drum standard.

In addition, soil samples were randomly collected for isotopic analysis (U-238, U-235, U-234, Th-232 and Th-228) at selected depths from several boreholes. These data were used along with the calibration drum data to develop a screening level for gamma logging to categorize material as less than Option 1, greater than Option 1 but less than Option 2, etc.

Please see Cimarron Corporation's responses to NRC Comment 1.b. in Attachment A of this submittal and State Comment 1.(d) of this Attachment for additional information relating to this issue.

State Comment 1.(d): It does not appear that SFC can reliably measure the relative quantities of isotopes in the soil by means of gross gamma scintillation probes. The soil probe data in the application shows little correlation between probe response and what is assumed (but not demonstrated by SFC) to be gamma spectrometric measurements of soil samples.

Cimarron Corp. Response: Material volume estimates were obtained from gamma logging of boreholes drilled in potentially contaminated areas at the Cimarron Facility. Cimarron Corporation emphasizes that this technique is a screening tool only and not intended to provide an isotopic analysis. We are confident the method appropriately identifies suspect areas requiring additional evaluation. Please see Cimarron's response to NRC comment 1.b. in Attachment A.

State Comment 1.(e): SFC should provide complete and detailed data on the chemical species in which the radioactive isotopes were bound when they entered the soil or water, and on the probable geochemical fate of those species in the shallow soil/bedrock environment at the Facility. The relationship between the various isotopes and other elements or compounds with which they were associated must be established to be able to characterize the non-radioactive aspects of any groundwater contamination at the Facility. Uranium is especially mobile in highly oxidizing environments, which could result in highly variable relationships between gamma count and actual isotope content of the soils and groundwater at the Facility. The time in which the contaminants have been in the subsurface is also of interest, as that will affect the observed gamma count rates, which are strongly dependent on the parent-daughter isotope relationships.

Cimarron Corp. Response: These points are comprehensively addressed in the James L. Grant and Associates report of the site investigation study for the Cimarron Facility. The monitor well analyses show there has been no impact to ground water associated with the uranium in soil; any impacts are confined downgradient of the previously closed lagoons and are steadily decreasing. The isotopic analyses address the isotope relationships.

State Comment 1.(f): SFC has not demonstrated that the wastes proposed for burial are insoluble. We also note that SFC appears to refer to 3% uranium enrichment on Page 3 of the revised application, in a context where it could be mistaken for a reference to 3% uranium solubility.

Cimarron Corp. Response: The statement on Page 3 of the Cimarron Corporation June 29, 1988 submittal refers to 3 percent enrichment in U-235, not 3 percent solubility. The solubility issue is fully evaluated and is presented in Exhibit 3 of that submittal.

State Comment 1.(g): It is not clear from the application, but it appears possible that soils meeting Option 1 Standards could be left in place as "cover" for Option 2 materials and remain within the plan proposed by SFC. Is this intended, and if so, is it within NRC's guidelines?

Cimarron Corp. Response:	Cimarron Corporation's interpretation of the Branch Technical Position is that soils with concentrations less than the Option 1 levels can be left in place without any cover requirements. Soil with concentrations greater than Option 1 levels but less than Option 2 levels may be left in place if a four foot soil cover is provided. Should soils meeting Option 1 concentration levels exist as part of the "cover" over Option 2 materials, Cimarron Corporation plans to leave this soil in place. We believe that this is permitted and appropriate under the guidance provided in the Branch Technical Position.
State Comment 1.(h):	The soils to be left in place should be delineated on a map, with distinct representation of which soils are to be treated as described on pages 4 through 6 of the revised application.
Cimarron Corp. Response:	The utility for such a "map" prior to beginning the soil reclamation program is not apparent. Cimarron's characterization program has identified the general areas meeting the option 1 and 2 criteria, but as has been stressed, additional evaluation will be done during removal to assure appropriate criteria are satisfied. Isopleth diagrams are attached (Annex I to Attachment B) which show the general areas and depths identified by the borehole gamma logging and that will be treated as described on pages 4 through 6 of the revised application dated June 29, 1988.
State Comment 1.(i):	Were soil and water samples taken in the areas downgradient from the backfilled waste ponds? It is not clear from the application how extensively these areas were sampled, but they should be sampled in assessing the groundwater and soil contamination issues. It appears that more sampling points may have been located upgradient from some of the ponds than downgradient.
Cimarron Corp. Response:	Soil and water samples were taken in areas downgradient from the previously cleaned, backfilled and released waste ponds. Additional wells were recently installed as part of the site characterization program conducted by James L. Grant and Associates. As is evident from the report, extensive sampling has been done and the status of the site has been assessed adequately.
State Comment 1.(j):	Where are wells 3011 and 3012 (see page 15, revised application)?
Cimarron Corp. Response:	The reference to well numbers 3011 and 3012 on page 15 of the June 29, 1988 revised application should be changed to well numbers 1311 and 1312. A page with these corrections is attached (Annex II to Attachment B) for insertion into that submittal.

State Comment 1.(k): SFC should clarify locations and names of features at the Facility, as the information in the application is unclear and apparently inconsistent in references to the ponds, lagoons, burial pit, and "land fill". All features should be clearly identified on the maps in the application.

Cimarron Corp. Response: Exhibits I and II to Attachment A of this submittal are maps which show the borehole, underground piping systems and the facilities to be left in place after decommissioning. These maps include the identification of the pertinent site features.

State Comment 2.(a): Monitoring data appended to the revised application show elevated concentrations of radioactive constituents, nitrates, and fluorides in several of the wells, particularly around the "landfill", which may correspond to the backfilled Waste Pond #1. Some of the concentrations reported exceed both Oklahoma's Water Quality Standards and the U.S. Environmental Protection Agency's Primary and Secondary Drinking Water Standards.

Cimarron Corp. Response: The elevated constituents are a result of previous use of the waste pond. The pond has since been cleaned, closed and released. The mechanism resulting in the appearance of uranium in the near downgradient shallow water in this area is addressed fully in the James L. Grant and Associates site investigation report. The presence of these localized concentrations is not germane to the soil disposal application. Further, as demonstrated in the site investigation report, there are not, and will not be, any discernible impacts to either groundwater or surface water potential use.

State Comment 2.(b): Additional data from Oak Ridge Associated Universities shows radioactivity in groundwater downgradient from the old burial area in the northeast part of the site.

Cimarron Corp. Response: There are four (4) groundwater monitoring wells located in and near the old burial area in the northeastern part of the Cimarron property. One of the wells is located upgradient, one well is between two of the waste trenches near the downgradient end of the old burial area and two wells are located downgradient. Elevated radioactivity levels have been detected in the well between the two trenches and in the other two downgradient monitoring wells. However, the concentrations drop significantly in the two wells located outside and downgradient of the old burial area. Radioactivity in the upgradient well is at natural background levels.

The wastes in those trenches have been excavated and shipped to a licensed facility. We believe the groundwater quality will steadily improve as any sources have been removed. Cimarron Corporation will continue to monitor, evaluate the results and report the findings to NRC and the State with the facility annual environmental monitoring report.

State Comment 2.(c): Groundwater levels in rainy seasons may be high enough to leach contaminants from the soils in the proposed soil burial and in site areas, which may violate the conditions expressed in NRC's Branch Technical Position. The application does not provide sufficient support for statements that "there are no concerns regarding contact [of the wastes] with groundwater".

Cimarron Corp. Response: The Site Investigation Report (Attachment C) submitted with this material clearly corroborates the referenced statement. In addition, a "Hydrologic Water Balance" for the Cimarron Facility was also done (Annex III to Attachment B of this submittal) and includes an evaluation of groundwater recharge at the facility. This water balance report was used by James L. Grant and Associates in evaluating the potential for local impacts. The evaluation shows there is no basis for the stated concern.

State Comment 3.(a): SFC should provide a complete assessment of the groundwater system at the site, including potentiometric maps and analyses of the groundwater sufficient to show extent and degree of radioactive and chemical contamination. Sample analyses should test for any chemical constituents found in the materials responsible for contaminating the soil that is the subject of SFC's application, as well as any constituents of other processes carried out at the plant that may have contributed to contamination of the groundwater.

SFC should include in the assessment an evaluation of the degree to which the material proposed for burial has contributed to the groundwater contamination, and a projection of continuing effects on groundwater (chemical as well as radiological) if the soils are left in place. The assessment should also contain an evaluation of the population that is or could be affected by the groundwater contamination.

Cimarron Corp. Response: The James L. Grant and Associate's Site Investigation Report is fully responsive to the matters stated above. There is no reasonably identifiable population that is or could be impacted by conditions at the site.

State Comment 3.(b): The application states that wells 1306, 1309, and 1310 are for monitoring the unsaturated zone, but that they have water in them during the rainy season. This implies that the seasonal high water table may be notably above that measured in the other wells, and that additional work is needed to assure proper determination of the seasonal water table.

Cimarron Corp. These wells were constructed near the wastewater treatment pond in the mid 60's to a predetermined depth of 20 feet. A groundwater hydrologist was not involved with these monitor wells and well construction information is not available. Periodically, these shallow wells have been noted to have a small amount of standing water. Although some amount of perched water develops on the shale layers in the unsaturated zone after periods of heavy rainfall and recharge, it is uncertain if these wells monitor a single perched zone or provide a temporary collection point for several shale layers penetrated by the well. Information derived from these wells is not considered to be reliable. The wells do not represent bonafide monitoring of the unsaturated zone.

More recently constructed monitor wells in the area, namely Wells 1320, 1325, 1335 and 1336, provide a more reliable record of seasonal water table fluctuations.

ATTACHMENT B

ANNEX I

Branch Technical Position
Option 2 Areas

Designated Impacted Areas
From Gamma Logging Results

THE FOLLOWING PAGES ARE OVERSIZED DRAWINGS OR FIGURES,

THAT CAN BE VIEWED AT THE RECORDS TITLED: GAMMA PROBE READINGS IN COUNTS / MINUTE (C/M)

WITHIN THIS PACKAGE...

D-03 THROUGH D-31

ATTACHMENT B

ANNEX II

Replacement Page 15

for Submittal of June 29, 1988

permeabilities determined from the tests of wells 1311 and 1312 are reasonable values. For the relocation site, permeabilities ranging from 0.35 to 1.7 feet per day are representative of the upper part of Garber Sandstone.

Direction and Rate of Groundwater Movement - Groundwater movement is to the north-northwest towards the Cimarron River. The difference in potentiometric surface elevation between monitor wells 1311 and 1312 along the direction of groundwater movement is 3.3 feet across a horizontal distance of 230 feet, which is equivalent to a hydraulic gradient of approximately 76 feet per mile. This relatively steep gradient is believed due to entrenchment of the prairie surface by the Cimarron River and its tributaries in the immediate vicinity. Calculations presented in Appendix C show the average velocity of groundwater movement through the upper part of the Garber Sandstone to be between 0.03 and 0.12 foot per day. Assuming the maximum velocity of 0.12 foot per day, groundwater would traverse the 230 feet along the hydraulic gradient between monitor wells 3011 and 3012 in approximately 1,917 days (5.3 years).

Meteorology:

The area climate is characterized by hot summers and moderate winters. July, the hottest month, has an average temperature of 82.9°F and January, the coldest month, averages 38.3°F. The average annual rainfall is 31 inches, received predominantly in the early spring and late fall months. The annual net evaporation rate is approximately 30 inches.

ATTACHMENT B

ANNEX III

Hydrologic Water Balance
Option Two Burial Site and Vicinity
Cimarron Corporation Facility
Crescent, Oklahoma

HYDROLOGIC WATER BALANCE
OPTION TWO BURIAL SITE AND VICINITY
CIMARRON CORPORATION FACILITY
CRESCENT, OKLAHOMA

Prepared by:

S.R. Lower
Area Hydrologist
Hydrology Department
Engineering Services Division
Kerr-McGee Corporation
May 18, 1989

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A. Cimarron Corporation Facility Water Balance Calculations
Case 1: Mean Annual Precipitation with Runoff

B. Cimarron Corporation Facility Water Balance Calculations
Case 2: Mean Annual Precipitation with no Runoff

C. Cimarron Corporation Facility Water Balance Calculations
Case 3: Maximum Recorded Annual Water-Year Precipitation with Runoff

ILLUSTRATIONS

FIGURE

1	Water-Year Precipitation at Oklahoma City, Oklahoma 1905-1987	6
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HYDROLOGIC WATER BALANCE
OPTION TWO BURIAL SITE AND VICINITY
CIMARRON CORPORATION FACILITY
CRESCENT, OKLAHOMA
May 1989

EXECUTIVE SUMMARY

A water balance has been developed for the Cimarron Corporation Facility located near Crescent, Oklahoma, following the procedures outlined in EPA publication EPA/530/SW-168 (Fenn, et al., 1975). Three soils reportedly underlie the study area, all of which are relatively thin (Mickles, et al., 1960). The compositions of the soils typically generate high runoff while precluding rapid infiltration. Based upon this analysis, it is concluded that no percolation (groundwater recharge) can be expected on the Cimarron Corporation Facility during years of average precipitation. Maximizing infiltration by artificially disregarding runoff, some groundwater recharge will occur on some areas of the site during years of average precipitation. Assuming the worst case, some groundwater recharge will occur on all parts of the site during years of maximum recorded annual precipitation.

INTRODUCTION

The water balance equates the water available to, and lost from, the site specific hydrologic regime. The purpose of this report is to estimate the water balance at the Option Two Burial Site and vicinity at the Cimarron Corporation Facility near Crescent, Oklahoma. Water availability at this site is represented by total precipitation. Water loss is by evapotranspiration, surface runoff, and soil moisture storage.

CLIMATE

Climatic data for central Oklahoma is collected at Oklahoma City by the National Oceanic and Atmospheric Administration's National Weather Service station located at Will Rogers World Airport. The climate of central Oklahoma is controlled predominantly by the continental effects of the Great Plains Region. The climate is characterized by the National Weather Service as having long and usually hot summers and comparatively mild and short winters. The continental effects of the Great Plains produce pronounced daily and seasonal temperature changes and considerable variations in seasonal and annual precipitation.

Air Flow

The climate of the Oklahoma City area and vicinity is dominated by continental air masses which assume the temperature and moisture characteristics of the land. Prevailing winds are out of the south except in January and February when northerly breezes predominate.

Precipitation

The mean annual water-year precipitation for central Oklahoma, based upon the 83-year Oklahoma City record extending from October 1905 through September 1988, is 32.25 inches. Annual water-year (October through September) precipitation during this period ranged from a minimum of 15.48 inches (1910-11) to a maximum of 51.79 inches (1984-85).

Approximately 64% of annual precipitation normally comes in the form of spring and summer thunderstorms. Snowfall averages less than 10 inches per year. The Oklahoma City precipitation record is presented in Table 1 and shown on Figure 1.

A cumulative departure histogram of the Oklahoma City precipitation data is shown on Figure 2. The cumulative

TABLE 1 (continued)
Oklahoma City Water-Year (Oct-Sep) Precipitation 1905 - 1987
Mean Annual Water-Year Precipitation (83 years) = 32.25 inches

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1951	1.54	1.42	0.05	1.07	1.89	2.95	1.92	5.87	0.76	3.09	2.72	0.25	23.53
1952	0.00	1.97	0.80	0.79	1.01	4.30	4.31	1.63	1.33	4.56	3.98	1.39	26.07
1953	6.17	0.74	1.20	0.43	0.69	0.67	3.04	6.21	0.93	0.79	1.24	0.63	22.74
1954	1.77	0.10	1.34	1.03	1.35	1.50	0.78	9.40	6.68	0.36	3.18	4.73	32.22
1955	8.34	0.04	0.03	0.26	1.31	0.56	2.43	5.07	2.46	2.19	0.86	0.20	23.75
1956	3.76	1.49	1.97	1.49	0.86	2.19	7.32	8.67	8.60	0.63	1.08	5.58	43.64
1957	2.65	2.25	0.72	1.29	0.83	3.39	2.22	3.10	7.17	2.02	3.56	3.87	33.07
1958	0.00	0.60	1.11	0.31	0.69	1.40	2.81	7.60	2.93	8.44	4.10	7.90	37.89
1959	6.08	0.94	3.26	1.47	2.12	0.85	3.01	6.79	5.68	7.69	2.89	1.62	42.40
1960	4.66	0.24	2.48	0.15	1.98	3.35	0.73	1.92	3.86	4.82	2.91	7.37	34.47
1961	2.86	3.81	1.04	1.45	1.02	0.80	2.16	2.64	7.84	1.71	2.26	3.08	30.67
1962	2.43	1.34	0.76	0.21	0.22	3.21	2.77	1.91	2.35	6.19	1.61	1.91	24.91
1963	2.05	2.45	0.89	0.83	2.17	1.30	2.06	5.21	0.77	2.01	4.91	2.96	27.61
1964	0.84	5.46	0.62	0.98	0.85	0.86	3.24	2.14	3.65	1.57	3.37	3.94	27.52
1965	1.00	0.06	2.51	1.05	2.39	1.30	3.68	0.88	2.63	2.38	6.77	2.82	27.47
1966	0.37	0.84	0.45	0.77	0.20	2.49	5.71	4.25	2.27	1.21	1.40	3.15	23.11
1967	2.92	0.40	1.04	2.19	1.02	2.84	3.03	8.40	2.39	1.41	3.75	2.64	32.03
1968	2.40	4.11	1.33	0.20	1.93	3.01	1.66	3.99	4.92	1.42	2.38	6.51	33.86
1969	1.58	0.06	1.44	0.32	0.29	2.09	5.33	6.53	2.45	1.30	0.80	9.64	31.83
1970	3.29	1.03	0.26	0.75	1.95	0.07	0.62	2.68	5.15	4.13	2.13	4.25	26.31
1971	2.62	0.29	2.79	0.21	0.43	1.13	3.10	4.03	1.36	3.22	1.82	2.04	23.04
1972	7.17	2.28	0.84	3.39	0.31	6.76	2.32	3.61	6.31	3.38	1.36	8.00	45.73
1973	3.05	2.81	0.47	0.10	2.68	3.12	4.66	5.01	3.36	0.48	4.42	6.24	36.40
1974	5.57	2.34	1.47	1.99	1.90	1.72	1.92	8.76	4.82	7.71	0.60	1.92	40.72
1975	0.84	1.77	1.30	0.00	0.33	3.09	2.94	4.36	0.88	1.38	1.46	1.53	19.88
1976	1.78	0.12	0.19	0.32	1.40	1.30	2.88	7.97	2.00	4.10	3.08	1.20	26.34
1977	2.41	1.59	0.34	1.26	3.23	1.32	1.65	10.12	4.04	3.75	0.25	0.96	30.92
1978	1.02	2.88	0.70	1.55	0.63	2.73	2.78	7.29	9.94	5.62	3.78	0.72	39.64
1979	1.58	1.93	2.57	1.69	1.29	1.38	2.16	9.00	2.52	0.42	0.60	2.21	27.35
1980	0.99	0.51	1.58	0.19	1.15	2.87	2.97	2.73	7.49	6.45	3.61	1.48	32.02
1981	7.70	2.11	0.20	3.68	0.98	1.63	1.92	12.07	4.06	2.11	1.13	2.86	40.45
1982	1.03	2.78	1.94	2.62	1.71	2.51	2.34	6.88	3.18	0.00	3.18	0.90	29.07
1983	13.18	1.90	0.70	0.35	1.16	4.70	1.79	1.62	3.48	0.30	2.35	1.01	32.54
1984	6.64	2.05	8.14	0.92	3.71	6.60	5.35	1.49	8.34	1.33	2.63	4.59	51.79
1985	5.23	3.73	0.26	0.00	0.68	1.75	4.42	8.21	3.11	0.38	3.29	9.54	40.60
1986	8.00	4.63	1.16	2.45	4.05	2.33	0.41	11.86	6.50	2.99	1.83	4.58	50.79
1987	1.82	1.92	3.75	1.24	0.41	7.85	3.19	1.07	3.59	1.92	1.60	5.19	33.55
Means	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
Minimum	0.00	0.00	0.03	0.00	0.02	0.02	0.03	0.43	0.02	0.00	0.17	0.06	15.48
Maximum	13.18	9.63	8.14	5.64	4.05	7.85	11.91	12.07	14.12	9.35	8.34	10.28	51.79

TABLE 1
Oklahoma City Water-Year (Oct-Sep) Precipitation 1905 - 1987
Mean Annual Water-Year Precipitation (83 years) = 32.25 inches

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
1905	1.29	1.42	0.70	0.89	0.56	2.28	4.77	1.43	1.54	7.30	8.34	3.93	34.45
1906	1.58	1.25	0.79	1.42	0.53	0.75	4.06	5.60	6.74	1.20	0.80	1.34	26.06
1907	3.42	0.91	2.02	1.25	3.14	0.82	6.73	9.17	12.12	1.27	1.59	4.37	46.81
1908	8.41	3.13	0.03	0.12	0.57	2.13	2.44	7.40	2.44	1.35	1.42	0.53	29.97
1909	1.73	5.29	0.34	0.89	0.53	0.65	4.31	2.72	1.09	0.94	3.08	1.72	23.29
1910	1.31	0.00	0.03	0.17	2.05	0.02	2.93	2.65	0.26	3.74	0.94	1.38	15.48
1911	1.29	0.54	3.86	0.10	1.37	4.11	2.81	2.91	4.75	2.32	3.61	2.64	30.31
1912	1.38	0.39	0.62	0.56	2.72	3.11	1.88	3.88	3.82	5.06	0.57	4.80	28.79
1913	2.52	3.71	3.38	0.05	0.86	1.68	2.41	5.07	0.02	0.62	2.76	1.70	24.78
1914	1.50	0.70	2.74	0.78	3.10	2.08	7.50	3.69	7.23	1.19	5.26	3.62	39.39
1915	2.84	1.01	0.33	4.28	0.39	1.66	3.15	0.59	6.16	2.87	0.68	2.38	26.34
1916	1.73	2.38	1.05	0.37	0.84	1.20	2.11	2.14	1.83	2.98	4.50	1.55	22.68
1917	0.02	0.80	0.04	0.95	0.07	1.55	2.45	8.31	3.09	0.13	1.91	4.28	23.60
1918	5.31	3.53	3.04	0.29	1.52	1.88	5.04	5.66	4.87	0.53	2.28	1.03	34.98
1919	8.12	2.84	0.12	2.09	0.19	4.20	2.11	8.66	2.08	4.02	4.86	3.60	42.89
1920	7.38	2.04	1.37	2.29	1.23	1.93	2.39	1.85	3.80	4.43	0.85	3.79	33.35
1921	0.18	0.33	0.18	1.15	0.64	4.37	7.67	6.83	0.30	2.31	0.19	0.90	25.05
1922	4.30	2.37	0.53	2.74	0.20	2.58	4.27	7.01	3.62	0.15	3.57	10.28	41.62
1923	9.64	2.13	2.06	0.18	0.54	3.83	3.67	2.58	3.15	3.55	3.10	2.65	37.08
1924	0.38	3.04	2.41	0.42	0.69	0.28	4.02	2.63	1.94	2.35	1.83	7.73	27.72
1925	3.12	2.42	0.31	2.13	0.04	1.81	2.66	2.09	3.77	6.69	1.23	9.58	35.85
1926	3.23	0.83	3.79	1.61	1.07	2.23	4.59	1.94	4.95	3.31	4.65	3.63	35.83
1927	7.81	0.63	1.23	0.31	1.33	1.75	3.68	1.92	4.21	2.86	1.98	0.61	28.52
1928	2.74	3.88	2.01	1.61	0.93	5.05	2.08	6.67	1.60	3.37	0.93	2.69	33.56
1929	4.49	1.74	0.57	2.69	1.29	0.25	2.30	7.53	8.76	0.60	3.12	0.16	33.50
1930	6.10	2.11	3.52	0.70	1.48	3.06	4.45	1.18	1.34	0.55	2.17	0.43	27.09
1931	1.83	9.63	1.08	4.92	1.33	0.39	0.93	5.50	14.12	2.40	2.74	1.20	46.07
1932	1.89	0.10	4.86	0.33	1.42	2.88	3.05	3.98	0.15	1.73	5.38	3.37	29.14
1933	3.34	1.88	1.61	2.06	1.15	0.95	1.46	3.61	1.98	0.13	7.44	6.45	32.06
1934	2.03	3.23	0.62	0.60	0.86	3.77	1.81	5.29	4.11	1.11	2.82	1.91	28.16
1935	2.84	2.00	1.81	0.09	0.76	0.21	0.03	5.56	0.23	0.06	0.17	8.49	22.25
1936	1.93	0.06	1.31	1.21	0.12	1.15	2.66	1.82	4.65	0.74	2.44	2.90	20.99
1937	2.25	2.47	1.12	0.92	3.66	5.51	3.06	5.92	5.45	2.75	0.84	1.23	35.18
1938	0.21	1.94	0.38	3.76	0.43	1.16	1.08	2.88	7.83	0.62	5.52	0.06	25.87
1939	2.39	0.84	0.93	0.70	3.35	0.02	4.46	3.89	3.05	5.21	3.14	2.71	30.69
1940	1.72	4.66	1.89	1.12	1.83	0.58	5.90	5.22	5.99	1.08	3.08	4.57	37.64
1941	10.35	1.49	1.07	0.37	1.40	0.53	8.58	0.43	6.97	0.60	4.87	6.73	43.39
1942	2.50	0.73	2.07	0.03	0.89	1.45	2.79	9.76	2.07	0.31	0.77	2.87	26.24
1943	1.28	0.37	2.92	2.30	2.03	3.82	4.87	2.72	6.14	1.79	1.97	2.20	32.41
1944	3.19	2.39	2.30	1.21	2.91	4.16	7.00	2.59	10.05	4.42	3.43	7.42	51.07
1945	0.37	0.27	0.08	3.31	1.92	2.64	2.07	6.92	3.80	0.18	2.39	1.70	25.65
1946	1.22	4.30	1.71	0.53	0.02	0.48	11.91	7.92	2.07	5.13	1.19	2.43	38.91
1947	0.79	1.68	2.35	0.56	3.11	6.18	2.06	4.97	9.42	3.54	1.63	0.17	36.46
1948	0.54	1.78	0.30	5.64	0.56	1.43	1.65	6.91	4.35	1.36	1.70	3.35	29.57
1949	2.97	0.00	1.07	1.76	1.32	0.12	0.85	10.34	2.60	9.35	2.92	1.55	34.85
1950	1.99	0.65	0.07	1.88	2.15	1.26	3.85	7.16	4.94	2.97	2.14	4.46	33.52

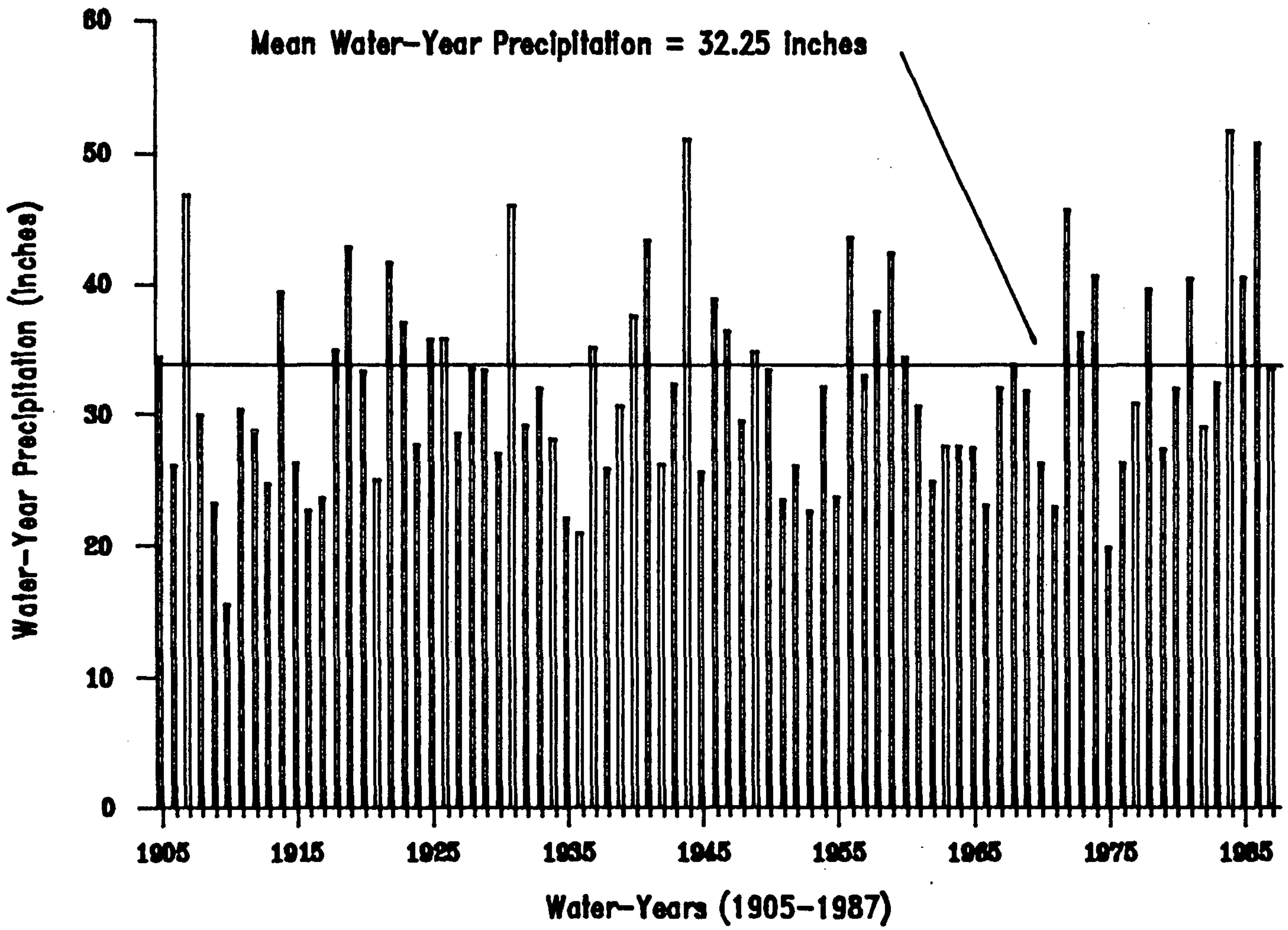


Figure 1: Water-Year Precipitation at Oklahoma City, Oklahoma 1905-1987

departure statistical analysis of precipitation typically shows the beginning, end, and duration of relative wet and dry periods.

Review of Figure 2 indicates that precipitation in central Oklahoma is not uniform. Annual precipitation is cyclic in nature, with relative wet and dry periods of several years duration alternating over the long term. Thus, soil moisture infiltration, percolation, and runoff will not be uniform. However, years of unusually high precipitation can and do occur during relatively dry periods. Likewise, years of unusually low precipitation can and do occur during otherwise relatively wet periods.

Temperature

Annual temperatures in central Oklahoma are relatively uniform. The mean annual temperature, based upon 32 years of temperature data extending from (water-year) 1956-57 through 1987-88, is 59.8 degrees (F). Annual temperatures during this period ranged from a minimum of 58.3 degrees (1979-80) to a maximum of 61.7 degrees (1965-66). Record highest and lowest temperatures are -4 degrees (January 1959) and 110 degrees (August 1980), respectively. A 32-year temperature record for Oklahoma City is presented in Table 2.

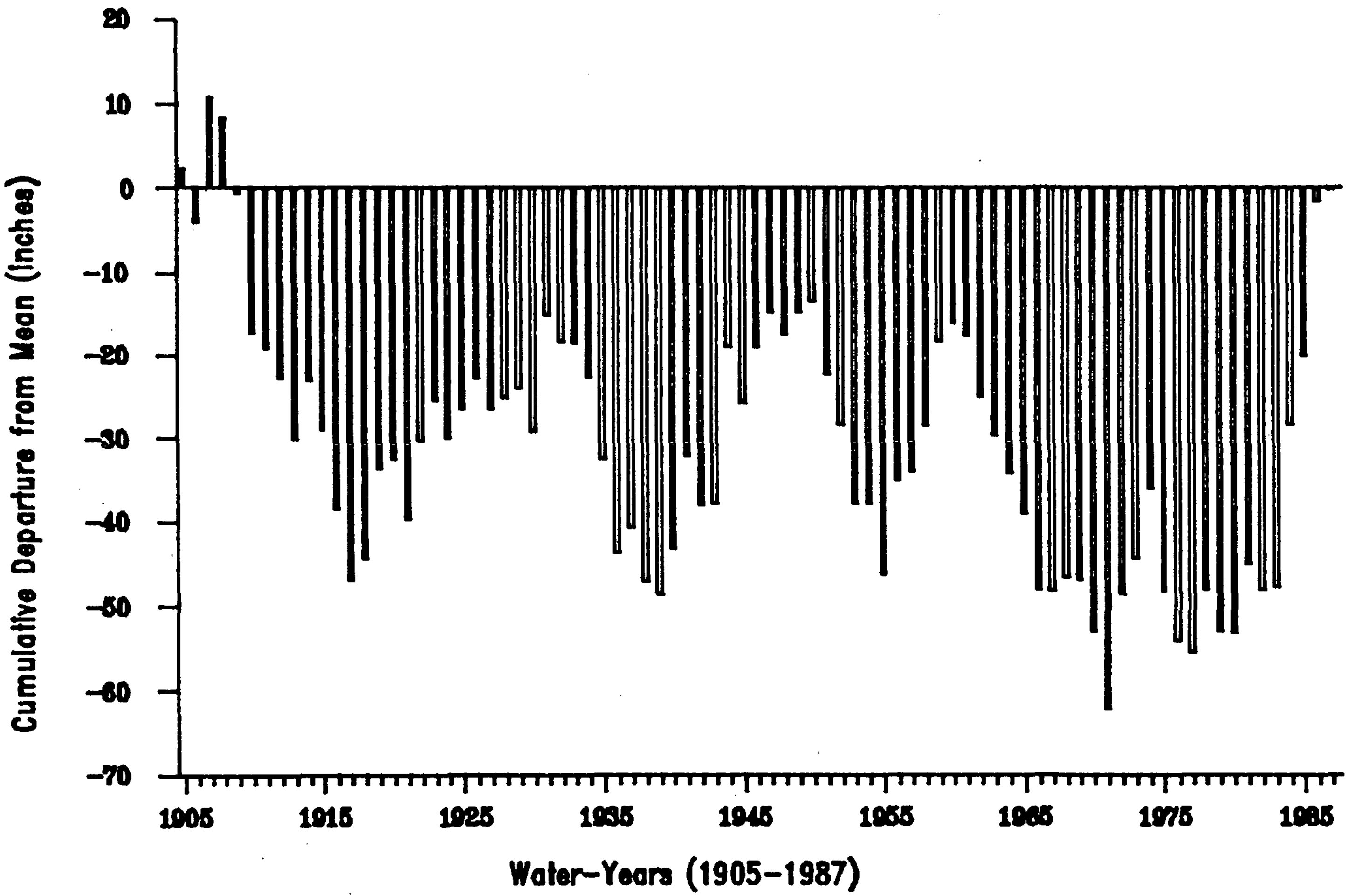


Figure 2: Cumulative Departure from Mean Water-Year Precipitation
Oklahoma City, Oklahoma 1905-1987

TABLE 2

Oklahoma City Water-Year (Oct-Sep) Temperatures 1956-1987

Mean Annual Water-Year Temperature (32 years) = 59.8 degrees

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Mean Water-Year Temp
1956	66.3	47.1	41.7	36.1	40.6	50.5	57.9	72.6	78.1	83.0	84.4	76.6	60.9
1957	57.3	45.6	44.3	33.2	45.4	46.7	55.9	65.7	74.2	83.5	80.7	69.3	58.7
1958	61.9	51.4	36.5	39.4	35.5	41.0	56.1	69.4	76.8	80.1	79.9	73.2	58.6
1959	58.3	43.5	44.2	33.0	40.0	49.6	58.5	70.4	75.7	77.4	80.1	72.6	58.8
1960	64.4	51.4	37.4	36.3	34.5	39.7	61.7	66.5	77.3	78.2	79.3	74.5	58.6
1961	63.0	46.5	36.7	36.3	42.7	52.2	59.2	67.7	74.1	79.1	78.4	70.6	59.0
1962	64.7	49.4	40.6	32.3	45.1	48.1	58.3	74.3	75.3	82.2	82.5	71.4	60.4
1963	71.1	52.3	33.0	28.3	40.0	53.8	64.8	70.3	78.7	83.1	82.0	75.1	61.0
1964	60.3	49.9	37.9	40.1	38.5	47.1	64.1	70.0	77.4	85.3	80.8	72.3	60.4
1965	62.8	56.3	48.8	38.8	39.5	40.7	65.5	71.3	78.0	84.6	80.6	73.9	61.7
1966	60.9	54.3	37.8	33.8	38.6	52.8	57.8	68.7	77.9	86.4	78.8	70.5	59.9
1967	62.6	49.4	39.8	41.8	41.7	56.4	65.4	66.9	77.4	79.7	79.3	70.9	60.9
1968	62.1	46.2	38.1	36.6	36.4	50.7	58.1	64.7	74.8	79.8	80.0	70.5	58.4
1969	57.6	48.7	40.4	38.8	42.3	42.0	60.4	67.7	75.0	83.9	80.2	73.3	59.3
1970	57.9	46.0	43.9	31.8	42.7	45.0	60.2	69.2	76.3	82.1	83.6	75.1	59.6
1971	63.4	49.0	42.2	36.9	39.1	49.1	60.4	67.3	78.6	80.7	77.2	73.3	59.9
1972	61.1	43.4	34.4	34.9	42.1	53.4	63.2	67.6	79.0	79.8	80.4	75.8	59.7
1973	64.3	53.1	39.3	33.3	39.8	52.5	56.0	66.8	75.2	79.8	79.7	70.6	59.3
1974	63.5	49.3	39.6	35.0	44.4	54.8	60.0	71.5	74.1	82.7	78.5	65.5	60.0
1975	63.4	50.7	41.8	40.3	36.5	46.1	58.7	67.4	75.1	78.0	80.1	68.3	59.0
1976	56.5	43.9	48.8	39.0	52.2	52.4	61.6	63.6	74.8	79.8	81.3	72.6	60.6
1977	62.7	50.9	40.0	29.2	45.9	54.1	62.5	70.0	79.6	83.0	80.7	78.0	61.3
1978	64.7	50.4	36.9	26.3	29.4	49.1	64.5	68.1	77.3	87.0	82.6	79.7	59.8
1979	65.7	46.5	43.3	25.4	31.5	51.2	58.1	65.8	75.2	81.0	80.0	73.1	58.3
1980	61.1	50.3	41.9	38.2	38.2	46.3	56.7	69.0	81.4	88.3	88.0	76.3	61.3
1981	60.1	50.3	39.1	37.7	43.9	51.9	65.6	65.7	78.4	84.2	78.8	74.1	60.8
1982	62.7	48.6	43.2	35.3	37.7	52.7	57.5	68.2	72.2	81.0	84.1	74.5	59.9
1983	62.7	50.4	25.8	38.6	42.6	48.8	54.0	64.6	73.4	81.6	84.0	74.9	58.6
1984	61.6	49.7	43.0	34.0	45.4	46.4	56.5	68.4	78.6	81.6	82.6	71.5	60.0
1985	61.2	46.1	35.1	30.6	37.2	53.0	62.7	70.0	76.0	80.9	81.3	73.1	59.1
1986	61.6	44.8	40.8	35.1	45.9	50.3	61.8	72.6	77.1	80.1	82.2	72.4	60.4
1987	60.0	50.5	40.6	34.2	40.3	49.5	58.9	70.3	78.4	81.6	82.8	73.5	60.1
Mean	62.1	48.9	39.9	35.0	40.5	49.3	60.1	68.5	76.6	81.9	81.1	73.0	59.8
Minimum	56.5	43.4	25.8	25.4	29.4	39.7	54.0	63.6	72.2	77.4	77.2	65.5	58.3
Maximum	71.1	56.3	48.8	41.8	52.2	56.4	65.6	74.3	81.4	88.3	88.0	79.7	61.7

Evapotranspiration

Evapotranspiration is the process by which water is returned to the atmosphere as vapor. It consists of the combined action of three factors:

- Evaporation: the vaporization of liquid phase water. Dunne and Leopold (1978) report a mean annual Class A pan evaporation rate of approximately 80 inches for central Oklahoma. This value is approximately equivalent to 58 inches of annual lake evaporation. This standing water evaporation rate is 180 percent of mean annual precipitation.

- Sublimation: the vaporization of solid phase water - ice and snow. Sublimation is not considered a major factor in central Oklahoma.

- Transpiration: the loss of water by plants to the atmosphere. During the biologic process, plants remove moisture from the soil and transpire part of it to the atmosphere through their leaves. Cottonwood trees, for instance, which grow along drainages with shallow water tables, can annually transpire up to 4.5 acre-feet of water per acre of fully developed trees.

The evapotranspiration for a given area is a function of the temperature and solar radiation received at the earth's surface. Evapotranspiration can be considered in two ways - potential and actual. Potential evapotranspiration (pE-T) is that which can theoretically occur for given site temperature and solar radiation data. It is the total amount of moisture (usually expressed in inches) which can dissipate into the atmosphere assuming the continuous presence of water in the soil.

As recommended by U.S. EPA publication EPA/530/SW-168 (Fenn, et al., 1975), potential evapotranspiration for the central Oklahoma Cimarron Corporation Facility was calculated by a procedure developed by Thornthwaite and Mather (1944, 1957). The product of this analysis is estimated potential evapotranspiration in inches per month. Mean monthly pE-T values for the Cimarron Corporation Facility are given in Table 3.

Actual evapotranspiration (aE-T) is the water loss that will, in fact, occur under given conditions of temperature, solar radiation, precipitation, runoff, and soil moisture. Monthly actual evapotranspiration is therefore dependent upon monthly precipitation and soil moisture conditions. Annual actual evapotranpiration is generally less than potential evapotranspiration since water (soil moisture) is not always available for evapotranspiration. For those months when soil

TABLE 3
Mean Monthly Potential Evapotranspiration Values
Cimarron Corporation Facility
Crescent, Oklahoma

Month	Mean Monthly Temperature Degrees F	Mean Monthly Temperature Degree C	Potential Evapotranspiration (inches)
October	62.1	16.7	2.27
November	48.9	9.4	0.78
December	39.9	4.4	0.21
January	35.0	1.7	0.04
February	40.5	4.7	0.26
March	49.3	9.6	0.94
April	60.1	15.6	2.34
May	68.5	20.3	3.91
June	76.6	24.8	5.67
July	81.9	27.7	6.74
August	81.1	27.3	6.19
September	73.0	22.8	4.19
Total Evapotranspiration -------------			33.54 inches

moisture recharge (infiltration) exceeds potential evapotranspiration, the rate of evapotranspiration is not limited by soil moisture and actual evapotranspiration is equal to potential evapotranspiration. During those months when potential evapotranspiration exceeds soil moisture recharge (typically the summer months), actual evapotranspiration is limited by declining soil moisture and is equal to potential evapotranspiration plus the difference between soil moisture recharge and potential evapotranspiration and the change in soil moisture. Actual evapotranspiration values for the Cimarron Corporation Facility are included in Table 5 later in this report, and in the water balance calculations presented in the Appendices.

SURFACE CONDITIONS

Surface runoff and soil moisture storage are functions of the soil types underlying the Cimarron Corporation Facility and vicinity and the extent to which these soils have been made impervious by development. The EPA water budget methodology results in maximum runoff and infiltration since the interception of precipitation by vegetative cover is not a factor.

The Cimarron Corporation Facility study area consists of approximately 150 acres. Of this area, about 17 acres or 11% of the total are developed with building complexes, parking lots, storage areas, and associated facilities and sanitary lagoons. The remaining land is primarily pasture. The actual water balance analysis will be limited to the 133 acres of undeveloped lands of the Cimarron Corporation Facility.

Soils

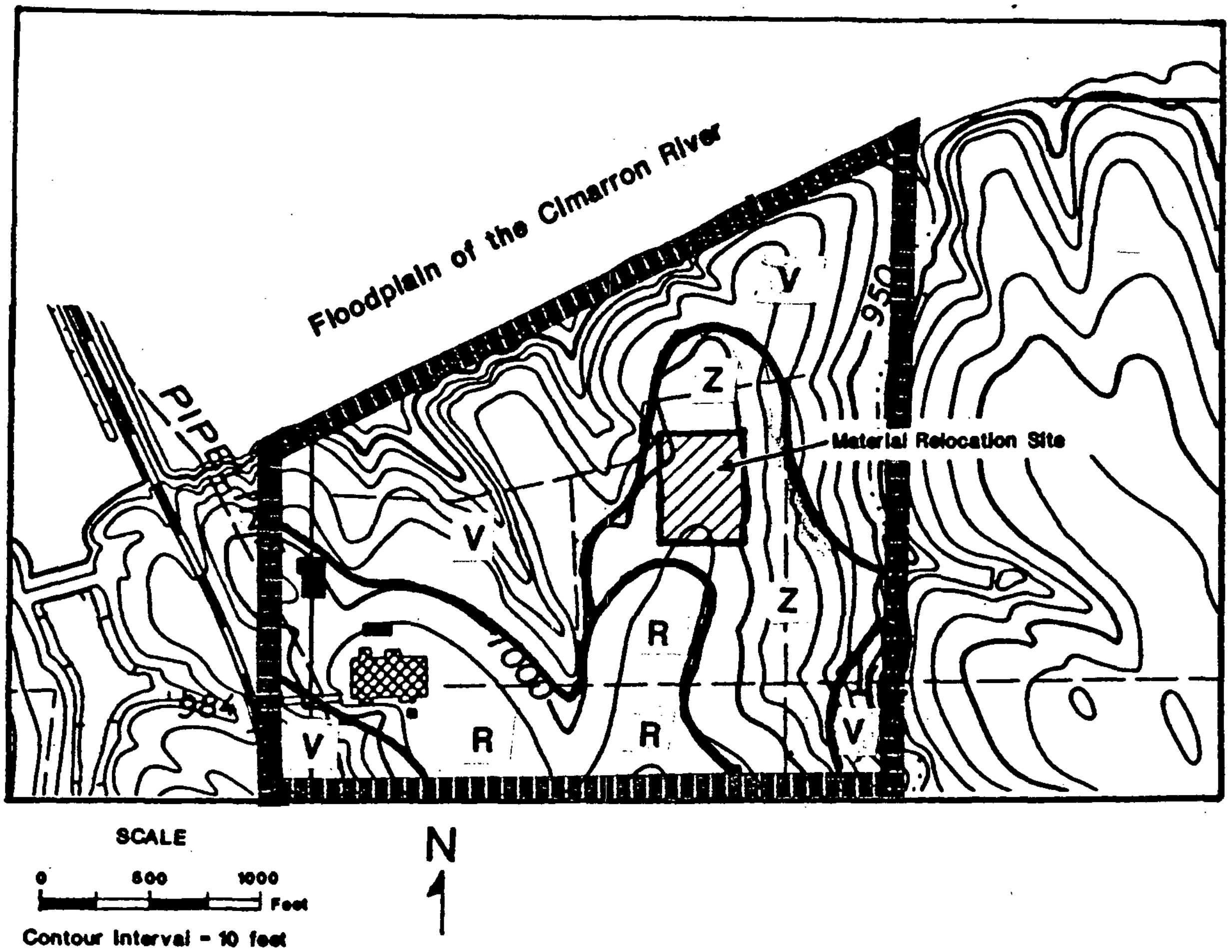
Three major soil series have been identified on the Cimarron Corporation Facility study area (Mickles, et al., 1960): 1) Renfrow silt loam, 2) Vernon clay loam, and 3) Zaneis silty loam. The distribution of these soils on the Cimarron Corporation Facility study area is shown on Figure 3.

The section that follows discusses the soils of the Cimarron Corporation Facility and the characteristics of these soils that affect the water balance. Field capacity, the maximum moisture content which a soil can retain against gravity without percolation, has been estimated based upon information provided by EPA publication EPA/530/SW-168 (Fenn, et al., 1975) and Thornthwaite and Mather (1957).

1. Renfrow silt loam: covers approximately 42 acres or 28% of the 150-acre Cimarron Corporation Facility study area. The soil is a silt loam developed from red clay beds on gentle to moderate slopes. It is very slowly permeable. Runoff is high. While the

FIGURE 3: Map Showing Distribution of Major Soil Types

Cimarron Corporation Facility



R Renfrow Silt Loam Soil

V Undifferentiated Vernon and Lucien Soils

Z Zaneis Loam Soil

▮▮▮▮▮ Boundary of Hydrologic Balance Study Area profile is recognized to a depth of 40 inches and greater, it is generally thin, with the soil consisting mostly of clay below a depth of about 13 inches. Available water capacity is moderate, with an estimated field capacity of 4.0 inches.

2. Vernon clay loam: covers approximately 67 acres or 44% of the 150-acre Cimarron Corporation Facility study area. Since the Vernon clay loam reportedly underlies the 17 developed acres of the Facility, the actual acreage that will be analyzed will be limited to 50 acres.

   Comprised of undifferentiated Vernon and Lucien soils, this is a clay loam developed from soft, unconsolidated clay banded with sandstone on steep slopes. It is slowly permeable. Runoff is typically high. While the profile is recognized to a depth of 20 inches, it is generally thin, with the organic soil typically not extending below 11 inches. Available water capacity is moderate, with an estimated field capacity of 4.2 inches.

3. Zaneis loam: covers approximately 42 acres or 28% of the 150-acre Cimarron Corporation Facility study area. The Zaneis soil underlies the Material Relocation Site.

The soil is a loam developed from red sandy and silty clay banded with sandstone on moderate slopes. It is permeable. Runoff is typically high. The profile is relatively thick, with the soil typically recognized to a depth of 54 inches and greater, although at depths deeper than 33 inches it typically consists of shale. Available water capacity is good, with an estimated field capacity of 10.2 inches.

Runoff

A portion of the precipitation that falls at the Cimarron Corporation Facility is lost to surface runoff before it can infiltrate the soil. The primary factors that determine the amount of surface runoff that will occur during any particular precipitation event are the intensity and duration of the precipitation, antecedent soil moisture conditions, the permeability and infiltration capacities of the soils, and the amount of soil that is made impermeable by development.

There is no surface runoff monitoring system at the Cimarron Corporation Facility. In lieu of actual runoff data, runoff has been calculated by the application of published empirical runoff coefficients as recommended by U.S. EPA publication EPA/530/SW-168 (Fenn, et al., 1975). The runoff coefficients of Chow (1964) and Dunne and Leopold (1978) were applied to precipitation data to develop estimates of mean monthly surface runoff for the site specific ground conditions at the Facility. Runoff coefficients for the various site specific conditions are listed in Table 4.

EPA publication EPA/530/SW-168 reports that the rational runoff calculation method will, in most cases, underestimate surface runoff. Therefore, the runoff estimates used in this water balance analysis, shown in Table 5 later in this report, yield probable maximum infiltration and percolation values.

WATER BALANCE CALCULATIONS

The method used here to calculate the water balance is that published as U.S. EPA publication EPA/530/SW-168 (Fenn, et al., 1975). The goal of this method is to estimate the amount of percolation (groundwater recharge) that may occur at a given site. Water balance calculations are made in the following manner:

1. The selected runoff coefficient is applied to the mean monthly precipitation to obtain mean monthly surface runoff.

TABLE 4

Ground Condition Classification and Coefficients
Cimarron Corporation Facility

Land Use	Acres	Percent of Total Area	Runoff Coefficient
Pasture	143	89%	0.45[1]
Building Complex and Associated Facilities	17	11%	0.50[2]

Sources: [1] Water in Environmental Planning, 1975 (Dunne and Leopold)
[2] Handbook of Applied Hydrology, 1964 (Chow)

2. Mean monthly surface runoff is subtracted from mean monthly precipitation. The result is the mean monthly infiltration of remaining precipitation into the soil, which constitutes soil moisture recharge.

3. Mean monthly potential evapotranspiration is subtracted from mean monthly infiltration; the difference is used to identify periods of soil moisture excess or deficiency. A negative value indicates a net loss of moisture from the soil, a positive value a net gain through excess infiltration.

4. The net gain or loss of available water, represented by the difference between infiltration and potential evapotranspiration, is added to or subtracted from the previous month's soil moisture storage. The mean monthly soil moisture storage represents moisture retained in the soil. During periods of monthly gains in soil moisture (generally the cooler months), the soil moisture increases until field capacity is reached or warmer weather and attendant increased evapotranspiration losses result in soil moisture deficiencies. Once field capacity is reached, additional net gains in excess infiltration become percolation.

In all cases of the current analysis, soil moisture is depleted by mid summer. Thus, the initial soil moisture storage value for the beginning of the water year (October through September) is set to zero.

5. The change in soil moisture storage represents the change in soil moisture on a month to month basis.

6. Percolation represents groundwater recharge. Significant percolation only occurs during those months when excess infiltration above field capacity is available.

7. Actual evapotranspiration is equal to potential evapotranspiration during months when the difference between infiltration and potential evapotranspiration is positive. During those months when this value is negative, actual evapotranspiration is equal to the sum of potential evapotranspiration and the difference between infiltration and potential evapotranspiration and the change in soil moisture.

The EPA water balance methodology does not provide for the interception of precipitation by vegetation. The estimates of infiltration and percolation developed by this methodology for the Cimarron Corporation Facility are thus maximum probable values.

A summary of water balance values for the undeveloped portion of the primary Cimarron Corporation Facility is presented in Table 5. Actual water balance tabulations are presented in Appendices A through C.

CONCLUSIONS

A water balance has been calculated for the Cimarron Corporation Facility located near Crescent, Oklahoma, following the procedures outlined in EPA publication EPA/530/SW-168 (Fenn, et al., 1975). Three soils reportedly underlie the study area, all of which are relatively thin. The compositions of the soils typically generate high runoff while precluding rapid infiltration.

The summary of water balance data listed in Table 5 and the tabulations presented in Appendix A show that no percolation (groundwater recharge) can be expected on the Cimarron Corporation Facility during years of average precipitation. As summarized in Table 5 and shown in Appendix B, if infiltration is maximized by disregarding runoff, a total of approximately 9.44 inches or 35.72 acres feet of percolation would occur in areas underlain by the Renfrow and Vernon soils during years of average precipitation. No percolation would occur through the thicker Zaneis soils.

Also included in this study of the Cimarron Corporation Facility water budget is an analysis of percolation for the maximum recorded annual water-year precipitation. During water-year 1984 (October 1984 through September 1985) a record 51.79 inches of precipitation were recorded in central Oklahoma. As summarized in Table 5 and shown in Appendix C, a total of approximately 14.88 inches or 56.34 acre-feet of percolation would have occurred in areas underlain by the Renfrow and Vernon soils. Approximately 1.33 inches or 4.66 acre-feet of percolation would have occurred through the thicker Zaneis soils.

TABLE 5
Summary of Water Balance Calculations
Cimarron Facility Water Balance Analysis

Case	Soil	Area (acres)	Field Capacity (inches)	Mean Annual Precipitation (inches)	Mean Annual Precipitation (ac/ft)	Mean Annual Runoff (inches)	Mean Annual Runoff (ac/ft)	Mean Annual Actual Evapotranspiration (inches)	Mean Annual Actual Evapotranspiration (ac/ft)	Mean Annual Percolation (inches)	Mean Annual Percolation (ac/ft)
Mean Annual Precipitation with Runoff	Renfrow silt loam	41	4.0	32.25	110.19	14.52	49.61	17.73	60.58	0.00	0.00
	Vernon clay loam	50	4.2	32.25	134.38	14.52	60.50	17.73	73.88	0.00	0.00
	Zaneis loam	42	10.2	32.25	112.88	14.52	50.82	17.73	62.06	0.00	0.00
Mean Annual Precipitation with no Runoff	Renfrow silt loam	41	4.0	32.25	110.19	0.00	0.00	27.43	93.72	4.82	16.47
	Vernon clay loam	50	4.2	32.25	134.38	0.00	0.00	27.63	115.13	4.62	19.25
	Zaneis loam	42	10.2	32.25	112.88	0.00	0.00	32.25	112.88	0.00	0.00
Maximum Recorded Annual Precipitation with Runoff	Renfrow silt loam	41	4.0	51.79	176.95	23.30	79.61	20.95	71.58	7.54	25.76
	Vernon clay loam	50	4.2	51.79	215.79	23.30	97.08	21.42	89.25	7.34	30.58
	Zaneis loam	42	10.2	51.79	181.27	23.30	81.55	27.15	95.03	1.33	4.66

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APPENDIX A

Cimarron Corporation Facility Water Balance Calculations

Case 1: Mean Annual Precipitation with Runoff

TABLE A-1
Cimarron Facility Water Balance Calculations

Case: Mean Annual Precipitation with Runoff
Land Use: Pasture
Soil Classification: Renfrow Silt Loam
Field Capacity: 4.0 inches
Runoff Coefficient: 0.45
Total Area: 41 acres
Percent of Total Facility Area: 27%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
*Precipitation	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
*Surface Runoff	1.43	.84	.64	.56	.59	1.01	1.48	2.26	1.87	1.17	1.17	1.50	14.52
*Infiltration	1.74	1.03	.79	.68	.73	1.23	1.80	2.76	2.29	1.42	1.43	1.83	17.73
*Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
*Infiltration Minus Potential Evapotranspiration	-.53	.25	.58	.64	.47	.29	-.54	-1.15	-3.38	-5.32	-4.76	-2.36	-----
*Actual Evapotranspiration	1.74	.78	.21	.04	.26	.94	2.34	3.91	2.83	1.42	1.43	1.83	17.73
*Soil Moisture Storage	0.00	.25	.83	1.47	1.93	2.23	1.69	.54	0.00	0.00	0.00	0.00	-----
*Change in Soil Moisture Storage	0.00	.25	.58	.64	.47	.29	-.54	-1.15	-.54	0.00	0.00	0.00	-----
*Percolation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00

TABLE A-2
Cimarron Facility Water Balance Calculations

Case: Mean Annual Precipitation with Runoff
Land Use: Pasture
Soil Classification: Vernon Clay Loam
Field Capacity: 4.2 inches
Runoff Coefficient: 0.45
Total Area: 50 acres
Percent of Total Facility Area: 33%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
*Precipitation	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
*Surface Runoff	1.43	.84	.64	.56	.59	1.01	1.48	2.26	1.87	1.17	1.17	1.50	14.52
*Infiltration	1.74	1.03	.79	.68	.73	1.23	1.80	2.76	2.29	1.42	1.43	1.83	17.73
*Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
*Infiltration Minus Potential Evapotranspiration	-.53	.25	.58	.64	.47	.29	-.54	-1.15	-3.38	-5.32	-4.76	-2.36	-----
*Actual Evapotranspiration	1.74	.78	.21	.04	.26	.94	2.34	3.91	2.83	1.42	1.43	1.83	17.73
*Soil Moisture Storage	0.00	.25	.83	1.47	1.93	2.23	1.69	.54	0.00	0.00	0.00	0.00	-----
*Change in Soil Moisture Storage	0.00	.25	.58	.64	.47	.29	-.54	-1.15	-.54	0.00	0.00	0.00	-----
*Percolation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00

TABLE A-3
Cimarron Facility Water Balance Calculations

Case: Mean Annual Precipitation with Runoff
Land Use: Pasture
Soil Classification: Zaneis Loam
Field Capacity: 10.2 inches
Runoff Coefficient: 0.45
Total Area: 42 acres
Percent of Total Facility Area: 28%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
#Precipitation	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
#Surface Runoff	1.43	.84	.64	.56	.59	1.01	1.48	2.26	1.87	1.17	1.17	1.50	14.52
#Infiltration	1.74	1.03	.79	.68	.73	1.23	1.80	2.76	2.29	1.42	1.43	1.83	17.73
#Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
#Infiltration Minus Potential Evapotranspiration	-.53	.25	.58	.64	.47	.29	-.54	-1.15	-3.38	-5.32	-4.76	-2.36	-----
#Actual Evapotranspiration	1.74	.78	.21	.04	.26	.94	2.34	3.91	2.83	1.42	1.43	1.83	17.73
#Soil Moisture Storage	0.00	.25	.83	1.47	1.93	2.23	1.69	.54	0.00	0.00	0.00	0.00	-----
#Change in Soil Moisture Storage	0.00	.25	.58	.64	.47	.29	-.54	-1.15	-.54	0.00	0.00	0.00	-----
#Percolation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00

APPENDIX B

Cimarron Corporation Facility Water Balance Calculations

Case 2: Mean Annual Precipitation with no Runoff

TABLE B-1
Cimarron Facility Water Balance Calculations

Case: Mean Annual Precipitation with no Runoff
Land Use: Pasture
Soil Classification: Renfrow Silt Loam
Field Capacity: 4.0 inches
Runoff Coefficient: 0
Total Area: 41 acres
Percent of Total Facility Area: 27%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
#Precipitation	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
#Surface Runoff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00
#Infiltration	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
#Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
#Infiltration Minus Potential Evapotranspiration	.90	1.09	1.22	1.20	1.06	1.30	.94	1.11	-1.51	-4.15	-3.59	-.86	-----
#Actual Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	5.08	2.60	3.33	27.43
#Soil Moisture Storage	.90	1.99	3.21	4.00	4.00	4.00	4.00	4.00	2.49	0.00	0.00	0.00	-----
#Change in Soil Moisture Storage	.90	1.09	1.22	.79	0.00	0.00	0.00	0.00	-1.51	-2.49	0.00	0.00	-----
#Percolation	0.00	0.00	0.00	.41	1.06	1.30	.94	1.11	0.00	0.00	0.00	0.00	4.82

TABLE B-2
Cimarron Facility Water Balance Calculations

Case: Mean Annual Precipitation with no Runoff
Land Use: Pasture
Soil Classification: Vernon Clay Loam
Field Capacity: 4.2 inches
Runoff Coefficient: 0
Total Area: 50 acres
Percent of Total Facility Area: 33%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
#Precipitation	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
#Surface Runoff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00
#Infiltration	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
#Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
#Infiltration Minus Potential Evapotranspiration	.90	1.09	1.22	1.20	1.06	1.30	.94	1.11	-1.51	-4.15	-3.59	-.86	-----
#Actual Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	5.28	2.60	3.33	27.63
#Soil Moisture Storage	.90	1.99	3.21	4.20	4.20	4.20	4.20	4.20	2.69	0.00	0.00	0.00	-----
#Change in Soil Moisture Storage	.90	1.09	1.22	.99	0.00	0.00	0.00	0.00	-1.51	-2.69	0.00	0.00	-----
#Percolation	0.00	0.00	0.00	.21	1.06	1.30	.94	1.11	0.00	0.00	0.00	0.00	4.62

TABLE B-3
Cimarron Facility Water Balance Calculations

Case: Mean Annual Precipitation with no Runoff
Land Use: Pasture
Soil Classification: Zaneis Loam
Field Capacity: 10.2 inches
Runoff Coefficient: 0
Total Area: 42 acres
Percent of Total Facility Area: 28%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
*Precipitation	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
*Surface Runoff	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00
*Infiltration	3.17	1.87	1.43	1.24	1.32	2.24	3.28	5.02	4.16	2.59	2.60	3.33	32.25
*Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
*Infiltration Minus Potential Evapotranspiration	.90	1.09	1.22	1.20	1.06	1.30	.94	1.11	-1.51	-4.15	-3.59	-.86	-----
*Actual Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	5.76	3.33	32.25
*Soil Moisture Storage	.90	1.99	3.21	4.41	5.47	6.77	7.71	8.82	7.31	3.16	0.00	0.00	-----
*Change in Soil Moisture Storage	.90	1.09	1.22	1.20	1.06	1.30	.94	1.11	-1.51	-4.15	-3.16	0.00	-----
*Percolation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	.00

APPENDIX C

Cimarron Corporation Facility Water Balance Calculations

Case 3: Maximum Recorded Annual Water-Year Precipitation with Runoff

TABLE C-1
Cimarron Facility Water Balance Calculations

Case: Maximum Recorded Annual Precipitation with Runoff
Land Use: Pasture
Soil Classification: Renfrow Silt Loam
Field Capacity: 4.0 inches
Runoff Coefficient: 0.45
Total Area: 41 acres
Percent of Total Facility Area: 27%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
#Precipitation	6.64	2.05	8.14	.92	3.71	6.60	5.35	1.49	8.34	1.33	2.63	4.59	51.79
#Surface Runoff	2.99	.92	3.66	.41	1.67	2.97	2.41	.67	3.75	.60	1.18	2.07	23.30
#Infiltration	3.65	1.13	4.48	.51	2.04	3.63	2.94	.82	4.59	.73	1.45	2.52	28.49
#Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
#Infiltration Minus Potential Evapotranspiration	1.38	.35	4.27	.47	1.78	2.69	.60	-3.09	-1.08	-6.01	-4.74	-1.67	-----
#Actual Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.50	.73	1.45	2.52	20.95
#Soil Moisture Storage	1.38	1.73	4.00	4.00	4.00	4.00	4.00	.91	0.00	0.00	0.00	0.00	-----
#Change in Soil Moisture Storage	1.38	.35	2.27	0.00	0.00	0.00	0.00	-3.09	-.91	0.00	0.00	0.00	-----
#Percolation	0.00	0.00	2.00	.47	1.78	2.69	.60	0.00	0.00	0.00	0.00	0.00	7.54

TABLE C-2
Cimarron Facility Water Balance Calculations

Case: Maximum Recorded Annual Precipitation with Runoff
Land Use: Pasture
Soil Classification: Vernon Clay Loam
Field Capacity: 4.2 inches
Runoff Coefficient: 0.45
Total Area: 50 acres
Percent of Total Facility Area: 33%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
#Precipitation	6.64	2.05	8.14	.92	3.71	6.60	5.35	1.49	8.34	1.33	2.63	4.59	51.79
#Surface Runoff	2.99	.92	3.66	.41	1.67	2.97	2.41	.67	3.75	.60	1.18	2.07	23.30
#Infiltration	3.65	1.13	4.48	.51	2.04	3.63	2.94	.82	4.59	.73	1.45	2.52	28.49
#Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
#Infiltration Minus Potential Evapotranspiration	1.38	.35	4.27	.47	1.78	2.69	.60	-3.09	-1.08	-6.01	-4.74	-1.67	-----
#Actual Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	1.03	1.45	2.52	21.42
#Soil Moisture Storage	1.38	1.73	4.20	4.20	4.20	4.20	4.20	1.11	.03	0.00	0.00	0.00	-----
#Change in Soil Moisture Storage	1.38	.35	2.47	0.00	0.00	0.00	0.00	-3.09	-1.08	-.30	0.00	0.00	-----
#Percolation	0.00	0.00	1.80	.47	1.78	2.69	.60	0.00	0.00	0.00	0.00	0.00	7.34

TABLE C-3
Cimarron Facility Water Balance Calculations

Case: Maximum Recorded Annual Precipitation with Runoff
Land Use: Pasture
Soil Classification: Zaneis Loam
Field Capacity: 10.2 inches
Runoff Coefficient: 0.45
Total Area: 42 acres
Percent of Total Facility Area: 28%

NOTE: All data in inches unless otherwise noted.

Water Balance Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
#Precipitation	6.64	2.05	8.14	.92	3.71	6.60	5.35	1.49	8.34	1.33	2.63	4.59	51.79
#Surface Runoff	2.99	.92	3.66	.41	1.67	2.97	2.41	.67	3.75	.60	1.18	2.07	23.30
#Infiltration	3.65	1.13	4.48	.51	2.04	3.63	2.94	.82	4.59	.73	1.45	2.52	28.49
#Potential Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	6.19	4.19	33.54
#Infiltration Minus Potential Evapotranspiration	1.38	.35	4.27	.47	1.78	2.69	.60	-3.09	-1.08	-6.01	-4.74	-1.67	-----
#Actual Evapotranspiration	2.27	.78	.21	.04	.26	.94	2.34	3.91	5.67	6.74	1.47	2.52	27.15
#Soil Moisture Storage	1.38	1.73	6.00	6.46	8.24	10.20	10.20	7.11	6.03	.02	0.00	0.00	-----
#Change in Soil Moisture Storage	1.38	.35	4.27	.47	1.78	1.96	0.00	-3.09	-1.08	-6.01	-.02	0.00	-----
#Percolation	0.00	0.00	0.00	0.00	0.00	.73	.60	0.00	0.00	0.00	0.00	0.00	1.33

ATTACHMENT C

Site Investigation Report
for the
Cimarron Corporation Facility
Logan County, Oklahoma

September 12, 1989

SITE INVESTIGATION REPORT

FOR THE

CIMARRON CORPORATION FACILITY
LOGAN COUNTY, OKLAHOMA

Prepared for

KERR-MCGEE CORPORATION
AND
CIMARRON CORPORATION
OKLAHOMA CITY, OKLAHOMA

Prepared By

James L. Grant and Associates, Inc.
Denver, Colorado
September 12, 1989

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1. EXECUTIVE SUMMARY

Cimarron Corporation (Cimarron), a wholly-owned subsidiary of Kerr-McGee Corporation (Kerr-McGee), operated a facility near Crescent, Oklahoma for the fabrication of mixed oxide (plutonium and uranium) and enriched uranium fuel elements. The facility was closed in 1975 and decommissioning, which commenced in 1979, is continuing at present. These activities are conducted under NRC Special Nuclear Materials Licenses SNM-928 and SNM-1174.

Decommissioning activities consist of dismantling the former production facilities and management of any waste materials related to production and decommissioning activities. Management of waste materials includes off-site disposal of equipment and soils and on-site stabilization of soils which contain either or both uranium and thorium at concentrations meeting Options 1 and 2 of the Nuclear Regulatory Commission Branch Technical Position (46 Federal Register 52061, October 23, 1981). Approximately 370 cubic yards of greater than Option 2 limit soil materials will be disposed at a licensed commercial radioactive waste disposal facility.

Approximately 14,800 cubic yards of Option 2 limit materials will be buried on-site at least four feet below the ground surface in a designated landfill. In addition, approximately 96,300 cubic yards of soil that meets Option 2 limits and which is already four or more feet deep will be left in place under the uranium plant yard. These volume estimates are based on results of a facility area soil boring program, logging of boreholes with a counter and comparison of count rates to reference standards of known radiological content. These data were then processed using a computer program. The volumes are believed to be conservative and samples will be taken during excavation to provide final volume definition.

As part of planning for the disposition of Option 2 limit materials, Cimarron has conducted site studies to characterize the local hydrogeologic system, establish a system for ground-water monitoring, evaluate current ground-water quality, and estimate the long-term effect on ground-water quality which on-site burial of Option 2 limit soil might have. This report summarizes the field investigation, laboratory analyses, and data evaluation conducted for the site characterization.

The facility is located south of the Cimarron River in an area of low, rolling hills and incised drainages. Local elevations range between about 940 along the river to 1010 feet at the plant. Subsurface materials at the site include one to eight feet of soil covering the Garber Sandstone. The rock strata in the upper 140 feet of the Garber include alternating sandstones and mudstones. The sandstone layers, which are between 30 and 55 feet thick, have been designated Sandstones A, B, and C. The three sandstones are separated by mudstone layers. The mudstones are designated Mudstones A and B and are between 6 and 20 feet thick.

Shallow ground water occurs in Sandstone A under water table conditions. Most of the site monitoring wells are completed in this zone. The depth to water is between 10 and 30 feet below ground surface. Ground-water flow is to the north-northwest where discharge to the surface or to Cimarron River alluvium is likely. The hydraulic conductivity of Sandstone A is 1.03 x 10^{-3} cm/sec. Ground water also occurs in Sandstones B and C. Four of the site wells are completed in Sandstone C. The hydraulic conductivity in the deeper unit is about 1.27 x 10^{-4} cm/sec. Flow in this stratum is toward the northwest where discharge to the Cimarron river alluvium is likely.

Current ground-water quality in Sandstone A indicates that past operations might have affected the water in the immediate vicinity of certain facility units. The units where down-gradient ground-water impacts may have occurred include: wastewater ponds #1 and 2, the former burial area, and the area between the plutonium and uranium buildings. Since closure, ground-water sampling around these units shows water quality has improved. No definite effects are apparent in the deeper Sandstone C stratum.

Soil and rock samples from the unsaturated and saturated zones were chemically analyzed. Radionuclides were not detected in significant concentrations and facility operations do not appear to have affected soil and rock in the subsurface.

The results of soil, rock, and water analyses have been analyzed to estimate effects which could result from infiltration of water through Option 2 limit materials buried on-site. The solubility and mobility of radionuclides in the subsurface have been estimated using infiltration models and measurements of aquifer properties, water chemistry, and elemental partition coefficients.

The calculations demonstrate that the Option 2 limit materials which will remain at the site after decommissioning will not present a real or potential threat to ground-water or surface-water use.

2. INTRODUCTION

2.1 Report Purpose and Scope

This report presents the results of a site investigation program conducted by James L. Grant and Associates (JLGA) during early 1989. The purpose of the investigation was to determine the possible impacts that facility production and decommissioning operations may have had on the hydrogeologic system underlying the site. The geotechnical characteristics of selected site materials that may be used in construction of the permanent repository for site soils that contain low levels of uranium and thorium were evaluated.

A "Work Plan for Site Investigation Program" (Work Plan) was submitted January 4, 1989 to Kerr-McGee Corporation and Cimarron Corporation. The Work Plan specified procedures for drilling, sampling soil and rock, well installation, ground-water sampling, conducting aquifer tests and cleaning drilling and sampling equipment. Procedures specified in the Work Plan were adhered to during the site investigation. The Work Plan is included in this report as Appendix A.

The report emphasis is on the local ground-water system and assesses the impacts facility operations may have had on this system. The anticipated behavior of radionuclides in the shallow subsurface of the site is addressed, as are the engineering properties of materials to be used in the permanent soil repository planned at the site. Data have been obtained that permit the following:

- Characterization of stratigraphy and lithology of the soils and bedrock strata at the site;
- Characterization of aquifer properties including hydraulic conductivity, ground-water flow direction, and gradient;
- Characterization of ground-water quality and determination of the effects that facility operations may have had on ground-water quality;
- Determination of the mobility of radionuclides, particularly uranium, in the subsurface and the ability of subsurface materials to retard migration;
- The suitability of selected site soil and rock for cover materials of the planned landfill.

2.2 Description of the Facility

Cimarron Corporation (Cimarron), a wholly-owned subsidiary of Kerr-McGee Corporation (Kerr-McGee), manages the decommissioning activities at the Cimarron Facility in Logan County, Oklahoma. Figure 2.1 shows the location of the facility. The facility was operational from 1965 to 1975. The principal operations at the facility involved the fabrication of fuel elements from plutonium and enriched uranium. Production ceased in 1975; decommissioning commenced in 1979 and is continuing at present. Figure 2.2 is a detailed map of the facility.

Enriched uranium fuel was produced from 1965 to 1975. In general, the process is described by the following steps:

- Uranium hexafluoride gas was passed through an ammonia solution, producing solid ammonium diuranate.
- Ammonium diuranate was calcined to produce uranium oxide powder (UO_3).
- Uranium oxide powder was pressed into pellets.
- The pellets were converted into ceramic-grade uranium dioxide (UO_2) in reduction furnaces.

Mixed-oxide fuel also was produced from 1970 to 1975 in the plutonium plant. Additional operations at the facility included a solvent extraction process to recover uranium from the processing of scrap and from material that did not meet contract specifications.

Liquid wastes from uranium processing were passed through an ion-exchange system for the recovery of uranium. The treated effluent was discharged to the Cimarron River under permit from 1965 to 1971. From 1971 to 1975, the treated effluent was pumped to wastewater evaporation ponds. Contaminated sludges that accumulated in the ponds were excavated in 1976 and 1977 and shipped to a licensed commercial low-level radioactive waste disposal facility. The ponds were subsequently reclaimed, inspected, and released for unrestricted use.

Sanitary water and laundry water from the uranium and plutonium operations was sent to the sewage lagoons. Contaminated sediments that accumulated were removed from the lagoons. The sediments contained up to 1300 pCi/g uranium and 11 pCi/g plutonium. These sediments were shipped off-site to a commercial disposal facility. Sediments that have accumulated since those shipments are from decommissioning activities and will be analyzed, excavated and disposed off-site if activity levels warrant.

Contaminated solid wastes generated from uranium plant activities were buried at a designated location on-site from 1966 to 1970. These solid wastes have since been excavated and shipped to a commercial disposal facility. Since 1970, all contaminated solid wastes were shipped off-site to a commercial disposal facility.

Thorium was present at the former burial site as drummed waste materials from the decommissioning of the Kerr McGee Corporation Cushing facility. Equipment from the Cushing facility also was stored at the uranium plant yard. The equipment and excavated drummed waste was shipped to a commercial disposal facility. Thorium has not been detected in soils or ground water at the Cimarron facility above background levels indicating there has been no impact from these materials. No plutonium waste was disposed on-site.

Only purified uranium and plutonium were used in the production processes. The concentrations of daughter products were negligible. Radium and thorium detected in ground-water and soil samples represent natural background levels and not the effects of facility activities.

Facility operations ceased in 1975 and Cimarron staff are presently decommissioning the facilities. Certain soil materials associated with the decommissioning activities will be left on-site, either in a designated, engineered site or in-situ, in accordance with the Nuclear Regulatory Commission's (NRC) Branch Technical Position (46 Federal Register 52061, October 23, 1981). The soils to be left on-site contain enriched uranium and thorium that meet the Branch Technical Position Options 1 and 2 concentration limits and conditions for disposal.

- NRC Branch Technical Position Option 1:

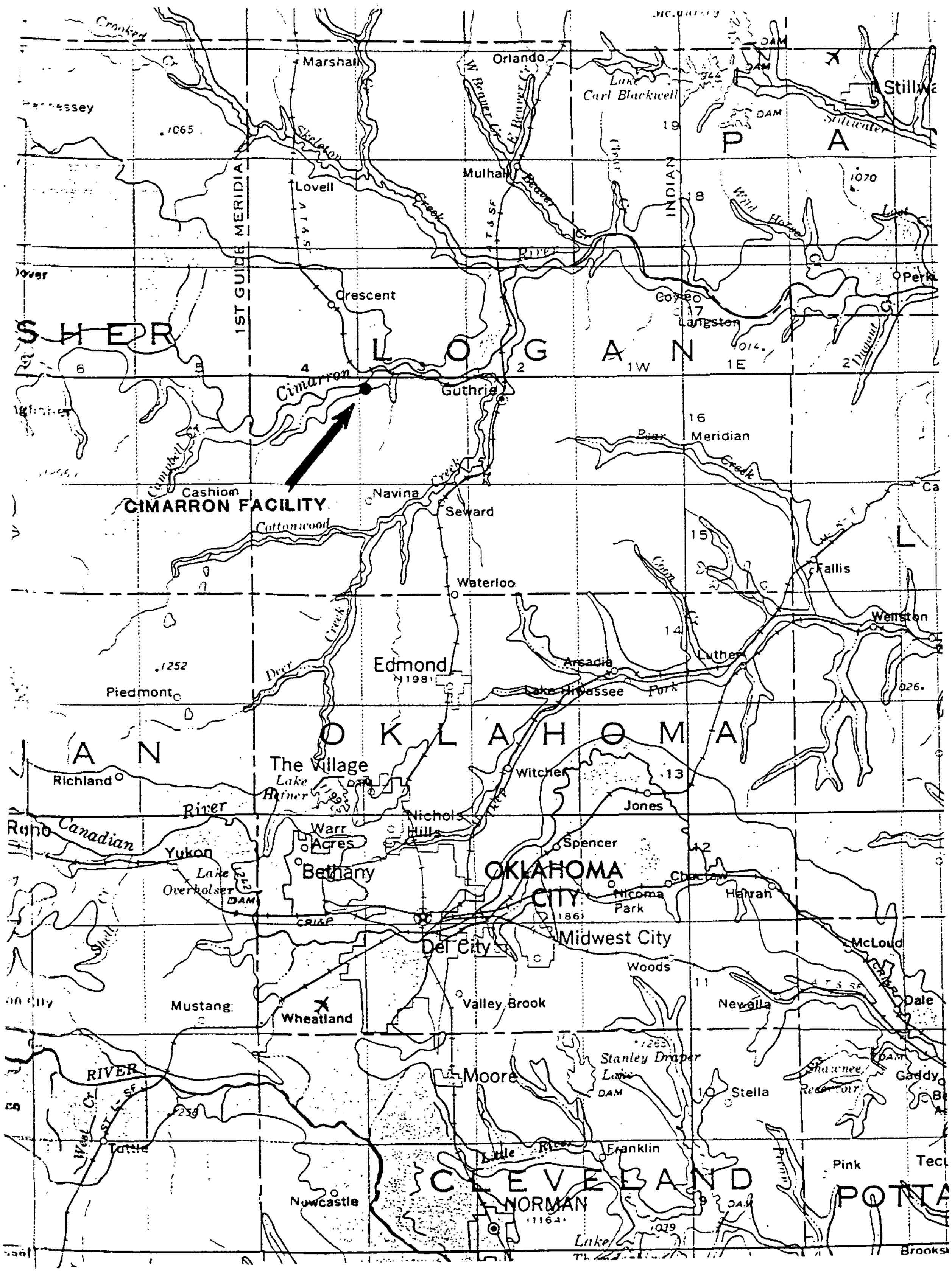
  This Option places no restrictions on the method of disposal or on-site storage of soils that contain up to 30 pCi/g enriched uranium, 35 pCi/g depleted uranium, and 10 pCi/g natural thorium (Th-232 plus Th-228).

- NRC Branch Technical Position Option 2:

  This Option permits the burial of soils containing low levels of uranium with no subsequent restrictions on land use or continued NRC licensing of the material. To meet this disposal criterion, soils must not contain more than 100 pCi/g soluble enriched uranium, 250 pCi/g insoluble enriched uranium, 100 pCi/g soluble depleted uranium, 300 pCi/g insoluble depleted uranium, or 50 pCi/g natural thorium. A minimum burial depth of four feet is required, and the proposed burial site must have acceptable hydrogeologic, meteorologic and topographic characteristics to mitigate against transport.

Cimarron plans to leave in place soils that contain Option 2 levels of uranium that are deeper than four feet below the ground surface. Soils that are shallower than four feet and meet the Option 2 disposal criterion will be excavated and transported to a designated on-site landfill.

The hydrologic, meteorologic and topographic characteristics of the Cimarron facility and the engineered on-site landfill are addressed in this report.



808211

JAMES L. GRANT & ASSOCIATES
geotechnical engineering • management • computer science
ENGLEWOOD, COLORADO

FIGURE 2.1

CIMARRON FACILITY LOCATION

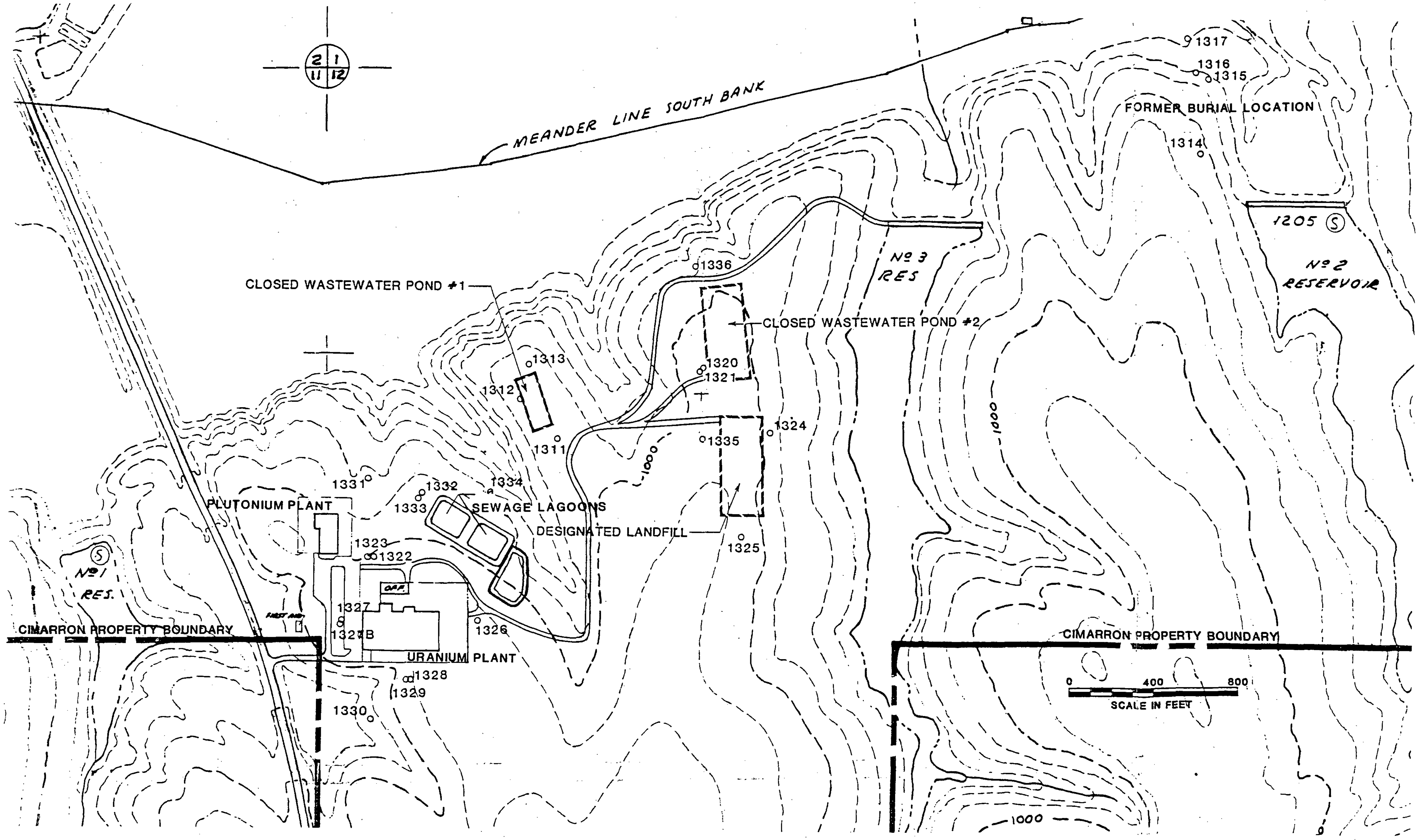


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FIGURE 2.2

CIMARRON FACILITY SITE MAP

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3. SITE INVESTIGATIONS

3.1 Previous Cimarron Investigations

The Cimarron facility has an extensive and continuous environmental monitoring program to determine the impacts of facility activities on the environment. This program consists of routinely collecting and analyzing air, surface water, ground water, soil and vegetation samples from the site and adjacent areas.

The environmental program includes many monitoring wells installed throughout the facility area for collection of ground-water samples from the shallow, unconfined aquifer which occurs at depths less than 50 feet below ground surface. Wells no. 1311 through 1317 shown on Figure 2.2 were installed during previous site investigations. Boring logs and well completion information were available for these wells; hydrologic and geologic data, and analyses of ground water collected from these wells have been incorporated into the JLGA investigation.

Cimarron also has conducted a detailed soil boring survey and sampling program to provide semi-quantitative information on the extent of facility-related radionuclide contamination in the shallow subsurface. The survey consisted of lowering a sodium iodide (NaI) probe into borings and measuring gamma radiation at one-foot intervals. The probe was calibrated against standards of known concentrations of uranium and thorium. Measurements of total gamma activity were recorded and concentrations of radionuclides were estimated by comparing counts in the boreholes with the standards.

The quantities of soils meeting the Option 1 and 2 disposal criteria have been conservatively estimated from the borehole gamma survey. Cimarron estimates that 14,800 cubic yards of soil at depths less than four feet meet the Option 2 on-site disposal criteria. This soil will be excavated and placed in the designated on-site landfill. An estimated 96,300 cubic yards of soil and rock that meets the Option 2 limits occurs at depths greater than four feet. Cimarron plans to leave this material in place.

3.2 JLGA Investigation

James L. Grant and Associates (JLGA) was retained by Cimarron to conduct a supplemental site characterization investigation. The field investigation was conducted between January 16 and April 1, 1989.

3.2.1 Drilling and Sampling.

A total of eighteen wells were installed during the field investigation. The wells were drilled using air rotary, water rotary and coring techniques. Drilling was conducted by Kerr-McGee and Jim Winnek, Inc. of Tulsa, Oklahoma. The equipment decontamination procedures presented in the Work Plan (Appendix A) were used to minimize the potential for introduction of contaminants into intervals penetrated by drilling. All drilling and sampling activities were observed by a JLGA geologist and descriptive sample logs were maintained.

The majority of wells were sampled by continuous coring. Both diamond and Criss bits were used. The cores are NX size and are stored in waxed cardboard boxes. The diamond bits cut a 1-7/8 inch diameter core and the Criss bits cut a 2-1/8 inch diameter core. Upon completion of coring to the designated depth, the bore holes were reamed to a 6 inch diameter using water rotary techniques.

Rock was sampled by continuous coring or rotary techniques. For the intervals drilled by air or water rotary, cuttings were collected and composited over 24-inch intervals. The cuttings were logged and stored in plastic bags. Descriptions are recorded on the monitoring well records in Appendix B.

Soil was sampled with split-spoon samplers following the procedures specified in ASTM 1586. Each sample represented a 24-inch interval except at the top of bedrock where refusal of the sampling tool resulted in a smaller sample collected. Samples were stored in plastic bags. Descriptions of the samples and the interval sampled are indicated on the monitoring well records included in Appendix B.

3.2.2 Well Installation.

Monitoring well installation procedures are described in the Work Plan (Appendix A). A 2.5 feet long sump was installed below the well screen to provide a repository for fines that accumulate during well development and evacuation prior to sampling. Figure 3.1 shows the relative placement of well screen, sand pack, and sealed sections of the well. Table 3.1 lists the pertinent completion details for the monitoring wells. Well completion information also is shown on the monitoring well records presented in Appendix B. The locations of the monitoring wells are indicated on Figure 2.2 and in Table 3.1.

At borings where wells were completed, the well casing was installed after completion of drilling to the desired depth. Two-inch diameter, flush-joint, threaded, schedule 80 PVC well casing and screen was used for all the monitoring wells (1320 through 1336).

3.2.3 Borehole Abandonment.

Sample recoveries were inadequate at two borings. These borings were abandoned and redrilled using drilling and sampling techniques suitable for the materials encountered. Wells 1323 and 1330 were constructed in the redrilled borings. The abandoned borings were backfilled to ground surface with a portland cement/sodium bentonite grout. A shallow concrete cap was placed on top of the hardened grout.

Two additional 10 feet deep borings were advanced adjacent to Well 1325 at the request of Cimarron personnel. These borings were drilled to obtain a continuous core sample from 5 to 10 feet. These additional borings were also backfilled with a portland cement/sodium bentonite grout.

3.2.4 Well Development.

The ground-water monitoring wells were developed soon after they were completed. Each of the wells was developed to remove fines and drill cuttings from the screened interval. Well development was accomplished by the air-lift method or by bailing with a cleaned PVC bailer. The wells developed by bailing were Nos. 1320 and 1322. The remainder were developed via air-lift. The air-lift method is described in the Work Plan (Appendix A). Development was terminated when the turbidity of the discharge water stabilized and a minimum of ten well volumes had been removed.

Water removed from each well during development was discharged to the ground surface. The volume of water removed was estimated by periodically measuring the quantity discharged into a bucket per unit of time. For the wells developed by bailing, water was discharged into buckets and the quantities recorded. The volume, color, odor, and clarity of water evacuated from each of the wells during development was established by visually noting these characteristics. Table 3.2 provides a summary of well-development data.

3.2.5 **Field Tests.**

3.2.5.1 Well Surveying.

Locations, datum and ground-surface elevations for wells and surface water elevations of the three reservoirs at the site were determined by R. E. Heinz and Associates of Guthrie, Oklahoma. The wells were surveyed between March 20 and March 27, 1989

All elevations and horizontal locations are based on the Cimarron Facility plant datum located due west of the the uranium building. The elevation of the datum was determined from facility construction plans. It is believed that the elevation of the plant datum is tied to the U. S. Geological Survey mean sea level datum since it corresponds to elevations noted on the U.S. Geological Survey topographic quadrangle of the area; however, no established benchmarks were located within several miles of the facility for verification. Horizontal coordinates for the wells are based upon a north-aligned grid system established at the plant datum. The elevations and coordinates for each well are noted on the monitoring well records in Appendix B and in Table 3.1.

3.2.5.2 Water-Level Measurements.

Water levels were measured at the site monitoring wells after installation and development. The levels were measured over a relatively short time interval so that the data are comparable. Measurements were made on March 21, 1989, and again on March 31, 1989. Additional measurements were made periodically during the drilling program to anticipate the depth ground water would be encountered at subsequent wells.

The depth to water below the measurement datum was recorded to the nearest 1/8 inch (0.01 feet). The ground-water levels measured during the investigation are included in Table 3.1.

3.2.6 Slug Tests.

In-situ field tests using the slug insertion and withdrawal procedure to obtain measures of hydraulic conductivity were conducted at all wells installed during this investigation. These tests were conducted by quickly inserting a weighted slug of known volume into the well and recording changes in head as a function of time as the water in the aquifer adjusts to the presence of the slug. After the water level in the well has stabilized, the slug is quickly withdrawn, and the resulting drawdown and recovery are recorded.

The water level in the wells recovered too quickly for head fluctuations to be measured manually. Head fluctuations were measured using an In-Situ Model SE-1000B Hermit Environmental Data Logger and a 10.13 psi down-hole pressure transducer. This unit allowed accurate measurement of rapid water level changes over very short time intervals. Recovery and drawdown data were recorded using a pre-programmed logarithmic sampling rate with very frequent measurements during the first 20 seconds and less frequent measurements during the remaining portion of the test.

The test data were interpreted using techniques described in Bouwer and Rice (1976), Cooper, Bredehoeft and Papadopulos (1967) and Hvorslev (1951). The results of these aquifer tests are presented in Table 3.3. The test data are presented in Appendix C. The three different analytical techniques were employed for comparison and to ensure that reliable estimates of hydraulic conductivity were obtained.

Hydraulic conductivities and transmissivities were calculated for both the slug insertion (falling head) and slug withdrawal (rising head) portions of the tests. From past experience the calculations based on rising head data are believed more representative of the aquifer since it partially removes the effects of the greater permeability of the sand packs around the well screens. Since the sand pack around the well screen has a greater permeability than the adjacent aquifer, it is believed that upon insertion of the slug, the water level will initially rise more rapidly and to a higher level in the sand pack than in the aquifer. The initial stages of the subsequent water-level recovery therefor reflect ground water reentering the well from the sand pack rather than the aquifer.

The rising head portion of the slug test serves to remove the effects of the sand pack. When the slug is withdrawn, the water level in the well drops an amount equivalent to the volume displaced by the slug. The subsequent recovery to the initial water level is due to ground water entering the well from the aquifer. The amount of water stored in the sand pack and available to enter the well after the slug is withdrawn is negligible. The calculations for both the falling and rising head portions of the test showed slightly higher values for hydraulic conductivity and transmissivity for the falling head tests.

According to Bouwer & Rice (1976), their method is applicable for partially or fully penetrating wells in unconfined aquifers, or for wells in leaky confined aquifers. Cooper, Bredehoeft & Papadopulus (1967) state their method is applicable to wells fully or partially screened in confined aquifers. The Hvorslev method (1951) is applicable to wells installed in unconfined aquifers. A comparison of the three methods is presented in Table 3.3 and shows reasonable agreement among the three methods.

The hydraulic conductivity of the shallow aquifer is best approximated by the Bouwer & Rice and Hvorslev methods since it is under water table conditions. The results of these two methods were averaged geometrically to arrive at an approximation for the hydraulic conductivity and transmissivity Geometric averages are more appropriate than arithmetic averages for data that differs by orders of magnitude. The hydraulic conductivity of the shallow aquifer ranges from 2.41×10^{-4} cm/sec to 5.7×10^{-3} cm/sec. The geometric mean of the measured values is 1.03×10^{-3} cm/sec. The transmissivity of this aquifer ranges from 10.3 ft sq/day to 108 ft sq/day, with a geometric mean of 33.4 ft sq/day.

The hydraulic conductivity and transmissivity of the confined aquifer screened in the deep wells is best approximated by the Cooper et. al. method. The results from those analyses were averaged geometrically. The hydraulic conductivity of the deep aquifer ranges from 1.39×10^{-5} cm/sec to 7.06×10^{-4} cm/sec, with a geometric mean of 1.27×10^{-4} cm/sec. The transmissivity ranges from .67 ft sq/day to 50 ft sq/day, with a geometric mean of 7.96 ft sq/day.

3.2.7 Ground-Water Sampling.

Monitoring wells installed during this program were sampled during the week of March 19, 1989. Cimarron sampled existing wells at the same time to provide a full-facility range of comparable data for the evaluation of ground-water quality. All samples were analyzed for the same constituents.

The ground-water samples were collected using the procedures described in the Work Plan (Appendix A). Specific conductance and pH were measured in the field for each sample collected. The ground-water samples were placed in containers provided by the laboratory and by Cimarron Corporation. Both one-gallon and one-quart plastic cubitainers were filled at each well. An additional one quart glass jar was filled for the samples requiring TOC and TOX analyses.

A label was placed on each sample container. This label contained the well number, date, type of sample, name of collector, and any special instructions. The ground-water samples were kept chilled and delivered to the laboratory within hours of collection. Chain of custody documentation was maintained for all the samples and is included in Appendix D. The analyses conducted are described in the following section.

3.2.8 Laboratory Tests.

3.2.8.1 Ground-Water Analyses.

Ground-water analyses were conducted by the Kerr-McGee Technical Center Laboratory. The samples were analyzed for nitrate, fluoride, gross alpha and beta activity, Pu-239, Ra-228, Ra-226, Th-232, Th-228, U-238, U-235, and U-234 in accordance with standard EPA methods. Four samples were also selected for Total Organic Carbon (TOC) and Total Organic Halide (TOX) analyses in accordance with standard EPA methods. Standard ground-water quality analyses for major cations and anions were performed in conjunction with the distribution coefficient (Kd) tests. Table 3.4 provides a summary of the ground-water analyses. Documentation of the analyses and the chain of custody documentation are included as Appendix D to this report.

3.2.8.2 Soil and Rock Analyses.

Selected soil and rock samples were submitted to the Kerr-McGee Technical Center laboratory for analysis. The samples were analyzed for parameters related to facility activities. The parameters analyzed for include nitrate, fluoride, gross alpha and beta activity, Pu-239, Ra-228, Ra-226, Th-232, Th-228, U-238, and U-234 in accordance with standard EPA methods. Table 3.5 provides a summary of the results. Documentation of these analyses and the chain of custody documentation are included as Appendix E.

The samples selected for site-specific parameter analyses are representative of the different strata encountered and different locations around the site. Sample selection was not random, but emphasized stratigraphic intervals where migration of contaminants may be restricted, such as at the top of less permeable, confining strata, or adsorbed in strata of favorable chemistry. The well number, interval sampled and lithologic description of the rock or soil also are indicated in Table 3.5.

Prior to submission to the laboratory, Cimarron measured the uranium activity in the samples by gamma spectrometry. The Cimarron gamma spectrometry analysis utilizes the EG&G Ortec ADCAM computer analysis program. The samples were analyzed inside a lead-shielded box to minimize background interference. These results also are presented in Table 3.5.

3.2.8.3 Physical Property Analyses.

Samples were submitted to Standard Testing, Inc. of Oklahoma City for physical property analyses. These analyses included characterization tests (grain size and Atterberg Limits), standard Proctor tests and compacted permeabilities. The Proctor and compacted permeability tests were performed on samples of borrow material from the designated landfill site which are representative of materials that may be used to construct the landfill cover. The results of these tests are presented in Table 3.6 and documentation is included in Appendix F.

3.2.8.4 Soil and Rock Mineralogical Analyses.

Samples were submitted to the Department of Agronomy and Soils at Auburn University for analysis of selected properties. The tests performed included cation exchange capacity (CEC), exchangeable cation (EXC), mineralogy, grain size and matric potential. The well number, interval sampled, lithologic description and analytical results are presented in Table 3.7. Documentation of the results are presented in Appendix G. The samples submitted are representative of the different strata encountered during this investigation.

3.2.8.5 Distribution Coefficient Analyses.

Five samples of site soils, rock and ground water were analyzed by the Kerr-McGee Technical Center to determine equilibrium distribution coefficients (Kd) for uranium and thorium. This test provides a measure of the affinity of the selected elements for soil and rock and the solubility of the material in the rock/ground-water system. The tests were conducted according to the batch test procedures included in Appendix H. Kd test results are summarized in Table 3.8 and documentation of the results is included in Appendix H.

The samples for Kd determinations were selected after the soil and rock mineralogical and chemical analyses were completed. The aquifer matrix materials can be broadly classified into one of four major groups: low clay (<18%), low calcite (<3%) content; high clay (>30%), low calcite content; low clay, high calcite (>3%) content; and high clay, high calcite content. For the aquifer matrix materials underlying the Cimarron facility, clay and calcite content were the important constituents affecting the distribution coefficients. The matrix samples submitted for Kd determinations are representative of the four groups identified, including "reduced" and "non-reduced" samples. The reduced samples are representative of iron-deficient intervals where ferric oxides have been reduced to ferrous oxides and removed by ground water.

Two distribution coefficient tests were conducted for each sample submitted for both uranium and thorium. The first test used 20 milliliters (ml) of site ground water spiked to a uranium concentration of 850 pCi/l and a thorium concentration of 850 pCi/l. This solution was applied to 5 gram samples of site aquifer matrix materials for a total concentration of 3.40 pCi/g uranium and 3.40 pCi/g thorium. After reaching equilibrium with the matrix materials, final concentrations of uranium in solution ranged from 1.2 pCi/l to 9.3 pCi/l. Final concentrations of thorium ranged from 0.6 to 1.2 pCi/l.

The second test used 100 ml of site ground water spiked to a uranium concentration of 850 pCi/l and a thorium concentration of 850 pCi/l. This solution was applied to 5 gram samples of matrix materials for a total concentration of 17 pCi/g uranium and 17 pCi/g thorium. After reaching equilibrium, final concentrations of uranium in solution ranged from 1.5 to 9.9 pCi/l. Final concentrations of thorium ranged from 0.6 to 1.3 pCi/l.

The experimentally derived Kd values for uranium range from 339 ml/g to 2829 ml/g. Experimental Kd values for thorium range from 2262 ml/g to 5662 ml/g. The experimentally derived values for both elements are within published value ranges. Isherwood (1981) reports Kd values for uranium in soil at near neutral pH that range from 4,400 ml/g to 62,000 ml/g. Kd values for thorium at near neutral pH are reported to range from 40 ml/g to 400,000 ml/g. The experimental Kd values did not exhibit a direct correlation with either the clay mineral or calcite content of the site soils.

Approximations of distribution coefficients can also be made by comparing the amount of uranium detected on the aquifer material with the amount detected in ground water from that interval. Six of the aquifer material samples submitted to the laboratory for uranium analyses represent screened intervals in monitoring wells. Comparing the uranium values found in the rock samples with the ground-water samples yield approximate Kd values ranging from 10 ml/g to 192 ml/g.

The difference between the approximated Kd values and those from the laboratory tests may be attributable to precipitation of uranium in the batch test. The laboratory Kd tests are conducted under controlled conditions using ground water spiked to a concentration greater than that typically found at the site. Precipitation of uranium during the test will result in higher Kd values than if adsorption were the sole mechanism removing uranium from ground water.

The distribution coefficient (Kd) tests demonstrate that uranium will have limited solubility in the subsurface ground water. Final concentrations of uranium in the test solutions ranged from 1.2 to 9.9 pCi/l. These concentrations are consistent with naturally occurring uranium concentrations in ground-water samples from most of the monitoring wells. The combined effects of uranium precipitation and adsorption on the aquifer matrix materials appear to produce equilibrium concentrations of uranium in ground water less than 10 pCi/l.

Water from certain wells sampled had uranium concentrations greater than the above equilibrium concentration. These wells are located adjacent to and immediately down-gradient from the closed wastewater ponds and the former solid-waste burial area, where the chemistry of the ground water probably was changed by the materials stored in these areas. The higher uranium concentrations probably result from the differences in water chemistry, especially the presence of nitrate and fluoride ions. As discussed in Section 7.3, uranium concentrations in the ground water decrease rapidly with distance from such a source as the concentrations of ions is reduced through dilution and sorption.

TABLE 3.1

Well Completion Details

WELL NO.	INSTALLED BY	DATUM ELEVATION (feet msl)	GROUND ELEVATION (feet msl)	COORDINATES EAST	COORDINATES NORTH	WELL DEPTH	DEPTH TO SCREEN TOP	DEPTH TO SCREEN BOTTOM	GROUND WATER LEVELS 3/31/89 DEPTH	GROUND WATER LEVELS 3/31/89 ELEVATION	GROUND WATER LEVELS 3/21/89 DEPTH	GROUND WATER LEVELS 3/21/89 ELEVATION
1311	Cimarron	995.69	993.9	11087.15	10949.24	80.00	25.00	40.00	28.28	967.41	28.07	967.62
1312	Cimarron	992.17	989.6	10917.11	11133.08	36.00	21.00	35.00	26.50	965.67	25.50	966.67
1313	Cimarron	994.70	992.4	10955.19	11278.42	38.00	23.00	38.00	28.95	965.75	28.70	966.00
1314	Cimarron	983.02	980.0	14093.26	12266.33	80.00	30.00	45.00	27.82	955.20	27.40	955.62
1315	Cimarron	955.98	953.0	14126.89	12610.52	27.00	12.00	27.00	13.64	942.34	13.92	942.06
1316	Cimarron	951.31	949.9	14066.96	12637.28	32.00	17.00	32.00	10.60	940.71	10.65	940.66
1317	Cimarron	946.62	943.9	14026.01	12798.60	18.00	3.00	18.00	10.30	936.32	10.95	935.67
1320	JLGA	998.14	995.6	11755.70	11266.69	41.30	28.50	38.50	27.66	970.48	27.01	971.13
1321	JLGA	998.38	996.0	11743.26	11261.76	124.40	111.60	121.60	59.85	938.53	60.25	938.13
1322	JLGA	1001.48	998.6	10238.93	10386.13	37.90	25.00	35.00	32.12	969.36	31.76	969.72
1323	JLGA	1001.85	998.9	10224.06	10387.37	129.60	116.80	126.80	57.20	944.65	57.48	944.37
1324	JLGA	997.58	995.2	12075.48	10972.36	35.00	25.00	35.00	25.58	972.00	25.03	972.55
1325	JLGA	1008.32	1005.9	11951.47	10494.65	48.30	35.50	45.50	33.08	975.24	32.49	975.83
1326	JLGA	1009.33	1006.5	10719.85	10112.93	45.10	32.30	42.30	37.62	971.71	37.11	972.22
1327	JLGA	1009.17	1006.2	10100.10	10103.73	41.80	29.00	39.00	dry		dry	
1327-B	JLGA	1008.42	1006.2	10100.10	10090.43	51.80	39.00	49.00	41.03	968.14	40.93	967.49
1328	JLGA	1008.44	1006.0	10411.70	9830.36	137.80	125.00	135.00	55.35	953.09	55.54	952.90
1329	JLGA	1008.55	1005.9	10405.36	9835.39	47.80	35.00	45.00	38.79	969.76	38.86	969.69
1330	JLGA	997.70	995.3	10231.32	9657.06	41.50	28.70	38.70	26.60	971.10	26.17	971.53
1331	JLGA	978.00	975.3	10202.71	10751.13	25.00	12.20	22.20	10.51	967.49	9.81	968.19
1332	JLGA	989.54	987.1	10457.35	10686.36	118.80	106.00	116.00	46.97	942.57	47.05	942.49
1333	JLGA	989.77	986.8	10442.73	10662.97	34.80	22.00	32.00	20.75	969.02	20.62	969.15
1334	JLGA	980.26	977.6	10776.31	10688.14	22.80	10.00	20.00	12.33	967.93	12.60	967.66
1335	JLGA	1002.50	1000.2	11758.09	10944.05	42.80	30.00	40.00	28.91	973.59	28.20	974.30
1336	JLGA	986.02	984.0	11722.31	11738.39	30.80	18.00	28.00	25.34	960.68	25.14	960.88

NOTE: DATUM IS TOP OF CASING FOR ALL WELLS.
ELEVATION OF WATER IN RESERVOIR 1: 959.3' 3/26/89
ELEVATION OF WATER IN RESERVOIR 2: 966.3' 3/26/89
ELEVATION OF WATER IN RESERVOIR 3: 971.0' 3/26/89

TABLE 3.2

Well Development Summary

WELL NO.	DATE	WELL TD (BTOC)	DEPTH TO WATER BEFORE (BTOC)	DEPTH TO WATER AFTER (BTOC)	GALLONS REMOVED	CLARITY AFTER DEVELOPMENT	COMMENTS
1320	3/14/89	41.2	26.88	34.65	30	Clear, with orange tint	Develop. by bailing
1321	3/16/89	128.4	60.2	74.91	130	Clear and colorless	
1322	2/16,22/89	40.8	29.9	30.56	20	Clear and colorless	Develop. by bailing & air-lift
1323	2/22-24/89	129.2	54.58	85.9	130	Clear, v. faint orange tint	
1324	3/15/89	34.95	24.17	27.9	30	Clear, pale orange tint	
1325	3/15/89	50.5	32.78	33.97	75	Clear, v. pale orange tint	
1326	3/16/89	47.9	N/M	N/M	>40	Colorless	Develop. by Kerr-McGee
1327		NOT DEVELOPED					
1327-B	3/20/89	N/M	N/M	N/M	40	Clear, pale orange tint	
1328	3/16/89	139.15	55.34	64.02	250	Clear, v. pale orange tint	Well made >4 gpm during devel.
1329	3/13/89	49.5	38.7	41.3	35	Clear, v. pale orange tint	
1330	3/16/89	43.7	26.21	27.1	80	Clear, pale orange tint	
1331	3/15/89	27.9	10.1	13.35	80	Clear, colorless	
1332	3/16/89	121.1	46.8	59.25	240	Clear, colorless	Well made about 4 gpm
1333	3/14/89	37.6	20.7	N/M	30	Clear, colorless	Well made about 1 qt/m
1334	3/16/89	25.1	9.85	N/M	30	Clear, pale orange tint	
1335	3/15/89	45.1	28.65	31.25	50	Clear, v.pale orange tint	
1336	3/15/89	32.7	25.18	N/M	20	Clear, colorless	Very slow flow rate

NOTE: N/M means not measured

TABLE 3.3

Aquifer Test Results

WELL NO.	BOUWER AND RICE METHOD Conductivity cm/sec	BOUWER AND RICE METHOD Transmissivity ft sq/day	COOPER ET.AL. METHOD Conductivity cm/sec	COOPER ET.AL. METHOD Transmissivity ft sq/day	HVORSLEV METHOD Conductivity cm/sec	HVORSLEV METHOD Transmissivity ft sq/day
			SHALLOW WELLS			
1320	2.34E-04	1.03E+01	2.30E-04	6.50E+00	2.57E-04	7.44E+00
1322	1.29E-03	2.10E+01			1.88E-03	3.09E+01
1324	5.19E-04	1.74E+01				
1325	9.66E-04	4.19E+01			2.72E-03	1.04E+02
1326	5.01E-04	1.06E+01			7.45E-04	1.70E+01
1327-B	8.98E-04	2.85E+01			2.41E-03	7.53E+01
1329	3.03E-03	1.02E+02			5.70E-03	1.94E+02
1330	8.60E-04	6.36E+01	7.40E-04	5.46E+01	1.41E-03	1.03E+02
1331	1.08E-03	4.34E+01	1.13E-03	4.00E+01		
1333	2.46E-04	9.92E+00				
1334	8.52E-04	2.50E+01			5.96E-04	5.76E+00
1335	4.11E-04	2.72E+01				
1336	2.28E-03	1.08E+02			4.61E-03	1.05E+02
			DEEP WELLS			
1321	2.25E-04	4.76E+01	4.41E-05	5.00E+00	1.09E-04	1.55E+01
1323	2.00E-05	4.58E+00	1.39E-05	6.70E-01	1.59E-05	5.90E-01
1328	1.03E-03	2.54E+02	7.06E-04	5.00E+01	1.06E-03	4.49E+01
1332	4.66E-04	1.03E+02	6.05E-04	2.40E+01		

TABLE 3.4

Ground Water Analyses

Well No.	pH	Conductivity umho	Fluoride mg/l	Nitrate mg/l	Gross Alpha pCi/l	Gross Beta pCi/l	U-238 pCi/l	U-235 pCi/l	U-234 pCi/l	TOTAL URANIUM pCi/l	Ra-228 pCi/l	Ra-226 pCi/l	TOTAL RADIUM pCi/l	Th-232 pCi/l	Th-228 pCi/l	Pu-239 pCi/l	TOC mg/l	TOX ug/l
1311			<0.20	66.00	<10.00	23.00	0.77 +-0.11	0.018 +-0.18	0.99 +-0.13	1.78	0.082 +-0.19	0.180 +-0.21	0.26	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		
1312			50.00	1020.00	59.00	2370.00	15.30 +-1.90	1.230 +-0.55	41.60 +-3.20	58.13	1.380 +-0.54	0.450 +-0.34	1.83	0.004 +-0.004	0.007 +-0.005	0.003 +-0.002		
1313			140.00	720.00	260.00	2200.00	30.00 +-2.00	2.700 +-0.70	84.00 +-4.00	116.70	2.340 +-0.91	0.490 +-0.49	2.83	0.004 +-0.004	0.004 +-0.004	0.003 +-0.002		
1314			<0.20	0.36	<10.00	<20.00	0.31 +-0.08	0.039 +-0.027	0.77 +-0.12	1.12	0.000 +-0.27	0.110 +-0.23	0.11	0.004 +-0.004	0.004 +-0.004	0.003 +-0.002		
1315			0.22	13.00	6440.00	660.00	1550.00 +-190.0	110.000 +-51.0	3570.00 +-285.0	5230.00	1.610 +-0.77	0.000 +-0.22	1.61	0.004 +-0.004	0.013 +-0.007	0.003 +-0.002		
1316			<0.20	16.00	331.00	100.00	67.00 +-10.0	10.000 +-3.8	210.00 +-17.0	287.00	0.470 +-0.58	0.000 +-0.30	0.47	0.004 +-0.004	0.004 +-0.004	0.003 +-0.002		
1317			<0.20	0.38	66.00	26.00	8.10 +-0.34	0.580 +-0.29	15.00 +-1.5	23.68	0.100 +-0.39	0.000 +-0.24	0.10	0.004 +-0.004	0.004 +-0.004	0.003 +-0.002		
1320	7.39	520	0.42	20.00	<10.00	<20.00	3.10 +-0.28	0.170 +-0.10	5.58 +-0.57	8.85	0.250 +-0.30	0.150 +-0.22	0.40	0.004 +-0.004	0.004 +-0.004	0.005 +-0.003		
1321	6.91	1910	<.20	9.10	18.00	26.00	2.75 +-0.40	0.120 +-0.08	8.10 +-0.70	10.97	0.021 +-0.14	0.000 +-0.14	0.02	0.004 +-0.004	0.004 +-0.004	0.004 +-0.003		
1322	7.32	560	<.20	9.20	15.00	<20.00	3.90 +-0.65	0.130 +-0.011	8.20 +-0.09	12.23	0.038 +-0.30	0.220 +-0.29	0.26	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002	<10.00	77.00
1323	7.27	2510	<.20	1.70	51.00	<20.00	9.80 +-1.00	0.420 +-0.21	17.00 +-1.30	27.22	0.012 +-0.24	0.046 +-0.20	0.06	0.004 +-0.004	0.004 +-0.004	0.004 +-0.003		
1324	7.55	440	0.26	18.00	<10.00	<20.00	0.20 +-0.07	0.022 +-0.022	0.44 +-0.10	0.66	0.059 +-0.27	0.000 +-0.27	0.06	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		
1325	7.32	460	0.35	13.00	<10.00	<20.00	1.00 +-0.12	0.046 +-0.026	1.49 +-0.015	2.54	0.260 +-0.26	0.086 +-0.26	0.35	0.004 +-0.004	0.004 +-0.004	0.006 +-0.003	12.00	130.00
1326	7.37	610	<0.20	14.00	14.00	25.00	1.48 +-0.15	0.058 +-0.029	4.43 +-0.25	5.97	0.150 +-0.20	0.000 +-0.16	0.15	0.004 +-0.004	0.008 +-0.005	0.002 +-0.001	<10.00	98.00
1327-B	7.71	450	0.20	8.20	<10.00	<20.00	1.52 +-0.20	0.140 +-0.06	2.80 +-0.28	4.46	0.009 +-0.10	0.052 +-0.082	0.06	0.004 +-0.004	0.004 +-0.004	0.006 +-0.003		
1328	7.39	2310	<0.20	2.20	29.00	<20.00	9.00 +-0.90	0.660 +-0.25	18.00 +-1.30	27.66	0.000 +-0.19	0.054 +-0.13	0.05	0.004 +-0.004	0.011 +-0.007	0.002 +-0.002		
1329	7.49	400	<0.20	0.40	12.00	<20.00	2.04 +-0.18	0.093 +-0.037	5.30 +-0.29	7.43	0.000 +-0.17	0.030 +-0.13	0.03	0.004 +-0.004	0.008 +-.006	0.006 +-0.003	<10.00	62.00
1330	6.99	1590	<0.20	172.00	16.00	62.00	2.40 +-0.22	0.100 +-0.05	5.17 +-0.33	7.67	0.000 +-0.31	0.088 +-0.22	0.09	0.008 +-0.008	0.008 +-0.008	0.006 +-0.003		
1331	7.10	710	<0.20	5.70	190.00	23.00	35.00 +-6.10	3.700 +-1.80	126.00 +-12.0	164.70	0.000 +-0.23	0.000 +-0.23	0.00	0.004 +-0.004	0.008 +-0.005	0.002 +-0.002		
1332	7.21	3190	1.30	3.40	23.00	<20.00	6.40 +-0.60	0.12 +-0.08	13.900 +-0.90	20.42	1.000 +-0.46	0.180 +-0.36	1.18	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		
1333	7.05	800	<0.20	6.30	47.00	<20.00	6.20 +-0.50	0.710 +-0.12	18.00 +-0.60	24.91	0.120 +-0.32	0.120 +-0.39	0.24	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		
1334	7.10	730	0.26	6.10	30.00	<20.00	5.00 +-0.33	0.230 +-0.07	13.20 +-0.50	18.43	0.200 +-0.14	0.029 +-0.13	0.23	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		
1335	7.01	470	0.24	22.00	<10.00	<20.00	1.25 +-0.15	1.640 +-0.17	1.640 +-0.17	4.53	0.000 +-0.32	0.000 +-0.32	0.00	0.004 +-0.004	0.004 +-0.004	0.006 +-0.004		
1336	7.30	664	17.00	1260.00	140.00	4970.00	23.00 +-2.40	2.400 +-0.80	76.000 +-4.0	101.40	7.830 +-1.63	1.950 +-1.02	9.78	0.004 +-0.004	0.085 +-0.018	0.002 +-0.002		
1337*	7.05	800	<0.20	5.70	33.00	<20.00	5.10 +-0.54	0.170 +-0.10	18.700 +-1.04	23.97	1.200 +-0.41	0.200 +-0.21	1.40	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		
1338**			0.32	<0.23	<10.00	<20.00	0.04 +-0.025	0.017 +-0.017	0.071 +-0.036	0.12	0.028 +-0.089	0.000 +-0.061	0.03	0.004 +-0.004	0.004 +-0.004	0.002 +-0.002		

MAJOR ION ANALYSIS
WELL 1324
(Sampled 6/12/89)

Ca	71.5 mg/l	Cl	3.8 mg/l
Mg	37.2 mg/l	HCO3	394 mg/l
F	0.6 mg/l	NO3(N)	20 mg/l
K	0.36 mg/l	SO4	72 mg/l
Na	40.1 mg/l		

NOTE: * 1337 is a duplicate of 1333.
** 1338 is an equipment blank
Blank spaces mean parameter not measured

TABLE 3.5

Rock and Soil Parameter Analyses

SAMPLE NO.	BORING NO.	SAMPLE INTERVAL	SAMPLE DESCRIPTION	FIELD GAMMA LOG counts/min	GAMMA SPECTROMETRY URANIUM ACTIVITY pCi/g	F (ppm)	NO3 (ppm)	TOC (ppm)	GROSS ALPHA pCi/g	GROSS BETA pCi/g	Pu-239 pCi/g	Ra-228 pCi/g	Ra-226 pCi/g	Th-232 pCi/g	Th-228 pCi/g	U-238 pCi/g	U-234 pCi/g
CS-100	1325	6.0-7.0'	Sandy mudstone	26930	5.76	170.00	14.00	45.00	16.00	<20.00	0.003 +-0.001	0.07 +-0.18	0.55 +-0.36	0.70 +-0.03	0.70 +-0.03	0.34 +-0.05	0.51 +-0.05
CS-101	1321	42.0-42.5'	Sandy mudstone	31845	7.92	560.00	3.00	<10.00	34.00	<20.00	0.002 +-0.001	1.84 +-0.39	0.51 +-0.28	1.37 +-0.07	1.37 +-0.07	0.66 +-0.07	0.57 +-0.07
CS-102	1323	8.7-9.7'	Sandy mudstone	30119	6.91	640.00	2.00	190.00	30.00	<20.00	0.001 +-0.001	0.29 +-0.20	0.21 +-0.21	1.39 +-0.06	1.42 +-0.06	0.67 +-0.08	0.63 +-0.08
CS-103	1323	35.0-36.0'	Sandy mudstone	30754	3.91	440.00	3.00	23.00	30.00	<20.00	0.001 +-0.001	0.27 +-0.85	0.28 +-0.95	1.17 +-0.10	1.28 +-0.10	0.51 +-0.06	0.60 +-0.06
CS-104	1326	16.0-17.0'	Sandy mudstone	30829	6.44	600.00	4.00	<10.00	35.00	<20.00	0.001 +-0.001	1.17 +-0.24	0.77 +-0.21	1.15 +-0.06	1.15 +-0.06	0.69 +-0.07	0.77 +-0.07
CS-105	1327	21.0-22.0'	Sandy mudstone	32050	4.11	470.00	3.00	<10.00	31.00	<20.00	0.001 +-0.001	0.77 +-0.35	0.65 +-0.34	1.00 +-0.08	1.20 +-0.08	0.68 +-0.04	0.68 +-0.04
CS-106	1328	19.0-20.0'	Sandy mudstone	30502	8.13	600.00	15.00	<10.00	38.00	<20.00	0.001 +-0.001	0.99 +-0.42	0.66 +-0.39	1.14 +-0.07	1.18 +-0.07	0.71 +-0.07	0.72 +-0.07
CS-107	1330	11.5-12.5'	Sandy mudstone	30944	6.36	560.00	16.00	420.00	19.00	<20.00	0.001 +-0.001	0.62 +-0.21	0.29 +-0.22	0.69 +-0.05	0.87 +-0.05	0.84 +-0.08	0.73 +-0.08
CS-108	1336	14.0-15.0'	Sandstone, fine-grained		8.87	140.00	9.00	1180.00	<10.00	<20.00	0.002 +-0.001	0.04 +-0.17	0.19 +-0.34	0.53 +-0.07	0.52 +-0.07	0.23 +-0.04	0.21 +-0.04
CS-109	1336	25.0-25.5'	Sandstone, fine-grained		10.79	190.00	27.00	<10.00	<10.00	<20.00	0.002 +-0.001	0.37 +-0.31	0.26 +-0.25	0.52 +-0.05	0.52 +-0.05	0.38 +-0.05	0.42 +-0.05
CS-110	1335	25.0-25.6'	Sandstone, fine-grained		8.34	40.00	3.00	840.00	<10.00	<20.00	0.001 +-0.001	0.10 +-0.14	0.08 +-0.11	0.27 +-0.03	0.27 +-0.03	0.24 +-0.04	0.24 +-0.04
CS-111	1324	16.0-18.0'	Very sandy mudstone	6271 *	13.25	39.00	4.00	27.00	<10.00	<20.00	0.006 +-0.001	0.00 +-0.16	0.11 +-0.26	0.45 +-0.02	0.41 +-0.02	0.19 +-0.05	0.19 +-0.05
CS-112	1321	69.5-70.0'	Sandstone, fine-grained		16.18	55.00	2.00	160.00	<10.00	<20.00	0.002 +-0.001	0.07 +-0.27	0.10 +-0.30	0.34 +-0.03	0.41 +-0.03	0.29 +-0.03	0.33 +-0.03
CS-113	1321	13.4-14.0'	Sandstone, fine-grained	7703	9.58	65.00	130.00	170.00	<10.00	<20.00	0.001 +-0.001	0.08 +-0.10	0.12 +-0.20	0.32 +-0.03	0.33 +-0.03	0.23 +-0.03	0.18 +-0.03
CS-114	1334	11.2-11.8'	Sandstone, fine-grained		9.08	51.00	4.00	18.00	11.00	<20.00	0.001 +-0.001	0.00 +-0.09	0.33 +-0.17	0.27 +-0.03	0.28 +-0.03	0.38 +-0.05	0.61 +-0.05
CS-115	1332	7.0-7.5'	Sandstone, fine-grained		10.29	150.00	5.00	440.00	<10.00	<20.00	0.002 +-0.001	0.02 +-0.16	0.26 +-0.26	0.61 +-0.05	0.65 +-0.05	0.38 +-0.04	0.36 +-0.04
CS-116	1332	68.0-68.5'	Conglomeratic sandstone		10.40	65.00	3.00	110.00	<10.00	<20.00	0.001 +-0.001	0.00 +-0.44	0.30 +-0.22	0.56 +-0.04	0.56 +-0.04	0.38 +-0.04	0.45 +-0.04
CS-117	1332	41.5-42.0'	Sandy mudstone		7.45	450.00	3.00	<10.00	25.00	<20.00	0.001 +-0.001	0.54 +-0.36	0.32 +-0.36	0.89 +-0.04	0.96 +-0.04	0.70 +-0.05	0.63 +-0.05
CS-118	1331	9.5-10.0'	Sandstone, fine-grained		5.99	210.00	3.00	250.00	12.00	<20.00	0.001 +-0.001	0.02 +-0.04	0.40 +-0.57	0.56 +-0.04	0.63 +-0.05	0.34 +-0.04	0.30 +-0.04
CS-119	1323	34.3-37.9'	Sandy mudstone	29253 *	17.6	330.00	3.00	130.00	18.00	<20.00	0.001 +-0.001	0.30 +-0.27	0.38 +-0.33	0.96 +-0.06	0.93 +-0.03	0.63 +-0.05	0.59 +-0.05
CS-120	1323	112-112.5'	Sandstone, fine-grained		7.05	59.00	3.00	140.00	<10.00	<20.00	0.001 +-0.001	0.00 +-0.14	0.03 +-0.20	0.42 +-0.05	0.42 +-0.05	0.27 +-0.04	0.27 +-0.04
CS-121	1326	2.0-4.0'	Sand, slightly silty	17255 *	12.1	170.00	5.00	3110.00	<10.00	<20.00	0.001 +-0.001	0.00 +-0.25	0.42 +-0.32	0.49 +-0.04	0.59 +-0.05	0.44 +-0.05	0.68 +-0.05
CS-122	1328	11.0-11.6'	Sandstone, fine-grained	12082	13.87	72.00	5.00	47.00	<10.00	<20.00	0.002 +-0.001	0.01 +-0.19	0.12 +-0.25	0.33 +-0.03	0.33 +-0.03	0.26 +-0.03	0.36 +-0.03
CS-123	1328	37.8-38.3'	Conglomeratic sandstone	8128	10.92	180.00	2.00	320.00	11.00	<20.00	0.003 +-0.001	0.30 +-0.21	0.37 +-0.22	0.50 +-0.06	0.68 +-0.06	0.45 +-0.04	0.45 +-0.04
CS-124	1328	83.5-84.0'	Sandstone, fine-grained		10.41	23.00	6.00	1180.00	<10.00	<20.00	0.002 +-0.001	1.90 +-0.54	0.00 +-0.06	0.27 +-0.04	0.47 +-0.04	0.19 +-0.03	0.19 +-0.03
CS-125	1330	20.5-21.0'	Sandstone, fine-grained	19269	10.86	88.00	12.00	240.00	NR	NR	0.001 +-0.001	0.00 +-0.25	0.11 +-0.32	0.26 +-0.03	0.26 +-0.03	0.22 +-0.03	0.23 +-0.03
CS-126	1321	131.5-132'	Sandy mudstone		5.98	18.00	4.00	130.00	<10.0	<20.0	0.002 +-0.001	0.00 +-0.09	0.01 +-0.13	0.41 +-0.04	0.41 +-0.04	0.16 +-0.02	0.21 +-0.03

NOTE: * Indicates value averaged over interval sample composited.
Gamma spectrometry performed by Cimarron personnel using the EG&G Ortec ADCAM computer analysis program.
NR means value not reported.

TABLE 3.6

Physical Property Analyses

SAMPLE NO.	PP-1	PP-2	PP-3	PP-4	PP-5	PP-6	PP-7	PP-8	PP-9	PP-10
WELL NO.	Landfill Borrow	Landfill Borrow	Landfill Borrow	1328	1328	1323	1332	1332	1334	1327
SAMPLE INTERVAL				6-8'	15-15.5'	2-4'	20-20.4'	10.5-11'	13.5-14	16.5-17'
ATTERBERG LIMITS										
LIQUID LIMIT	24.0	23.0	23.0	26.0	34.0	NP	NP	25.0	36.0	NP
PLASTIC LIMIT	10.0	9.0	8.0	8.0	9.0	NP	NP	8.0	13.0	NP
PERCENT PASSING SIEVE										
#10	93.8	98.3	97.3	100.0	100.0	100.0	100.0	100.0	100.0	95.9
#40	90.0	95.4	93.5	94.8	95.6	99.9	99.2	99.9	98.5	71.8
#200	70.5	73.3	72.9	62.8	87.7	39.2	89.2	94.6	94.1	44.7
STANDARD PROCTOR TEST ASTM D698										
% MOISTURE	13.1	13.0	14.0							
DRY DENSITY	119.7	120.5	117.8							
PERMEABILITY TEST ASTM STP-479										
% MOISTURE	13.4	15.3	16.9							
% COMPACTION	80.8	77.9	77.1							
PERMEABILITY cm/sec	1.02E-04	1.98E-05	1.38E-04							
% MOISTURE	12.8	14.7	15.5							
% COMPACTION	89.6	88.2	87.7							
PERMEABILITY cm/sec	1.18E-05	2.99E-06	1.60E-05							
% MOISTURE	14.3	14.6	16.0							
% COMPACTION	96.1	97.4	97.1							
PERMEABILITY cm/sec	3.00E-07	3.08E-08	2.48E-08							

TABLE 3.7

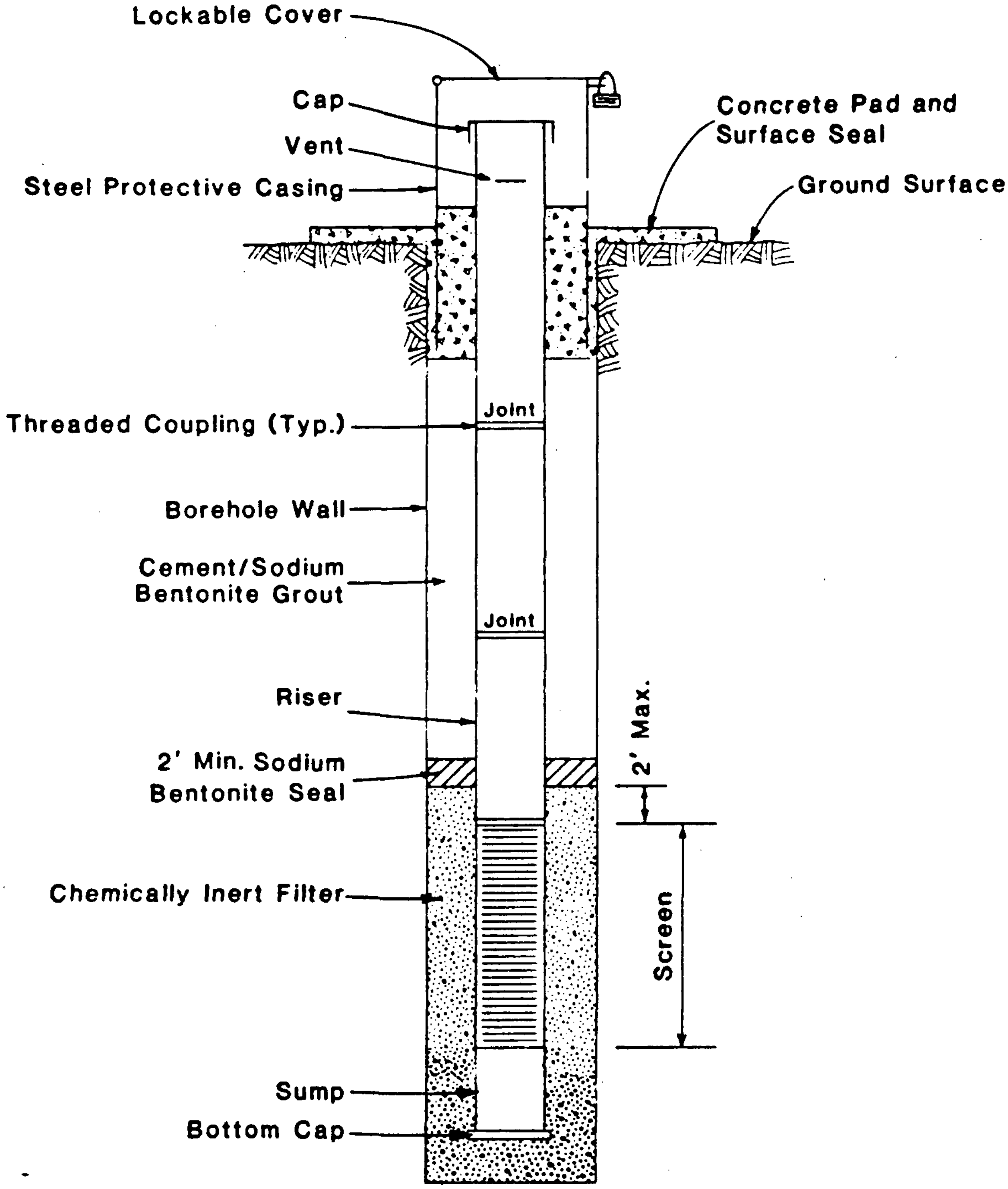
Rock and Soil Mineralogical Analyses

SAMPLE NO.	BORING NO.	SAMPLED INTERVAL	ABBREVIATED FIELD DESCRIPTION	GRAIN SIZE DISTRIBUTION % FRACTION < 2mm Sand	Silt	Clay	pH	CEC meq/100g	EXCHANGEABLE CATIONS (meq/100g) Ca	Mg	K	Na	MINERALOGICAL COMPOSITION (wt. percent) Kaolinite	Fe Oxides/ Hydroxides	Expanding Silicates	Feldspar + mica	Calcite	Quartz	Adsorbed Water
CH-1	1323	37.9-38.4'	VFG sandy mudstone	0.70	78.74	20.56	8.43	10.83	6.96	3.29	0.32	0.30	15	4	12	17	<1	48	1.63
CH-2	1323	34.3-37.9'	Comp. of red. zones	15.50	64.94	19.56	8.72	7.96	17.25	2.78	0.23	0.28	12	2	8	17	<1	56	2.25
CH-3	1326	2-4'	Silty sand	57.70	27.82	14.48	6.87	7.71	5.01	1.61	0.16	0.11							
CH-4	1328	20-20.4	Slightly sandy mudstone	18.70	47.22	34.08	8.53	18.56	27.37	6.62	0.47	0.30							
CH-5	1328	37.2-38'	Sandstone conglomerate	82.40	10.48	7.12	9.18	2.55	18.84	1.14	0.08	0.21	1	3	3	5	29	58	0.5
CH-6	1336	15.3-15.7	VFG sandy mudstone	2.50	58.18	39.32	8.18	22.75	26.26	5.97	0.48	0.35	27	8	23	27	<1	12	3.63
CH-7	1321	25.5-26	VFG sandy mudstone	39.60	45.56	14.84	7.91	4.59	8.35	1.62	0.11	0.33							
CH-8	1321	25-25.3	FG-VFG sandstone	80.00	13.08	6.92	8.30	3.37	10.93	1.43	0.07	0.33	1	<1	3	3	1	90	0.38
CH-9	Landfill	borrow	silt, sand, rock frags.	37.50	39.66	22.84	8.76	9.93	21.14	2.94	0.25	0.21	8	3	10	14	3	59	1.63
CH-10	1324	20-22'	Sandy mudstone	74.20	16.12	9.68	5.99	2.96	10.50	1.36	0.10	0.17							
CH-11	1325	24-26'	Sandy mudstone	56.40	25.56	18.04	8.86	6.00	17.82	5.71	0.22	0.29							
CH-12	Landfill		Grab - gray red. zone	47.00	43.44	9.56	8.69	6.20	9.29	4.03	0.50	0.27	7	1	6	9	3	72	1
CH-13	1332	4-5.5'	Silty sand	25.50	55.34	19.16	8.89	8.02	20.24	4.95	0.34	0.47							
CH-14	1334	16.4-16.7'	Gray, silty red. zone	59.20	24.16	16.64	8.95	6.87	17.71	4.2	0.50	0.21	1	1	7	11	12	59	1.25
CH-15	1334	15.6-15.9'	Sandy mudstone	21.90	51.94	26.16	8.62	11.32	12.35	5.18	0.58	0.15	10	4	11	17	3	52	1.88

TABLE 3.8

Distribution Coefficient Analyses

Sample No.	Initial Water Conc. (pCi/ml)	Total Spike (pCi)	Initial pH	Final pH	Equilibrium Water Conc. (pCi/ml)	Soil Conc. (pCi/g)	Distribution Coefficient (ml soln/g soil)
TEST 1 - Uranium-232							
CH-1R	0.85	17.00	7.45	7.90	1.20E-03	3.40	2829.333
CH-5R	0.85	17.00	7.45	7.76	2.70E-03	3.39	1255.259
CH-6R	0.85	17.00	7.50	7.82	9.30E-03	3.36	361.591
CH-8R	0.85	17.00	7.49	7.75	1.20E-03	3.40	2829.333
CH-14R	0.85	17.00	7.50	7.82	3.00E-03	3.39	1129.333
- Thorium-228							
CH-1R	0.85	17.00	7.45	7.90	6.00E-04	3.40	5662.667
CH-5R	0.85	17.00	7.45	7.76	9.00E-04	3.40	3773.778
CH-6R	0.85	17.00	7.50	7.82	6.00E-04	3.40	5662.667
CH-8R	0.85	17.00	7.49	7.75	1.20E-03	3.40	2829.333
CH-14R	0.85	17.00	7.50	7.82	1.20E-03	3.40	2829.333
TEST 2 - Uranium-232							
CH-1R	0.85	85.00	7.11	7.38	7.50E-03	3.37	449.333
CH-5R	0.85	85.00	7.22	7.46	3.60E-03	3.39	940.444
CH-6R	0.85	85.00	7.19	7.40	9.90E-03	3.36	339.434
CH-8R	0.85	85.00	7.20	7.42	1.50E-03	3.39	2262.667
CH-14R	0.85	85.00	7.23	7.46	2.10E-03	3.39	1615.048
- Thorium-228							
CH-1R	0.85	85.00	7.11	7.38	1.50E-03	3.39	2262.667
CH-5R	0.85	85.00	7.22	7.46	9.00E-04	3.40	3773.778
CH-6R	0.85	85.00	7.19	7.40	9.00E-04	3.40	3773.778
CH-8R	0.85	85.00	7.20	7.42	9.00E-04	3.40	3773.778
CH-14R	0.85	85.00	7.23	7.46	6.00E-04	3.40	5662.667



808211

JAMES L. GRANT & ASSOCIATES
geotechnical engineering • management • computer science
ENGLEWOOD, COLORADO

FIGURE 3.1

MONITORING WELL DESIGN

4. REGIONAL HYDROGEOLOGY

4.1 Regional Structure and Stratigraphy

Subsurface rock units in the central Oklahoma region range in age from Precambrian through Permian. Outcropping bedrock in the area consists of Permian and Pennsylvanian strata. Near drainages and flood plains the rocks are capped with unconsolidated Quaternary alluvium and terrace deposits. Figure 4.1 is a geologic map of the region.

The principal structural feature in the central Oklahoma region is the Nemaha ridge or uplift, a north-northwest trending subsurface uplift formed during the Mississippian. Figure 4.2 is a map of Oklahoma showing the tectonic provinces.

The Phanerozoic (Cambrian and younger) geologic history of central Oklahoma is characterized by periods of marine and non-marine sedimentation punctuated by periods of extensive erosion. Four widespread unconformities have been identified marking periods of uplift, erosion, and subsequent deposition. These unconformities occur at the top of the Ordovician Arbuckle formation, at the base of the Mississippian system, at the base of the Pennsylvanian system, and during the Tertiary Period.

Of particular importance to the central Oklahoma region is a period of uplift and erosion that occurred between the Mississippian and Pennsylvanian systems. This period of activity produced the north-northwest trending normal faults and anticlinal structures that comprise the Nemaha ridge. Early Pennsylvanian strata onlap and thin over the structures signifying continued uplift into the Pennsylvanian. Reactivation of the faults is not documented after early to middle Pennsylvanian time.

The Nemaha ridge controlled sedimentation during part of the Pennsylvanian by partially subdividing the existing basin. Sediments east of the ridge are generally representative of shallow marine and non-marine deposition, while strata west of the ridge were deposited from essentially shallow and deeper marine environments. The axis of the Nemaha ridge or uplift lies west of the site.

By Permian time, the central Oklahoma region lay along the eastern shelf of a shallow sea. The Permian strata underlying the Cimarron facility area are the Garber and Wellington formations. These formations consist of interbedded sandstones, siltstones and shales primarily and were deposited from a west-flowing deltaic system. These clastic units are characteristically interbedded and of limited areal extent with rapid facies changes.

A widespread unconformity has truncated all pre-Quaternary formations in the region. This has produced the characteristic north-trending outcrop pattern indicated in Figure 4.1.

Along rivers and streams, Quaternary terrace and alluvial deposits have formed. These deposits consist of unconsolidated gravels, sands, silts and clays. The deposits generally range in thickness from 10 to 50 feet. Locally, they may be as much as 100 feet thick. In the vicinity of the Cimarron facility, the Cimarron terrace is Pleistocene in age and is the result of glacial outwash.

4.2 Regional Ground-Water Occurrence

Ground water in the central Oklahoma region occurs principally in the Permian-aged Garber/Wellington aquifer. The Oklahoma Geological Survey groups the Garber and Wellington formations together as a single hydrologic unit on the basis of similar lithologies and water-bearing characteristics (Bingham and Moore, 1975).

The water-bearing sandstones are fine grained and friable, with numerous interbedded siltstones and shales. The matrix of the sandstones is frequently a fine red mud. Sandstones are generally thin and the percentage of sandstone versus shale increases from north to south in the central Oklahoma region. The combined thickness of the Garber and Wellington formations is approximately 600 to 800 feet.

Carr and Marcher (1977) have identified differences in ground-water flow patterns within the Garber/Wellington aquifer. The shallow ground water generally flows laterally towards streams and springs where it discharges to the surface. A minor component of flow is vertical and leakage partially recharges deeper confined aquifers. The authors also note that shallow ground water occasionally flows upward where rivers or streams have deeply entrenched the bedrock and the potentiometric surface is higher than the surface-water elevation.

Ground water in the deeper portion of the Garber/Wellington aquifer flows primarily to the southwest along the regional dip. The points of discharge of the deeper ground water are outside the central Oklahoma region. Figure 4.3 shows the potentiometric surface of the Garber/Wellington aquifer in southern Logan and northern Oklahoma counties.

Recharge of the Garber/Wellington aquifer is accomplished through precipitation and infiltration in areas of outcrop. Infiltration through overlying porous and permeable strata also provides considerable recharge. Johnson (1983) identified the principal recharge area for the Garber/Wellington aquifer as an area lying generally north of the Canadian River, south of Guthrie, east of the Canadian County line, and west of Shawnee. Figure 4.4 shows the recharge area.

Bingham and Moore (1975) estimated the amount of water available for recharge of ground water in the central Oklahoma region. Average annual precipitation ranges from 28 inches per year near Kingfisher to about 41 inches per year near Holdenville. Approximately 24 to 30 inches per year is returned to the atmosphere through evaporation and transpiration. Runoff ranges from 2.5 to 8 inches per year. The authors estimate that 1.5 to 3.5 inches per year is subsequently available for recharge.

In addition to the Garber/Wellington aquifer, Quaternary-aged terrace and alluvial deposits are locally important sources of ground water. These deposits consist of lenticular unconsolidated gravels, sands, silts, and clays. Alluvium refers to sediments deposited along modern stream channels and flood plains. Terrace deposits are older alluvial deposits that remain after rivers shift position, or may represent previous flood plains. Figure 4.1 shows the extent of the surficial alluvium and terrace deposits in the area near the Cimarron facility.

According to Bingham and Moore (1975), well yields of 200 to 250 gallons per minute (gpm) are common and that up to 500 gpm have been reported locally from these deposits. Engineering Enterprises (1973) reports that ground water in the terrace deposits near the town of Crescent flows southward towards the Cimarron River and contributes to its base flow. Recharge of the terrace and alluvial aquifers also occurs through precipitation and infiltration; however, water levels in the alluvial aquifers are commonly maintained by streams and rivers.

4.3 Ground-Water Use

The principal source of ground water in the area near the Cimarron facility is the Garber/Wellington formation. Well fields supply water to the towns of Edmond, Cashion, and others from this aquifer. North of the Cimarron River, domestic and agricultural users frequently obtain ground water from the Cimarron terrace deposits. Engineering Enterprises (1973) reports that well density in the terrace is approximately three wells per square mile. The river alluvium in the vicinity of the Cimarron facility is not used for ground water or drinking water supplies because of the salinity of the Cimarron River.

4.4 Regional Ground-Water Quality

Bingham and Moore (1975) discuss ground-water quality in the region encompassed by the Oklahoma City quadrangle. Previously published water quality data were combined with samples collected by the authors to characterize ground-water quality in the region. A summary of their results is presented in Table 4.1. Table 4.2 is a summary of ground-water quality analyses compiled by the U.S. Geological Survey for wells in the Garber/Wellington aquifer in Logan County.

In general, the water from bedrock aquifers is of good quality although the water usually is hard to very hard. Ground water from terrace deposits is also of good quality. Water from the alluvium along the Cimarron, North Canadian and Canadian Rivers is generally fair to poor because of the poor quality of the river water (Bingham and Moore, 1975). Engineering Enterprises (1973) reports that the Cimarron River has elevated naturally occurring chlorides derived from the Big Salt plains area approximately 100 miles upstream from the Cimarron facility.

The Garber/Wellington aquifer generally has good water. Bingham and Moore (1975) report that in the central Oklahoma region, hardness ranges from 4 ppm to 538 ppm, with a median value of 156 ppm; sulfate ranges from 3 ppm to 1450 ppm with a median of 17 ppm; chlorides range from 0.2 ppm to 458 ppm, with a median of 14 ppm; and nitrate ranges from 0 ppm to 100 ppm with a median of 1 ppm. Generally, hardness and dissolved solids tend to increase with depth. These data are presented in Table 4.1.

Table 4.2 presents data compiled by the U.S. Geological Survey for wells screened in the Garber/Wellington aquifer at depths less than 200 feet below ground surface in the area near the Cimarron facility. The data represents wells located in an area defined by Township 15 North, Range 2 West on the southeast to Township 16 North, Range 4 West on the northwest. In this area, hardness ranges from 130 ppm to 1300 ppm, with an average of 381 ppm; sulfate ranges from 7 ppm to 1900 ppm, with an average of 245 ppm; chlorides range from about 5 ppm to 110 ppm, with an average of about 32 ppm; and nitrates plus nitrite ranges from 0.3 to 63 ppm, with an average of about 15 ppm.

Near the town of Crescent, ground water from the terrace deposits above the Cimarron River is generally of good quality. Engineering Enterprises (1973) reports that wells screened in the terrace deposits near Crescent have a hardness ranging from 100 ppm to 200 ppm; total dissolved solids range from 400 ppm to 1000 ppm; and chlorides average about 50 ppm. They also report, however, that the terrace aquifer is locally impacted by brines that were disposed in unlined pits in the Crescent oilfield. Chlorides have been measured up to 17,000 ppm in this area.

According to Engineering Enterprises (1973), the water quality in the alluvial aquifers is similar to the terrace aquifers where the alluvium is recharged by the terrace ground water. In general, however, the alluvial aquifers are of poor quality because they are recharged by the Cimarron River which contains high chlorides that result from water from the natural salt springs about 100 miles upstream.

4.4.1 Background Nitrate and Fluoride Concentrations.

In the Garber/Wellington aquifer in the central Oklahoma region, Bingham and Moore (1975) report nitrate concentrations of 0 ppm to 100 ppm. Carr and Havens (1976) report nitrate concentrations of 1 ppm to 32 ppm from six wells in the Garber/Wellington aquifer near the Cimarron facility. The average nitrate concentration for the six wells is 12 ppm.

Carr and Havens (1976) also sampled one well in section 29, Township 15 North, Range 4 West for fluoride. The fluoride concentration was 0.9 ppm. At the Cimarron facility, twenty of the twenty four wells sampled had fluoride levels less than 0.5 mg/l. Regional fluoride concentrations in the Garber/Wellington aquifer are believed similar to these values.

4.4.2 Background TOC and TOX Concentrations.

Total organic carbon (TOC) and total organic halides (TOX) are general indicators of ground-water impacts from organic origins. At the Cimarron facility, three of the four wells sampled had TOC concentrations less than the laboratory detection limit of 10 mg/l. A fourth sample had a TOC content of 12 mg/l. These are equivalent to regional background concentrations in the Garber/Wellington aquifer.

Regional TOX concentrations in the Garber/Wellington aquifer probably are similar to values in the shallow ground water at the facility. These values range from 62 ug/l to 130 ug/l.

4.4.3 Background Radionuclide Concentrations.

Cimarron personnel installed monitoring wells approximately one-half mile south of the facility near the intersection of State Highways 33 and 74 to provide background data. These wells are up-gradient from the facility. Samples have been collected and analyzed for radionuclides since 1971. The data indicates that background values of U-238 are generally less than 0.7 pCi/l; Pu-239 is generally less than 0.010 pCi/l; gross alpha activity is less than 10 pCi/l; and gross beta activity is less than 20 pCi/l.

TABLE 4.1

Regional Ground-Water Quality

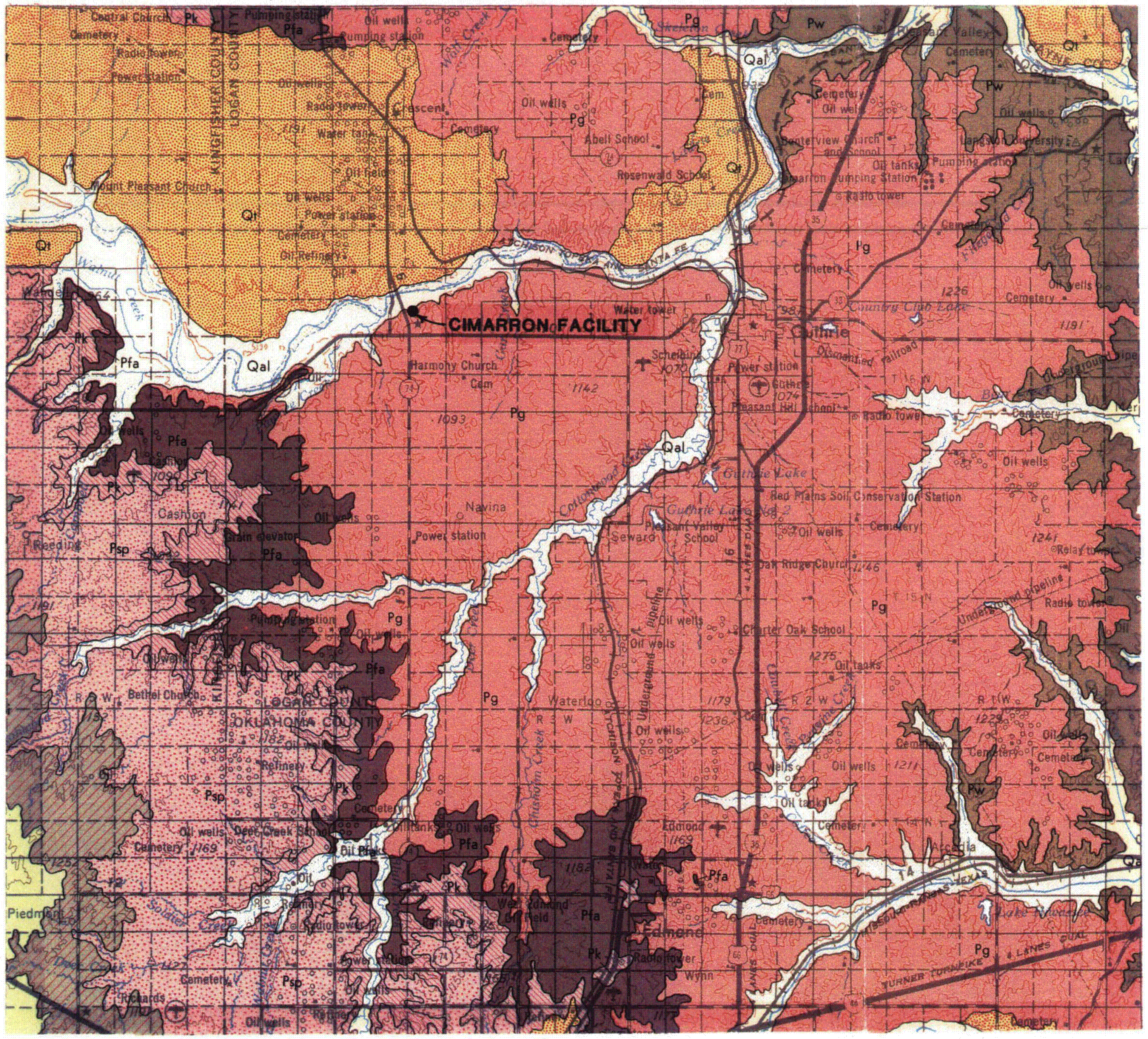
(from Bingham and Moore, 1975)

AQUIFERS	HARDNESS (ppm)			SULFATE (ppm)			CHLORIDE (ppm)			NITRATE (ppm)			TDS (ppm)		
	minimum	maximum	median	minimum	maximum	median	minimum	maximum	median	minimum	maximum	median	minimum	maximum	median
Alluvium and Terrace deposits	14	1320	297	3.3	1320	64	2.0	1450	40	0.0	189	5.8	82	3060	520
Garber/Wellington	4.0	538	156	3.0	1450	17	0.2	458	14	0.0	100	1.0	101	2110	320
Other Permian Formations	40	1670	310	12	5350	73	9.0	945	40	0.0	175	14	246	5900	577
Vamoosa Formation	36	600	200	3.5	796	28	4.0	320	13	0.0	214	0.8	113	1540	357
Other Pennsylvanian Formations	9.0	2760	164	4.8	4850	35	3.0	2100	38	0.0	160	2.0	77	9580	416

TABLE 4.2

GARBER/WELLINGTON AQUIFER GROUND-WATER QUALITY
LOGAN COUNTY WELLS
Townships 15N-R2W to 16N-R4W
(From Carr & Havens, 1976)

PARAMETER	HIGH (ppm)	LOW (ppm)	AVERAGE (ppm)	STD. DEVIATION
Calcium	370	29	108.7	100.9
Chloride	110	4.8	31.7	32.6
Dissolved Solids				
- residue on evaporation	3260	215	758.2	907.5
Hardness	1300	130	381.2	316.2
Bicarbonate	420	136	293.2	74.8
Magnesium	89	15	35.2	22.6
Sodium	690	22	104.2	187.7
Nitrate	32	1	12	11.4
Nitrate + Nitrite	63	0.3	14.9	21.9
pH	8.1	7.2	7.8	0.3
Sulfate	1900	7	245.4	562.6
Depth (feet)	200'	41'	121.7'	



QUATERNARY

Symbol	Description
Qal	**ALLUVIUM** Sand, silt, clay, and lenticular beds of gravel. Thickness ranges from about 30 to 100 feet and probably averages about 50 feet along major streams. Along minor streams, thickness ranges from a few feet to about 50 feet and probably averages about 25 feet. Alluvium is a major aquifer in parts of quadrangle.
Qt	**TERRACE DEPOSITS** Lenticular beds of sand, silt, clay, and gravel. Thickness ranges from a few feet to about 100 feet and probably averages about 50 feet along major streams. These deposits are major aquifers along Cimarron, Canadian, and North Canadian Rivers.

PERMIAN

Symbol	Description
Pd	**DUNCAN SANDSTONE** Mainly red-brown to orange-brown fine-grained sandstone, with some mudstone conglomerate and shale; grades northward into Cedar Hills Sandstone and Chickasha Formation. Thickness, 450 feet near Chickasha, 300 feet near Oklahoma City, and 100 feet or more near Okarche.
Pbi	**BISON FORMATION** Mostly red-brown shale; grades northward into many thin greenish-gray calcitic siltstones and some orange-brown fine-grained sandstones and siltstones. *Reeding Sandstone Bed* at base. Thickness ranges from 95 feet in south to 120 feet in north.
Psp	**SALT PLAINS FORMATION** Red-brown blocky shale and orange-brown siltstone, grades southward into Purcell Sandstone in Norman area. Thickness, 200 feet.
Pfa	**FAIRMONT SHALE** Red-brown blocky shale; grades into Garber Sandstone at base. Thickness, 30 feet at Oklahoma City, 110 feet near Purcell, and 120 feet near Kingfisher.
Pg	**GARBER SANDSTONE** Mostly orange-brown to red-brown fine-grained sandstone, irregularly bedded with red-brown shale and some chert and mudstone conglomerate. Thickness ranges from 150 feet in south to 400 feet or more in north. The Garber and underlying Wellington are major aquifers in Cleveland and Oklahoma Counties.
Pw	**WELLINGTON FORMATION** Red-brown shale and orange-brown fine-grained sandstone, containing much maroon mudstone conglomerate and chert conglomerate to south. Thickness ranges from about 150 feet in south to 500 feet in north.

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

CONTOUR INTERVAL 100 FEET
WITH SUPPLEMENTARY CONTOURS AT 50-FOOT INTERVALS
DATUM: MEAN SEA LEVEL

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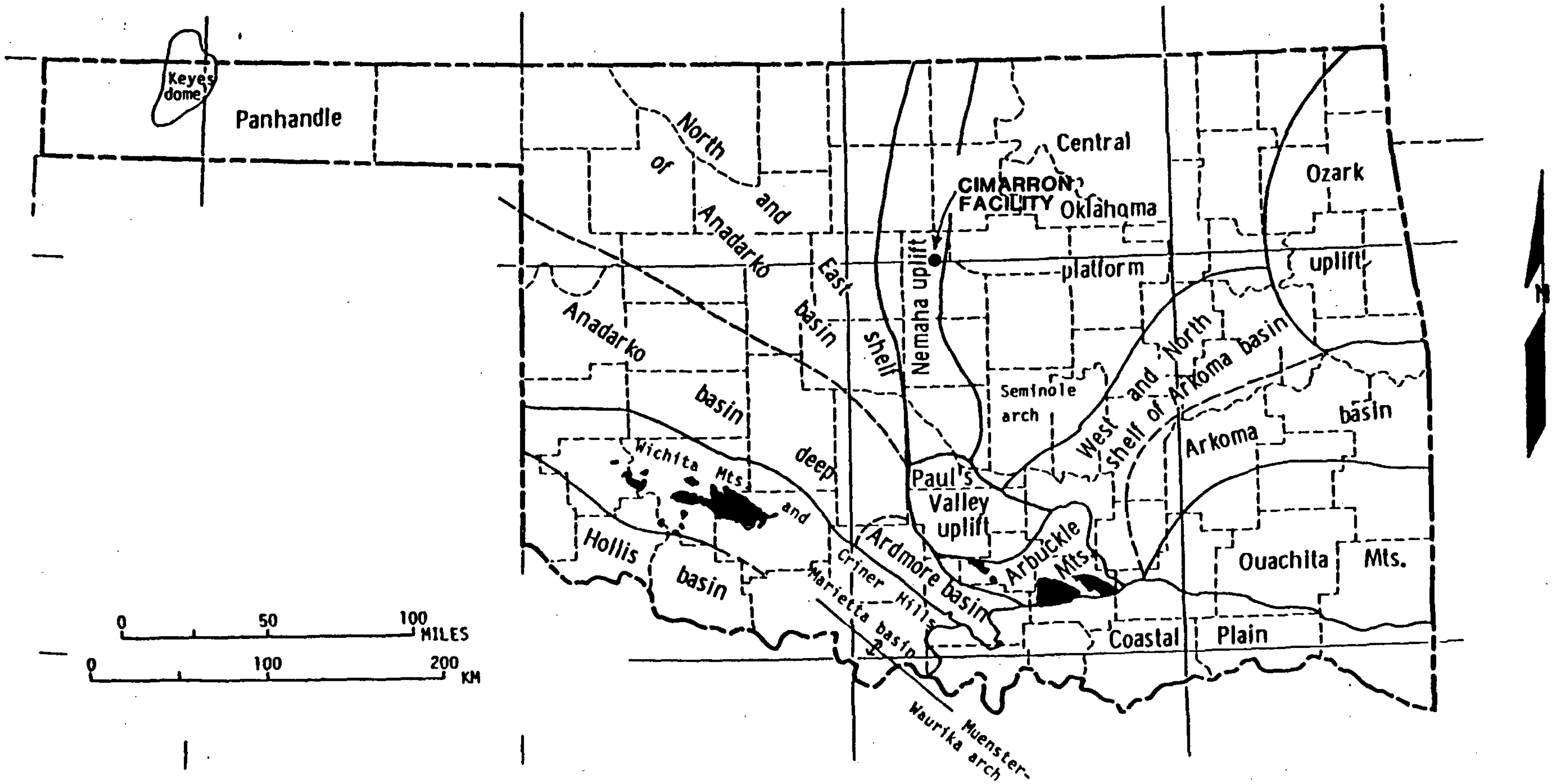
FIGURE 4.1

GEOLOGIC MAP



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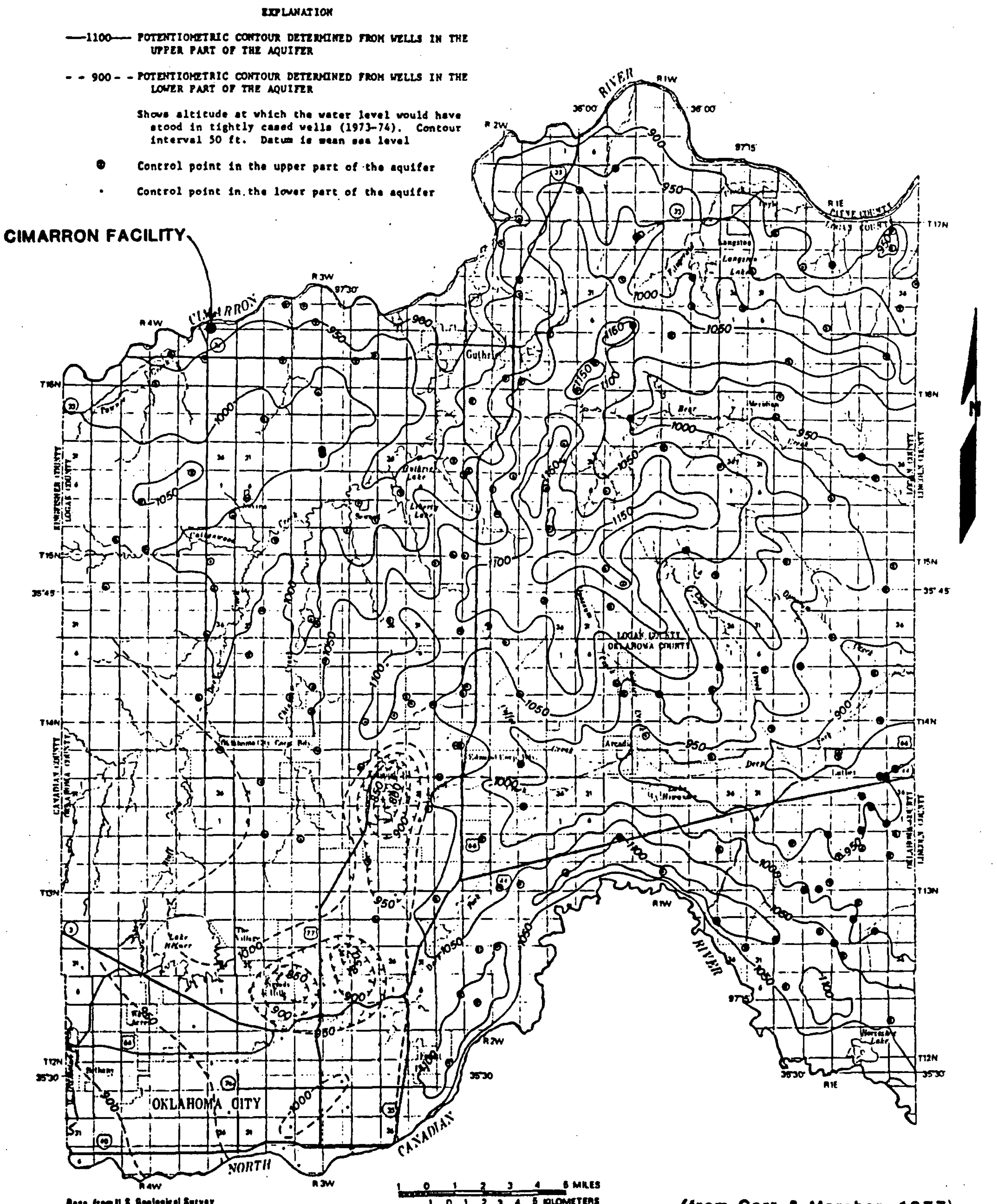
(from Landes, 1970)

FIGURE 4.2

TECTONIC PROVINCE MAP OF OKLAHOMA



(from Carr & Marcher, 1977)

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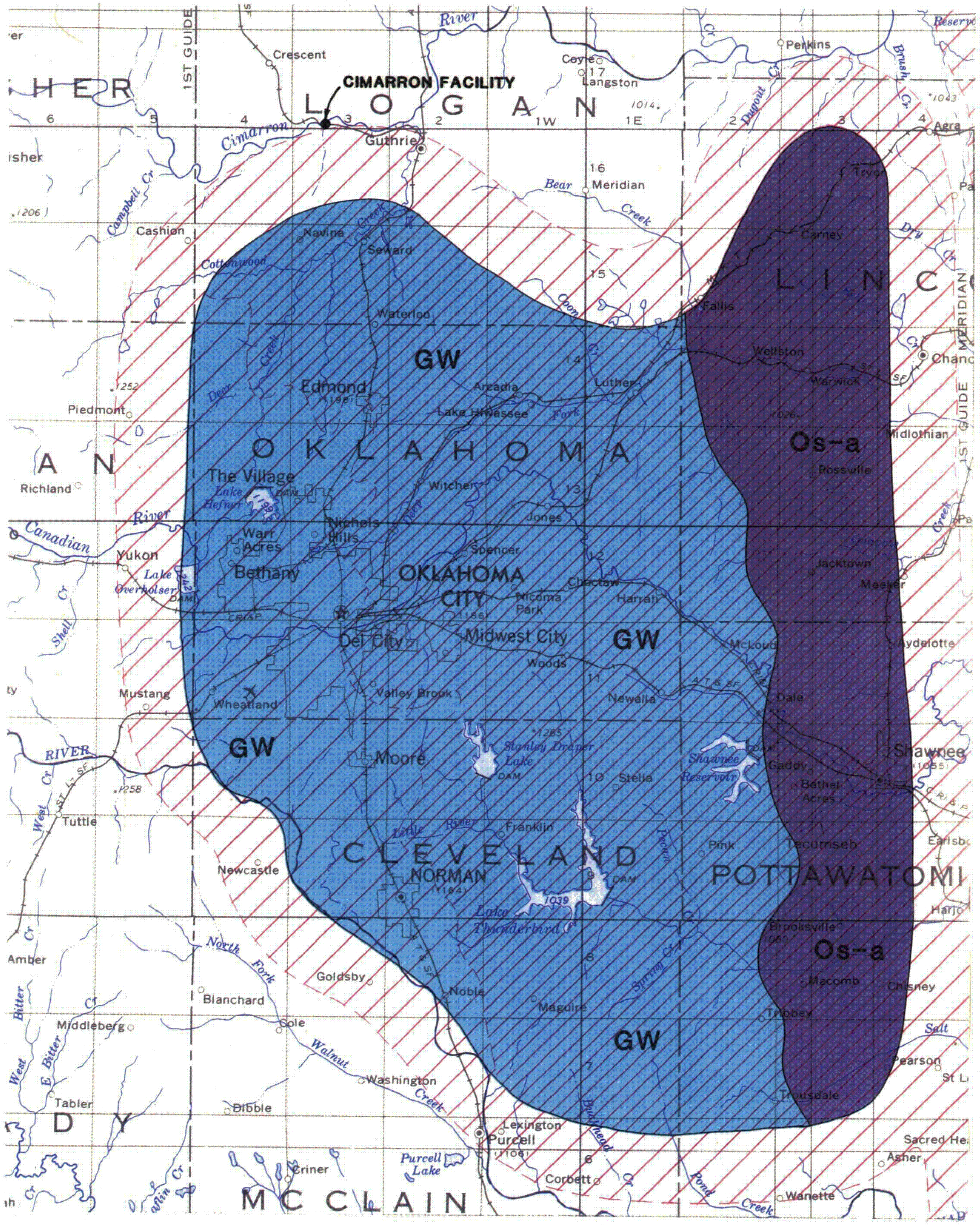
FIGURE 4.3

GARBER/WELLINGTON AQUIFER

PIEZOMETRIC SURFACE



EXPLANATION

RECHARGE AREAS

Patterns of red lines on the map show known or potential recharge areas for the various bedrock aquifers.

Recharge Areas. This pattern shows areas that are known to be part of the recharge area for a bedrock aquifer: includes outcrops of the aquifer and of overlying porous and permeable rocks hydraulically connected with the aquifer.

Potential Recharge Areas. This pattern shows areas that may be part of the recharge area for a bedrock aquifer: includes areas where confining strata may contain pathways for downward movement of water to the aquifer, and safety zones (generally extending 4 miles beyond the known limits of the aquifer) that may overlie unknown extensions of the aquifer or rocks hydraulically connected with the aquifer.

BEDROCK AQUIFERS

GW — Garber Sandstone and Wellington Formation (Permian in age). Fine-grained sandstone irregularly interbedded with shale and siltstone in central Oklahoma; grades into shale to north and south. Thickness of aquifer ranges from about 300 ft. in the south to about 800 ft. in the north. Wells commonly yield 25 to 400 gpm of water that is of good quality (generally 200 to 1,000 mg/L dissolved solids). Recharge areas consist of outcrops of the aquifer and extend eastward to the approximate top of shales that make up much of the lower one-third of the Wellington Formation. Potential recharge areas include areas in the west where aquifer underlies younger Permian strata; also areas that extend 4 miles south, west, and north of aquifer limits. References: HA-4; also Other Reports 4, 5, 29, 33, 61, 67, 68.

Os–a — Oscar Group (Early Permian or Late Pennsylvanian in age). Area designated a consists of fine-grained sandstone interbedded with shale and siltstone in central Oklahoma; contains some conglomerate in the south. Main part of aquifer is in lower half of Oscar Group; upper half of Oscar is predominantly shale. Thickness of aquifer ranges from about 150 ft. in south to 300 ft. in north. Wells commonly yield 25 to 50 gpm of water that is of good quality (generally 300 to 1,000 mg/L dissolved solids). Recharge areas include outcrops of Oscar Group; also included are outcrops of shales and sandstones in lower part of overlying Wellington Formation that appear to be hydraulically connected with either the Oscar or the Garber-Wellington aquifer. Potential recharge areas extend 4 miles north, east, and south of aquifer limits. References: HA-4.

Scale: 1:500,000
1 inch equals approximately 8 miles

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometers

Base map modified from U.S. Geological Survey, 1:500,000 series, dated 1972

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FIGURE 4.4
GARBER/WELLINGTON AQUIFER PRINCIPAL RECHARGE AREA

5. SITE HYDROGEOLOGY

5.1 Site Physiography

The Cimarron facility lies in the Central Lowlands portion of the Great Plains physiographic province. The topography is characterized by low, rolling hills and incised drainages and floodplains. The elevation of the site above sea level ranges from about 940 to 1010 feet. The principal geomorphic feature at the site is the Cimarron River floodplain which is approximately one-half mile in width and trends east-west.

Vegetation in the site area is mainly native grasses with well developed tree stands in the drainages and along the bluff overlooking the Cimarron River.

Precipitation averages about 39 inches per year. Table 5.1 shows average monthly precipitation at the Cimarron facility. The majority of the precipitation occurs during the spring and fall months.

5.2 Site Geology

5.2.1 Site Stratigraphy.

A veneer of soil, one to eight feet thick, covers most of the site. The shallow rock at the site consists of sandstones and siltstones of the Garber formation (Garber Sandstone). The Garber Sandstone is relatively thick in the facility area and no other formations were penetrated by drilling conducted during this investigation to depths of up to 140 feet. Figures 5.1 and 5.2 are geologic cross-sections showing the shallow subsurface stratigraphy underlying the site.

The deeper stratigraphic units in the area were penetrated by a proposed deep disposal well that was completed in 1969. This well is the deepest borehole known to have been drilled in the immediate vicinity of the site. The deep well is on Cimarron facility property near the uranium plant. The depth of the well is 2078 feet. The top of the unit immediately underlying the Garber, the Wellington formation, was identified at 200 feet below the ground surface. The Wellington consists of 960 feet of red shale with several thin siltstone beds. The top of the Wolfcampian age Stratford formation was found at 1160 feet. It is 870 feet thick and consists of red and gray shale with thin anhydrite beds in the upper part. The lower part of the Stratford is predominately red and gray sandy shale with three porous sandstone members.

Process wastes were planned to be injected into one of the sandstone members of the Stratford; however, no injection into the well ever was conducted. The injection well will be plugged and abandoned in accordance with State regulations as part of the site decommissioning activities.

5.2.1.1 Shallow Stratigraphic Units.

SOIL LAYER:

The soil layer ranges from one to eight feet thick and is chiefly a reddish-brown silty sand. This soil type predominates and is present where the underlying rock type is sandstone. A very fine sandy silt/clay also occurs at the site where the underlying bedrock is a sandy siltstone or mudstone. The silt/clay type soils are less abundant than the silty sand soils.

ROCK LAYERS:

The upper portion of the Garber Sandstone at the site consists primarily of sandstone layers separated by relatively continuous siltstone and mudstone layers. For the purposes of this report, the lithologically similar sandstones are designated, from shallowest to deepest, Sandstones A, B, and C. Similarly, the intervening siltstones and mudstones are designated Mudstones A and B. The discussion of the stratigraphy and lithology of these strata, and later references to hydrogeologic and chemical properties, are keyed to this arbitrary nomenclature.

- SANDSTONE A: The first or uppermost sandstone is up to 35 feet thick. The bottom of this sandstone occurs at an elevation of about 970 feet (msl).
- MUDSTONE A: The mudstone stratum separating Sandstones A and B ranges from about 6 to nearly 20 feet thick.
- SANDSTONE B: The second or intermediate sandstone is up to about 30 feet thick and lies roughly between the 925 and 955 feet elevations (msl).
- MUDSTONE B: The mudstone stratum separating Sandstones B and C ranges from about 6 to 14 feet thick.

- SANDSTONE C: The third significant sandstone may not have been fully penetrated during this investigation. The presence of a basal siltstone or mudstone layer was not verified at the depth penetrated by the site wells; but, Sandstone C appears to be at least 55 feet thick and contains interbedded siltstones.

These strata are inferred to have been deposited in a fluvial/upper deltaic system. Lateral facies changes are frequent and correlations over long distances are difficult, perhaps as a result of shifting channel locations. Each of the major strata identified above has interbedded, thin and discontinuous sandstones and siltstones. Patterson (1933) interprets the Garber as originating from a deltaic system that entered the Permian sea from the east.

5.2.1.2 Description of Sandstones:.

All three sandstones encountered during this investigation can be described as generally fine to very fine grained with well sorted subangular to rounded grains. Variable silt content was observed in the sandstones. The estimated silt content ranges from less than 10 to up 50 percent. Where the silt content is high, distinction between sandstone and siltstone is difficult. The sand grains are virtually all quartz, with minor amounts of potassium feldspar and occasional mafic grains such as magnetite. Micas are minor constituents. Intergranular porosity is generally good, though obviously varies with silt content.

The sandstones typically are weakly cemented and friable. The cementing agents appear to be calcite and hematite; however, silt and clay-sized fractions in the matrix may also contribute to cementation. Thin intervals are present occasionally that are well cemented and hard. These intervals are frequently conglomeratic with gypsum and possibly barite providing additional intergranular cement.

The sandstones often are cross-stratified with thin, silty laminae. The cross-stratification is planar and might be indicative of bar deposition in fluvial systems. Cross stratification was usually found near the middle of the sandstone intervals.

Conglomeratic intervals were encountered in most of the borings. These intervals are associated with the sandstone strata although, in some instances, the matrix materials are mudstones. The conglomeratic intervals are 2.5 feet or less in thickness. The matrix is either sandstone or mudstone and the clasts are predominately mudstone. Patches of sandstone clasts also are present. These conglomeratic intervals commonly possess a vuggy porosity. The vugs probably formed through dissolution of lithic clasts. The presence of vugs is not attributed to drilling fluids because the vugs often are lined with euhedral calcite, gypsum and barite crystals.

The origin of the conglomeratic sandstones and mudstones might be related to an influx of more rapidly moving water, such as a flood. The influx could have caused the pre-existing rocks and sediments to be torn up and re-transported. Transport distance probably was minimal as the weakly-cemented clasts would have disintegrated if they were agitated for prolonged periods. In all cases, a fining upward sequence in grain size accompanies the conglomeratic intervals, as is typical in fluvial and deltaic systems.

5.2.1.3 Description of Mudstone:.

Separating the sandstones are fine-grained, silty and shaley beds. These beds were identified in the field as mudstones, a genetic description inferring their origin. Dessication cracks in the mudstones were observed in several borings and these beds might represent flood plain deposits. Stratification within the mudstones is largely absent and they lack the fissile nature characteristic of shales.

The mudstone units typically are poorly consolidated as indicated by the tendency for core samples to deteriorate rapidly. The mudstone cores have a consistency more like a very stiff to hard sandy silt or clay than rock, even at depths greater than 100 feet below ground.

Encapsulating the mudstone layers were thin, bluish-gray zones or layers that ranged from less than 0.1 inches to over 4 inches in thickness. These layers tentatively were identified in the field as "reduction zones." Reduction spots were also observed. This phenomenon is common in red bed formations and is not unique to the site. In the subsurface at the facility, the thickness of the bluish-gray layers is directly proportional to the thickness of the silt and clay-rich layers they bound.

The reduction zones might represent intervals where ferric oxides have been reduced to ferrous compounds. Ferrous iron is soluble and is removed by ground water. Al-Shaieb et.al. (1977) attribute the reduction of ferric iron to a reaction with hydrogen sulfide produced either by the contact of sulfate with hydrocarbons, or hydrogen sulfide released directly from naturally occurring hydrocarbons.

5.2.2 Structure.

The strata underlying the Cimarron facility are largely undeformed. Dip is westerly to southwesterly and has been described by various authors as ranging from 20 to 40 feet per mile. Measurements at outcrops at the facility indicate the sandstones strike to the northwest and dip very slightly to the southwest. The site lies to the east of the Nemaha ridge, a narrow, subsurface north-northwest trending uplift formed during the Mississippian.

The Nemaha ridge or uplift is characterized by a series of en-echelon, parallel normal faults which are down-thrown on the west side, with anticlinal folding across the top. Some reactivation of the faults occurred during the early Pennsylvanian; however, movement has not been described since that time. Regional dip is to the southwest into the Anadarko basin and is the result of post-Paleozoic uplift and erosion.

5.2.3 Mineralogy and Rock Chemistry.

Analysis of selected samples for mineralogy and chemical parameters including cation exchange capacity and exchangeable cation were performed by Auburn University. These tests were performed to verify the field classification of soils and rocks, and to provide information useful for determining the capacity of selected rock units to adsorb radionuclides and inhibit their migration. Table 3.7 summarizes the results of these analyses.

5.2.3.1 Mineralogy.

5.2.3.1.1 Testing

Site representative samples were analyzed via X-ray diffraction at Auburn University for major mineral constituents. X-ray diffraction is one of the more effective analytical methods for identifying clay minerals in rock material. The mineral constituents of the samples analyzed are listed in Table 3.7.

5.2.3.1.2 Discussion

The mineralogical analyses indicate that quartz and feldspar are the predominant minerals of the larger sized fractions. Kaolinite and 2:1 expanding layer clay minerals (montmorillonites) dominate the fine fraction in nearly equal proportions. Minor amounts of calcite, iron oxides and iron hydroxides are identified and are probably the cementing agents.

The particle size distributions reflect the field descriptions listed in Table 3.7. The rock units identified as mudstones and sandy mudstones are composed predominantly of silt-size particles. The sandstones are dominated by particle sizes in the 0.25 to 0.05 mm range, which corresponds to the fine and very-fine grained descriptions assigned in the field.

Samples from the "reduction zones", Nos. CH-2, CH-12, and CH-14, are of particular interest. The distinction between these samples and the "non-reduced" samples is subtle. Samples CH-1 and CH-2 are from essentially the same interval and are nearly identical in gross mineralogy. The principal difference between the two samples is that the iron content of sample CH-2 is about one-half that of CH-1. Samples CH-12 and CH-14 had low iron values compared to non-reduced samples as well.

5.2.3.2 <u>Soil and Rock Chemistry.</u>

5.2.3.2.1 Testing

In addition to mineralogy, the samples submitted to Auburn University were analyzed for cation exchange capacity (CEC) and exchangeable cation (EXC). These results are presented in Table 3.7.

5.2.3.2.2 Discussion

Cation exchange capacity ranges from 2.96 to 22.75 meq/l. The majority of samples had CEC's less than 10 meq/l. The clay minerals responsible for the cation exchange capacity of the samples are identified as montmorillonites.

The most prevalent exchangeable cations are divalent. Calcium and magnesium are the significant exchangeable cations. Potassium and sodium are also present but their concentrations are about an order of magnitude less than calcium and magnesium.

5.2.3.3 <u>Chemical Interactions.</u>

The hydrogeologic environment underlying the site is composed of physical and chemical systems. The physical system is characterized by lithologies, structures, hydraulic conductivities, and flow gradient and directions. The chemical system is characterized by the interaction between ground-water chemistry and the enclosing strata.

5.2.3.3.1 Chemical Environments

The chemical environment underlying the site is characterized by the chemistry of the unsaturated and saturated zones. The unsaturated zone environment will be dominated by the chemistry of the soils and rock strata. The saturated zone will be dominated by the chemistry of the ground water.

Ground water at the site is oxygenated and slightly alkaline. The strata appear oxidized and have a relatively low cation exchange capacity. The organic content of the strata is negligible.

5.2.3.3.2 Site-Related Elements

Elements targeted in this investigation that may interact with the subsurface environment include fluoride, nitrate, plutonium, uranium, thorium and radium. Thorium and radium were not used in the facility processes; however analyses were conducted to determine background concentrations. The availability of plutonium for interaction with the environment is considered negligible. Plutonium was only present within the plutonium plant and in very small concentrations in the sewage lagoon sediments.

Thorium was present as drummed waste in the former burial location. The drums containing thorium were removed and disposed in a commercial disposal facility. Some thorium processing equipment from the Cushing facility was stored at the uranium facility yard; however thorium has not been detected above natural background levels. Radium was not used in the facility production processes and there is no source for radium to enter the environment. Consequently, thorium and radium encountered in this investigation are considered to be representative of background sources, and not derived from materials processed by the Cimarron facility.

5.3 <u>Surface-Water Hydrology</u>

5.3.1 **Local Surface-Water Bodies.**

The principal surface-water bodies at the site are the three reservoirs indicated on the site map and the Cimarron River.

The water elevation of the three reservoirs was determined at the time the monitoring wells were surveyed. The water elevations for reservoirs 1,2 and 3 are 959.3, 966.3, and 959.7 feet above mean sea level, respectively. The average stage for the Cimarron River near the facility is approximately 940 feet above mean sea level.

5.3.2 Influence on Ground-Water System.

The three reservoirs appear to influence shallow ground-water flow at the site. Reservoirs 1 and 3 have water levels significantly below the water table in the nearest wells indicating that shallow ground water maintains the water level of these reservoirs and hence provides the base flow for the streams that exit the reservoirs.

5.4 Site Ground-Water Hydrology

5.4.1 Ground-Water Occurrence.

Shallow ground water occurs under water table and partially confined conditions at the site. The depth to water in the shallow wells ranges from about 10 to 30 feet below ground level. The shallow wells constructed during this investigation are all screened at about the same stratigraphic interval. This interval is approximately the base of the first major sandstone (sandstone A). Figure 5.4 is a map of the potentiometric surface of the shallow ground water.

The water table shows a strong influence exerted by topography and the surface-water bodies. Seepage faces were observed along the slope above the Cimarron River floodplain. In the vicinity of Well 1334, seepage occurs at an elevation of about 964 feet with standing water occurring in a marshy area at an elevation of about 960 feet.

All the rocks below the water table are saturated. The deep wells were screened in a confined sandstone that occurs approximately 80 to 100 feet below the ground surface. This interval was subsequently identified as the third major sandstone (sandstone C) underlying the site. Figure 5.5 is a map of the potentiometric surface defined by the deep wells.

5.4.2 Ground-Water Flow System.

Shallow ground water is strongly influenced by topography and the surface-water bodies. Flow direction is primarily north-northwest toward the Cimarron River. The incised drainages and bluff overlooking the river's floodplain exert local influences. The gradient averages approximately 0.025 except where it steepens as a result of proximity to discharge areas.

Ground water from the confined aquifer screened in the deep wells also flows to the north-northwest. The gradient is approximately 0.014. This deeper ground-water interval probably recharges the Cimarron alluvium and contributes to the base flow of the Cimarron River.

5.4.3 Hydraulic Properties of Water-Bearing Strata.

Hydraulic conductivities of the Garber Formation sandstones generally are moderate. The primary hydraulic conductivity control is the good intergranular porosity observed in the core samples. The sandstones are poorly cemented and show few diagenetic effects, thus the primary porosity restrictions are the variable amounts of fines present in the sandstones. Inspection of outcrops at the site and core samples revealed minimal jointing indicating that the effect of fractures on hydraulic conductivities is expected to be low.

The hydraulic conductivities of the sandstones that are screened in both the deep and shallow wells have been measured by slug test methods. Descriptions of the test methods and analytical techniques was presented in Section 2.2.6.

The hydraulic conductivity of the shallow aquifer ranges from 2.41×10^{-4} cm/sec to 5.7×10^{-3} cm/sec. The geometric mean of the measured values is 1.03×10^{-3} cm/sec. The transmissivity of this aquifer ranges from 10.3 x 10 ft sq/day to 108 ft sq/day, with a geometric mean of 33.4 ft sq/day.

The hydraulic conductivity of the deep aquifer ranges from 1.39×10^{-5} cm/sec to 7.06×10^{-4} cm/sec, with a geometric mean of 1.27×10^{-4} cm/sec. The transmissivity ranges from .67 ft sq/day to 50 ft sq/day, with a geometric mean of 7.96 ft sq/day. Slug test results are included in Table 3.3.

5.5 Ground-Water Quality

A standard water quality analysis was performed on a sample of ground water from Well 1324. This well is up-gradient from all facility components and is representative of background presence of major cations and anions in the shallow ground water. Shallow ground-water quality at the site is consistent with the regional average concentrations of major ions reported by Bingham and Moore (1975) and Carr and Havens (1976). The results are presented in Table 3.4.

5.5.1 pH and Conductivity.

At the time of sampling, pH and specific conductance were measured for all ground-water samples collected. In general, the ground water at the site is near neutral to slightly alkaline. Ground water from the deep wells is similar in pH to the shallow, but has significantly higher specific conductance.

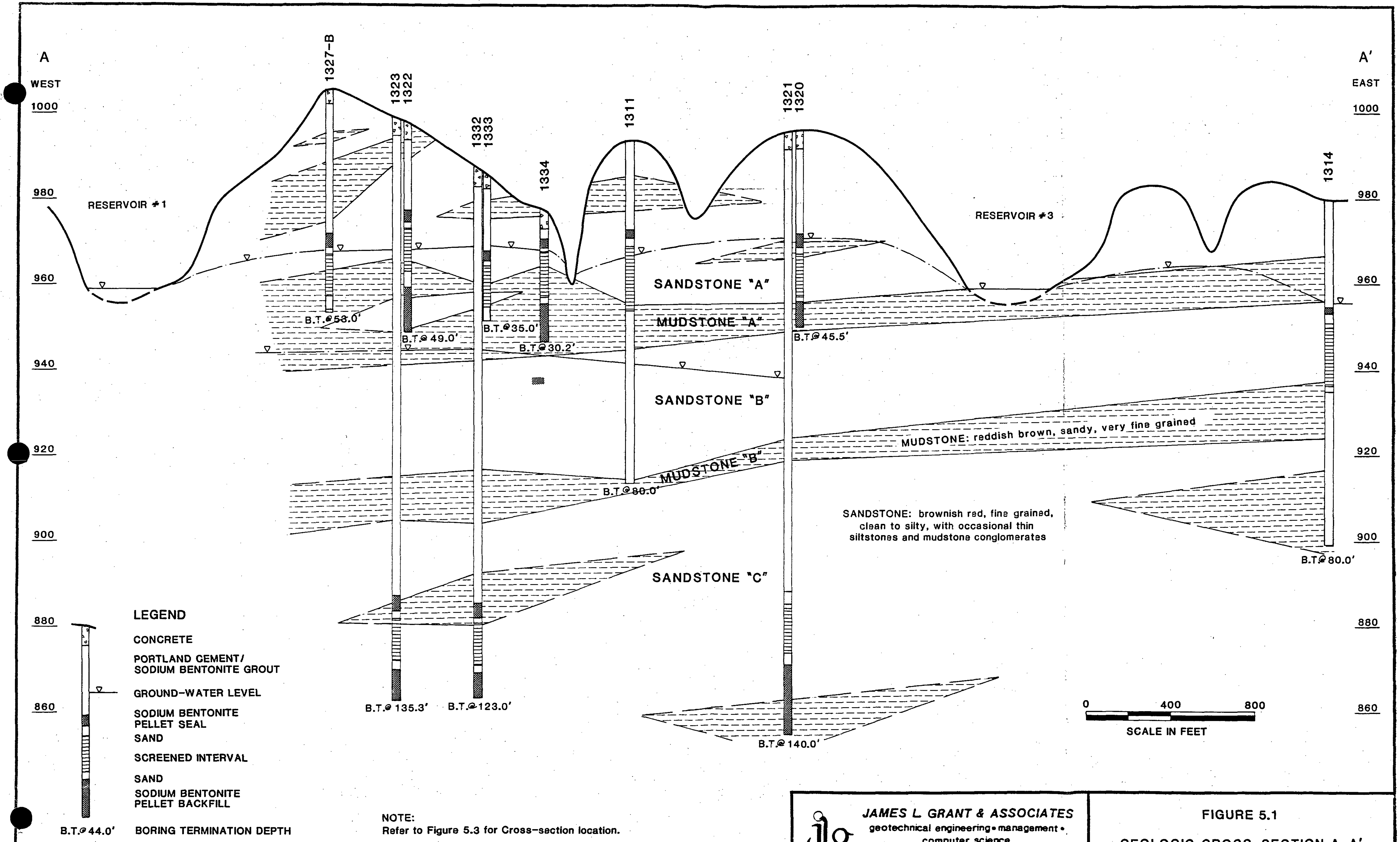
Ground water from the shallow wells has a pH ranging from 6.99 to 7.71. Specific conductance ranges from 400 to 1590 micromhos per centimeter (umho/cm) and averages 646 umho/cm. The highest value indicated for the shallow wells, 1590 umho/cm, is from Well 1330. Ground water from the deep wells has a pH ranging from 6.91 to 7.39. Specific conductance ranges from 1910 to 3190 umho/cm, and averages 2480 umho/cm.

Specific conductance values are higher in the deeper ground water as a result of limited infiltration and mixing of precipitation, according to Bingham and Moore (1975).

TABLE 5.1

Average Monthly Precipitation

MONTH	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	AVERAGE
January	0.5	1.3	0.9	0.0	0.0	1.2	1.0	2.9	0.0	2.2	1.3	1.0
February	4.0	0.5	0.8	1.2	1.1	4.0	1.0	8.8	0.8	2.7	0.2	2.3
March	1.3	4.1	2.0	3.1	1.7	3.6	4.2	8.5	0.4	5.0	3.8	3.4
April	2.1	4.1	5.8	0.3	2.4	2.9	2.7	5.9	3.6	0.9	5.0	3.2
May	11.4	6.5	9.8	4.4	13.4	6.5	2.4	2.9	5.9	7.5	0.8	6.5
June	7.2	3.9	3.6	7.6	6.2	5.5	4.7	6.0	4.0	4.6	3.2	5.1
July	2.3	1.9	0.0	5.6	0.8	1.4	0.2	4.8	2.3	5.6	1.7	2.4
August	2.5	4.8	0.3	5.5	1.5	2.6	2.5	2.6	3.5	2.5	2.5	2.8
September	3.9	8.4	1.6	2.7	0.7	1.1	1.4	6.5	9.9	5.1	7.5	4.4
October	0.6	0.9	1.7	3.6	0.5	8.1	4.0	6.4	12.8	0.1	2.4	3.7
November	5.0	3.2	0.3	1.9	2.7	2.0	2.9	2.7	2.6	2.8	4.2	2.7
December	0.0	1.6	2.0	0.6	1.2	0.4	4.8	0.2	3.2	2.6	0.5	1.5
Totals	40.7	41.1	28.6	36.2	32.0	39.1	31.7	58.1	48.9	41.5	32.9	39.2



NOTE:
Refer to Figure 5.3 for Cross-section location.

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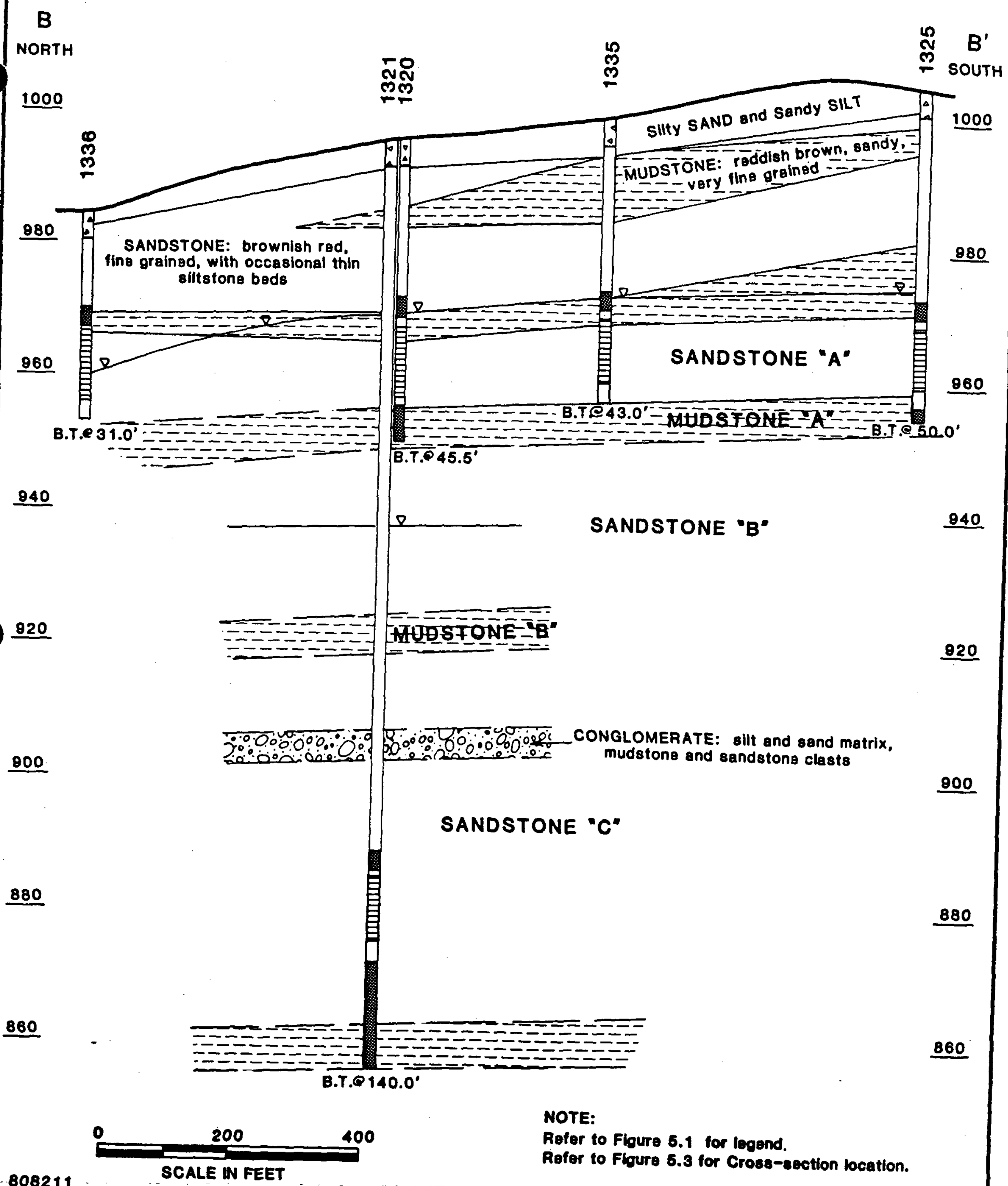
FIGURE 5.1
GEOLOGIC CROSS-SECTION A-A'



NOTE:
Refer to Figure 5.1 for legend.
Refer to Figure 5.3 for Cross-section location.

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FIGURE 5.2

GEOLOGIC CROSS-SECTION B-B'

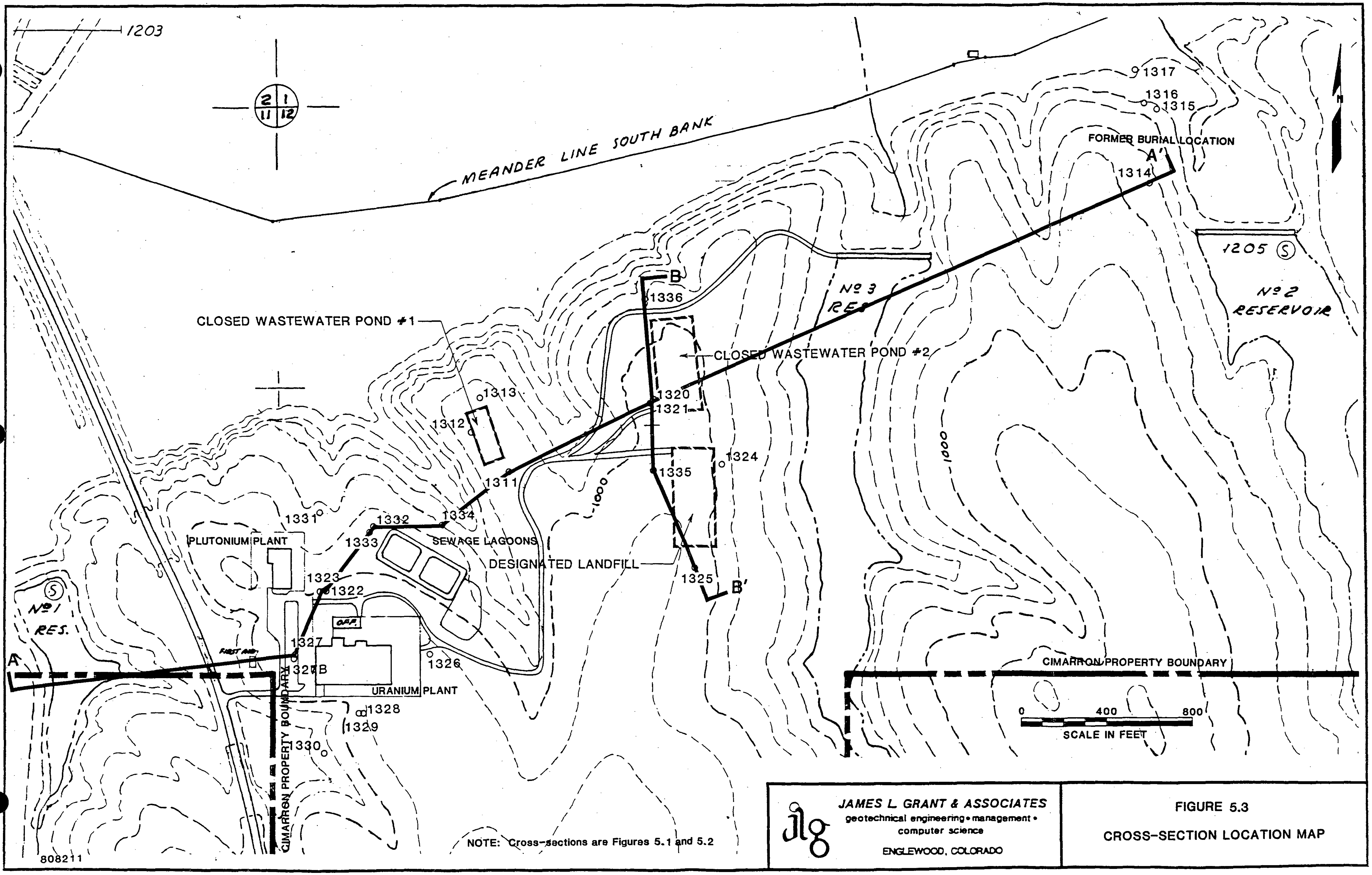

FIGURE 5.3

CROSS-SECTION LOCATION MAP

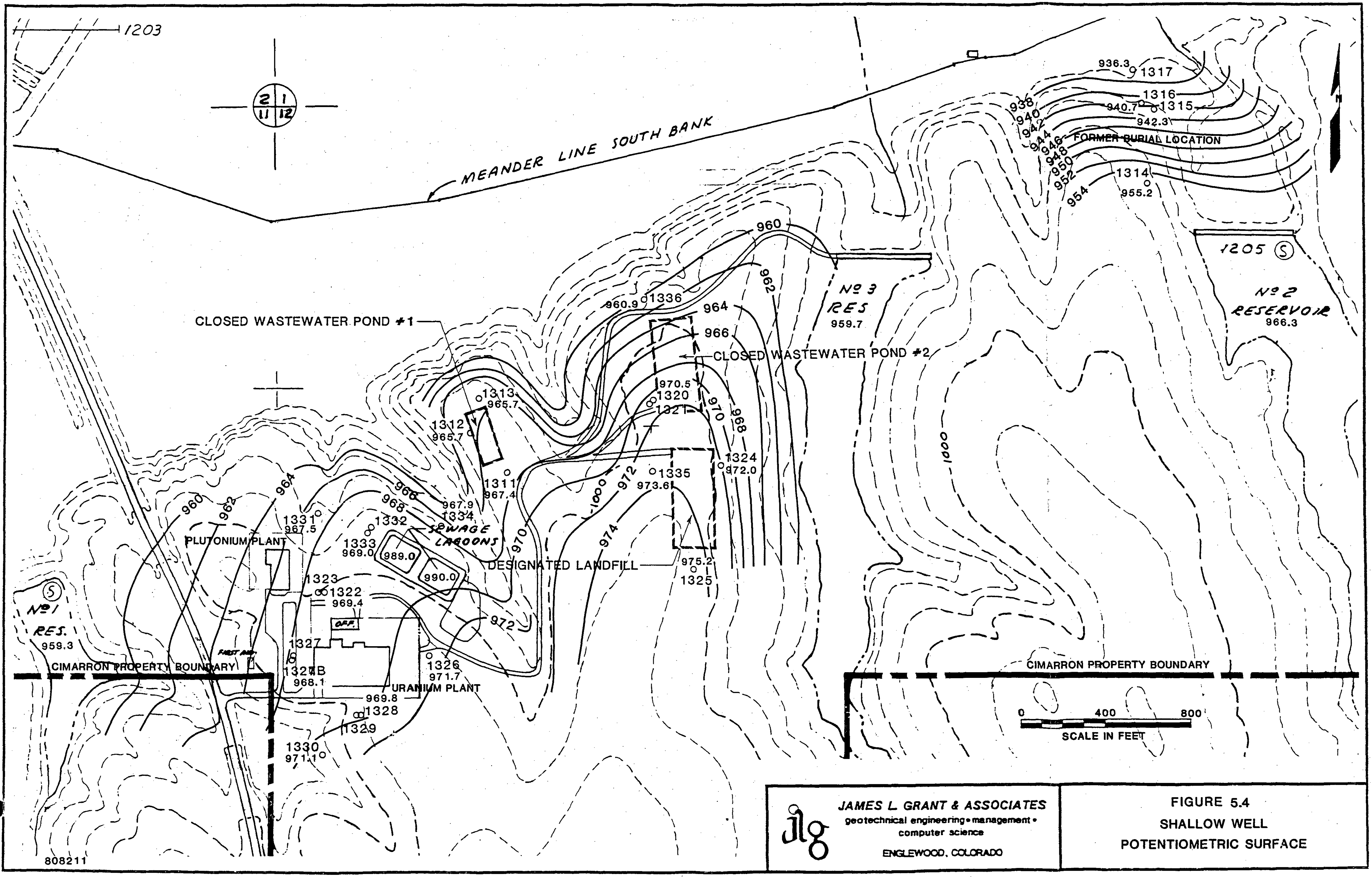

FIGURE 5.4
SHALLOW WELL
POTENTIOMETRIC SURFACE

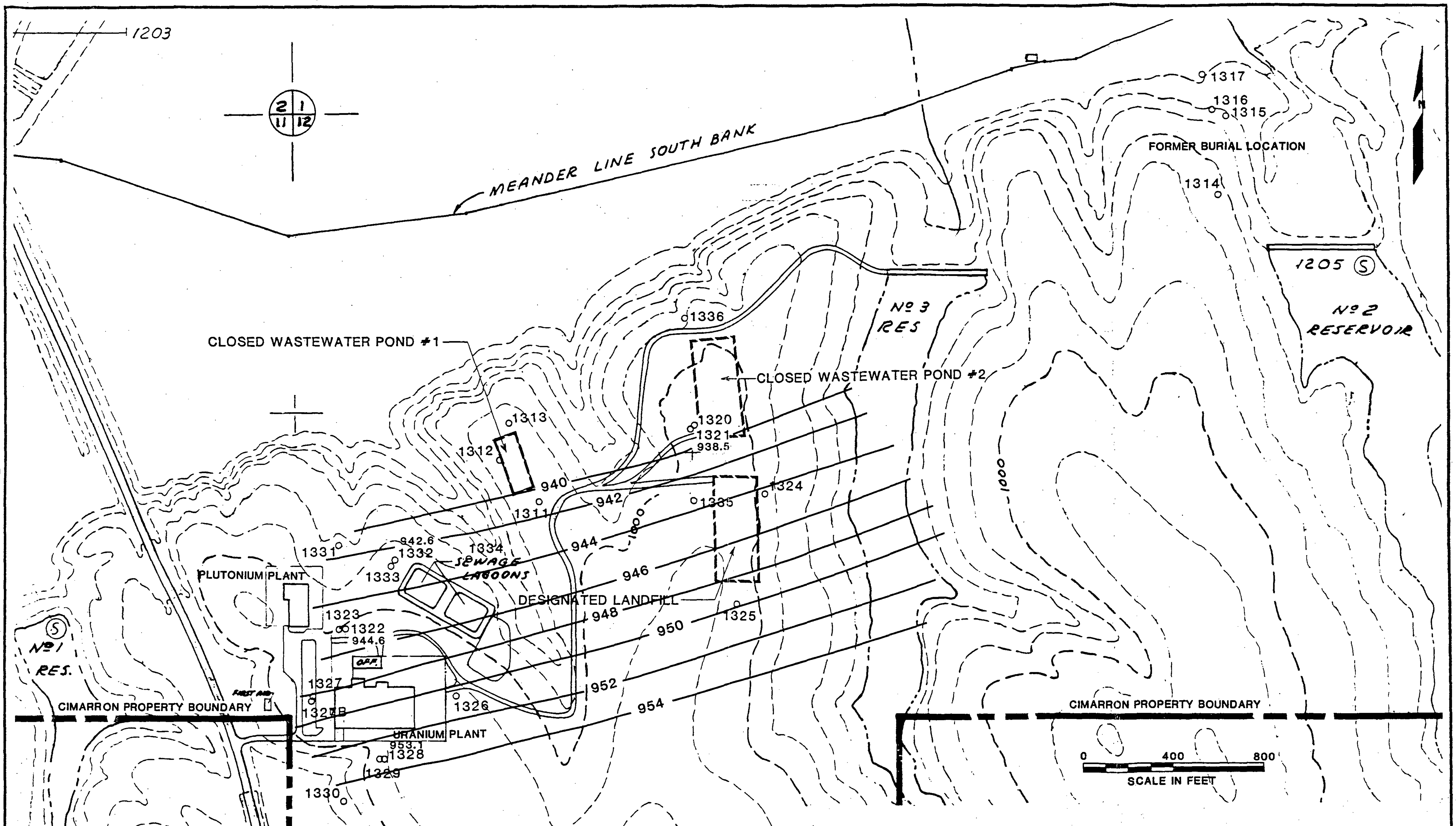

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FIGURE 5.5

DEEP WELL POTENTIOMETRIC SURFACE

6. SITE-SPECIFIC PARAMETER ANALYSIS

6.1 Site Ground-Water Analyses

Ground-water samples were collected and analyzed for specific parameters which potentially are related to facility production and decommissioning activities. The parameters include fluoride, nitrate, TOC and TOX, gross alpha and beta activity, Pu-239, Ra-228, Ra-226, Th-232, Th-228, U-238, U-235, and U-234. Each of these parameters are discussed in the following sections.

6.1.1 Fluoride and Nitrate.

Fluoride and nitrate were present in the wastewater stream discharged from production operations. The presence of these ions at concentrations above background could be an indication of facility effects. Figure 6.1 shows the concentrations of fluoride in ground-water samples from around the site. Figure 6.2 shows the concentrations of nitrate in ground water.

Fluoride

The background concentration of fluoride is interpreted to be approximately 1 milligram per liter (mg/l) or less. Twenty of the twenty-four wells had concentrations less than 1 mg/l. Well 1332 had a fluoride concentration of 1.30 mg/l.

In the March, 1989 data, three wells had fluoride concentrations significantly higher than the background value. These wells and the fluoride concentrations were: Well 1312 - 50 mg/l; Well 1313 - 140 mg/l; and Well 1336 - 17 mg/l. These wells all are completed in Sandstone A, the shallowest water-bearing stratum.

These three wells contain levels of fluoride in excess of the EPA Maximum Contaminant Level (MCL) of 4.0 mg/L. These wells are down-gradient from the two closed wastewater ponds. The ground-water monitoring results from the annual sampling of these wells indicates that the concentration of fluoride is decreasing. The results of the annual sampling are tabulated in Table 6.1.

The proximity of Wells 1312, 1313, and 1336 to the two wastewater retention ponds indicates that the ponds had been sources of fluoride. The ponds have since been closed, back-filled, and reclaimed, and the detections at the monitoring wells reflects residual amounts of fluoride remaining in the un-saturated zone or in the water-bearing stratum.

Nitrate

The average nitrate concentration reported by Carr and Havens (1976) for wells completed in the Garber/Wellington aquifer is 12 mg/l, which is probably representative of regional background in the Cimarron facility area. Wells at the site which are located in areas up-gradient of plant facilities, including Wells 1324, 1325, and 1335, show nitrate concentrations between 13 and 22 mg/l. The nitrate concentrations depicted in Figure 6.2 indicate that twelve of the twenty-four wells show nitrate concentrations above the MCL of 10 mg/l. Local nitrate background is higher than the MCL.

Only five monitoring wells have concentrations greater than 22 mg/l; four of these wells have concentrations greater than 100 mg/l. All five of these higher concentration wells are completed in the shallowest water-bearing stratum, Sandstone A. Wells 1311, 1312, 1313, and 1336 show concentrations of 66 mg/l, 1020 mg/l, 720 mg/l, and 1260 mg/l, respectively. Well 1311 is up-gradient, but near, closed wastewater pond #1. The three remaining wells are down-gradient from closed wastewater ponds #1 or #2.

The nitrate concentration at Well 1330 was 172 mg/l. This well is located near the edge of a cultivated wheat field. The location is also adjacent to a small drainage that begins in the uranium plant areas. Surface runoff from part of the plant area drains toward the well location. A significant portion of the runoff comes from cultivated fields and is believed reflect the application of nitrogen-based fertilizers.

6.1.2 TOC and TOX.

Total organic carbon (TOC) and total organic halide (TOX) analyses were performed on four ground-water samples. These organic species parameters are general indicators of ground-water quality. Three wells near the facility production operations and one well near the designated landfill area were tested. These all are Sandstone A wells and include Well 1322 between the uranium and plutonium plants, Well 1326 east of the uranium plant, Well 1329 south of the uranium plant and near the former solvent extraction area, and Well 1325 south of the designated landfill area. Well 1325 was chosen to provide background data.

Only the background well, Well 1325, showed a TOC concentration above the laboratory detection limit of 10 mg/L. The source or type of organic compounds responsible for the 12 mg/l concentration at the background well is not known but probably is related to natural causes.

The total organic halide concentrations ranged from 62 ug/l in Well 1329 to 130 ug/l in Well 1325. 130 ug/l is probably representative of local background. The TOX results do not indicate that organic constituents used during facility production operations have impacted the shallow ground-water quality.

6.1.3 **Radionuclides.**

The ground-water samples also were analyzed for gross alpha and beta activity, Pu-239, Ra-226, Ra-228, Th-232, Th-228, U-238, U-235, and U-234. These results are presented in Table 3.4. Figure 6.3 shows alpha activity in ground water; Figure 6.4 shows beta activity; Figure 6.5 shows total uranium activity; and Figure 6.6 shows total radium activity. Plutonium and thorium activities are not indicated on separate figures because the ground-water analyses indicate they are not present in quantities above background.

6.1.3.1 Gross Alpha Activity.

Figure 6.3 shows four areas where ground water shows gross alpha activity greater than 50 picoCuries per liter (pCi/l). These are the two closed wastewater ponds, the former burial ground, and an area down-gradient from the uranium plant.

- Down-gradient from waste water ponds #1 and 2: Well 1312, 59 pCi/l, and Well 1313, 260 pCi/l, are down-gradient from pond 1. Well 1336, 140 pCi/l is down-gradient from pond #2. These wells are completed in Sandstone A.
- Down-gradient from former burial area: Wells 1315, 1316, and 1317 had gross alpha levels of 6440 pCi/l, 331 pCi/l, and 66 pCi/l, respectively. These wells are completed in Sandstone A.
- Down-gradient from the uranium plant: Well 1331, 190 pCi/l, and Well 1323, 51 pCi/l. Well 1331 is completed in Sandstone A and Well 1323 is completed in Sandstone C.

At four locations, wells completed in Sandstone A are paired with wells completed in the deeper Sandstone C. At three of these locations, the deep well has higher gross alpha activity levels than the shallow well. These data are summarized below:

Well	Completion	Gross Alpha Concentration
1320	A	<10 pCi/l
1321	C	18 pCi/l
1322	A	15 pCi/l
1323	C	51 pCi/l
1329	A	12 pCi/l
1328	C	29 pCi/l
1333	A	47 pCi/l
1332	C	23 pCi/l

The generally higher activity levels in the deeper, Sandstone C wells reflect higher natural background level in the confined sandstone. The Sandstone C data are not interpreted to reflect effects of the plant since several significant confining layers separate Sandstone C from the most shallow stratum.

The MCL for gross alpha excluding uranium and radon is 15 pCi/l. Fourteen of the twenty-four wells sampled had values greater than 15 pCi/l. These wells generally are located in one of the areas previously identified as locally impacted.

6.1.3.2 Gross Beta Activity.

Thirteen of the twenty-four wells sampled had gross beta activity levels less than the detection limit of 20 pCi/l, and five more wells had values between 20 and 26 pCi/l. These data suggest that background levels are generally comparable to these values. The EPA has not published guidelines or standards for beta activity in ground water.

Figure 6.4 depicts gross beta activity in ground water. The map shows that the highest gross beta concentrations occur down-gradient from the two closed wastewater ponds and the former burial ground, and in the surface-water drainage feature north and down-gradient from the uranium building.

The six wells with gross beta values of 50 pCi/l or more are summarized below.

- Down-gradient from waste water pond #1: Wells 1312, 2370 pCi/l and 1313, 2200 pCi/l. These wells are completed in Sandstone A.

- Down-gradient from waste water pond #2: Well 1336, 4970 pCi/l. This well is completed in Sandstone A.

- o <u>Down-gradient from former burial area:</u> Wells 1315, 660 pCi/l and 1316, 100 pCi/l. These wells are completed in Sandstone A.

- o <u>Southwest and down-stream (surface water) from the uranium building:</u> Well 1330, 62 pCi/l. This well is completed in Sandstone A.

Gross beta values do not exceed background in shallow or deep wells at any of the locations of paired Sandstone A and C wells.

6.1.3.3 <u>Uranium.</u>

The EPA has not yet established specific guidelines or limits on uranium activity in drinking water; however the proposed rules governing uranium in drinking water supplies will be announced in the summer of 1990. It is anticipated that the MCL for uranium will be in the 20 to 40 pCi/l range (Mr. Bob Clement, U.S. EPA Drinking Water Section, Denver, personal communication).

Figure 6.5 shows total uranium (U-238 + U-235 + U-234) activity at the facility. The distribution of uranium activity levels is comparable to the gross alpha activity levels shown in Figure 6.3. Figure 6.5 also suggests that four site-activity related sources for uranium are present. Locations and wells where uranium levels exceed 30 pCi/l are summarized below.

- o <u>Down-gradient from waste water ponds #1 and 2:</u> Well 1312, 58 pCi/l, and Well 1313, 117 pCi/l, are down-gradient from closed wastewater pond #1. Well 1336, 101 pCi/l is down-gradient from closed wastewater pond #2. These wells are completed in Sandstone A.

- o <u>Down-gradient from former burial area:</u> Wells 1315, 5230 pCi/l, and 1316, 287 pCi/l. These wells are completed in Sandstone A.

- o <u>Down-gradient from the uranium plant:</u> Well 1331, 165 pCi/l. This well is completed in Sandstone A.

At three of the four locations where paired Sandstone A and C wells were completed, the deep well has higher uranium levels than the shallow well. These data are summarized below:

Well	Completion	Total Uranium Concentration
1320	A	8.85 pCi/l
1321	C	10.97 pCi/l
1322	A	12.23 pCi/l
1323	C	27.22 pCi/l
1329	A	7.43 pCi/l
1328	C	27.66 pCi/l
1333	A	24.91 pCi/l
1332	C	20.42 pCi/l

These wells show the same pattern as described for gross alpha activity levels. The slightly higher uranium activity levels in the deep wells is representative of regional background values.

6.1.3.4 Radium.

Figure 6.6 shows areal variations in total radium activity (Ra-228 + Ra-226) in the ground-water samples. The analyses are tabulated in Table 3.4. Radium sources were not used at the facility, and concentrations detected in the ground-water samples represent naturally-occurring levels. Table 6.2 presents the radium analyses in order of increasing concentration. Statistical analyses of the radium data were performed to determine background levels and the statistical significance of any variations.

A visual inspection of Table 6.2 indicates that two populations of radium values may exist. Nineteen of the twenty-four wells have values less than 0.5 pCi/l, four of the twenty-four lie between 1.1 and 2.9 pCi/l, and Well 1336 showed a concentration of 9.78 pCi/l. A histogram and probability distribution were constructed to determine how the data are distributed.

Figure 6.7 is a histogram of the natural logarithm of radium concentrations in ground water, which shows a log-normal distribution skewed to the right. A second population may be indicated by the increased number of observations in the last three classes.

Figure 6.8 is a probability plot of the log-transformed radium values. The majority of values in Figure 6.8 generally lie along a straight line, confirming the data are log-normally distributed (EPA, 1989). Two populations and an outlier are suggested in Figure 6.8.

A t-test was performed to determine the statistical significance of the radium values greater than 1 pCi/l. The calculations were performed in accordance with the procedures presented in 40 CFR Part 264, Appendix IV. The outlier, 9.78 pCi/l, was not included in the calculations.

The t-test assumed the data represents one population (all background) and the statistical significance of the values lying above 1 pCi/l compared to the population mean was calculated. The test conducted in this manner is more likely to fail to recognize a statistical difference in the larger values. Statistical significance was determined by calculating a t-statistic at the 0.05 level of significance and comparing it to a comparison t-statistic (40 CFR, Part 264, Appendix IV).

The t-statistic, t^*, is calculated to be 3.72. The comparison t-statistic, t_c, is calculated to be 2.26. Since t^* is greater than t_c, the group of values lying between 1.1 and 2.9 pCi/l represent a significant increase compared to background (40 CFR, Part 264, Appendix IV).

Since nineteen of the twenty-four wells had total radium concentrations less than 0.5 pCi/l and the log-transformed probability plot of radium concentrations suggests two populations are present, background is believed to be represented by the group of values below 0.5 pCi/l. The background mean is 0.155 pCi/l with a standard deviation of 0.141 and a variance of 0.020. Values above 1 pCi/l lie greater than six standard deviations from the background mean. The locations and wells where radium values elevated above background were reported are summarized below.

- <u>Down-gradient from waste water ponds #1 and 2:</u> Well 1312, 1.83 pCi/l, and Well 1313, 2.83 pCi/l, are down-gradient from pond 1. Well 1336, 9.78 pCi/l is down-gradient from pond #2. These wells are completed in Sandstone A.

- <u>Down-gradient from former burial area:</u> Well 1315, 1.61 pCi/l. This well is completed in Sandstone A.

- <u>Well 1332:</u> Well 1332 with a level of 1.18 pCi/l is a deep Sandstone C well northwest of the sewage lagoons. The shallower Sandstone A wells in the area do not exhibit radium levels above background.

Since no sources of radium were managed at the facility, the elevated radium cannot result from leaching of waste materials. Changes in ground-water chemistry from natural background near the wastewater ponds and the former burial location could be responsible for the slightly elevated values. The wastewater disposed in the now-closed ponds may have altered the ground-water chemistry sufficiently to elute naturally occurring radium from the aquifer matrix.

The maximum contaminant level (MCL) for combined Ra-228 and Ra-226 in community water supplies is 5 pCi/l. Only Well 1336, down-gradient from wastewater pond #2, exceeds this standard.

6.1.4 Facility Impacted Areas.

The ground-water analyses indicate that there are four likely sources of site-related activity impacts. These include the closed wastewater ponds #1 and #2, the former burial ground, and the uranium plant areas. Elevated fluoride, nitrate, uranium, and gross alpha and beta activities were detected near the wastewater ponds. Elevated uranium, and alpha and beta activity were detected near the former burial location. Elevated nitrate and uranium concentrations, and alpha activity were detected near the uranium plant.

6.2 Site Soil and Rock Analyses

Selected soil and rock samples were submitted to the Kerr-McGee Technical Center laboratory for fluoride, nitrate, TOC, gross alpha and beta activity, Pu-239, Ra-228, Ra-226, Th-232, Th-228, U-238, and U-234 analyses. The samples selected were representative of the various strata encountered in the shallow subsurface, and emphasize those intervals that may be the host for the contaminants and retarding medium for the vertical and horizontal movement of contaminants. Before the samples were shipped to the laboratory, the uranium activity in each sample was measured by Cimarron personnel by gamma spectrometry. The results of the analyses are summarized below.

6.2.1 Fluoride and Nitrate.

Fluoride and nitrate were detected in all selected soil and rock samples submitted to the laboratory. Fluoride concentrations ranged from 18 ppm to 640 ppm and are comparable to the average naturally-occurring crustal abundance of fluoride in sedimentary rocks reported by Levinson (1980) and Mason (1966), which ranges up to 740 ppm. Although Figure 6.9 shows a positive correlation between fluoride and uranium, neither set of values are above natural background levels and may not be directly related to past activities at the facility.

- Nitrate concentrations ranged from 2 ppm to 130 ppm and show no apparent correlation with the other parameters analyzed.

6.2.2 Total Organic Carbon.

Total organic carbon (TOC) was analyzed to determine if organic materials in the subsurface adsorbed uranium. TOC in the soil and rock samples ranged from less than the detection limit of 10 ppm to 3110 ppm. The highest value occurred at Well 1326 in soil from the two to four feet deep interval. Organic carbon does not appear to have adsorbed uranium as no correlation between TOC and uranium concentrations was determined.

6.2.3 Radionuclides.

Site soil and rock samples were analyzed for gross alpha and beta activity, Pu-239, Ra-228, Ra-226, U-238, U-234, Th-232, and Th-228. The laboratory analyses are tabulated in Table 3.5.

6.2.3.1 Alpha and Beta Activity.

Gross alpha activity values ranged from less than the detection limit of 10 pCi/g to 38 pCi/g. The higher values were all associated with mudstone samples. No sandstone samples had gross alpha values higher than 12 pCi/g. Alpha activity is probably related to naturally-occurring isotopes and the higher concentrations detected in the mudstones samples reflects adsorption on the clay-rich mudstone matrix.

None of the samples submitted had values for gross beta activity greater than the detection limit of 20 pCi/g.

6.2.3.2 Plutonium.

No plutonium above background was detected in any samples submitted. Reported values range from 0.001 to 0.006 pCi/g, which are representative of background values. The precision of these analyses is 0.001 pCi/g.

6.2.3.3 Uranium.

Uranium-238 ranged from 0.16 to 0.84 pCi/g. Uranium-234 ranged from 0.21 to 0.73 pCi/g. The higher concentrations for both isotopes were associated with mudstone samples. There is no apparent correlation with proximity to facility components and is therefore attributed to be representative of naturally-occurring uranium rather than an impact from plant activities. A greater concentration in the higher surface area mudstone matrix is to be expected as it provides an active adsorption environment.

6.2.3.4 Radium.

Radium-228 ranged from 0 to 1.9 pCi/g. Radium-226 ranged from 0 to 0.77 pCi/g. As was reflected in the uranium values, the higher radium values are associated with mudstone samples. These values represent naturally-occurring radium and do not indicate an impact from plant activities. Radium was not used in the production processes. The facility processed high purity enriched uranium isotopes.

6.2.3.5 Thorium.

Thorium was present at the site either as drummed waste buried at the former burial location or as contamination on equipment from the Cushing facility which was stored at the uranium plant yard. The drums and equipment were removed and disposed in an off-site licensed commercial disposal facility. No thorium was processed at the facility and its presence in the subsurface is attributed to naturally-occurring isotopes.

6.2.4 Correlation with Field-Measured Gamma Activity.

A comparison of laboratory measured values for uranium-238 and the borehole gamma probe measurements was made and is presented in Figure 6.10. Although the data does not show a strong correlation the method does provide a gross evaluation tool to distinguish between naturally occurring background gamma activity and that resulting from plant activities.

A threshold count is apparent (see Figure 6.10) at approximately 27,000 to 30,000 counts/minute. Below that threshold, uranium activities are typically less than 1 pCi/g. Above the threshold, uranium activities significantly greater than 1 pCi/g are apparent. This threshold is believed to represent the division between natural background gamma activities and facility related impacts.

6.3 Uranium Mobility

The mobility of uranium at the site depends upon the chemistry of the ground water and the soil and rock chemistry. The stability and mobility of particular species in the subsurface depends primarily on active matrix adsorption sites, ligands available for complexation, pH, and Eh of the ground water. Uranium has limited solubility in the slightly alkaline and oxidizing ground water typical of the site. The solubility is higher near the ponds because of the altered ground-water chemistry in these areas and the presence of complexing agents, e.g. fluoride and nitrate.

The dominant uranium species in the natural environment are uranyl complexes. Uranium exists in the hexavalent state as the uranyl ion UO_2^{+2} in this environment (Levinson, 1980). The solubility of uranium is limited by precipitation and adsorption on the aquifer matrix. Uranyl hydroxide and uranium trioxide will precipitate from slightly alkaline and oxidizing ground water. These compounds are relatively insoluble. Uranyl ions in solution also will be sorbed onto the aquifer matrix.

The distribution coefficient analyses described in Section 3.2.8.5 indicate that the equilibrium concentration of uranium in ground water should be less than 10 pCi/l. The tests performed on five representative samples of aquifer material yielded final concentrations of uranium in test solutions less than 10 pCi/l and relatively large equilibrium distribution coefficients. The ground-water analyses from most of the monitoring wells showed similar values.

Concentrations of uranium above the typical equilibrium level were detected in some monitoring wells. These wells generally were located down-gradient from the closed wastewater ponds and former burial area. Materials stored in these areas could cause changes in the chemistry of the ground water near the facilities. The process wastewater discharged to the ponds contained dissolved uranium and was significantly different chemically from the natural ground water (Wayne Norwood, personal communication, 1989). The difference is responsible for the higher uranium concentrations near the ponds. Likewise, leaching of materials stored at the former burial location would alter the ground-water chemistry in that area.

Uranium concentrations decreased rapidly to background levels with distance from the sources, as is discussed in Section 7.3.

TABLE 6.1

Annual Ground-Water Sampling Results

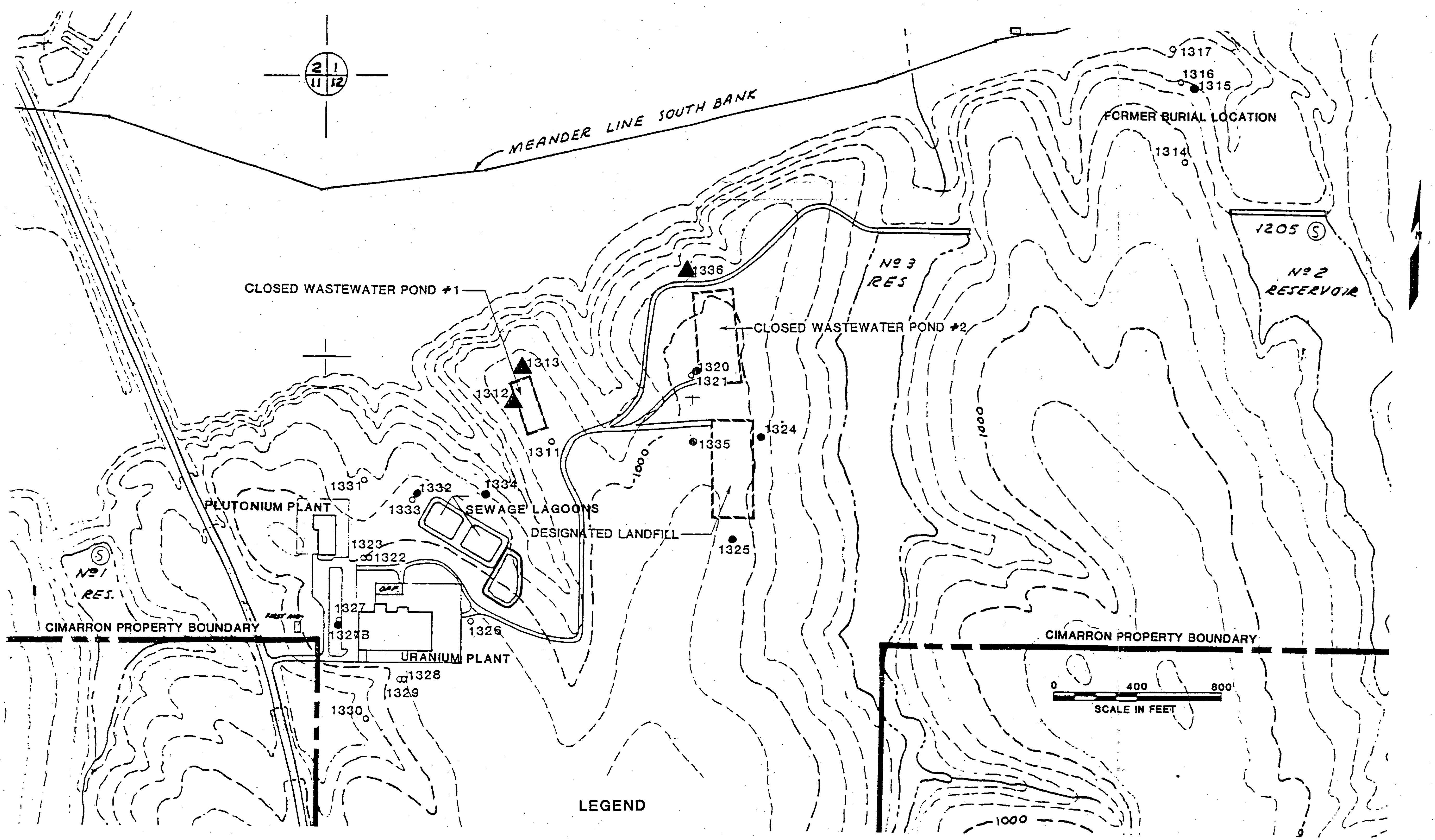
Date	Alpha pCi/l	Beta pCi/l	NO3 mg/l	F mg/l	U-238 pCi/l	Pu-239 pCi/l	Ra-224 pCi/l	Ra-226 pCi/l
WELL No. 1311								
06/21/85	10.0	31.0	57.0	< 0.2	< 0.7	0.015	NR	NR
06/26/86	<10.0	< 20.0	87.0	0.4	1.0	< 0.100	NR	NR
06/16/87	<10.0	< 20.0	34.0	0.4	1.7	0.010	0.081	0.3
06/28/88	<10.0	< 20.0	38.0	< 1.0	1.7	0.008	0.040	0.2
03/21/89	<10.0	23.0	66.0	< 0.2	0.8	0.002	NR	0.2
WELL NO. 1312								
06/21/85	2200.0	8275.0	< 20.0	83.0	86.0	0.020	NR	NR
06/28/86	94.0	7300.0	1310.0	59.0	5.6	< 0.100	NR	NR
06/16/87	41.0	65.0	620.0	18.0	15.0	0.002	0.290	0.6
06/30/88	90.0	231.0	480.0	22.0	48.0	0.012	0.410	1.1
03/21/89	59.0	2370.0	1020.0	50.0	15.3	0.003	NR	0.5
WELL NO. 1313								
06/21/85	453.0	1512.0	< 5.0	120.0	23.0	0.003	NR	NR
06/28/86	230.0	3000.0	690.0	157.0	25.4	< 0.100	NR	NR
06/16/87	84.0	25.0	450.0	120.0	26.0	0.004	0.350	0.2
06/28/88	61.0	24.0	570.0	3.1	42.0	0.006	0.120	0.3
03/21/89	260.0	2200.0	720.0	140.0	30.0	0.003	NR	0.5
WELL NO. 1314								
07/02/85	< 10.0	< 20.0	2.0	0.4	< 0.7	0.007	NR	NR
06/26/86	< 10.0	< 20.0	9.0	1.5	0.7	< 0.100	NR	NR
06/15/87	< 10.0	< 20.0	4.8	1.3	1.7	0.027	0.057	0.2
06/29/88	< 10.0	< 20.0	12.0	1.8	2.3	0.002	0.070	0.2
03/21/89	< 10.0	< 20.0	0.4	< 0.2	0.3	0.003	NR	0.1
WELL NO. 1315								
07/02/85	3125.0	189.0	11.0	< 0.2	1800.0	0.019	NR	NR
06/26/86	5400.0	740.0	5.0	0.5	2310.0	< 0.100	NR	NR
06/16/87	3850.0	2450.0	6.7	0.6	1600.0	0.005	0.036	0.1
06/27/88	3800.0	989.0	< 2.0	< 1.0	1590.0	0.002	0.210	0.2
09/13/88	3560.0	240.0	< 10.0	< 1.0	1340.0	NR	0.000	1.9
03/21/89	6440.0	660.0	13.0	0.2	1550.0	0.003	NR	0.0
WELL NO. 1316								
07/02/85	200.0	< 20.0	11.0	< 0.2	63.0	0.020	NR	NR
06/26/86	608.0	140.0	4.0	0.8	530.0	< 0.100	NR	NR
06/15/87	420.0	300.0	4.6	0.6	180.0	0.002	0.100	0.1
06/29/88	378.0	116.0	12.0	< 1.0	99.0	0.012	0.060	0.1
03/21/89	331.0	100.0	16.0	< 0.2	67.0	0.003	NR	0.0
WELL NO. 1317								
07/02/85	20.0	27.0	25.0	< 0.2	< 0.7	0.003	NR	NR
06/26/86	< 10.0	21.0	8.0	0.4	7.0	< 0.100	NR	NR
06/15/87	13.0	< 20.0	2.2	0.3	3.3	0.002	0.100	0.2
06/29/88	105.0	< 20.0	< 1.0	< 1.0	42.0	0.002	0.030	0.1
03/21/89	66.0	26.0	0.4	< 0.2	8.1	0.003	NR	0.0

NOTE: NR means result not reported

TABLE 6.2

Radium Concentrations in Ground Water

Well No.	TOTAL RADIUM pCi/l	ln(Ra)	Frequency	i	Cumulative Frequency
1331	0.000		2	2	8.00
1335	0.000				
1321	0.021	-3.86	1	3	12.00
1329	0.030	-3.51	1	4	16.00
1328	0.054	-2.92	1	5	20.00
1323	0.058	-2.85	1	6	24.00
1324	0.059	-2.83	1	7	28.00
1327-B	0.061	-2.80	1	8	32.00
1330	0.088	-2.43	1	9	36.00
1317	0.100	-2.30	1	10	40.00
1314	0.110	-2.21	1	11	44.00
1326	0.150	-1.90	1	12	48.00
1334	0.229	-1.47	1	13	52.00
1333	0.240	-1.43	1	14	56.00
1322	0.258	-1.35	1	15	60.00
1311	0.262	-1.34	1	16	64.00
1325	0.346	-1.06	1	17	68.00
1320	0.400	-0.92	1	18	72.00
1316	0.470	-0.76	1	19	76.00
1332	1.180	0.17	1	20	80.00
1315	1.610	0.48	1	21	84.00
1312	1.830	0.60	1	22	88.00
1313	2.830	1.04	1	23	92.00
1336	9.780	2.28	1	24	96.00



LEGEND

○	< 0.20 mg/l
●	0.20–2.00
■	2.00–4.00
▲	> 4.00

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FIGURE 6.1
FLUORIDE CONCENTRATIONS IN GROUND WATER

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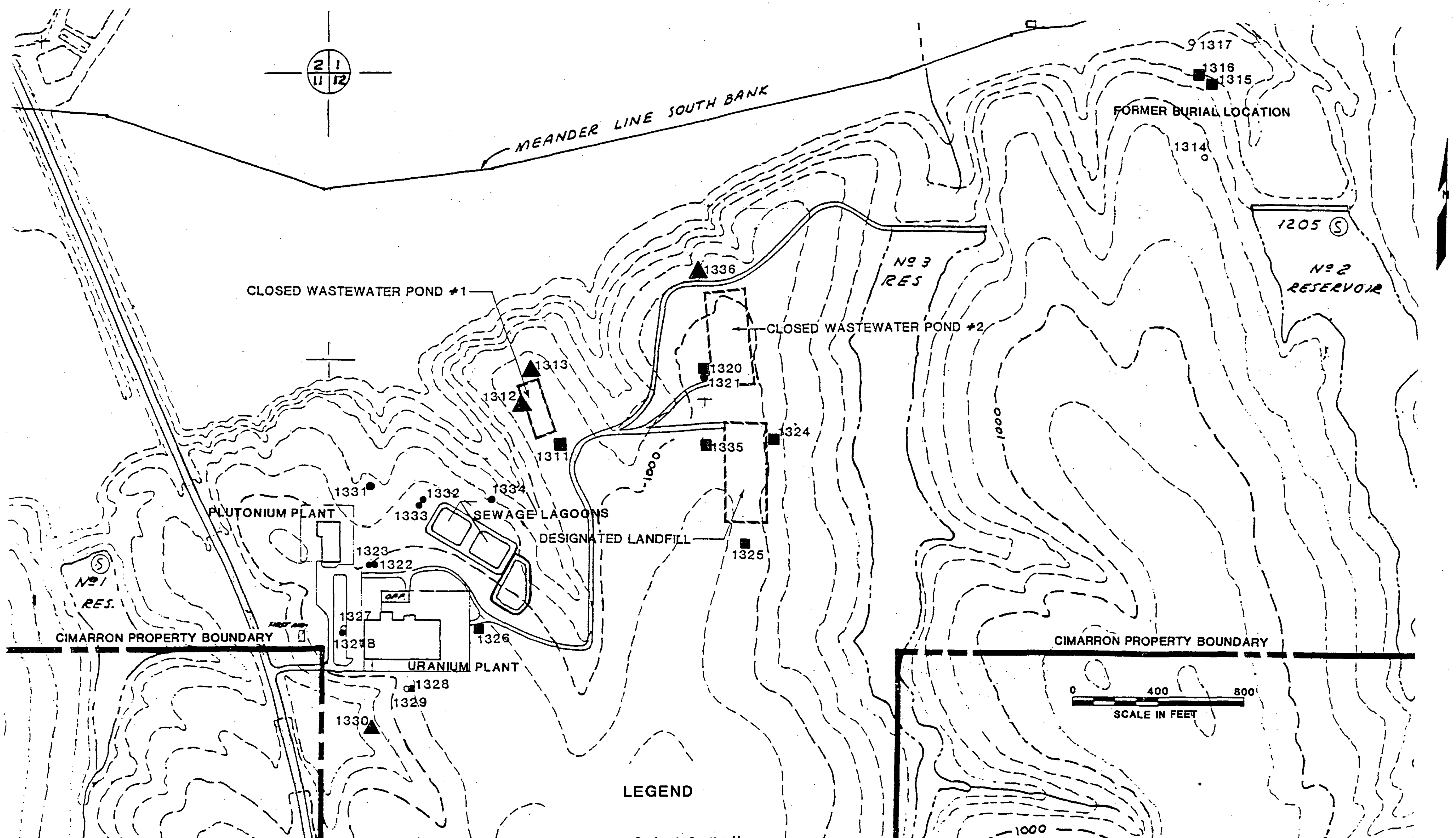

LEGEND

○ 0.1–1.0 mg/l

● 1.0–10.00

■ 10.0–100.00

▲ > 100.00

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FIGURE 6.2

NITRATE CONCENTRATION IN GROUND WATER

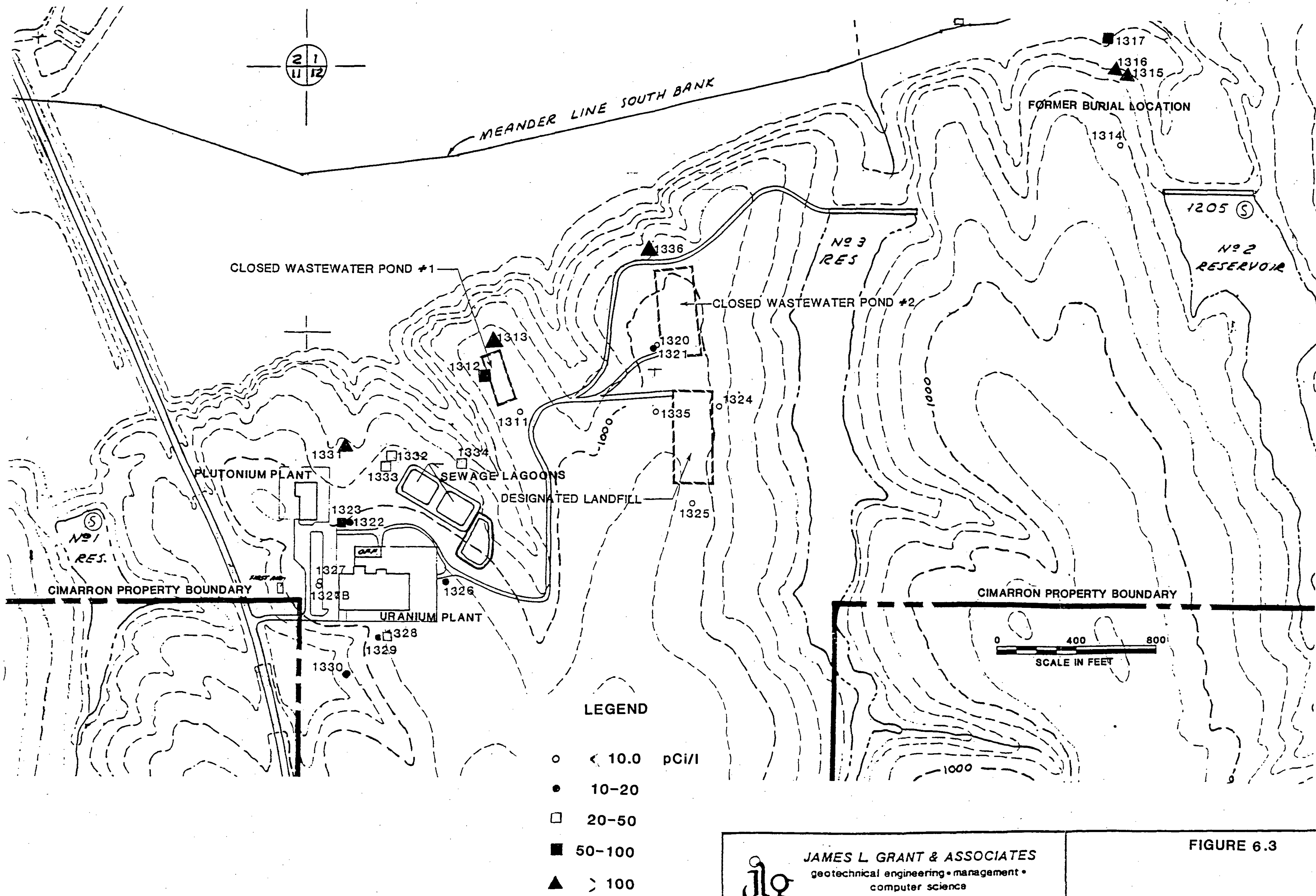

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FIGURE 6.3

ALPHA ACTIVITY IN GROUND WATER

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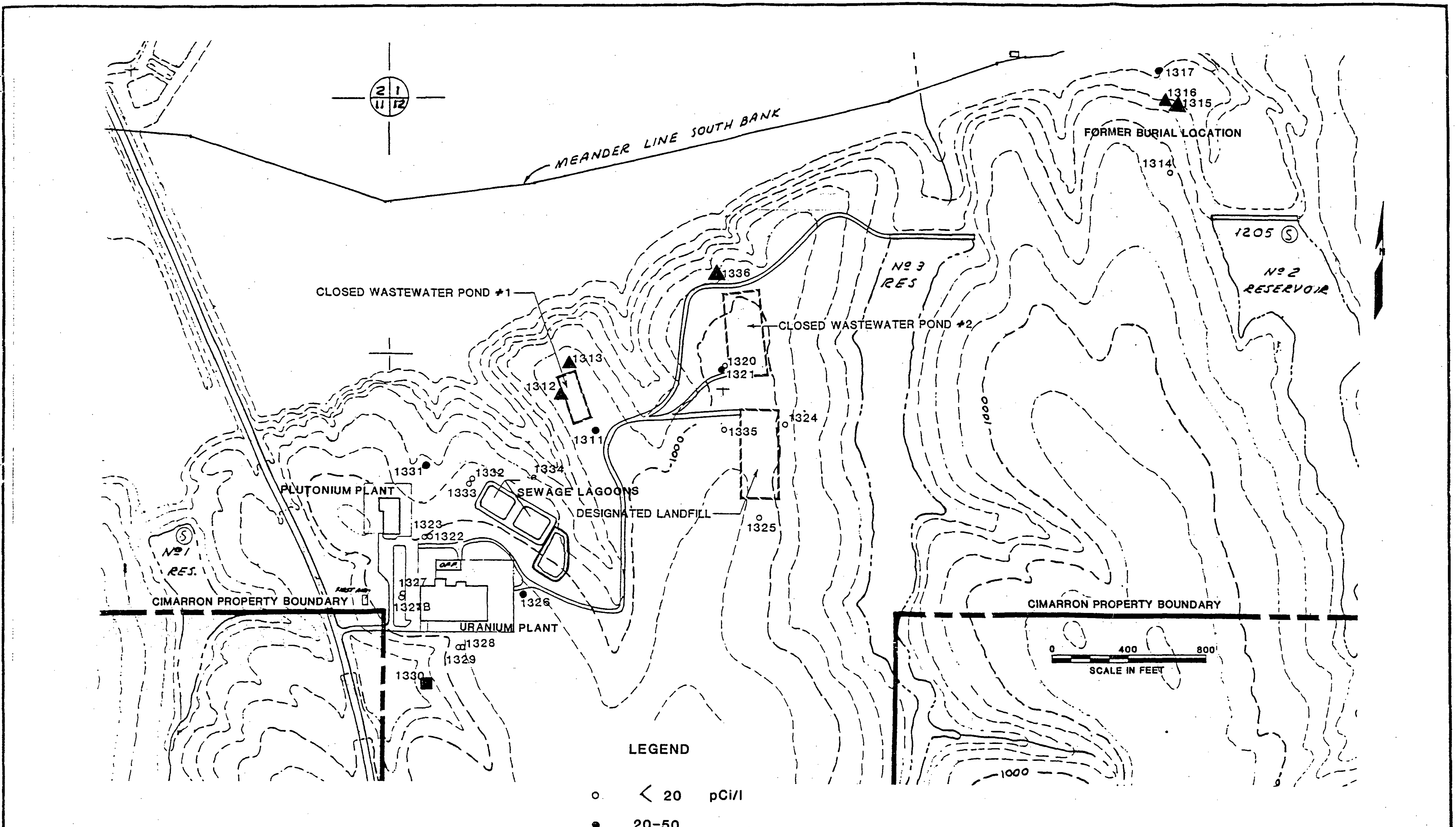

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FIGURE 6.4

BETA ACTIVITY IN GROUND WATER

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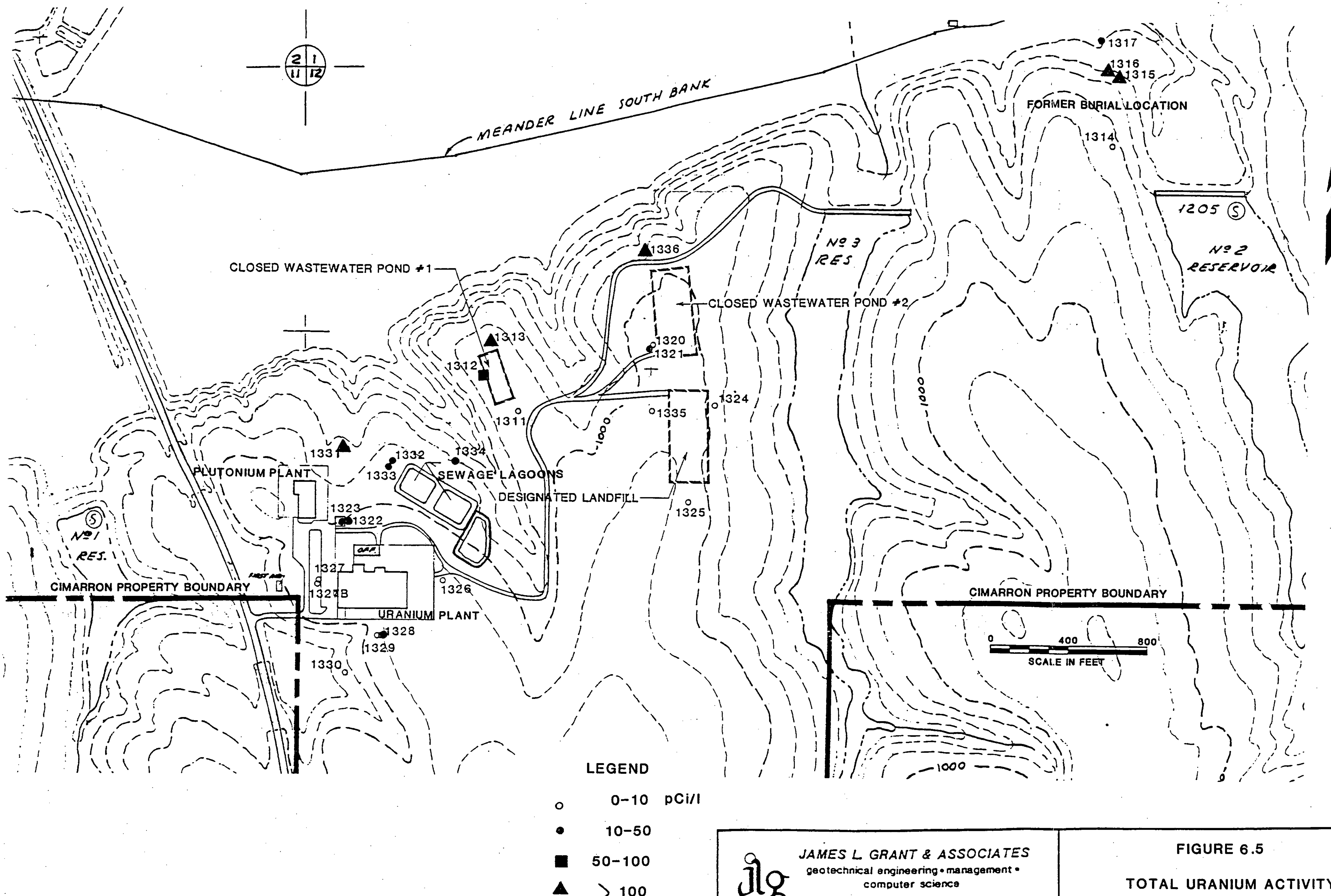

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FIGURE 6.5

TOTAL URANIUM ACTIVITY IN GROUND WATER

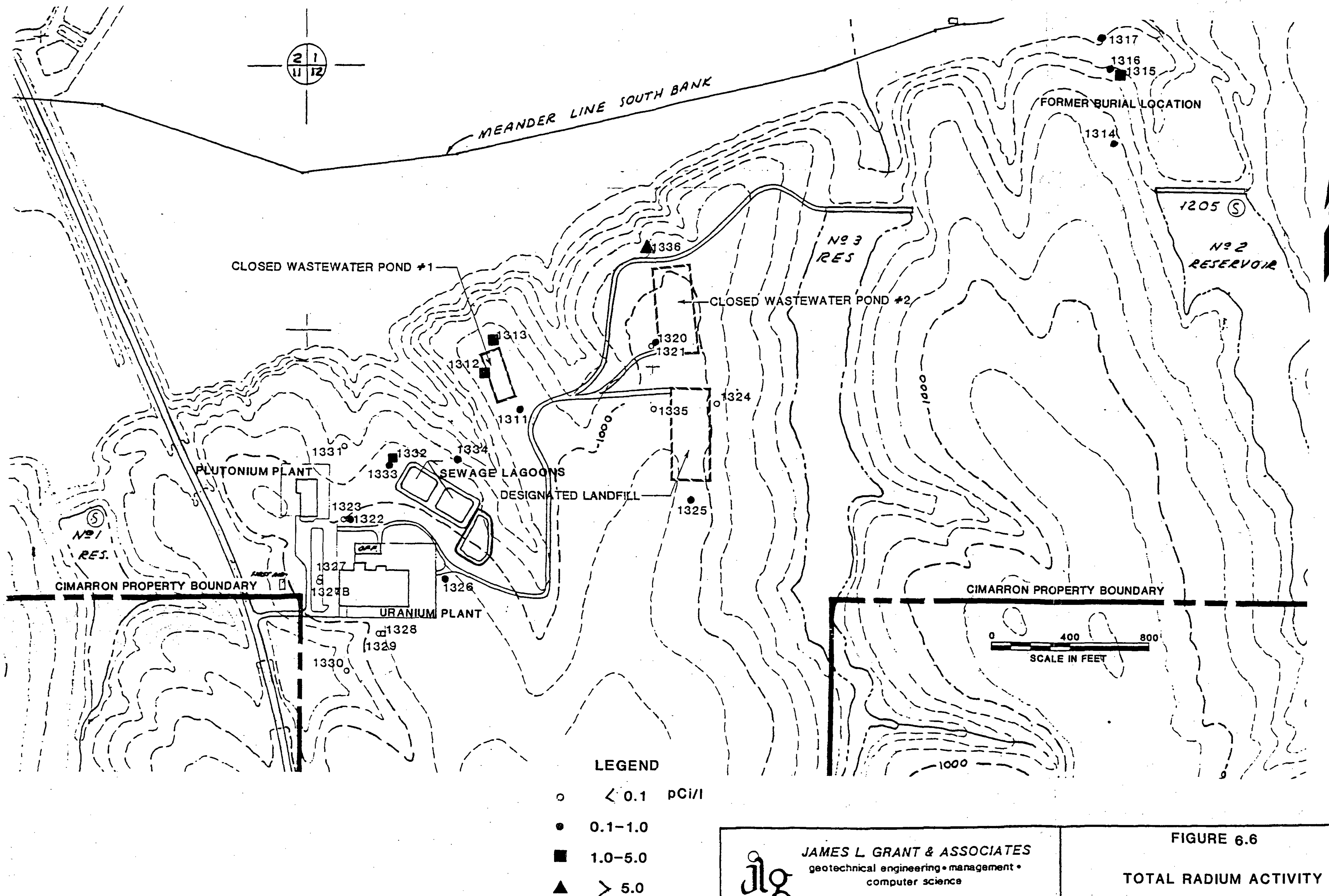

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FIGURE 6.6

TOTAL RADIUM ACTIVITY IN GROUND WATER

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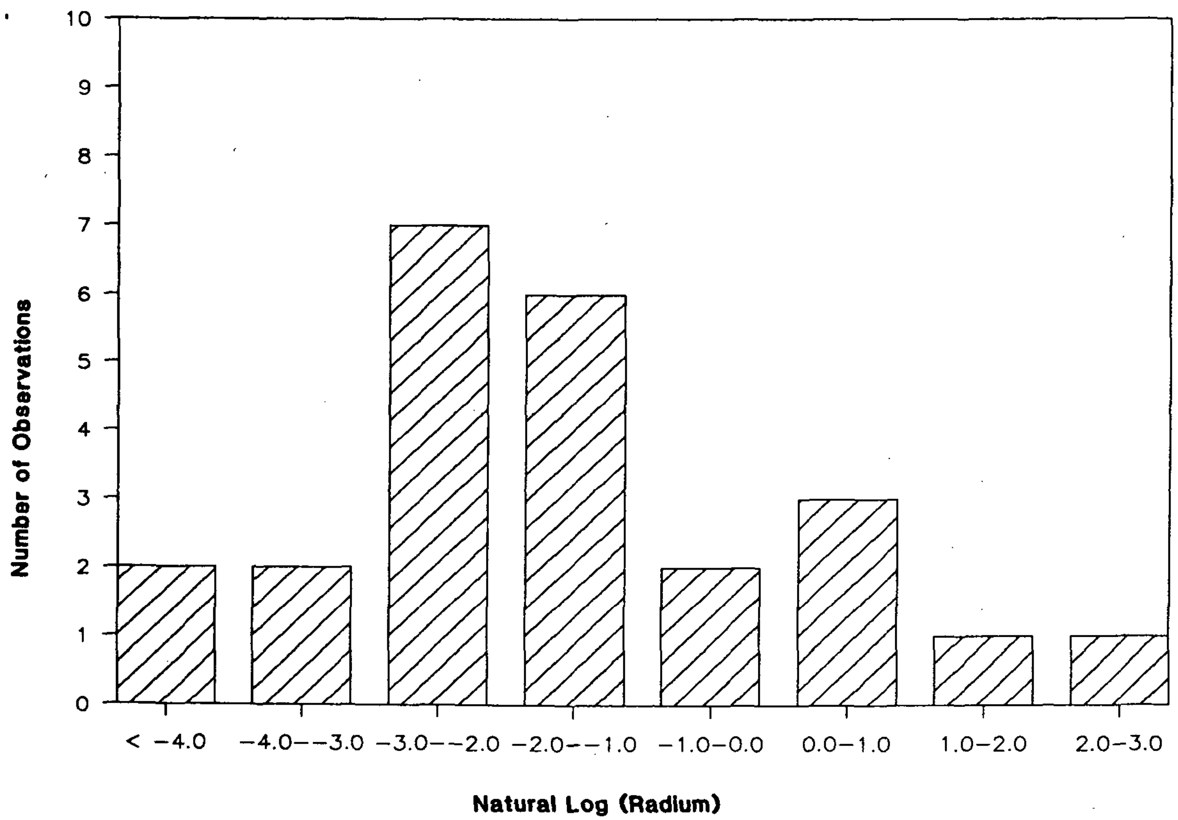

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FIGURE 6.7

HISTOGRAM OF RADIUM CONCENTRATIONS IN GROUND WATER

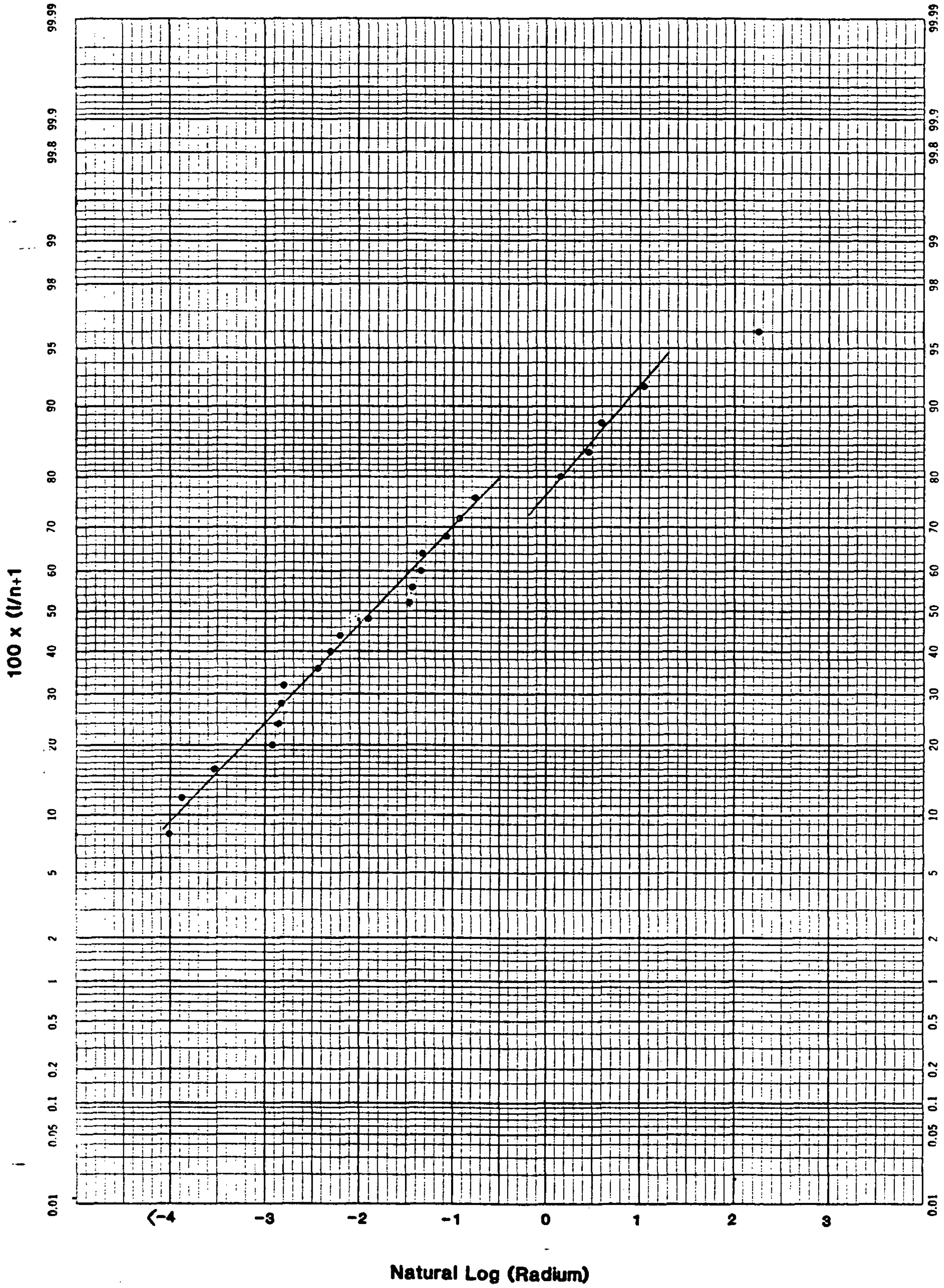

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FIGURE 6.8

LOG-TRANSFORMED PROBABILITY PLOT OF RADIUM IN GROUND WATER

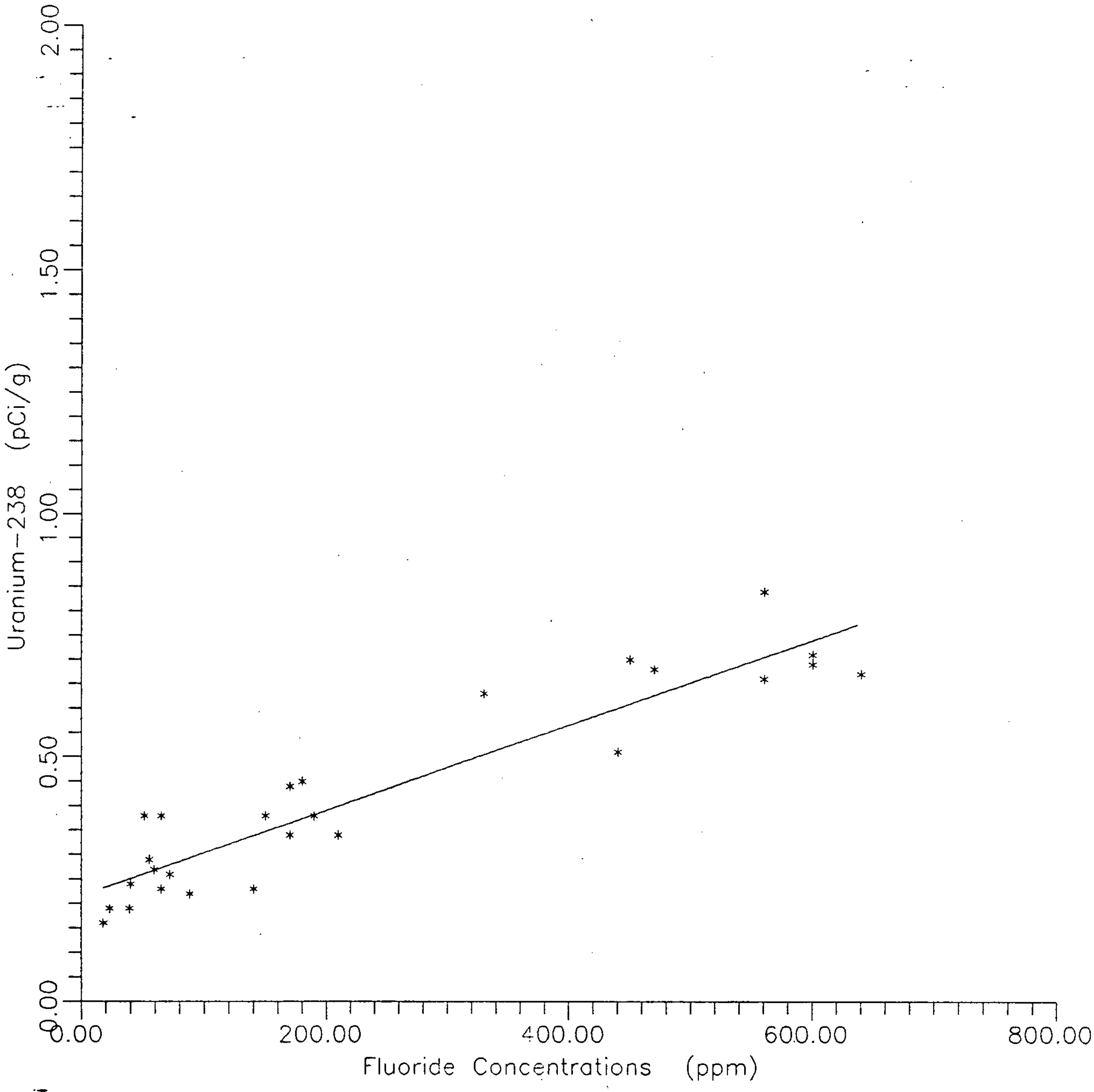

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FIGURE 6.9

FLUORIDE VERSUS U-238 IN SOIL AND ROCK

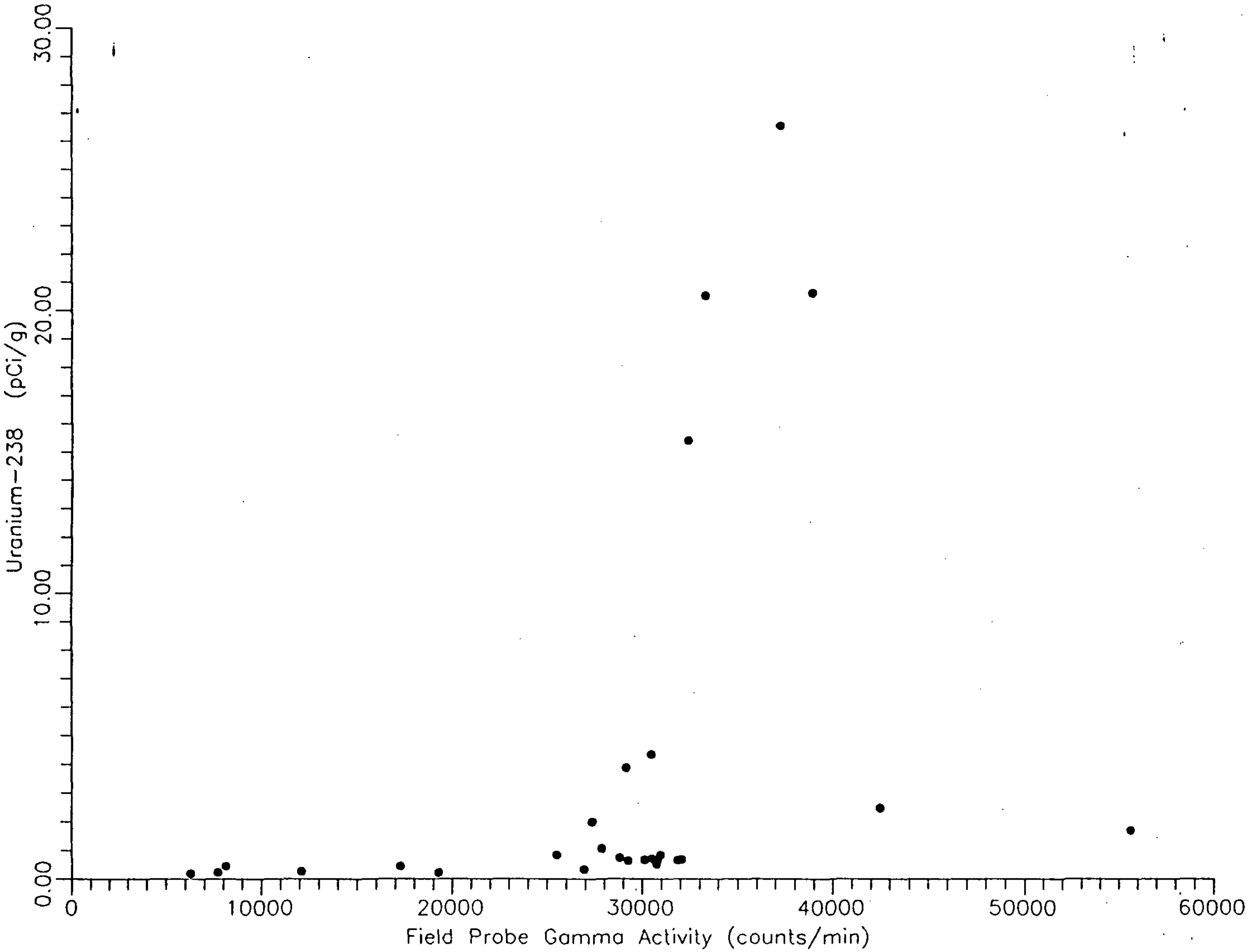

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FIGURE 6.10

FIELD PROBE GAMMA ACTIVITY VERSUS U-238

7. MOBILITY AND MATRIX RETENTION OF RADIONUCLIDES

This section describes the solubility and mobility of radionuclides in the subsurface at the Cimarron site. The discussion presents estimates of natural rainfall infiltration and percolation through the proposed landfill. Elemental partition coefficients are used to describe the solubility of the radionuclides in the undisturbed soil and in the proposed landfill. The percolation estimates are used to assess the rate and quantity of radionuclides that might leach from the soils.

The potential impacts of these radionuclides on ground-water and surface-water quality are discussed. The calculations in this section demonstrate that the materials which will remain at the site after decommissioning will not represent a real or potential threat to ground-water or surface-water use in the surrounding area.

7.1 Infiltration

7.1.1 Methods of Analysis.

The HELP model (Schroeder et.al., 1984; Schroeder, 1988) was used to develop estimates of potential infiltration through a natural soil profile and through the cover of the proposed landfill. The HELP model is a water balance model developed by the U.S. EPA to calculate infiltration and percolation into and through solid waste disposal facilities. The program is a quasi-two-dimensional, deterministic model adapted from an earlier EPA model, HSSWDS, and the U.S. Department of Agriculture CREAMS model.

The HELP model uses the Soil Conservation Service runoff curve number method to calculate storm-water runoff. Evapotranspiration is calculated using a modified Penman method. Percolation is calculated using a modification of Darcy's law. The program provides default and synthetically-derived climatic data, and default soil properties. Default or site-specific properties can be used in the analysis.

The program allows layered profiles comprising vertical percolation layers, lateral drainage layers, and hydraulic barriers. The program uses daily climatic data to calculate daily, monthly, and annual water budgets at critical points in the soil profile. The simulations performed are included in Appendix I.

7.1.1.1 Data.

The HELP model requires climatic data, soil properties, and the soil profile to be specified for each water budget simulation. Synthetically-generated 20-year records were used for Cimarron analyses. The records were generated using climatic data for Oklahoma City contained within the HELP model. Soil properties were developed from laboratory measurements of density, porosity, saturated hydraulic conductivity, and matric potential described in Section 2 of this report. Values appropriate for site soils were tabulated and matched with similar default values provided within the HELP database. The soil properties used in the analyses are summarized in Table 7.1. Hydraulic conductivity and porosity values are shown for "loose" and "dense" soil conditions. Surficial soil layers were assumed to be loose, and compacted layers were assumed to be dense.

Soil texture descriptions were used to estimate soil hydraulic classifications and to determine curve numbers for the surficial soils. An hydraulic group C was determined appropriate for the surficial site soils. Assuming a "fair" grass cover, a curve number of 65 for antecedent moisture condition II was obtained from standard references. This curve number was used for all soil analyses. The curve number is at the lower range of appropriate values for the site soils and is therefore conservative. Larger curve numbers would increase surface runoff and decrease infiltration estimates, although this effect would be relatively small within the range of realistic curve numbers.

7.1.1.2 Calculations.

Calculations were made for a range of profiles described in Table 7.2. These profiles consist of differing arrangements of the two basic soil types identified in the laboratory testing program on site generated samples. The different arrangements were analyzed to determine the sensitivity of the percolation estimates to variations in the soil profile. The results of the calculations are summarized in Table 7.3. Table 7.4 presents average monthly water balances for the cases analyzed.

Estimates of natural percolation range from 5.3 inches per year for the more-permeable surface soil to 3.8 inches per year for the less-permeable soil. These differences reflect the differences in water-holding capacity of the two soils. These numbers are comparable to the infiltration estimates that range up to 3.5 inches per year presented by Bingham and Moore (1975).

Estimates of percolation through the landfill cover ranged from 0.14 inches to 4.9 inches per year. The percolation estimates for cases LF1, LF3, and LF4 are nearly equal to the saturated hydraulic conductivity of the barrier layer, indicating that percolation is limited by the capacity of the barrier to transmit water in these cases. The percolation estimate for case LF2 is significantly less than the saturated hydraulic conductivity of the barrier, indicating that percolation through this cover is limited by evapotranspiration demands in the vegetative layer. The latter value essentially is equal to the estimates of percolation through the natural profile.

The sensitivity analyses can be summarized by noting that for barrier layer hydraulic conductivities larger than about $5x10^{-7}$ cm/sec, percolation will be limited by evapotranspiration at a constant value of about 5 inches per year. For smaller barrier layer hydraulic conductivities, percolation will be limited by the barrier layer, and will be essentially equal to the hydraulic conductivity of the barrier layer.

7.2 Leachability

The radionuclide analyses and distribution coefficient (Kd) analyses indicate that uranium has limited solubility and mobility in the ground water beneath the Cimarron facility. The Kd analyses show equilibrium concentrations of uranium of about 10 pCi/l or less. Kd values obtained from the tests are high. The measured Kd values range from about 300 to 3000 ml/g.

Concentrations of dissolved uranium in the test solutions after soil contact were less than 10 pCi/l. These concentrations are typical of uranium concentrations in the site monitoring wells, where corresponding uranium concentrations on the soil are smaller than those in the laboratory tests. The larger distribution coefficients in the laboratory tests are believed reflective of the influence of solubility upon the calculated value of Kd. In other words, a larger source of uranium does not create higher concentrations of uranium in solution, but, because of the insolubility of the uranium, results in a larger apparent Kd. As described in Section 3.2.8.5, the amount of uranium used in the Kd laboratory tests was equivalent to 3 pCi/g and 17 pCi/g of soil for the two test conditions.

The uranium concentrations in the test fluids are consistent with the concentrations of uranium measured in the natural site ground water. Samples of ground water from twenty-four wells were tested to determine the concentration of U-238. Eighteen of the samples had concentrations less than 10 pCi/l. The six wells where U-238 concentrations were higher are located near the wastewater ponds and the former burial area, facility components where the natural chemistry of the ground water has been altered due to seepage. Samples from wells down-gradient from these facilities show that the U-238 concentrations decrease to background levels away from these facilities where natural background conditions are again prevalent.

Soils which will be buried in the proposed landfill will contain soluble and insoluble uranium compounds in concentrations less than those prescribed in the NRC Branch Technical Position Option 2. The Option 2 concentration limit for soluble uranium is 100 pCi/g. Materials with soluble concentrations between 30 and 100 pCi/g will be placed in the landfill. Some materials placed in the landfill may have concentrations of soluble uranium less than 30 pCi/g. This point is important since the concentrations of uranium in the landfill soils is of the same order of magnitude as the concentration used in the laboratory Kd tests.

The materials to be placed in the proposed landfill are soils identical to the soils encountered during the site investigation. Leaching of these materials will not alter the chemistry of the leachate appreciably. Leachate chemistry will therefore reflect the chemistry of the unaltered ground water beneath the site. Under these conditions, leaching of the uranium from the landfill will be controlled by equilibrium established between the leachate and the soil matrix. The concentration of uranium in the leachate will be related to the concentration of uranium on the soil by the relation (Isherwood, 1981)

Cw = Cs*n/(rho*Kd)

Where

Cw is the concentration of uranium in the leachate (pCi/ml)
Cs is the concentration of uranium on the soil (pCi/g)
n is the porosity of the soil in the landfill
rho is the bulk density of the soil in the landfill, and
Kd is the equilibrium distribution coefficient of uranium in the soil/leachate system.

For typical values of porosity and bulk density of the soil in the landfill of about 0.4 and 1.6 respectively, the concentration of uranium in the leachate will range from about 0.00008 to 0.00083 times the concentration of uranium in the soil. In units of pCi/l, the concentration of uranium in the leachate will range from about 0.08 to 0.83 times the concentration of uranium in the soil in units of pCi/g.

7.3 Potential for Migration

The mobility of dissolved uranium in the ground water is limited by solubility constraints and the affinity of uranium for site soils. The results of the Kd tests indicate that distribution coefficients of uranium in the natural ground-water system at the Cimarron facility range between 300 and 3000 ml/g. Estimates of Kd values from site well data indicate that the Kd of uranium may be on the order of 10 to 200 ml/g at low uranium concentrations. Even these smaller values are representative of immobile materials. With a Kd of ten, dissolved uranium will move about 40 times slower than water in the ground-water system. With a Kd of 200, the uranium will move about 800 times slower than ground water.

Site water-quality data reflect the immobility of uranium in the subsurface. Figure 7.1 is a plot of U-238 concentrations in water from wells near the former burial ground. Wastes were buried in this facility and later exhumed and disposed off-site. The concentration of uranium in well 1315, located within the burial ground, and well 1316, located near well 1315, increase during the year 1986. This temporary increase may be related to abnormally high rainfall during 1985. The peak concentration of uranium in well 1315 is about 2300 pCi/l, and the peak concentration in well 1316 is about 530 pCi/l. An increase in concentration is observed in well 1317 in 1988, two years after the increase in the wells nearer the former burial ground. The peak concentration in well 1317 is 42 pCi/l, or about 12 times less than well 1316.

The changes in U-238 concentrations with distance from the former burial ground are illustrated in Figure 7.2. Up-gradient well 1314 shows background U-238 concentrations of about one to two pCi/l. Concentrations are increased to as much as about 2300 pCi/l across the former burial area, and decrease rapidly with distance down-gradient of the area. Migration around this area reflects the influence of the leachate chemistry upon uranium Kd's. Within the former burial area, Kd's probably are much smaller than in the natural system. The Kd's increase with distance from the facility as the ground-water chemistry approaches that of the native ground water.

Migration from the proposed landfill will be much less pronounced than from the former burial ground because the landfill will not influence ground-water chemistry, and because only soils with low levels of uranium will be buried in the landfill. Leaching of the uranium will be limited by solubility and by sorptive processes in the landfill. Migration of uranium that does leach will be limited by the sorption of the material in the subsurface.

7.4 Computer Simulation of Leaching and Migration

Leaching and subsurface migration of uranium from the Option 2 limit soils disposed at the proposed landfill was simulated using the TRANSS model (Simmons et.al., 1986). The TRANSS model is a one-dimensional, convective, dispersive transport program based on Van Genuchten analytical solutions, modified to include the simultaneous decay of the source and released radionuclides. The program can model concentration or solubility limited releases, adsorption (Kd) limited releases, or diffusion beneath a barrier to the water table.

Simulations of distribution coefficient-limited releases were performed to predict uranium migration through the unsaturated zone to the water table, and through the saturated zone to the Cimarron River alluvium.

7.4.1 Kd limited release simulation - Vadose zone.

Two simulations of uranium leaching and migration to the water table directly below the proposed landfill were performed using Kd values representative of the range of aquifer matrix materials. Kd values of 2000 ml/g and 300 ml/g were used. Kd is entered into the model through the retardation factor, R, which is related to Kd by the relation:

$$R = 1 + rho/(theta*Kd)$$

where
rho = dry bulk density of material (1.6 g/cc)
theta = moisture content (0.3)
Kd = distribution coefficient

The source term used in the simulations is calculated to be 1.81 Curies, based upon a total of 14,800 cubic yards soil disposed at the Option 2 Limit of 100 pCi/g soluble uranium. The leachate velocity through the unsaturated zone is low, and dispersion will be negligible. Leachate velocity is calculated from the infiltration rate and soil field capacity calculated for the HELP model described in Section 7.1. The parameters used in the simulations are listed in Table 7.5, and the output generated is included in Appendix J.

Both simulations show that very little uranium will leach and enter the water table. For a distribution coefficient of 2000 ml/g, a maximum leachate concentration of about 10 pCi/l is estimated to arrive at the water table in approximately 170,000 years. Figure 7.3 shows leachate concentration with time at the water table directly under the landfill for Kd=2000 ml/g simulation.

A distribution coefficient of 300 ml/g results in a maximum leachate concentration of about 67 pCi/l arriving at the water table in approximately 27,000 years. Figure 7.4 shows leachate concentration with time for the Kd=300 simulation.

7.4.2 Kd limited release simulation - Saturated zone.

Two simulations of leaching and migration of uranium from the landfill to the Cimarron River alluvium were performed using Kd values of 2000 and 300 ml/g. The pathline selected for the simulation is indicated on Figure 7.5. A length of 1000 feet, width of 360 feet, and thickness of 10 feet was estimated for the flowtube. Transport was modeled in the first saturated sandstone, which is approximately 10 feet thick, for a flowtube cross-sectional area of 3600 square feet. The same initial source concentration of uranium was modeled. The input parameters are listed in Table 7.5. The simulation output is included in Appendix J.

With a Kd of 2000 ml/g, a maximum leachate concentration of about 4 pCi/l is seen at the end of the flowtube in approximately 237,000 years. Figure 7.6 shows leachate concentration with time for the Kd=2000 ml/g simulation.

A Kd of 300 ml/g produces a maximum leachate concentration of about 27 pCi/l at the end of the flowtube in approximately 36,000 years. Figure 7.7 shows leachate concentration with time for this simulation.

7.4.3 Discussion of Results.

The results of the TRANSS model simulations support interpretations that leaching and migration of uranium in the subsurface of the Cimarron facility will be limited. The simulations show that the combined effects of precipitation, adsorption and dilution of uranyl complexes will prevent significant migration of uranium from the proposed landfill site.

7.5 Migration of Uranium Left In-Situ

The TRANSS model simulations also indicate that migration of radionuclides from soils left in place at the facility will be negligible. The simulations of leaching through the proposed landfill represent a case where soils containing the maximum permissible concentration of soluble uranium under the NRC Branch Technical Position Option 2 criterion are confined in a small area. Since the uranium concentration in soils left in place will be less than those disposed in the proposed landfill and are present over a greater area, the concentration of uranium in ground water that leached from the in-situ soils will be considerably less than that predicted for the landfill.

Subsurface conditions are essentially identical to those under the landfill and Kd values up to 2000 ml/g are expected. The concentration of uranium in ground water resulting from leaching of soils left in place is not anticipated to exceed the estimated equilibrium concentration of 10 pCi/l described in Section 3.2.8.5.

TABLE 7.1

Assumed Soil Properties for HELP model simulations

	Sand	Clay
Porosity		
(loose)	0.42	0.42
(dense)	0.33	0.33
Field Capacity	0.24	0.29
Wilting Point	0.104	0.187
K (cm/sec)		
(loose)	$1x10^{-4}$	$5x10^{-5}$
(dense)	$1x10^{-6}$	$1x10^{-7}$

TABLE 7.2

Cover Profiles Analyzed for HELP model simulations

Profile	Upper Layer Material	Upper Layer Thickness (inches)	Barrier Layer Material	Barrier Layer Thickness (inches)
LF1	Sa	24	Cl	12
LF2	Sa	24	Sa	12
LF3	Cl	24	Cl	12
LF4	Sa	24	Cl*	12
NA1	Sa	36	--**	12
NA2	Cl	36	--**	12

Notes: Soil types correspond to those in Table 7.1

* Hydraulic conductivity = $1x10^{-8}$ cm/sec.

** Hydraulic conductivity = $1x10^{-6}$ cm/sec.

TABLE 7.3

Summary of Percolation Calculations for HELP model simulations

CASE	AVERAGE PERCOLATION (inches/yr)	STD.DEV.	SOIL PROFILE
LF1	1.32	0.55	Sa/Cl
LF2	4.87	2.62	Sa/Sa
LF3	1.24	0.51	Cl/Cl
LF4	0.14	0.06	Sa/Cl*
NA1	5.27	2.92	Sa**
NA2	3.77	2.17	Cl**

* Hydraulic conductivity of Clay = $1x10^{-8}$ cm/sec.

** Hydraulic conductivity of underlying soil = $1x10^{-6}$ cm/sec.

TABLE 7.4

Average Monthly Water Balances for HELP model simulations (inches)

LF1

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
RUNOFF	0.011	0.012	0.045	0.357	0.883	0.039
	0.010	0.000	0.013	0.120	0.159	0.039
EVAPOTRANSPIRATION	0.790	0.882	1.456	1.789	3.284	6.254
	4.491	2.456	2.689	1.727	1.044	0.857
PERCOLATION	0.1267	0.1199	0.1494	0.1771	0.2237	0.1723
	0.0440	0.0000	0.0049	0.0652	0.1075	0.1332

LF2

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
RUNOFF	0.000	0.000	0.000	0.051	0.234	0.000
	0.010	0.000	0.012	0.121	0.057	0.000
EVAPOTRANSPIRATION	0.781	0.885	1.459	1.803	3.306	5.454
	3.007	2.449	2.691	1.745	1.037	0.858
PERCOLATION	0.2337	0.2089	0.3218	0.6076	1.0633	0.5912
	0.0348	0.0000	0.0447	0.5105	0.6927	0.5559

LF3

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
RUNOFF	0.009	0.000	0.063	0.467	1.109	0.085
	0.124	0.034	0.305	0.407	0.188	0.030
EVAPOTRANSPIRATION	0.836	0.947	1.532	1.900	3.498	5.878
	3.092	2.388	2.741	1.844	1.094	0.925
PERCOLATION	0.1247	0.1184	0.1476	0.1765	0.2169	0.1328
	0.0093	0.0000	0.0050	0.0621	0.1110	0.1387

Average Monthly Water Balances (continued)

LF4

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
RUNOFF	0.032	0.076	0.224	0.543	1.168	0.075
	0.010	0.000	0.013	0.127	0.176	0.063
EVAPOTRANSPIRATION	0.789	0.887	1.461	1.788	3.221	6.315
	4.833	2.458	2.690	1.722	1.043	0.859
PERCOLATION	0.0137	0.0132	0.0164	0.0189	0.0235	0.0185
	0.0057	0.0000	0.0005	0.0066	0.0111	0.0140

NA1

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
RUNOFF	0.000	0.000	0.000	0.051	0.152	0.000
	0.010	0.000	0.012	0.121	0.012	0.000
EVAPOTRANSPIRATION	0.780	0.885	1.459	1.803	3.306	5.253
	2.914	2.449	2.698	1.741	1.039	0.866
PERCOLATION	0.2733	0.2087	0.3131	0.5762	1.0641	0.7856
	0.2592	0.0077	0.0369	0.4647	0.6638	0.6193

NA2

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
RUNOFF	0.000	0.000	0.014	0.189	0.577	0.035
	0.125	0.034	0.306	0.397	0.082	0.000
EVAPOTRANSPIRATION	0.834	0.948	1.540	1.906	3.542	4.823
	2.697	2.387	2.735	1.834	1.102	0.923
PERCOLATION	0.1773	0.1476	0.2632	0.4975	0.8370	0.4777
	0.0295	0.0000	0.0339	0.3759	0.5397	0.3885

Note: All values in inches

TABLE 7.5

Hydrologic Parameters used in TRANSS Model

Parameter	Kd Limited Vadose Zone Simulation	Kd Limited Saturated Zone Simulation
Dispersion Coefficient	1.0 sq ft/yr	1.0 sq ft/yr
Retardation Factor: Kd=2000	10600	10600
Kd=300	1600	1600
Radionuclide Inventory	1.81 Ci	1.81 Ci
Pathline Length	20 ft	1000 ft
Travel Time in Unsat. Zone	14.5 years	14.5 years
Effective Porosity	0.30	0.30
Flowtube Area	80,000 sq ft	3,600 sq ft
Depth of Source Distribution	10 ft	10 ft
Infiltration Flux	0.3 ft/yr	0.3 ft/yr

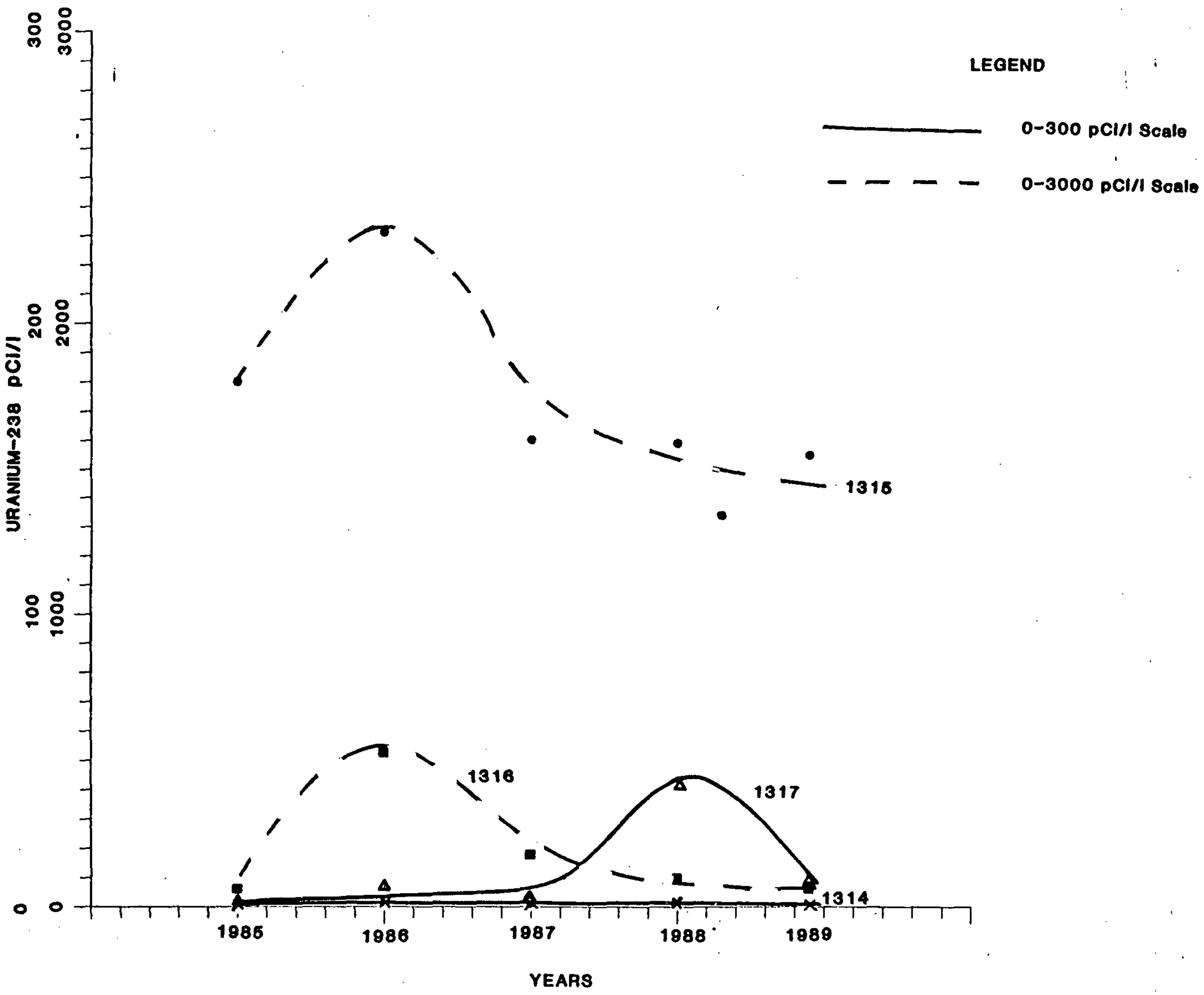

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FIGURE 7.1

ANNUAL URANIUM CONCENTRATIONS: 1985–1989
AT THE FORMER BURIAL LOCATION

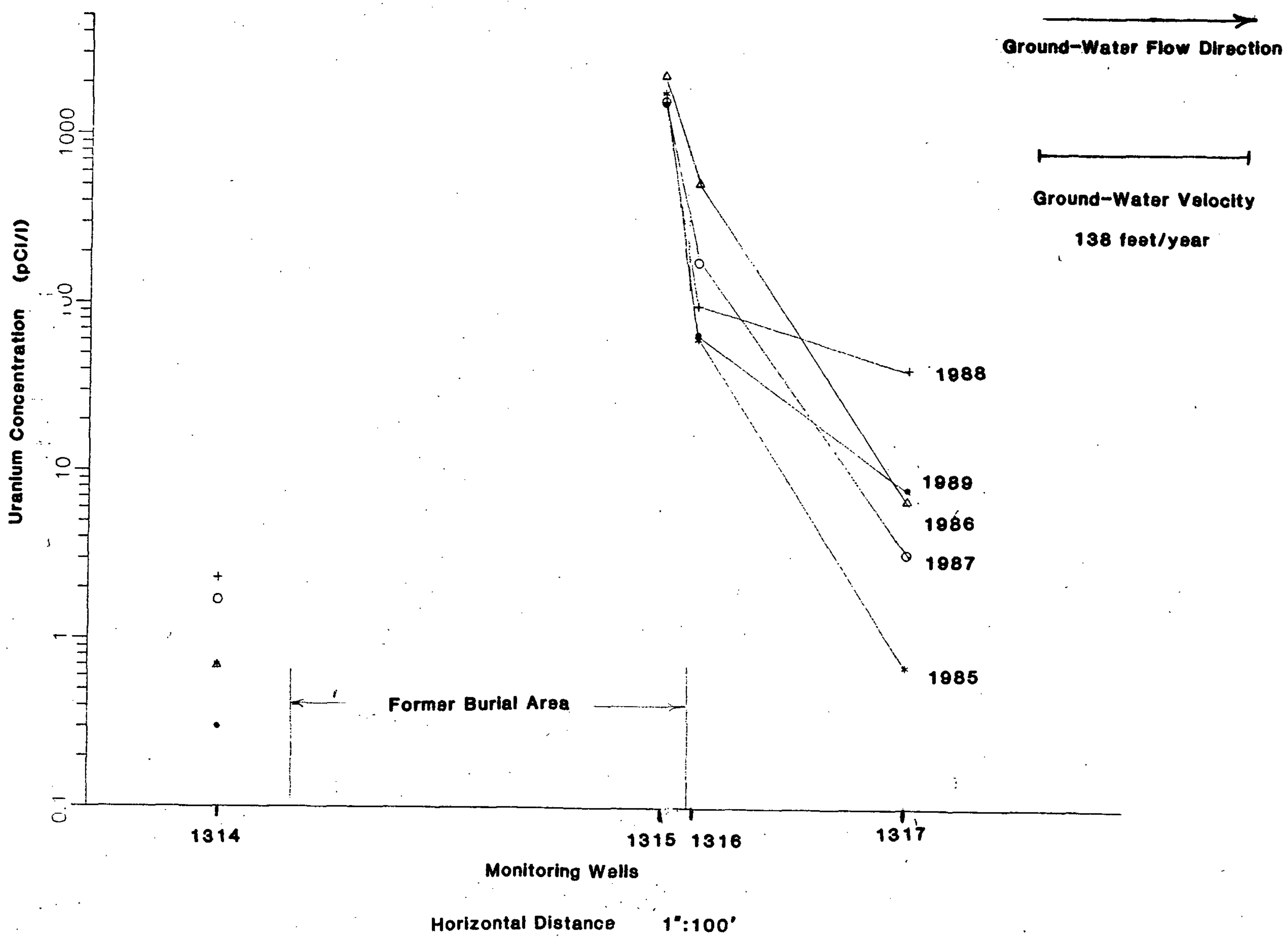

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FIGURE 7.2

URANIUM CONCENTRATIONS IN GROUND WATER AT THE FORMER BURIAL LOCATION

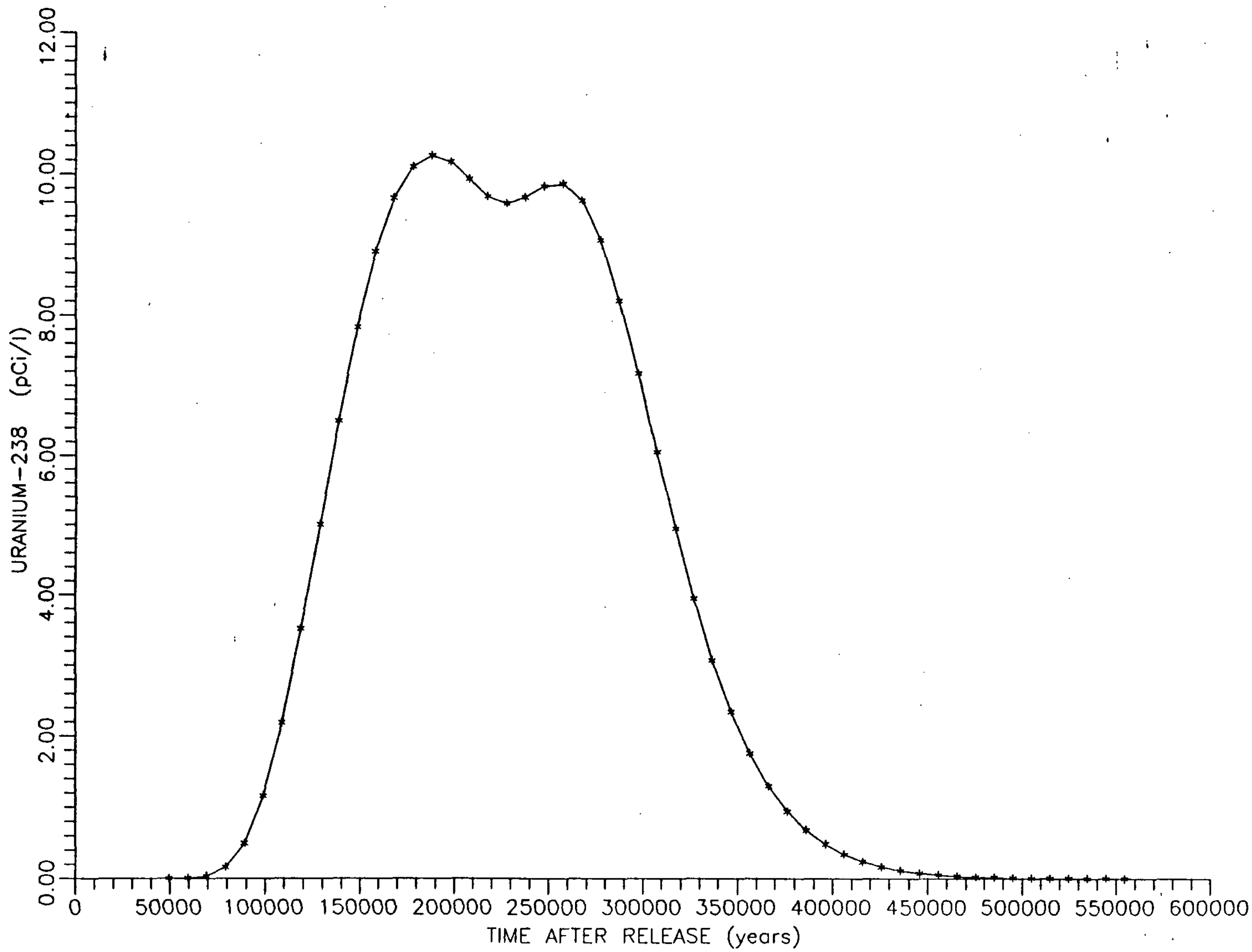

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FIGURE 7.3

LEACHATE CONCENTRATION WITH TIME

VADOSE ZONE: Kd=2000

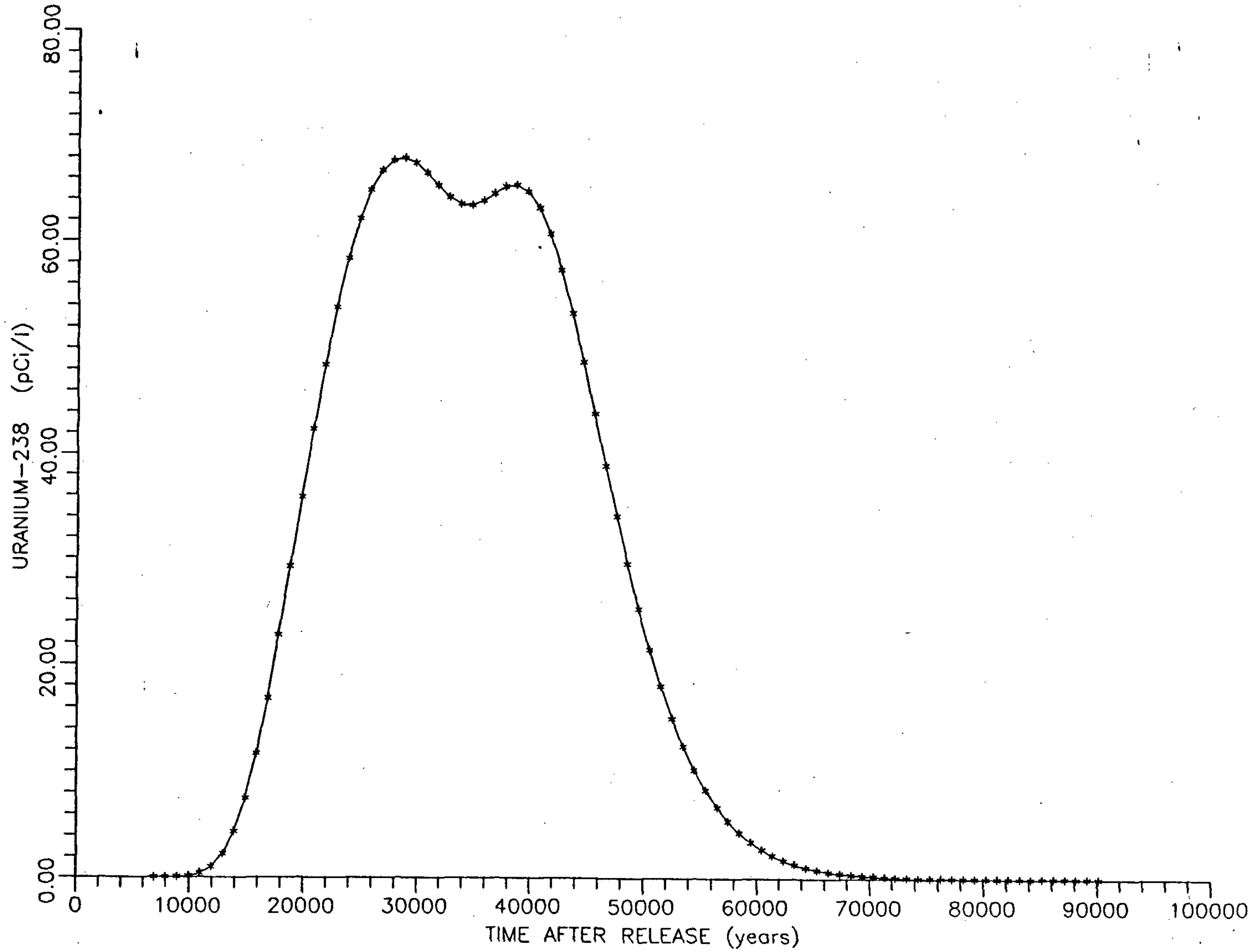

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FIGURE 7.4

LEACHATE CONCENTRATION WITH TIME

VADOSE ZONE: Kd = 300

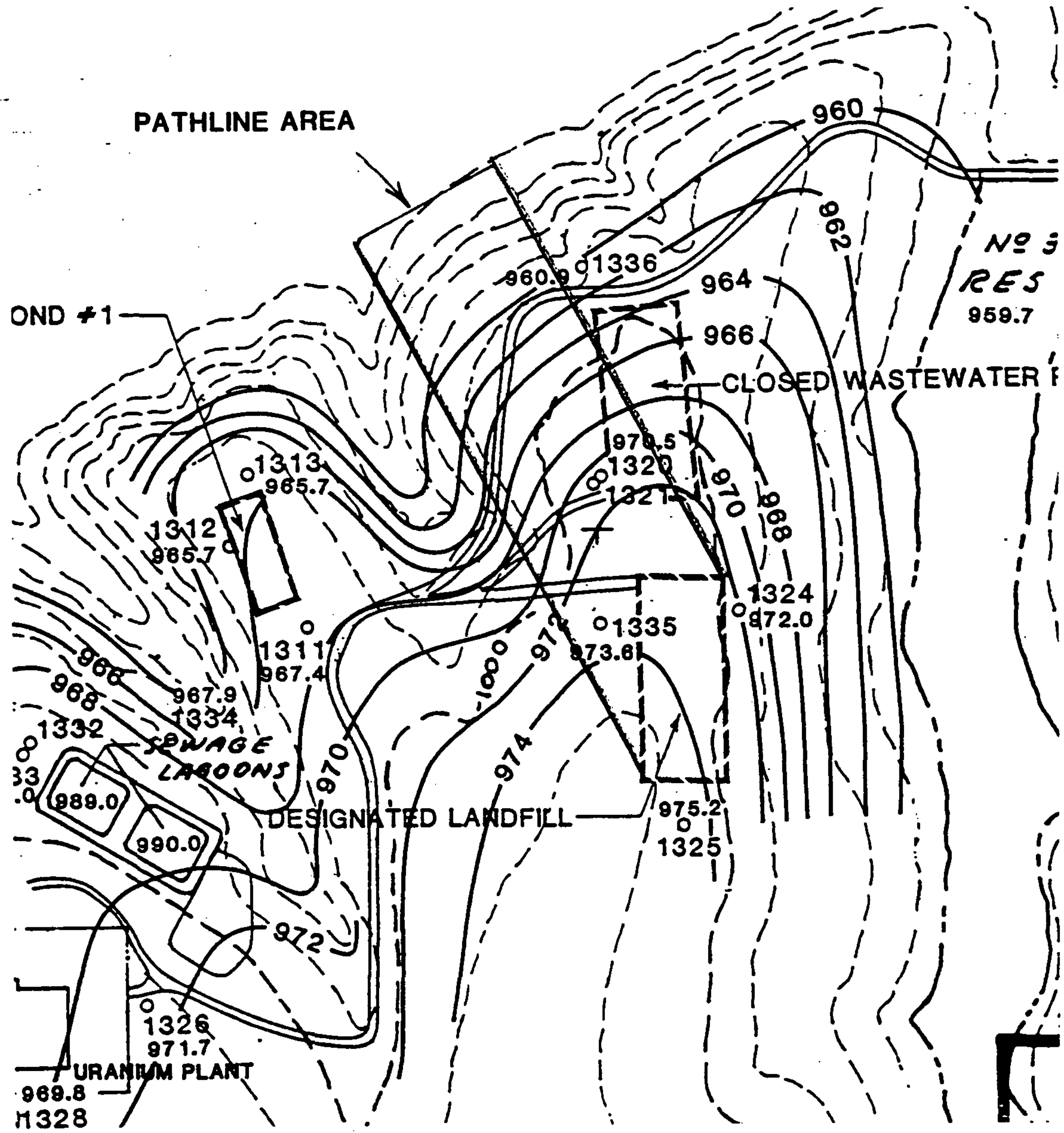

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FIGURE 7.5

PATHLINE FOR SATURATED ZONE SIMULATIONS

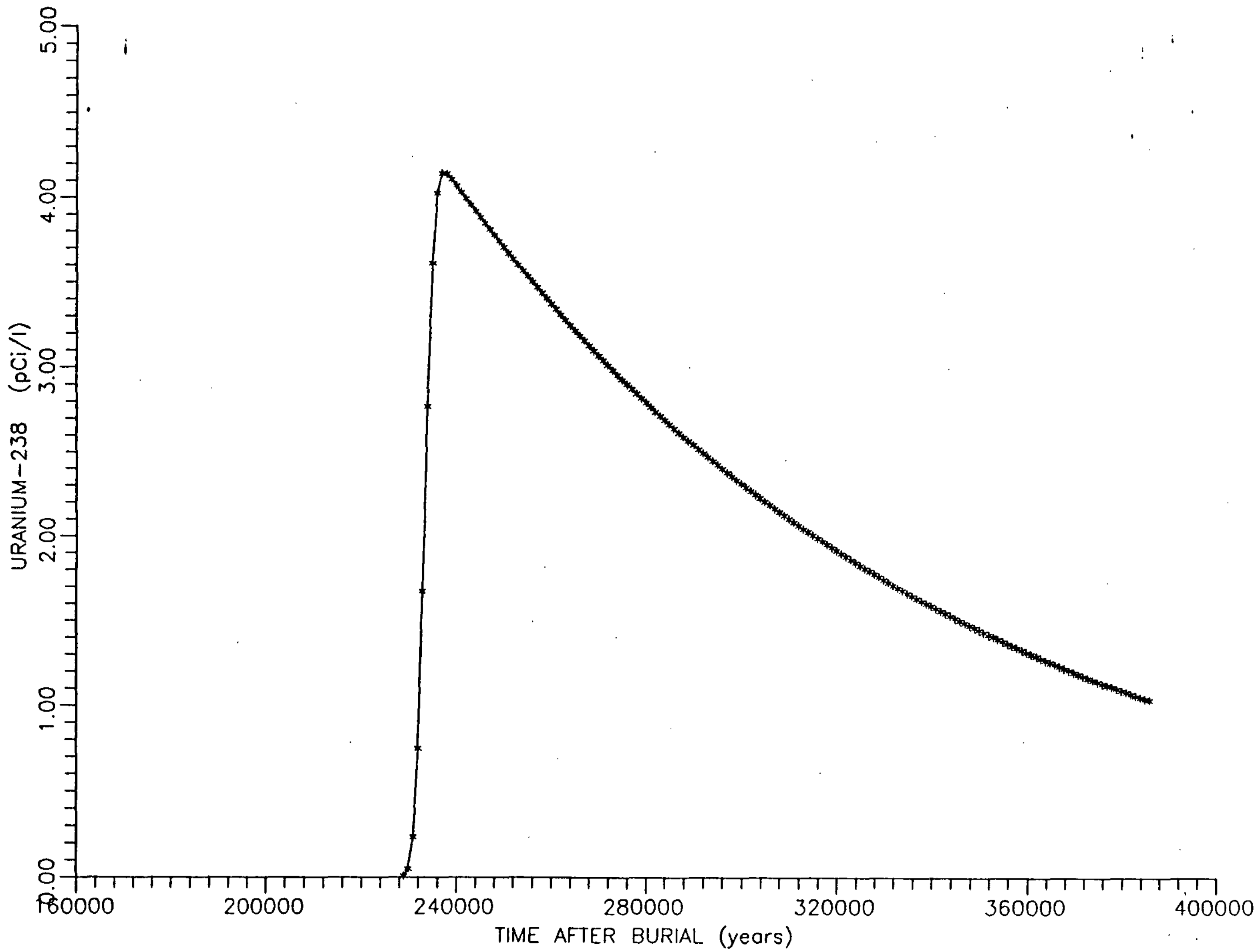

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FIGURE 7.6

LEACHATE CONCENTRATION WITH TIME

SATURATED ZONE: Kd= 2000

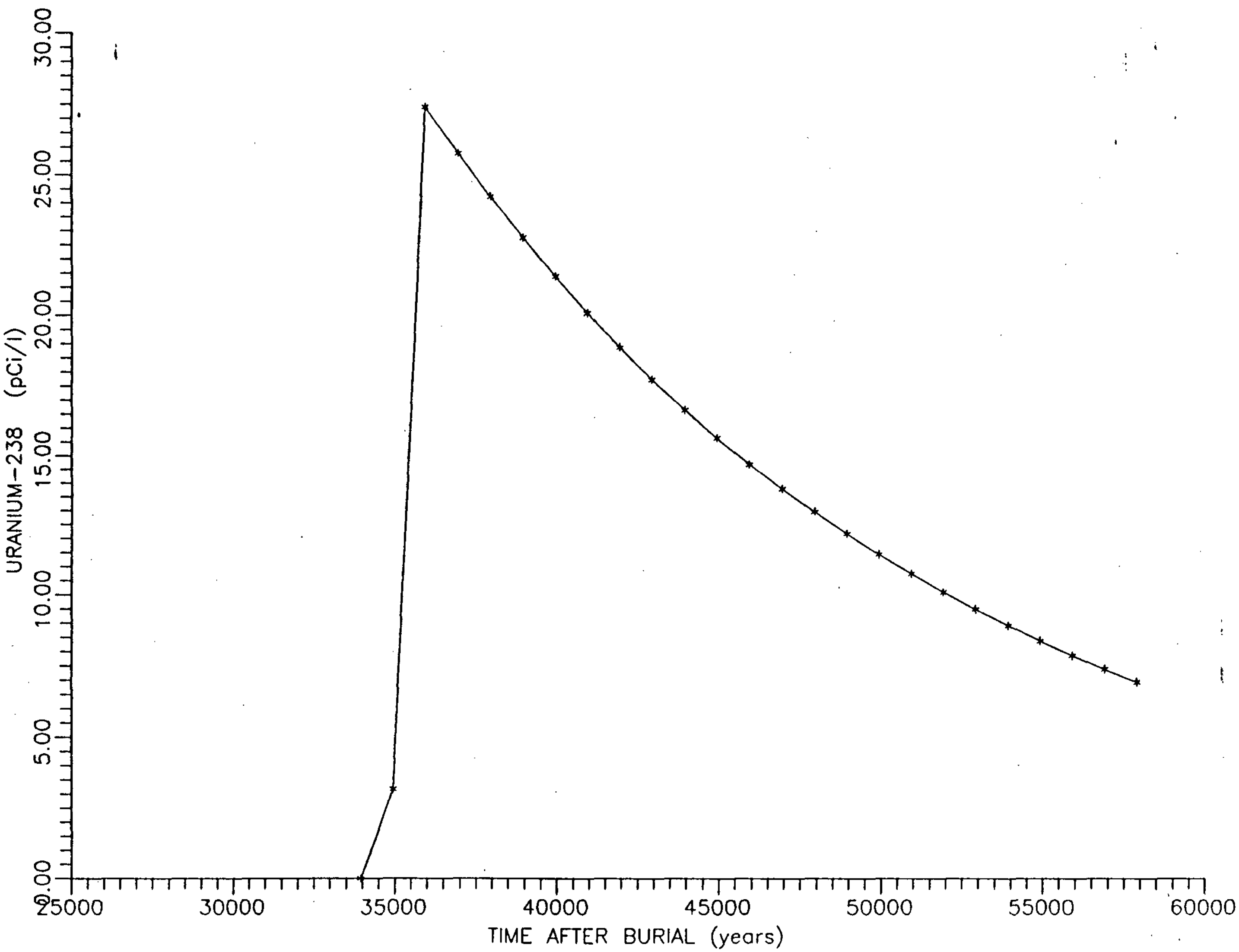

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FIGURE 7.7

LEACHATE CONCENTRATION WITH TIME

SATURATED ZONE: Kd=300

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APPENDIX A

WORK PLAN FOR SITE INVESTIGATION PROGRAM

WORK PLAN
FOR
SITE INVESTIGATION PROGRAM

CIMARRON CORPORATION FACILITY
LOGAN COUNTY, OKLAHOMA

Submitted to

Kerr-McGee Corporation
and
Cimarron Corporation

Oklahoma City, Oklahoma

Prepared By

James L. Grant and Associates, Inc.
Denver, Colorado
January 4, 1989

808211: 1-4-89

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WORK PLAN
FOR
SITE INVESTIGATION PROGRAM

Cimarron Facility
Logan County, Oklahoma

1. INTRODUCTION

1.1 Project Information

1.1.1 Facility Information.

Cimarron Corporation (Cimarron), a wholly-owned subsidiary of Kerr-McGee Corporation (Kerr-McGee), operates the Cimarron Facility in Logan County, Oklahoma. The principal operation at the plant involved the fabrication of fuel elements from plutonium and enriched uranium. Cimarron is decommissioning the facilities. Certain materials associated with the decommissioning activities will be left on-site, either in a designated area or in-situ, in accordance with the Nuclear Regulatory Commission's (NRC) Branch Technical Position (46 Federal Register 52061, October 23, 1981). The soils contain uranium and thorium that meet the Branch Technical Position Options 1 and 2 concentration limits and conditions for disposal.

1.1.2 Investigations.

Cimarron has been conducting an extensive and continuous environmental monitoring program at the facility to determine the impacts of facility activities on the environment. This program consists of routinely collecting and analyzing air, surface water, ground water, soil and vegetation samples from the site and adjacent areas.

A number of monitoring wells have been installed throughout the facility area for collection of ground water samples from the unconfined aquifer which occurs at depths less than 50 feet below ground surface. Significant areas of radiological contamination of the ground water are not present; however, elevated levels of uranium and gross alpha and beta have been detected in soils near the uranium plant yard. Elevated concentrations of nitrate (NO3) and fluoride (F) have been detected in ground water near the closed wastewater disposal ponds. Figure 1.1 shows the location of these facility components.

Cimarron has conducted a detailed soil sampling program to quantify the extent and concentration of uranium in the shallow subsurface. The survey consisted of lowering a calibrated sodium iodide (NaI) probe into borings and measuring gamma radiation at one-foot intervals. The quantities of soils meeting the Option 1 and 2 disposal criteria have been estimated from the survey. A large quantity of soil has been identified as containing levels of uranium that pose no threat to human health and will be left in place.

1.2 Site Hydrogeology

1.2.1 Geology.

The Cimarron Facility is located in the Central Lowlands region of the Great Plains physiographic province. Bedrock in the region are Permian-aged clastic formations, which dip gently to the west-southwest at about 30 feet per mile into the Anadarko Basin. The formations of principal interest are the Hennessey Shale and the Garber Sandstone. Overlying the Hennesey is an unconformity upon which Quaternary terrace deposits and alluvium have been deposited in the vicinity of the Cimarron River.

The Garber group is mostly composed of orange to red brown fine-grained sandstones, interbedded with siltstones, shales and local chert and mudstone conglomerate. The Pleistocene terrace deposits are lenticular sands, silts, clays and gravels and represent glacial outwash. They lie predominantly north of the Cimarron River. Recent alluvium is restricted to the Cimmaron River flood plain, with minor development in the intermittent drainages.

Ground water at the facility occurs in a shallow, unconfined aquifer and in a deeper, confined aquifer within the Garber Sandstone. The unconfined aquifer water table occurs at depths ranging from 15 to 40 feet below land surface. Ground water in the unconfined aquifer at the site is estimated to flow to the north-northwest under a gradient of 90 to 120 feet per mile, and contribute to the base flow of the Cimarron River. Local flow direction is influenced by topography. The hydraulic conductivity has been measured and ranges from 1×10^{-4} to 6×10^{-4} centimeters per second.

The deeper, confined aquifer in the Garber sandstone is found at depths greater than 100 feet below ground surface. The piezometric surface is substantially below the water table found in the unconfined aquifer. A fresh water/salt water transition is found in the confined aquifer at a depth of approximately 200'. Flow direction in the confined aquifer is likely to be more influenced by regional dip than the unconfined aquifer. It is anticipated that the flow direction will be toward the west. Hydraulic conductivities of the deeper Garber aquifer in the region have been estimated at 9×10^{-4} to 2×10^{-3} centimeters per second.

1.3 Proposed Work Plan

1.3.1 Proposed Scope of Work.

To more fully understand and determine the impact of facility activities on the environment, additional data will be collected to characterize the hydrogeologic regime and complement the on-going environmental monitoring program conducted by Cimarron. Data also will be collected to determine the geotechnical properties of site soils, particularly in the vicinity of the planned NRC Branch Technical Position Option 2 landfill.

This work plan describes the procedures which will be used to:

- obtain lithologic and hydrologic data for the soils and the Garber Sandstone aquifers,
- install ground-water monitoring wells in the Garber aquifers,
- determine ground-water flow direction, gradient and other hydraulic properties of the aquifers,
- sample and analyze site soils for engineering behavior, mineralogy, uranium, plutonium, NO3 and F,
- sample and analyze ground water from the aquifers for uranium, plutonium, gross alpha and beta activity, NO3 and F, and
- prepare a report summarizing these data.

1.3.2 Areas of Investigation.

The areas at the Cimarron Facility to be investigated include the uranium plant yard, the closed wastewater disposal ponds, the sanitary lagoons, and the NRC Branch Technical Position Option 2 landfill site. The possibility of off-site sources of NO3 will be investigated by sampling ground water from background wells. The facility components to be investigated are identified on Figure 1.1.

1.3.3 Investigation Team.

The team which will perform the investigation and analyses described in this program will consist of personnel from James L. Grant and Associates (JLGA), Cimarron Corporation and Kerr-McGee. The investigation team will be competent in the disciplines and skills required to complete their respective project assignments. Training will be required only in the program-specific aspects of the investigation.

The field data acquisition team, including professional and support personnel, will be trained in the specific project activities to which they are assigned. Professional personnel will be trained in program-specific activities required for drilling and well installation, soil and ground-water sampling. Drilling support personnel will be trained in program-specific requirements for equipment operation and drilling, soil sampling, and well installation. All on-site personnel will have completed safety training required for their specific work assignments.

The personnel performing the laboratory analyses will be trained for the program-specific aspects of the analyses to be performed. Proper quality assurance/quality control procedures will be followed to ensure the integrity of results.

1.3.4 Health and Safety.

The investigative activities described in this Work Plan will be conducted under the Cimarron facility Health and Safety Plan. This program includes provisions for training, site access control, personnel monitoring, and other measures necessary or prudent to protect the health and safety of site personnel. It is anticipated that this work will be conducted with modified-level D protective measures. These measures include standard safety equipment such as hard hat, safety glasses, hard toe/shank boots, and coveralls for splash protection.

No individual will be allowed on-site unless he is familiar with the provisions of the Health and Safety Plan. The Cimarron Health and Safety Officer will be responsible for instructing individuals in the requirements and contents of the Health and Safety Plan prior to the commencement of program activities. The Health and Safety Officer also will be responsible for verifying and maintaining records that site personnel have received the proper Health and Safety training.

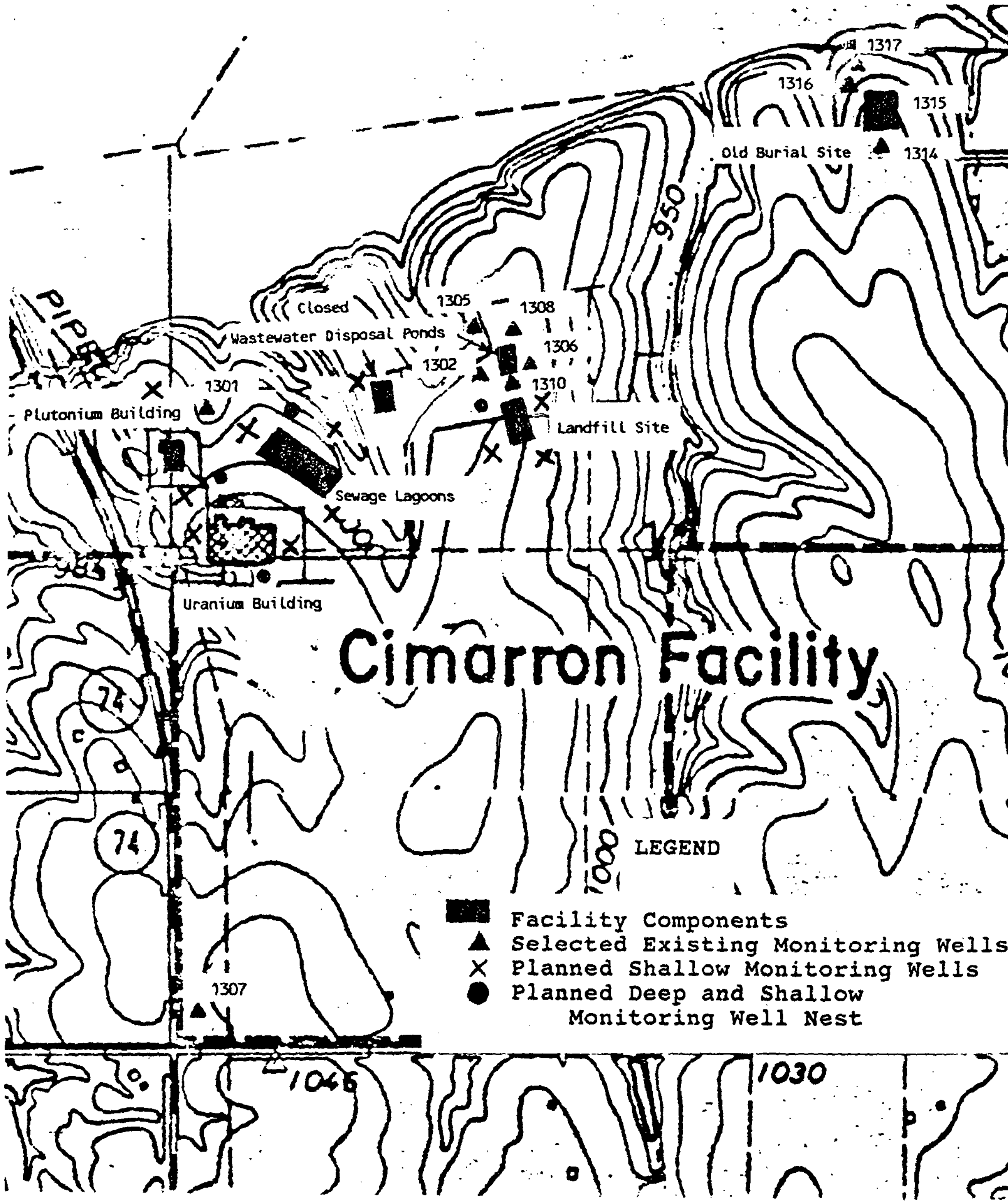

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FIGURE 1.1

Facility Components and Monitoring Well Locations

2. WORK PLAN

This investigation includes the installation of monitoring wells in the unconfined and confined aquifers underlying the Cimarron facility, sampling and categorizing site soils and bedrock, and collecting and analyzing ground-water samples. The major components of the investigation are summarized in the succeeding sections and include:

- Drilling and well installations
- Field testing
- Ground-water sampling
- Laboratory analyses
- Data evaluation and reporting

2.1 Drilling and Well Installation

Procedures to be followed for drilling borings and obtaining soil and rock samples are specified in Appendix A. The completion procedures to be used for the monitoring wells are specified in Appendix B.

2.1.1 Well Locations.

The installation of monitoring wells at locations down-gradient from the uranium plant yard, closed wastewater disposal ponds, landfill site, and the sanitary lagoons is one of the principal objectives of the investigation plan. The locations of the planned monitoring wells are shown on Figure 1.1. The locations of wells located down-gradient of the possible contamination sources may be adjusted as additional data allows better definition of the hydrologic flow of the site. Well locations may also be moved to minimize disturbance of plant activities and to adjust for cultural and topographic features. Well locations may be adjusted with approval of the Project Manager.

2.1.2 Drilling and Soil Sampling.

Four deep borings will be drilled into the confined Garber Sandstone aquifer. The estimated total depth for each deep boring is 135 feet. The actual termination depth of each boring will be determined by the field geologist and will be sufficient for penetrating a significant portion of the confined, saturated zone.

One additional boring at each of the deep boring locations will be drilled to complete a monitoring well nest of two wells. The monitoring well nest will consist of a shallow well screened in the unconfined aquifer and a deep well screened in the deep, confined aquifer. The shallow well will be drilled approximately thirty feet deep; however, the actual termination depth will be determined by the field geologist. Total depth of the well will be sufficient to penetrate approximately 10 feet into the shallow, unconfined aquifer. Based on sample examination and the appearance of water during drilling, the field geologist will set a ten foot well screen across the water-bearing zone in the borings. Longer lengths of well screen may be permitted with approval of the Project Manager.

Eleven additional borings will be drilled at locations indicated on Figure 1.1. Of the eleven additional borings, four will be drilled in the vicinity of the uranium plant yard, one near the closed wastewater disposal ponds, three adjacent to the new landfill site, and three in the vicinity of the sanitary lagoons. The borings will be approximately 30 feet in depth and will penetrate the shallow, unconfined aquifer. The field geologist will determine the total well depth and the screen interval of these borings based on sample examination and appearance of water during drilling. The borings should extend approximately 10 feet below the water table.

Samples of soil and rock materials will be obtained at each of the four deep borings and eleven additional shallow borings using standard sampling methods appropriate for the type of material present. Continuous sampling of soils is planned; however, this plan might be modified in the field if the nature of the soils indicates that continuous sampling is not possible or is unnecessary. The four shallow borings constructed for the monitoring well nests will not be sampled. Changes to the sampling program will be approved by JLGA.

Rock penetrated in the four deep borings will be sampled by continuous coring. Rock penetrated in the additional eleven shallow borings will be sampled by collection of rock cuttings or by continuous coring. One of the additional shallow borings drilled at each of the four specific areas of investigation will be sampled by continuous coring for correlation purposes. When rock cuttings are collected, they will be composited over each 2 feet interval of rock drilled.

If subsurface conditions are such that the planned drilling or sampling technique does not produce acceptable results, e.g. unstable borehole walls or poor sample recovery, another drilling or sampling technique deemed more appropriate to the type of material present will be used. Changes to the drilling or sampling techniques will be approved by the Project Manager.

A field geologist or geotechnical engineer will monitor all drilling and well installation activities and maintain a log of these activities. The field representative also will keep a detailed, descriptive log of materials penetrated by the boring. An example of the format to be followed for the descriptive log is shown in Appendix A.

Representative soil samples will be selected for physical and chemical properties analyses. Physical tests will be conducted to verify field classification of soil and rock types, and to provide quantitative measures of hydraulic and engineering properties of the subsurface materials. Chemical analyses will be conducted to determine the chemical properties of the subsurface materials. Samples will be selected for testing that are representative of the major strata found within the zone of investigation, including both the unsaturated and saturated zones. Approximately one sample will be selected from each boring in the uranium plant yard and landfill site. Additional samples will be collected from the wastewater treatment pond and sewage lagoon areas. Soil analysis procedures are discussed in Section 2.4.2 and Appendix E.

Representative samples will also be analyzed for the presence of uranium, plutonium, NO3 and F.

2.1.3 Monitoring Well Installation.

Ground-water monitoring wells will be installed in each of the nineteen borings using the procedures outlined in Appendix B. The wells will be screened in either the unconfined or the confined aquifers which underlie the surface deposits. The purpose of the shallow wells is to determine the hydraulic properties of the unconfined aquifer and to determine if any contaminants have migrated through the soils and impacted the shallow ground water. The purpose of the deep wells is to determine the hydraulic properties of the confined aquifer and to determine if contaminants have impacted the deep ground water.

The Garber is composed of interbedded sandstones, siltstones and shales. It is anticipated that both aquifers will be composed of several relatively thin, water-bearing zones separated by fine-grained, less permeable beds. The wells should be screened to include the upper ten feet of the water-bearing strata.

Before the wells are used for monitoring water levels, testing, or taking water samples, they will be thoroughly developed. Development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. Well development will not be performed until at least 24 hours after well grouting is completed. Well development will be performed after all wells have been installed.

The procedure to be used for well development is included in Appendix B.

The horizontal position and elevation of the measurement datum at the monitoring wells will be surveyed soon after well completion. Surveying will be conducted by a qualified surveyor.

2.2 Field Testing

Procedures to be followed in conducting field tests are included in Appendix C. The following field tests or measurements will be made at the monitoring wells constructed during this investigation and at selected previously existing monitoring wells.

2.2.1 **Water-Level Measurement.**

Water levels at all monitoring wells constructed during this investigation will be measured within a short time interval so that the water-level data are comparable. Water levels in the monitoring wells will not be measured until the wells are developed. Water levels will also be measured at the following existing monitoring wells: 1307, 1311, 1312, 1313, 1314, 1315, 1316, 1317 and 1318. See Figure 1.1 for approximate locations of these monitoring wells. The depth to water below the measurement datum will be made to the nearest 1/8 inch (0.01 feet).

2.2.2 Slug Tests.

To measure the hydraulic conductivity of the aquifers, "slug tests" will be performed. A slug test will be performed in each of the nineteen monitoring wells installed during this investigation. The procedure involves lowering a slug, or sealed tube, into the water in the well and allowing the raised water level to recover to the pre-insertion level. The slug then is removed quickly and the recovery of the lowered water level to static level monitored, timed, and recorded.

2.3 Ground-Water Sampling

In order to characterize current water quality in the aquifers at the site, the monitoring wells installed during this investigation will be sampled. Ground water samples will also be collected from the existing monitoring wells shown in Figure 1.1. Sampling will be conducted no sooner than 24 hours after the wells have been completed in order for aquifer conditions to stabilize after the disturbance caused by drilling, well installation, and well development. Samples will be collected from all the designated wells on the same day within a relatively short time frame to produce results that are comparable. Ground-water sampling, sample handling, and chain of custody procedures are presented in Appendix D.

2.4 Laboratory Analyses

Laboratory analyses will be performed by Kerr-McGee Technical Center personnel. If the services of an outside laboratory are required, Kerr-McGee laboratory personnel will responsible for ensuring that the proper analyses are performed and that acceptable QA/QC procedures are maintained.

2.4.1 Ground-Water Analyses.

Ground-water samples will be analyzed for the presence of uranium, plutonium, gross alpha and beta, NO3 and F. The number of ground-water samples to be collected at each area of investigation are identified in Table 2.1. Additional samples may be collected with the approval of the Project Manager. Analyses will be conducted under procedures specified by the EPA or NRC for the particular constituents. Specific procedures are identified in Appendix E.

2.4.2 Laboratory Soil Analyses.

2.4.2.1 Physical Analyses.

Physical analyses will be performed on samples of soils and rocks taken from the borings. The results of the tests will verify field descriptions and classifications, and will provide quantitative measures of hydraulic and engineering properties of the subsurface materials. Physical analyses to be performed include particle size distribution, Atterberg limits, Proctor tests, density, moisture content, matric potential, and permeability. Physical tests will be conducted in accordance with the current edition of ASTM Standards, American Laboratory Soils Testing and Materials, Part 19. The recommended testing procedures are identified in Appendix E.

The proposed numbers of these tests are presented in Table 2.2. The numbers of tests in this table represent the current estimate of the number of physical analyses necessary to support the characterization of the subsurface. The number of physical analyses may be increased by the field representative with the approval of the Project Manager if additional tests are necessary to characterize the subsurface strata.

The samples to be tested will be selected by the field representative and the Project Manager. Approximately one sample will be selected from each boring in the uranium plant yard and the landfill site. These samples will be selected to represent the major strata found within the zone of investigation, including both saturated and unsaturated zones. The samples selected to measure matric potential will be selected after the other characterization tests have been completed, and the lithologies in the subsurface has been tentatively delineated. It is expected that the matric potential samples will be selected from the unsaturated zone. At least one matric potential sample will be fabricated from a blend of shallow soils to represent compacted fills constructed during the decommissioning of the facility.

Different samples may be selected for the various analyses at the discretion of the Project Manager.

Additional samples will be selected from the borings in the wastewater pond and sanitary lagoon areas. These samples will be selected to represent any strata not found in the uranium plant yard and landfill site borings and to duplicate tested samples from these locations. The duplication will allow lithologic changes in the major strata to be quantified.

2.4.2.2 Soil Chemical Analyses.

Chemical analyses of soil and rock samples will be completed to quantify the chemical properties of the soils and rocks within the zone of investigation. The tests to be performed to characterize the chemical properties of the soils and rocks include total organic carbon, cation exchange capacity, exchangeable cations, and equilibrium distribution coefficients for uranium and thorium.

The numbers and approximate distribution of tests to be performed are summarized in Table 2.3. The numbers of tests shown in this table are approximate, and may be changed by the Project Manager should additional or fewer tests be found necessary to characterize the subsurface. The samples to be tested will be selected according to the same rationale used to select the soil samples for physical analyses. In most instances, the samples selected for physical analyses will be used for the chemical characterization, although other samples may be selected for testing by the Project Manager. The distribution coefficient samples will be selected after the chemical and physical tests have been completed. These samples will be composites selected to represent the range of chemical and mineral soil conditions within the zones of potential contaminant movement.

2.4.2.3 Soil Contamination Analyses.

Chemical analyses of selected soils will be performed to determine the presence and concentration of potential contaminants on the soil. The contaminants to be tested include uranium, plutonium, nitrate and fluoride. Cimarron has completed an extensive program to detect and characterize radioactivity in the soils in the uranium plant yard. The current program will complement that effort. Table 2.4 lists the numbers of samples for the contamination analyses by area. The actual samples to be tested will be selected by the field representative and the Project Manager from samples at and within the most shallow saturated zone in the uranium plant yard, and from the unsaturated zone and the most shallow saturated zone in the other areas.

2.5 Data Evaluation and Reports

Data analyses, evaluations, and reports to be prepared during the project are described in the following section. The scheduling of these investigation components are discussed in Section 3 and are shown in Figure 3.1.

2.5.1 Data Evaluation.

Upon completion of the field program, all of the pertinent subsurface and hydraulic properties data will be used to prepare a characterization of the site hydrogeologic system and to quantify the impact, if any, which the facility has had on the hydrogeologic system. These data evaluations will be used to prepare a written description of the hydrogeologic system and to prepare graphic depictions (cross-sections, maps, and graphs) necessary to support the description.

2.5.2 Report.

2.5.2.1 Progress Reports.

Brief progress summary reports will be prepared during the course of the investigation to describe activities completed and revisions to the program during the prior 30-day period. Data acquired during the month prior to the report will be included in progress reports, as appropriate. The progress report will identify problems encountered, solutions applied, and possible schedule revisions. The progress report also will list activities planned and products expected to be completed during the following 30-day period.

2.5.2.2 Project Report.

The Project Report will be prepared upon the conclusion of the project. The report will contain a description of the field and laboratory data collection program, including procedures used, and will include all data obtained. The report also will describe analytical activities conducted for this program and present the characterization of the hydrogeologic system.

The report will be submitted first in draft form and later in final form which incorporates any necessary revisions or corrections. Submittal of the draft report is planned for approximately four weeks after receipt of the laboratory test results. The completion of the final report is planned for three weeks later.

TABLE 2.1

Summary of Ground-Water Analyses

Location	Uranium	Plutonium	Gross Alpha,Beta Activity	NO3	F
URANIUM PLANT YARD	8	8	8	8	8
CLOSED WASTEWATER TREATMENT PONDS	6	6	6	6	6
LANDFILL SITE	8	8	8	8	8
SEWAGE LAGOONS	4	4	4	4	4
Total	26	26	26	26	26

TABLE 2.2

Summary of Physical Properties Analyses

Location	Particle Size	Atterberg Limits	Proctor Tests	Density	Moisture Content	Permeabil.	Matric Potential
URANIUM PLANT YARD	6	6	6	6	6	6	1
CLOSED WASTEWATER TREATMENT PONDS	1	1	1	1	1	1	1
LANDFILL SITE	6	6	6	6	6	6	1
SEWAGE LAGOONS	4	4	4	4	4	4	1
Total	17	17	17	17	17	17	4

TABLE 2.3

Summary of Soil Chemical Analyses

Location	Total Organic Carbon	Cation Exchange Capacity, Exchangable Cation	Mineralogy	Equilibrium Distribution Coefficient
URANIUM PLANT YARD	6	6	3	On Three Composite:
CLOSED WASTEWATER TREATMENT PONDS	1	1	1	U Th
LANDFILL SITE	6	6	3	
SEWAGE LAGOONS	4	4	2	
Total	17	17	9	3

TABLE 2.4

Summary of Soil Contamination Analyses

Location	Uranium	Plutonium	NO3, F
URANIUM PLANT YARD	6	6	6
CLOSED WASTEWATER TREATMENT PONDS	1	1	1
LANDFILL SITE	6	6	6
SEWAGE LAGOONS	4	4	4
Total	17	17	17

3. SCHEDULE FOR IMPLEMENTATION

Figure 3.1 shows the anticipated project schedule. This schedule presents the order that the investigation described in the preceding sections will be completed. The investigation is anticipated to commence January 16, 1989. The project as structured will require approximately three months to complete.

The drilling, soil and rock sampling, and well installation is estimated to take approximately three weeks. Well development, slug tests, and ground water sampling will take approximately ten days. The laboratory analyses will take approximately one month to complete. Data reduction and evaluation, and the presentation of a draft report should be completed three weeks after receipt of all analyses.

Project management is shown as a continuous task over the duration of the project. This represents the commitment of the project team to the project. The project management staff are available throughout the project to assure that the project is completed in a timely, orderly, and successful manner.

FIGURE 3.1

PROJECT SCHEDULE

WEEKS AFTER PROJECT COMMENCEMENT

	1	2	3	4	5	6	7	8	9	10	11	12
Field Program:												
Well drilling, installation	*****	*****	*****									
Soil sampling	*****	*****	*****									
Ground water sampling				*****								
Slug tests				*****								
Laboratory Testing			*****	*****	*****	*****	*****					
Data Reduction, Analysis					*****	*****	*****	*****	*****			
Reporting												
Progress Reports				*****				*****				
Project Report (draft)										*****	*****	
Project Report (final)												*****

APPENDIX A

DRILLING AND SAMPLING PROCEDURES

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APPENDIX A
DRILLING AND SAMPLING PROCEDURES

1. EQUIPMENT DECONTAMINATION PROCEDURES

When drilling through or sampling in potentially contaminated materials, the following procedures will be followed to minimize the potential for introduction of contaminants from the surface or shallow strata into the deeper strata penetrated by drilling activities and to minimize the potential of cross-contamination during sampling:

- Equipment to be used for the project will be steam-cleaned prior to arrival at the site. This includes drilling rigs, water tanks (flushed inside), augers (if used), bits, casings, rods, samplers, tools, etc.

- All sampling tools will be cleaned on-site, prior to use and between each sampling event with clean water and a phosphate-free detergent. A source of potable water, approved by the Field Hydrogeologist, must be used. Other cleaning procedures may be required, but are task specific. These procedures will be described in the task specific sampling protocols.

- The down-hole portion of drilling equipment will be cleaned on-site prior to use and between each boring with a high-pressure, hot-water cleaner using approved water.

- Well completion materials will be cleaned with a high-pressure, hot-water cleaner using approved water prior to use. Materials which cannot be cleaned to the satisfaction of the responsible Field Hydrogeologist will not be used.

- If contaminated soils are encountered during drilling, and the potential for significant cross-contamination is anticipated, modified drilling procedures will be used to prevent the transfer of contaminants to a deeper zone by the drilling method.

- Cleaning and decontamination procedures will be performed in an area that is remote from any site to be sampled, to the extent feasible. All downhole tools and equipment will be checked with a geiger counter or scintillometer after cleaning.

2. DRILLING AND SAMPLING PROCEDURES

2.1 General

A final borehole diameter of between 6.5 and 8 inches will be required for the installation of wells with a two inch inside diameter (i.d.) casing.

Fuel, lubricants, and other similar substances will be handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials will not be stored near or in areas which could be effected by these substances.

Surface runoff such as miscellaneous spills and leaks, precipitation, and spilled drilling fluid shall not be allowed to enter any boring or well either during or after drilling/well construction. To prevent this from happening, the use of starter casing, recirculation tanks, berms around the borehole, and surficial bentonite packs, as appropriate, are suggested.

Cuttings and cores will be checked with a geiger counter or scintillometer for radiological contamination. Where contaminants exist in shallow strata, a double-casing procedure will be required to minimize the potential for transferring contaminants to deeper strata. For these installations, a five-inch or larger PVC casing will be grouted through the contaminated strata before the boring is continued to its termination depth.

The Field Hydrogeologist will be present to observe all drilling and well installation activities and maintain a log of these activities. The Field Hydrogeologist also will keep a detailed descriptive log of materials penetrated by the boring. An example descriptive log is shown on Figure A-1.

2.2 Water Supply

Water used in drilling, equipment cleaning, or grouting will be taken from the the local potable water supply. Identification of the water source will be verified by contacting the appropriate plant personnel. If sources of non-potable water are present which might be confused with the proper water source, both the acceptable and unacceptable sources will be clearly marked to avoid possible confusion.

2.3 Soil Drilling and Sampling

Drilling in soil will be performed with equipment and procedures complying with the latest revision of ASTM specifications D 1586 and D 1587. Drilling in soil is planned to be accomplished using a hollow-stem auger drilling technique. If subsurface conditions are such that the planned technique does not produce acceptable results, e.g. unstable borehole walls or poor soil sample recovery, another technique deemed more appropriate to the type of soils present will be used. The procedure used must be appropriate for the subsurface lithologies present and also must be compatible with the efficient soil sampling in accordance with ASTM specifications D 1586 and D 1587 or an alternate soil sampling methods approved in advance by JLGA. If hollow-stem augering is used with the intent of installing the well casing through the augers, the inside diameter of the augers must not be less than four inches.

If borehole caving is experienced, bentonitic drilling fluid can be used only after approval of the Field Hydrogeologist. No organic additives will be used.

Soil sampling will be performed in accordance with ASTM specifications D 1586 or D 1587 or another similar method judged acceptable by the field geologist. Samples will be taken continuously over the full thickness of the soil deposits unless an alternative sampling frequency is requested by the Field Hydrogeologist. Good sample recovery is most important, and procedures will be modified, as necessary, to improve sample recovery.

Samples will be stored in clear glass containers, or waxed cardboard containers, labeled with the project number, boring number and sample number and depth. Exceptions will be thin-wall tube samples which are designated for undisturbed tests. These samples will be described on the basis of materials exposed at the top and bottom of the sample tube and will be sealed in the tube, labeled, and handled in a manner consistent with this work plan and the testing requirements.

The Field Hydrogeologist will be responsible for maintaining a descriptive log of materials recovered, photographing representative samples, and properly labeling and storing samples. A copy of the proposed field soil boring record form is presented in Figure A-1. The descriptive log will contain:

1. sample interval (top and bottom depth);

2. sample recovery;

3. blow count (ASTM D1586) or hydraulic pressure (ASTM D1587);

4. presence or absence of contamination;

5. material description, including: relative density, color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, grain size, structure or stratification, and any other significant observations.

6. lithologic contacts: the depth of contacts between differing lithologic units will be measured and recorded to the nearest 0.05 feet.

2.4 Rock Drilling and Sampling

Drilling in rock will be by diamond core drilling techniques or by a rotary drilling technique. Diamond coring will be conducted in accordance with the latest revision of ASTM D 2113. Rotary drilling, wherein only cuttings samples are returned to the surface, will be used only in conjunction with diamond core drilling. The Field Hydrogeologist will determine the appropriate drilling technique.

For core drilling, the acceptable core diameter will be approximately two inches. The drilling contractor will modify drilling procedures, as necessary, to maximize the recovery of cored rock. The Field Hydrogeologist will monitor drilling production and core recovery and notify the drilling contractor of unacceptable performance.

For rock intervals not cored, cuttings brought to the surface in the drilling fluid will be sampled. Cuttings samples will be composited to represent each 2.0 feet long interval of rock penetrated by the drill bit. Cuttings samples will be placed in properly labeled, clear glass containers.

The Field Hydrogeologist will handle all recovered core or cuttings samples. He will prepare a descriptive log, take photographs, and properly label and store the samples. Recovered rock core will be placed in properly labeled waxed cardboard, plastic, or wood core boxes. Each box will be marked in accordance with ASTM D 2113 with the project name, boring number, depth interval represented, and the box number. Cuttings samples will be places in properly labeled glass container. Container labels will show the project name, boring and sample number, and sample depth.

The descriptive log of recovered core will include:

1. cored interval and recovery;

2. Rock Quality Designation (RQD): RQD = cumulative length of recovered core pieces greater than or equal to four inches in length divided by the total length of the core run;

3. discontinuity description: depth, character, and orientation of joints, fractures, and other non-depositional breaks in the rock;

4. partings description: depth, character, and orientation of depositional (bedding) features;

5. rock weathering: description of weathering or weathered zones;

6. geohydrologic description: qualitative description of permeability;

7. penetration rate: where applicable, a record of the speed of drill bit penetration in minutes per foot;

8. rock lithology: description of rock lithology and depths of significant features or contacts. Description to include rock name, relative hardness, color, texture or grain size, cementation, structure or stratification, and other pertinent information such as accessory minerals or fossils.

9. lithologic contacts: the depth of contacts between differing lithologic units will be measured and recorded to the nearest 0.05 feet.

10. presence or absence of odors or visible evidence of contamination;

11. presence of radionuclides determined by use of a hand-held scintillometer.

Figure A-2 is an example of the form to be used for recording core boring information.

2.5 Site Cleanup

After completion of drilling, any cuttings brought to the surface which might be contaminated will be placed in drums and stored on-site. These materials will be included with other site materials moved to a location identified for long-term stabilization. Temporary on-site storage of such cuttings will be at a controlled location.

JAMES L. GRANT & ASSOCIATES, INC. SOIL TEST BORING FIELD REPORT

BORING NO. ____

JOB NO. ____ DRILLER ____ GROUND SURFACE ELEV. ____

JOB NAME ____ HOURS DRILLING ____ HOURS MOVING ____

DATE: ____ WEATHER ____ PAGE ____ OF ____

SAMPLING					SCALE	UD	REC	SOIL CLASSIFICATION AND REMARKS
No.	Depth	"N" 1ST 6"	2ND 6"	3RD 6"				
					0			
					5			
					0			
					5			
					0			
					5			
					0			
					5			
					0			

+STANDARD PENETRATION RESISTANCE IS SUM OF BLOWS FOR 2ND 6" AND 3RD 6" TO DRIVE 1-3/8" I.D., 2" O.D. SPLIT BARREL SAMPLER WITH 140 POUND HAMMER FALLING 30 INCHES.

BORING TERMINATED: ____

BORING REFUSAL: ____

WATER TOB DEPTH ____

WATER 24 HR.: DEPTH ____

WATER LOSSES ____

CASING: SIZE ____ LENGTH ____

METHOD OF ADVANCING BORING	DEPTH
POWER AUGER	TO
HAND CHOP: W/MUD: W/WATER	TO
ROTARY DRILL: W/MUD: W/WATER	TO
DIAMOND CORE	TO

JAMES L. GRANT & ASSOCIATES, INC.

CORE BORING FIELD REPORT

BORING NO. ______

PROJECT NAME ______ PROJECT NO. ______ BORING LOCATION ______

DRILLED BY ______ LOGGED BY ______ CHECKED BY ______

DRILLING DATES - FROM ______ TO ______ DATUM ______ DATUM ELEVATION ______

DEPTH (FEET)	CORE INFO		RQD		DISCONTINUITIES JOINTS/FRACTURES			PARTINGS BEDDING/FOLIATION			ROCK WEATHERING	GEOHYDROLOGIC INFORMATION	PENETRATION RATE (MIN/FT)	DEPTH	LITHOLOGIC DESCRIPTION	DEPTH (FEET)
	CORE SZ RUN NO	REC. %	PIECE LN.	RQD	NATURE	SPACING	DIP & DIRECTION	NATURE	SPACING	DIP & DIRECTION						

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FIGURE A-2

APPENDIX B

WELL INSTALLATION PROCEDURES

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APPENDIX B
MONITORING WELL INSTALLATION PROCEDURES

1. MONITORING WELL INSTALLATION PROCEDURES

1.1 Materials Decontamination

Well completion materials will be inspected by the Field Hydrogeologist and determined to be clean and acceptable for use. Casing, screen and casing plugs and caps will be cleaned with a high-pressure, hot-water cleaner using approved water prior to use. Pre-packaged sand will be used in well construction and the bags will be inspected for possible external contamination before use. Pre-packaged bentonite and portland cement, inspected for possible external contamination, also will be used. Materials which cannot be cleaned to the satisfaction of the responsible Field Hydrogeologist will not be used.

1.2 Well Casing

Upon completion of drilling to the proper termination depth, a monitoring well casing will be installed in each boring. A schematic representation of a completed well is shown on Figure B-1.

Blank well casing and well screen will be constructed of Schedule 40 PVC with an inside diameter of two inches. All well casing sections will be flush-threaded. Glued joints are not acceptable. The casing at each well will be fitted with a bottom plug and a top cap constructed of the same type material as the well casing.

The Field Hydrogeologist will verify and record the boring depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus between the casing and borehole wall. All lengths and depths will be measured to the nearest 0.1 foot.

1.3 Well Screen

Well screens will be constructed of flush-threaded, Schedule 40 PVC with an inside diameter of two inches. Each well will be screened in the water-bearing stratum underlying the soil deposits. The screened intervals will be 10 feet in length. The position of the screen will be selected by the Field Hydrogeologist after consideration is given to the geometry and hydraulic characteristics of the stratum in which the well will be screened.

Each well screen will be isolated from the overlying deposits using an annular seal consisting of a combination of a two-feet thick bentonite pellet seal overlain by an interval of cement/bentonite grout. The grout interval will extend from the top of the pellet seal to the ground surface.

The slots in the screens will be factory cut. A slot size of 0.010 inches is estimated to be appropriate for use in the rock.

1.4 Sand Filter

A graded sand filter will be placed against the screened interval and extend one to two feet above the top of the screen. If the screen is set in sound rock, the filter gradation will be selected so that no more than about ten percent of the filter material is finer than the size of the well screen slots. If fine grained materials are present in the rock, such as joint filling material, the gradation of the sand filter will be intermediate of the mean diameter of the fine-grained material and the screen slot size. The procedure use to select filter grain size is described by Driscoll.[1]

1.5 Annular Sealant

An annular seal will be placed above the sand filter using sodium bentonite pellets. The pellet seal will be a minimum of two feet thick.

---

[1] Driscoll, Fletcher G. "Groundwater and Wells". Johnson Division St. Paul Minnesota. 1986.

A portland cement/sodium bentonite grout will be placed from the top of the pellet seal to the ground surface. The grout mixture used will consist of one 94-pound sack of cement and about five pounds bentonite for each seven gallons of water used. All grouting below the ground-water level or deeper than 10 feet below ground surface will be performed by pumping using a small-diameter tremie pipe positioned several feet above the top of the bentonite pellet seal.

1.6 Protective Surface Casing

Each monitoring well will be completed with a five-foot long, 6 inch diameter, steel protective casing with a hinged, lockable cover. The inside diameter of the protective casing will be at least four inches. A one-half inch diameter drain hole will be drilled in the steel casing just above the ground surface. Each protective casing will be painted with a rust-retardant primer and a bright paint. A 4 foot by 4 foot concrete pad (well apron) will be constructed around each of the wells. The concrete pad will have a minimum thickness of 4 inches, except where underlain by the borehole where a minimum thickness of three feet is required.

1.7 Well Survey

The location and elevation of the new well will be surveyed by a surveyor registered in the State of Oklahoma soon after well completion. The horizontal location will be measured relative to established facility coordinates. Horizontal coordinates will be measured to the nearest 1.0 foot. Vertical location of the ground surface adjacent to the well casing and the measurement datum (top of interior casing), will be measured relative to U.S.G.S. datum. The ground surface elevation will be measured to the nearest 0.1 foot and the measurement datum to the nearest 0.01 foot.

2. WELL DEVELOPMENT

Before a new well can be considered in proper condition for monitoring water levels, testing, or taking water samples, it will be developed. Development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen.

Well development will not be performed until at least 24 hours after well grouting is completed. Well development will be performed within one week of well installation. Development water will be put into barrels and disposed of in the Cimarron waster-water treatment facilities.

2.1 Procedure for Air-Lift Well Development

The following procedure describes an air-lift technique for well development. The hardware used for this technique is installed so that air used to lift water from the water does not contact the well casing and does not enter the well screen.

1. Clean all apparatus to be used down-hole by first steam-cleaning and then using a detergent and tap water wash, tap water rinse, distilled water rinse.

2. Measure and record the depth to ground water and total depth of the well, before development.

3. Assemble the small diameter development tubing (e.g. 1" or 1.5" o.d. for 2" i.d. well casing), with a one-way, check-valve at the bottom and a total length which can extend from the bottom of the well to the ground surface.

4. Place the first section of the development tubing inside the well and place the air line inside the tubing. Assemble and lower additional sections of the development tubing and air line until the tubing rests at, or just above, the bottom of the well.

5. Lift the tubing several inches above the bottom of the well and secure the lifting line to the well protector pipe.

6. Secure the air line to prevent air pressure from lifting the air line.

7. Attach an in-line hydrocarbon filter to the air line.

8. Using the shut-off valve, send a pulse of air down the air line. Shut off the air when a column of water comes out of the well.

9. Water produced during development will be discharged to the ground surface at a location away from the well. Ground water from the water from the rock stratum is not anticipated to have been contaminated by prior activities at the facility and special provisions for management of this water are not planned.

10. Allow the well several seconds (or minutes, if necessary) to recover, then send another "air pulse".

11. Repeat the pulsing process, occasionally moving and securing the tubing at different levels within the well screen.

12. Repeat this process until water from the well is clear (or nearly clear).

13. Record the development time, the number of pulses and the estimated volume of water produced during development, and the color of water at the beginning and end of development.

14. Disconnect and remove the development apparatus from the well for cleaning before use in another well.

15. Verify that the protector pipe drain is functional and development water is not held inside the protector pipe.

16. Measure and record the post-development depth to ground water and total depth of the well.

2.2 Alternate Well Development Procedures

Well development also can be accomplished using surge blocks, cleaned bailers or manual or automatic pumps. A loosely-fitting surge block can be used to agitate the water and sediment in the well before water is removed from the well using bailer or pump. The bailer or pump intake regularly must be lowered to the bottom of the well so that fines which have accumulated in the bottom are agitated and removed from the well in the development water. If a pump is used, the intake level should be moved to different positions within the well screen so as to draw water into the well from different levels.

Development should be continued until a minimum of ten casing volumes of water have been removed from the well and the water produced is clear. If the development water still is turbid after removal of ten casing volumes, development should be continued until the water become clear or the turbidity of the water produced has been stable for the removal of several casing volumes.

2.3 Development Records

Development records should include:

- Well Number
- Date and time of development
- Development method
- Pre-development water level and well depth
- Volume of water produced
- Description of water produced
- Post-development water level and well depth

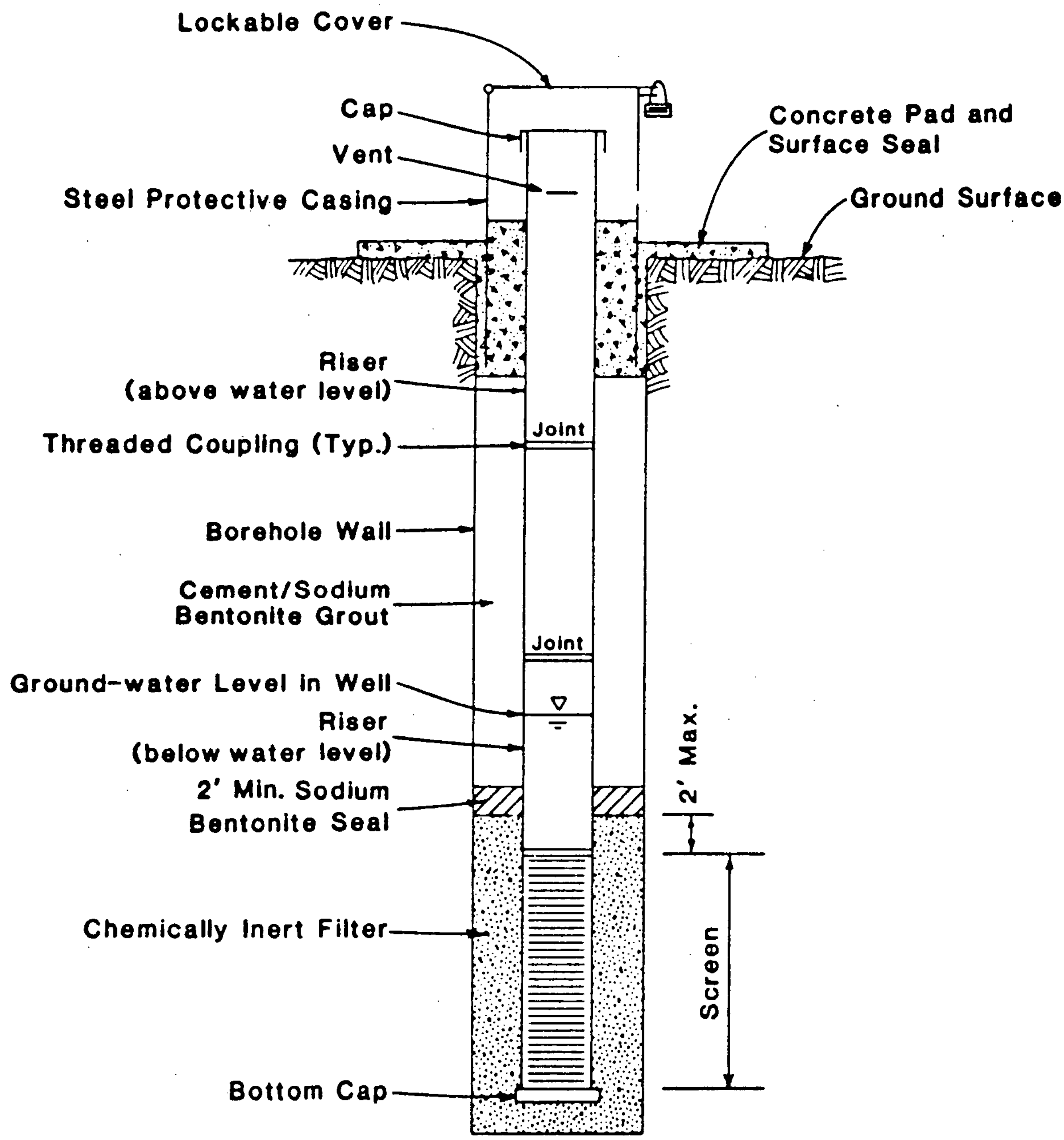
3. WELL ABANDONMENT

Any boring or well to be abandoned shall be sealed by grouting from the bottom of the boring/well to ground surface. This shall be done by placing a grout pipe to the bottom of the boring/well and pumping grout through the pipe until undiluted grout flows from the boring well at ground surface.

A portland cement/sodium bentonite grout will be used for grouting. The grout mixture used will consist of one 94-pound sack of cement and about five pounds bentonite for each seven gallons of water used. Additives or cuttings are not to be added to the grout mixture. The grout materials are to be combined in an above-ground rigid container or mixer and mechanically mixed to produce a thick, lump-free mixture. The mixed grout is to be recirculated through the grout pump prior to placement. These procedures may require some modification to meet state requirements regarding borehole abandonment.

An abandoned well may be grouted with the well screen and casing in place. However, if the integrity of the casing seal is questioned, the Field Hydrogeologist may require that the casing be removed prior to abandonment. In this instant, partial or total hole re-drilling will be necessary prior to sealing the well. Each boring/well that is abandoned must have a record of abandonment completed.

Twenty-four hours after abandonment, the Field Hydrogeologist, or his designate, shall check the abandoned site for grout settlement and specify the addition grout, as necessary. This process is to be repeated until firm grout remains at the surface.



JAMES L. GRANT & ASSOCIATES geotechnical engineering • management • computer science ENGLEWOOD, COLORADO	FIGURE B-1 MONITORING WELL DESIGN

APPENDIX C

FIELD TESTING PROCEDURES

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APPENDIX C
FIELD TESTING PROCEDURES

1. WATER-LEVEL MEASUREMENT

To determine the ground-water level and flow direction, water levels will be measured at all wells within a short time interval so that the data are comparable. Water levels will not be measured until the water level in the new wells have equilibrated to static conditions. The depth to water below the measurement datum will be made to the nearest 1/8 inch (0.01 feet).

Water-level data will be recorded on an appropriate data form. An example form is presented in Figure C-1.

2. SLUG TEST PROCEDURE

To measure the hydraulic conductivity at new wells, "slug tests" will be performed. The procedure involves lowering a slug, or sealed tube, into the water in the well and allowing the raised water level to recover to the pre-insertion level. The slug then is removed quickly and the recovery of the lowered water level to static level monitored, timed, and recorded. Slug test results will be evaluated in accordance with the methods presented by Bouwer and Rice.[1]

To provide useful data, slug tests usually must be conducted using a recording pressure transducer to measure ground-water levels. In sandy or other permeable aquifers, the useful portion of the recovery curve can occur within the first five seconds of the test. A log-type measurement frequency is necessary to allow very frequent measurements (0.5 second or less) in the first several seconds and less frequent measurements after about 10 to 20 seconds.

Using manual measurement methods, it is unlikely that any measurements can be made in the first several seconds. Manual measurement of recovery probably is adequate in low permeability materials where recovery is very slow.

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[1] Bouwer, H. and R. C. Rice, 1976, "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers With Completely or Partially Penetrating Wells", Water Resources Research, Vol. 12, No. 3.

Test data from a slug test will be recorded on a Variable Head Permeability Test form, such as the one shown on Figure C-2.

3. STEP-DRAWDOWN TEST PROCEDURE

The step drawdown test procedure involves monitoring drawdown as the well is pumped at several pumping rates. The test results can be used to predict well drawdown from pumping at various rates for extended periods and are useful for selecting the proper pumping rate for 8 hour, 24 hour, or longer pumping tests. The results also can be used to compute specific capacity, transmissivity, and head losses in the well.

During a step-drawdown test, the well is pumped at several rates for short periods. Usually the initial pumping rate is small, often less than five gpm, and the rate is stepped up by approximately doubling the rate on each step. Pumping at each step is continued for about the same length of time. Ideally, the well would be allowed to recover to the initial static level between tests, but it is acceptable to conduct a continuous test by just stepping up the pumping rate at the proper time.

Drawdown measurements at the beginning of the test, and at the beginning of each successive step are made on a frequent interval. As the measurements are made, drawdown and log time are plotted. Examination of the plot allows estimation of the drawdown expected over the pumping period for each pumping rate. The step drawdown test data are evaluated in accordance with procedures presented by Brereton.[2]

The test is continued for several pumping rates. If the results are to be used to determine the proper pumping rate for a longer, constant-rate pumping test, the stepped rates are selected to bracket the required drawdown for the constant-rate test. The proper rate for the constant-rate test is selected using the planned test duration and required drawdown and comparing these numbers to the drawdown curves (from the step test) to select the proper pumping rate.

Pumping rates are measured with an in-line, totalizing water meter, an orifice weir, or timed filling of a container of known volume. Discharge rates will be measured frequently during the test.

---

2 Brereton, N. R., 1979, "Step-drawdown Pumping Tests for the Determination of Aquifer and Borehole Characteristics" Water Research Center Technical Report TR 103 (UK)

Test data are recorded on the following data forms or in the Field Log Book:

- o Aquifer Test Pump Log (Figure C-3) for recording pumping steps and drawdown at the pumping well
- o Aquifer Test Recovery Log (Figure C-4): for recording draw-down changes during recovery

Upon completion of the final pumping test (unless the step test goes directly into a constant-rate test) a recovery test is conducted. Recovery test procedures involve monitoring the rate of water-level rise following cessation of pumping. Recovery test data can be evaluated using the straight-line methods contained in Lohman on pages 23 to 27.[3]

Water produced during a step-drawdown test, if considered contaminated, will be discharged to the ground surface in an area of know surface contamination. Otherwise, the water will be discharged to the Cimarron wastewater treatment facilities.

The equipment used for step-drawdown and constant-rate pumping tests are identical. The following list summarizes these items.

1. Pump - when final drawdowns will not exceed about 12 to 14 feet below ground surface, it is possible to use a surface pump with a suction intake hose set within the well screen. When the final water level is expected to exceed 12 to 14 feet, a submersible pump usually is required. (Jet pumps set at the surface can lift water from depths greater than 12 to 14 feet) Pump size (for submersed operation) and intake or discharge hoses must be sized to allow measurement equipment, power cords, safety lines, etc. to fit in the well.

2. Power source for the pump - "plug-in" electricity is preferable, but a generator properly sized for the pump usually is required. For submersible pumps, a power cable to the pump is required. Surface suction-type pumps often have gasoline engines.

3. Intake hose, properly sized for the well.

4. Discharge hose, to discharge pumped water to a container or to an impoundment.

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[3] Lohman, S. W., 1979, "Ground-Water Hydraulics", U. S. Geological Survey Professional Paper 708.

5. Safety line for submersible pump.

6. Water-level measurement device - electric probe or transducer. When a part of pump flow is recirculated to the well (for low pumping rates) a "stilling well" (0.5 to 1.0 inch i.d. hose) is advisable for measuring water levels in the pumped well. The stilling well is not necessary when a transducer is used in the pumped well.

7. Valves, "T" coupling, and hoses - necessary to recirculate water to the pumped well and control discharge rate. Partial flow recirculation during low pumping rate is advisable during longer tests to prevent pump damage.

8. Discharge measurement device - bucket and stop-watch, water meter, or weir.

9. Tools, electrical tape, measurement tape, etc.

The attached sketch illustrates a typical set-up of pump test equipment.

4. CONSTANT-RATE PUMPING TEST PROCEDURE

A sustained pumping test involves pumping a well at a nearly-constant discharge for several hours to several days. This procedure usually requires monitoring water levels in one or more observation wells in addition to the pumped well. Data are evaluated to determine aquifer transmissivity, storativity, and hydraulic conductivity.

Procedures and set-up for the constant-rate test are essentially identical to those for the step-drawdown test except that pumping rate is controlled at a constant rate. After the initial hour of the test, the measurement of drawdown in the pumped well and observation well(s) and discharge rate is made each half hour to one hour until the test is completed. Upon test completion, a recovery test is conducted.

The drawdown during the constant-rate test must be monitored to make sure the drawdown does not exceed the planned maximum. Usually limitations on drawdown are: pump lift capacity (12-14 feet for suction pumps, variable for submersible pumps), height of water column in the well (usually do not want to draw water level down below the top of the well screen), or a pre-determined maximum drawdown. As drawdown increases, pump lift increases and pumping rate (with set valve openings) decreases. Thus, as drawdown increases, the valve on the discharge hose probably must be opened to maintain a constant discharge rate.

Test data are recorded on the following data forms:

- Aquifer Test Pump Log (Figure C-3): for pumping and drawdown data at the pumping well.
- Aquifer Test Recovery Log (Figure C-4): for recovery data a pumping and observation wells.
- Observation Well Log (Figure C-5): for drawdown data at observation wells.

Constant-rate pump test data for the pumped well usually are evaluated using Lohman's straight-line method. Data for the observation well(s) are evaluated using curve-matching techniques which also are included in Lohman (1979).

Water produced during a step-drawdown test, if considered contaminated, will be discharged to the ground surface in an area of know surface contamination. Otherwise, the water will be discharged to the wastewater treatment system.

WELL INFORMATION							WATER LEVELS							
Well Number	Installation Date	Ground Surface Elevation (Ft. MSL)	Reference Point Elevation (Ft. MSL)	Total Depth from Ref. Pt. (Feet)	Stickup (Feet)	Depth from Ground Surface (Feet)	Date	Measured by	Depth from Reference Point (Feet)	Water Surface Elevation (Ft.MSL)	Date	Measured by	Depth from Reference Point (Feet)	Water Surface Elevation (Ft. MSL)

Job Name Job Number		WATER LEVEL AND WELL INFORMATION

FIGURE C-1

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Variable Head Permeability Test

Test Performed By ___________________________ Date ____/____/______

Well or Boring No. _________________________ Total Well Depth ____ ft.

Length of Solid Casing _______ ft. Length of Solid Casing ______ ft.

Initial Depth from Datum _____ ft. Quantity of Water Bailed _____ gal.

Datum (check one): Ground Surface ___ Top of Casing ____

Type of Test (check one): Inflow ___ Outflow (Bailing) ____

Time Slug Inserted _____ hrs. ______ min ______ sec

Time Slug Removed _____ hrs. ______ min ______ sec

Time (min.)	Depth* (ft.)	Remarks

FIGURE C-3

AQUIFER TEST PUMP LOG

FILING NO.

COMPANY

WATER MEASURED FROM

WELL NO.

ELEV. OF MEASURING POINT

CITY COUNTY

STATE JOB NO.

STATIC WATER LEVEL FT.

LOCATION

DATE

AQUIFER SCREENED

SEC. TWP RGE

TYPE OF DISCHARGE DEVICE

TIME PUMPING BEGAN HRS. (A.M.) (P.M.) MIN. SEC. DATE

TYPE OF W/L MEASURING DEVICE

TIME PUMPING ENDED HRS. (A.M.) (P.M.) MIN. SEC. DATE

DATA TAKEN BY

TIME	ELASPED TIME (MIN)	TAPE HELD/ NEAREST BAND (FT)	WETTED/ DIST TO NEAREST BAND (FT)	WATER LEVEL (FT)	DISCHARGE MEASUREMENT	DISCHARGE RATE (GPM)	REMARKS

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FIGURE C-4

AQUIFER TEST RECOVERY LOG

LING NO.

WATER MEASURED FROM

ELEV. OF MEASURING POINT

STATIC WATER LEVEL FT.

AQUIFER SCREENED

COMPANY

WELL

CITY COUNTY

STATE JOB NO.

LOCATION:

SEC. TWP RGE

DATE

TYPE OF W/L MEASURING DEVICE

TIME PUMPING BEGAN (A.M.) HRS. (P.M.) MIN. SEC. DATE

TIME PUMPING ENDED (A.M.) HRS. (P.M.) MIN. SEC. DATE

DATA TAKEN BY

TIME	ELAPSED TIME (MIN)	TAPE HELD/ NEAREST BAND (FT)	WETTED/ DIST. TO NEAREST BAND ± (FT)	WATER LEVEL (FT)	REMARKS	TIME	ELAPSED TIME (MIN)	TAPE HELD/ NEAREST BAND (FT)	WETTED/ DIST. TO NEAREST BAND ± (FT)	WATER LEVEL (FT)	REMARKS

FIGURE C-5

OBSERVATION WELL LOG

FILING NO.

COMPANY ______

WELL ______

WATER MEASURED FROM

CITY ______ COUNTY ______

ELEV. OF MEASURING POINT

STATE ______ JOB NO. ______

STATIC WATER LEVEL FT.

LOCATION:

DATE

AQUIFER SCREENED

SEC.______ TWP ______ RGE ______

TYPE OF W/L MEASURING DEVICE

TEST PUMP WELL

TEST RECOVERY WELL

DATA TAKEN BY

TIME	ELAPSED TIME (MIN)	TAPE HELD/ NEAREST BAND (FT)	WETTED/ DIST. TO NEAREST BAND ± (FT)	WATER LEVEL (FT)	REMARKS	TIME	ELAPSED TIME (MIN)	TAPE HELD/ NEAREST BAND (FT)	WETTED/ DIST. TO NEAREST BAND ± (FT)	WATER LEVEL (FT)	REMARKS

SHEET ______ OF ______

APPENDIX D

GROUND-WATER SAMPLING PROCEDURES

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APPENDIX D
GROUND WATER SAMPLING AND ANALYSIS PROCEDURES

1. GROUND-WATER SAMPLING PROCEDURES

1.1 Sampling and Analysis Personnel

Sampling and analysis will be conducted by trained personnel. All sampling and analysis personnel will be trained in the performance of the specific task to which they are assigned. Training documentation will be available if requested.

Sampling personnel will have thoroughly reviewed this Sampling and Analysis Plan prior to conducting sampling and will have a copy of the plan available for reference.

1.2 Summary of Sampling Procedures

Activities which will occur during ground-water sampling are summarized as follows:

- pre-arrangement with testing laboratory
- assembly and preparation of equipment and supplies
- ground-water sampling
  - water-level measurements
  - visual inspection of borehole water
  - well bore evacuation
  - sampling
- sample preservation and shipment
  - sample preparation
  - on-site measurement of parameters
  - sample labeling
- completion of sample records
- completion of chain-of-custody records
- sample shipment

Detailed sampling and analysis procedures are presented in following sections.

1.3 Arrangements with Analytical Laboratory

Prior to sampling, arrangements will be made with an analytical laboratory which will conduct the sample analyses. The requirements for the laboratory are included in Section 2 of this Sampling and Analysis Plan.

The laboratory will provide a sufficient number of sample containers for the wells to be sampled and the blanks to be included. The laboratory will determine the proper type and size for the containers based upon the analyses to be conducted. For samples requiring chemical preservation, preservatives will be added to containers by the laboratory prior to shipping containers to the facility. Shipping containers, ice chests with adequate container padding and cooling media, will be sent to the facility with the containers.

1.4 Preparation for Sampling

Prior to the sampling episode, all equipment to be used will be assembled and its operating condition verified, calibrated (if required), and properly cleaned (if required). In addition, all record-keeping materials will be prepared.

1.4.1 Equipment Check-Out.

This activity includes the verification that all equipment is in proper operating condition. Also, arrangements for repair or replacement of any equipment which is inoperative are made.

1.4.2 Equipment Calibration.

Where appropriate, equipment will be calibrated according to the manufacturer's specifications prior to field use. This applies to the equipment for making on-site chemical measurements of pH, eH, conductivity, and temperature of water.

1.4.3 Equipment Cleaning.

All portions of sampling and test equipment which will contact the sample will be thoroughly cleaned before use for sampling. This includes water-level tapes or probes, pumps, tubing, bailers, lifting line, test equipment for on-site use, and other equipment or portions thereof which are to be immersed.

The procedure for equipment cleaning will depend upon the type of analyses to be conducted with the sample. Changes to the procedure are noted.

- o Clean with potable water and phosphate-free laboratory detergent;
- o Rinse with potable water;
- o Rinse with dilute (0.1N) reagent-grade hydrochloric or nitric acid (for samples planned for inorganic constituent analyses)
- o Rinse with distilled or deionized water;
- o Rinse with reagent-grade acetone (for samples planned for organic constituent analyses)
- o Rinse with reagent-grade hexane (for samples planned for organic constituent analyses)
- o Air dry the equipment prior to use.

Any deviations from these procedures should be documented in the permanent record of the sampling event.

Laboratory-supplied sample containers will be cleaned and sealed by the laboratory before shipping. The type of container provided and the method of container should be in the laboratory's permanent record of the sampling event.

1.5 <u>Sampling Procedures</u>

Special care will be exercised to prevent contamination of the ground water and extracted samples during the sampling activities. The two primary ways in which such contamination can occur are:

- o contamination of a sample through contact with improperly cleaned equipment; or

- cross-contamination of the ground water through insufficient cleaning of equipment between wells.

To prevent such contamination, sampling equipment and sample containers will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures in Section 1.4.3. In addition to the use of properly cleaned equipment, two further precautions will be followed:

- a clean pair of new, disposable latex (or similar) gloves will be worn each time a different well is sampled; and
- sample collection activities will progress from the least affected (up-gradient) area to the most affected (down-gradient) area. Wells described as "background" or "up-gradient" wells will be sampled first.

The following paragraphs present procedures for the several activities which comprise ground-water sample acquisition. These activities will be performed in the same order as presented below. Exceptions to this procedure will be noted in the permanent sampling record.

1.5.1 Preparation of Location.

Prior to starting the sampling procedure, the area around the well should be cleared of foreign materials, such as brush, rocks, debris, etc. A clean (new), disposable, plastic sheet should be placed around the well casing so that the sheet is flat on the ground and the well projects through and above the center of the sheet. Flush-with-ground wells will not project through the sheet. For projecting protective well casings, a clean (new) plastic trash bag should be placed around the projecting casing or protector pipe and secured (with tape) to the casing so that only the interior well casing is visible.

This preparation will prevent sampling equipment from inadvertently contacting the ground or exterior parts of the well.

1.5.2 Water-Level Measurement.

The first sampling operation is water-level measurement. An electrical probe will be used to measure the depth to ground water below the datum to the nearest 1/8 inch (0.01 foot). The datum, usually the top of the inner casing (inside and below the protective steel cover), will be described in monitor well records. A permanent mark or scribe will be visible on inspection of the inner casing.

If the wells to be sampled are closely spaced, such as in well clusters, the water levels at all of the closely-spaced wells should be measured before any of the wells are evacuated. The water level probe should be cleaned with phosphate-free detergent in distilled water and with a distilled water rinse between usage at different wells.

1.5.3 Total Depth Measurement.

Once the water level has been measured and recorded, the water-level probe should be slowly lowered to the bottom of the well. The depth to the bottom should be measured and recorded. The probe then should be slowly withdrawn from the well. The bottom of the probe should be examined after withdrawal to determine if evidence of any viscous, heavy contaminants is apparent. Observations, and measurements if possible, of such materials should be made from examination of the probe.

1.5.4 Visual Inspection of Well Water.

Prior to well evacuation, a small quantity of water will be removed with a bailer, in a manner which will not totally immerse the bailer. The recovered sample is representative of the top of the water column in the well casing. If immiscible materials accumulate at the top of the water column, this technique can allow their detection. The water from the bailer will be decanted into a clean container. If a transparent bailer is used, decanting is unnecessary and the observation can be made through the bailer. The water will be inspected for the presence of any floating films or other indications of immiscible materials. Any sample odors will be noted. These observations regarding odor or visual evidence of immiscible materials will be recorded in the sampling record.

The sample taken in this manner will be discarded unless the site-specific protocol calls for retention of this sample. If the sample is to be discarded but is suspected to be contaminated, the water should be placed in a container for proper disposal.

1.5.5 Well Bore Evacuation.

Water contained within, and adjacent to, the well casing potentially can reflect chemical interaction with the atmosphere (by diffusion of gases down the casing) or the well construction materials (through prolonged residence adjacent to the casing). This water will be removed and discarded.

The volume of water contained within the well bore at the time of sampling will be calculated, and three times the calculated volume will be removed from the well and discarded. The use of a bailer for well evacuation is planned. Calculation of the volume of water to be evacuated will be done as follows.

$$\text{Number of Bailers} = 3 \times \frac{\text{volume of water in well } (V_w)}{\text{volume of bailer } (V_b)}$$

<u>Volume of water in well</u>

$$V_w = \frac{3.142 \times d_w^2}{4} \times L_w$$

where:
V_w = water volume in well (ft^3)
d_w = inside diameter of well (ft)
L_w = length of water column in well (ft)

<u>Volume of water in full bailer</u>

$$V_b = \frac{3.142 \times d_b^2}{4} \times L_b$$

where:
V_b = water volume in bailer (ft^3)
d_b = inside diameter of bailer (ft)
L_b = length of bailer (ft)

Alternatively, the chart in Figure D-1 and be used to determine the evacuation volume.

For wells which can be evacuated to a dry state, the well will be evacuated completely, and the sample taken as soon as sufficient water for sampling is present in the well. Sample compositing, or sampling over a lengthy period by accumulating small volumes of water at different times to eventually obtain a sample of sufficient volume, will not be allowed.

Water produced during well evacuation should be contained in a suitable container and discharge to the ground surface in an area of known surface contamination. In some instances, discharge to the city sanitary sewer also might be acceptable.

1.5.6 **Sample Extraction.**

A bailer or pump will be used to extract water samples from the well. Care will be taken during insertion of sampling equipment to prevent undue disturbance of water in the well.

If a pump is used, it will be a down-hole, bladder-type pump designed for use in small diameter wells. Pumps which would subject the sample to a negative pressure or could introduce a gas into the sample will not be used for sampling. However, suction pumps might be used for well evacuation.

When a pump is used, the immersed portion of the pump or suction line will be inserted gently into the water and the sample directed into the appropriate containers, or composited in a larger container and then transferred by pumping, siphoning, or carefully pouring into the appropriate container. The discharge line will be placed within the container, such that its end is below the water level in the container, in order to prevent significant aeration of the sample.

When a bailer is used for sampling, the bailer will be constructed of stainless steel or teflon. The bailer will be lowered into the water gently to prevent splashing and extracted gently to prevent creation of an excessive vacuum in the well. The sample will be transferred directly into the appropriate container. While pouring water from a bailer, the water will be carefully poured down the inside of the sample bottle to prevent significant aeration of the sample. If a bottom-discharge bailer is used, the discharge line will be placed so that its end is below the water level in the container. Unless other instructions are given by the analytical laboratory, the sample containers should be completely filled so that no air space remains in the container.

Excess water taken during sampling is placed in a container for proper disposition at the facility wastewater treatment plant.

1.5.7 **Quality Control Samples.**

Ground-water samples will include one split sample for each sampling event. If more than 20 wells are sampled, one additional split sample will be added. The decision of which sample to split will be made by sampling personnel. The split sample will be given a designation which can not be confused with other samples to be tested.

For each sampling event, a trip blank sample (distilled water) will be shipped from the laboratory to the facility and will be returned to the laboratory for analysis. The blank will not be opened in the field.

One equipment blank sample (distilled water) will be prepared for each day of the sampling event by pouring distilled water into a cleaned, sampling bailer or by pumping distilled water through the cleaned sampling pump and then filling a sample container in the sample manner that would be used for a ground-water sample.

1.5.8 On-Site Parameter Measurement.

Certain chemical and physical parameters in water can change significantly within a short time of sample acquisition. These parameters cannot be accurately measured in a laboratory located more than a few hours from the facility, and so will be measured on-site with portable equipment. These parameters are:

- pH,
- eH (if appropriate),
- specific conductance, and
- temperature.

These parameters will be measured in unfiltered, unpreserved, "fresh" water taken by the same technique as the samples taken for laboratory analyses. The measurements will be made in a clean glass container separate from those intended for laboratory analysis. The tested sample will be discarded after use. The measured values will be recorded in the sampling record.

1.6 Sample Handling

1.6.1 Sample Preservation.

Water samples will be properly prepared for transportation to the laboratory by refrigeration and chemical preservation (for water samples), if necessary. The laboratory providing sample containers will have added any necessary chemical preservatives to the sealed containers provided. The samples collected for uranium, plutonium and gross alpha and beta analyses will be preserved with 2% by volume concentrated HCl after being filtered.

As a general rule, and in accordance with EPA analytical procedures, water samples will not be filtered in the field, with the following exception. Samples planned for uranium, plutonium, and gross alpha and beta analyses either will be field-filtered before being acid-preserved, or, if the time between sampling and arrival at the laboratory are sufficiently short, the samples will be shipped with no chemical preservation. In the latter instance, the water samples will be filtered in the laboratory.

1.6.2 Container and Labels.

Glass containers and appropriate container lids will be provided by the laboratory. The containers will be filled and container lids will be tightly closed. All sample container lids will be sealed so that it will be obvious if the seal has been tampered with or broken. The label will be firmly attached to the container side (not lid). The following information will be legibly and indelibly written on the label:

- o facility name,
- o sample identification,
- o sample type (ground water, surface water, etc.)
- o sampling date,
- o sampling time,
- o preservatives added
- o sample collector's initials.

1.6.3 Sample Shipment.

In most instances, the concentration and type of compounds present in the ground-water are considered by the U.S. Department of Transportation to be non-hazardous. Thus, the following packaging and labeling requirements for the sample materials are appropriate for shipping the sample to the testing laboratory:

- o package sample so that is does not leak, spill, or vaporize from its packaging;
- o label package with
  - sample collector's name, address, and telephone number;
  - laboratory's name, address, and telephone number;
  - description of sample;

- quantity of sample; and
- date of shipment.

If the materials to be shipped are considered hazardous or if their nature is uncertain, the samples will be appropriately labelled and will be transported by sampling personnel directly to the analytical facility or will be shipped using a carrier licensed to transport hazardous materials.

To comply with packaging regulations and to take practical measures to prevent damage to expensive ground water samples, JLGA will follow packaging and shipping instructions supplied by the certified testing laboratory.

1.6.4 Chain of Custody Control.

After samples have been obtained, chain of custody procedures will be followed to establish a written record concerning sample movement between the sampling site and the testing laboratory. Each shipping container will have a chain of custody form completed by the site sampling personnel packing the samples. The chain of custody form for each container will be completed in triplicate. One copy of this form will be maintained at the site, and the other two copies at the laboratory. One of the laboratory copies will become a part of the permanent record for the sample and will be returned with the sample analyses.

A copy of a sample chain of custody form is shown in Figure D-2. The record must contain the following minimum information:

- o Collector's sample number,
- o Signature of collector,
- o Date and time of collection,
- o Place and address of collection,
- o Material type,
- o Preservatives added,
- o Analyses requested,
- o Signatures involved in the chain of possession,
- o Inclusive dates of possession.

The shipping container will be sealed so that it will be obvious if the seal has been tampered with or broken. The Chain of Custody documentation will be placed inside the container so that will be immediately apparent to the laboratory personnel receiving the container but will not be damaged or lost during shipping.

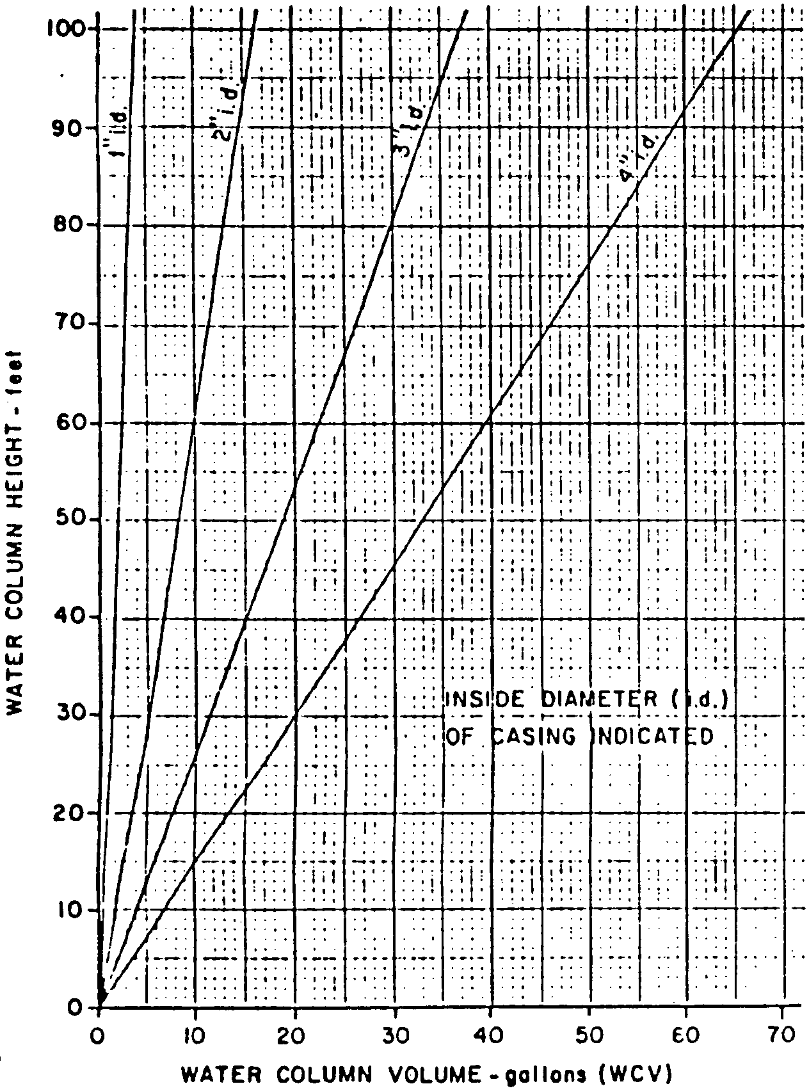
1.7 Sampling Records

To provide complete documentation of sampling, detailed records will be maintained during sampling. These records will include the information listed below:

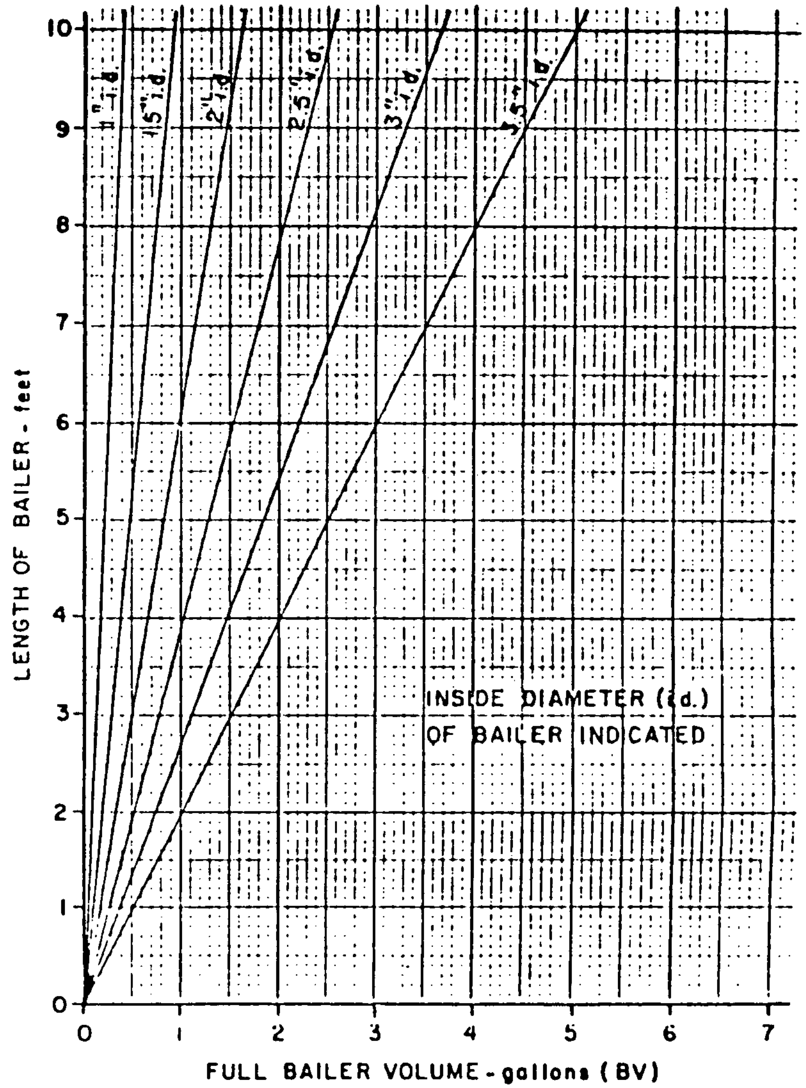
- o sample location (facility name);
- o sample identification (cleaning area name and sample number)
- o sample location map or detailed sketch
- o date and time of sampling;
- o sampling method;
- o field observations of
    - sample appearance,
    - sample odor
- o weather conditions;
- o sampler's identification; and
- o any other information which is significant.

Ground-water sampling information will be recorded on the Water Sampling Record as shown in Figure D-3.

CASING VOLUME



BAILER VOLUME



NUMBER OF FULL BAILERS TO EVACUATE ONE (1) CASING WATER COLUMN VOLUME $= \frac{WCV}{BV}$

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CALCULATION OF WELL EVACUATION VOLUMES

FIGURE D-1

Chain-of-Custody Form.

CHAIN OF CUSTODY RECORD-Environmental Samples

PROJECT	SAMPLING FIRM	SAMPLE
Name	Name	☐ Soil ☐ Groundwater
Address	Address	☐ Waste ☐ Surface Water
	Signature	☐ ______

SAMPLE I.D.	DESCRIPTION	DATE	TIME	WEATHER TEMP	WEATHER PREC	COMP	GRAB	OTHER	MAN	NO. OF CONTAINERS	ANALYSIS REQUIRED	REMARKS

RELINQUISHED BY (SIGNATURE)	RELINQUISHED TO	DATE	TIME	ADDITIONAL REMARKS
RELINQUISHED BY (SIGNATURE)	RELINQUISHED TO	DATE	TIME	
RELINQUISHED BY (SIGNATURE)	RELINQUISHED TO	DATE	TIME	
DISPATCHED BY (SIGNATURE) DATE TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME	LAB PO #
CARRIER	LABORATORY			PO # AND SAMPLE I.D. #'S MUST BE ON THE LAB INVOICE
ADDRESS	ADDRESS			ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES
METHOD OF SHIPMENT				☐ Yes ☐ No, explain above

FIGURE D-2

FIGURE D-3

SAMPLING LOCATION ______________

SAMPLING DATE(S) ______________

III. SAMPLING RECORD - MONITOR WELL ________ (number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling

DATE AND TIME OF SAMPLING: ____________, 19__ ________ a.m./p.m.

SAMPLE COLLECTED BY: ______________ of ______________

WEATHER: ______________________________

DATUM FOR WATER DEPTH MEASUREMENT (Describe): ______________

MONITOR WELL CONDITION:

☐ LOCKED: ☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: ______________

INNER PVC CASING CONDITION IS: ______________

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

Check-Off ☐ MONITOR WELL REQUIRED REPAIR (Describe): ______________

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH ______________

Items Cleaned (List): ______________

2 ☐ WATER DEPTH ______________ FT. BELOW DATUM

Measured with: ______________

3 ☐ WATER CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: ______________

Odor: ______________

Other Comments: ______________

4 ☐ WELL EVACUATION:

Method: ______________

Volume Removed: ______________

Observations: Water (slightly - very) cloudy

Water level (rose - fell - no change)

Water odors: ______________

Other comments: ______________

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of: ____________________

☐ Pump, type: ____________________

☐ Other, describe: ____________________

____

Sample obtained is ☐ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS:

Temp: __________° _____ Measured with: ____________________

pH: ____________________ Measured with: ____________________

Conductivity: __________ Measured with: ____________________

Other: ____________________

____

7 ☐ SAMPLE CONTAINERS (material, number, size): ____________________

____

____

____

8 ☐ ON-SITE SAMPLE TREATMENT:

☐ Filtration: Method ______________ Containers: ______________

Method ______________ Containers: ______________

Method ______________ Containers: ______________

☐ Preservatives Added:

Method ______________ Containers: ______________

Method ______________ Containers: ______________

Method ______________ Containers: ______________

Method ______________ Containers: ______________

9 ☐ CONTAINER HANDLING:

☐ Container Sides Labeled

☐ Container Lids Taped

☐ Containers Placed in Ice Chest

10 ☐ OTHER COMMENTS: ____________________

____

____

____

____

APPENDIX E

LABORATORY ANALYSIS PROCEDURES

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      1.3.2 Chemical Laboratory Sample Custody Procedures .. E-5

APPENDIX E
LABORATORY ANALYSIS PROCEDURES

1. LABORATORY ANALYSIS PROCEDURES

1.1 Chemical Analyses

1.1.1 Ground Water Analyses.

Ground-water samples will be analyzed for uranium, plutonium, gross alpha and beta, nitrate (NO3) and fluoride (F). The suggested procedures for determining gross alpha and beta, and nitrate are EPA methods 9310 and 9200, respectively, found in EPA publication SW-846, "Test Methods for Evaluating Solid Waste". Fluoride may be determined by ASTM method D-1179-72, Method A. Uranium and plutonium may be analyzed using procedures found in ASTM publication "1988 Annual Book of ASTM Standards, Section 11: Water and Environmental Technology", or by an appropriate test method provided in another accepted standard. The laboratory doing the analyses will have a QA/QC program which specifies procedures and references to be used.

1.1.2 Soil Analyses.

Soil samples will be analyzed for uranium, plutonium, nitrate, fluoride, total organic carbon (TOC), cation• exchange capacity (CEC), exchangeable cation (EXC), mineralogy, matric potential, and distribution coefficient for uranium and thorium. The suggested procedures for analyzing for uranium, plutonium, nitrate and fluoride will be the same used for ground water after an appropriate extraction procedure has been applied. Total organic carbon may be analyzed by EPA procedure 9060. Cation ion exchange capacity will be analyzed by EPA procedure 9081. These procedures are found in EPA publication SW-846, "Test Methods for Evaluating Solid Waste". Exchangeable cation, mineralogy, matric potential, and distribution coefficient will be determined by an appropriate test method provided in an accepted standard.

1.2 Physical Analyses

Physical tests will be conducted in accordance with the current edition of ASTM Standards, American Laboratory Soils Testing and Materials, Part 19. Soil classification will be determined according to the Unified Soil Classification System (ASTM D 2487). Liquid limit will be determined by ASTM D 423, and plastic limit and plasticity index will be determined by ASTM D 424. Other tests include particle size analysis (ASTM D 422) and moisture content (ASTM D 2216). Proctor tests will be conducted according to ASTM D 698, and density will be determined by ASTM D 2049, unless the soil composition dictates use of a different method.

1.3 Laboratory Quality Assurance

1.3.1 QA/QC Program Components.

The laboratory doing the analyses will have a QA/QC program which specifies procedures and references to be used. As a minimum, the program will contain:

1. Laboratory instrument calibration procedures and schedules.

2. Specification of adherence to accepted test methods.

3. Equipment inspection and servicing schedules.

4. The regular use of duplicate or split sample analyses.

5. The regular use of standard or spiked sample analyses.

6. Operator or analyst training procedures and schedules.

7. A program of continuous review of results, procedures, and compliance with the QA/QC program.

8. Documentation of compliance with the program.

The QA/QC program will be available for review.

1.3.2 Chemical Laboratory Sample Custody Procedures.

A sample custodian in the chemical analysis laboratory will be assigned to receive the samples. Upon receipt of a sample, the custodian will inspect the condition of the sample and the sample seal, reconcile the information on the sample label against that on the chain of custody record, assign a laboratory number and mark this number on the sample, log in the sample in the laboratory log book, and store the sample in a secured sample storage room or cabinet until assigned to an analyst for analysis. Discrepancies between the information on the sample label and the chain of custody record and the sample analysis request sheet will be resolved before the sample is assigned for analysis.

The laboratory portion of the sample analysis request form will be completed by the laboratory personnel and include:

- Name of person receiving the sample,
- Laboratory sample number,
- Date of sample receipt,
- Sample allocation
- Analyses to be performed.

APPENDIX B

MONITORING WELL RECORDS

SAMPLE INFORMATION

SOIL SAMPLING

SPLIT-SPOON SAMPLE (PER ASTM D1586)

THIN-WALL TUBE SAMPLE (PER ASTM D1587)

CUTTINGS COLLECTED

ROCK CORING INFORMATION

1	CORE RUN NO. AND LIMITS
100 / 78	RECOVERY / RQD
NX	CORE SIZE

USC = UNIFIED SOIL CLASSIFICATION (ASTM D-2487)

"N" VALUE IS BLOWS PER 12 INCH PENETRATION UNLESS OTHERWISE SPECIFIED.

SAMPLE ODORS, WHERE APPROPRIATE

NO	NO ODOR	MO	MODERATE ODOR
WO	WEAK ODOR	SO	STRONG ODOR

GRAPHIC LOG

FILL

CLAY

SILT

SAND

GRAVEL

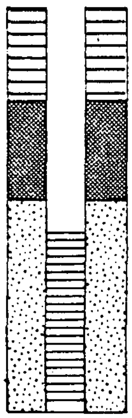
SHALE (*SH)

LIMESTONE (*LS)

SILTSTONE (*SIS)

SANDSTONE (*SS)

WELL COMPLETION DETAIL



PORTLAND CEMENT/ SODIUM BENTONITE GROUT

SODIUM BENTONITE SEAL

SAND OR GRAVEL BACKFILL

SCREENED INTERVAL

CAP

NOTE:

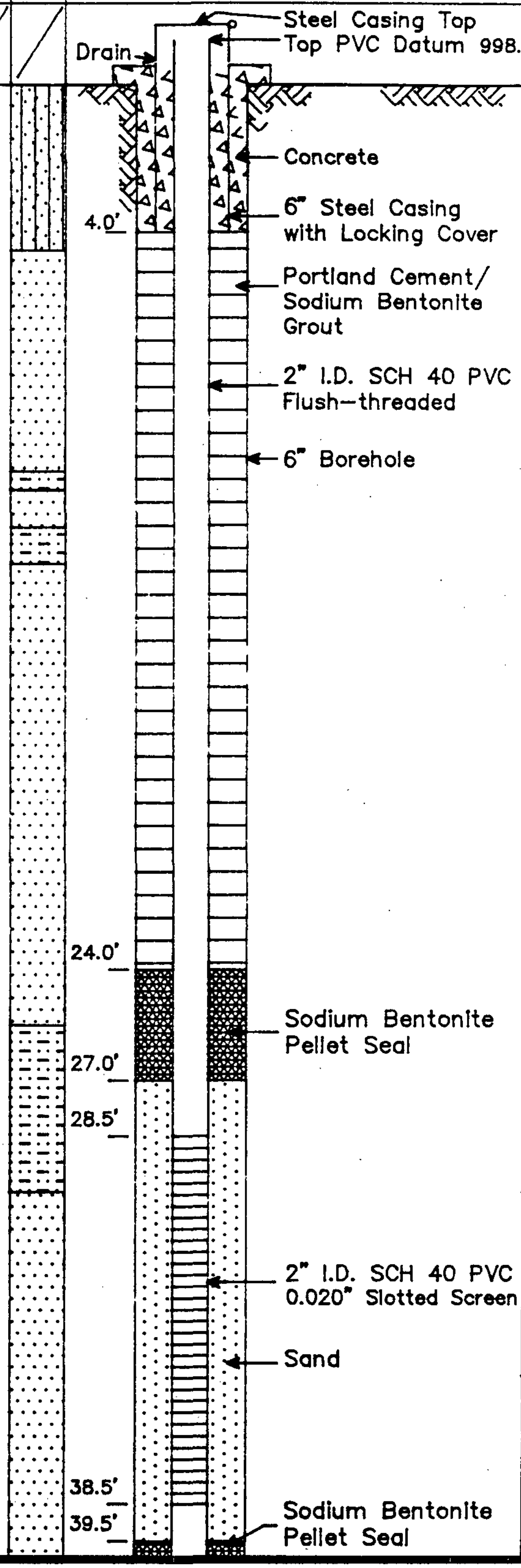
A BORING/WELL RECORD IS CONSIDERED REPRESENTATIVE OF SUBSURFACE CONDITIONS AT THE BORING/WELL LOCATION ON THE DATES SHOWN. IT IS NOT WARRANTED TO REPRESENT SUBSURFACE CONDITIONS AT OTHER LOCATIONS OR TIMES.

SUBSURFACE CONDITIONS SHOWN ON THESE RECORDS OR ON PROFILES DEVELOPED FROM THESE RECORDS ARE NOT WARRANTED. THEY ARE ESTIMATED BASED ON ACCEPTED SOIL ENGINEERING PRINCIPLES AND PRACTICES AND REASONABLE ENGINEERING JUDGEMENT.

JAMES L. GRANT & ASSOCIATES geotechnical engineering • management • computer science ENGLEWOOD COLORADO	**LEGEND FOR MONITORING WELL RECORDS**

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 995.6'			
	0–4.5	Stiff to hard, reddish brown SILT and very fine SAND, calcareous, low plasticity, moist	SM–ML		
	4.5–25.5	SANDSTONE: brownish red, fine to very fine grained, well sorted, rounded to subrounded grains, weak calcite and hematite cement ... thin, very fine grained Sandy MUDSTONE beds at 10.5' to 11.0' and 12.0' to 13.0'	SS		
	25.5–30.0	MUDSTONE: very fine grained, sandy, with bluish-gray reduction spots and laminae	MS		
	30.0–40	SANDSTONE: brownish red, very fine grained, silty, well sorted, rounded, weak to moderate calcite, hematite cement, silt content about 20%, cross bedding, medium grains appear at 35'	SS		

Well Completion Detail



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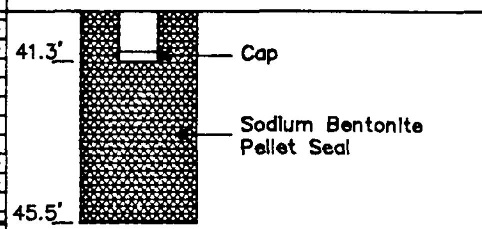
Monitoring Well Record 1320

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 11,266.69 N 11,755.70 E
Drilled By KERR–MCGEE Drilling Method AIR ROTARY
Logged By PFB Checked By SLW
Installation Date January 20, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40–45.5	MUDSTONE: very fine grained, sandy, occasionally conglomeratic with lithic clasts, slightly calcareous, sand content variable, 15% – 50%. Contacts are bluish gray reduction zones	MS					41.3' Cap; Sodium Bentonite Pellet Seal; 45.5'	40–45
	45.5	B.T. @ 45.5'							
	50	NOTE: description taken from well 1321 which offsets this location 12' E–NE							50

Depth scale: 40, 45, 45.5, 50, 55, 60, 65, 70, 75, 80



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Monitoring Well Record 1320

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 11,266.69 N 11,755.70 E

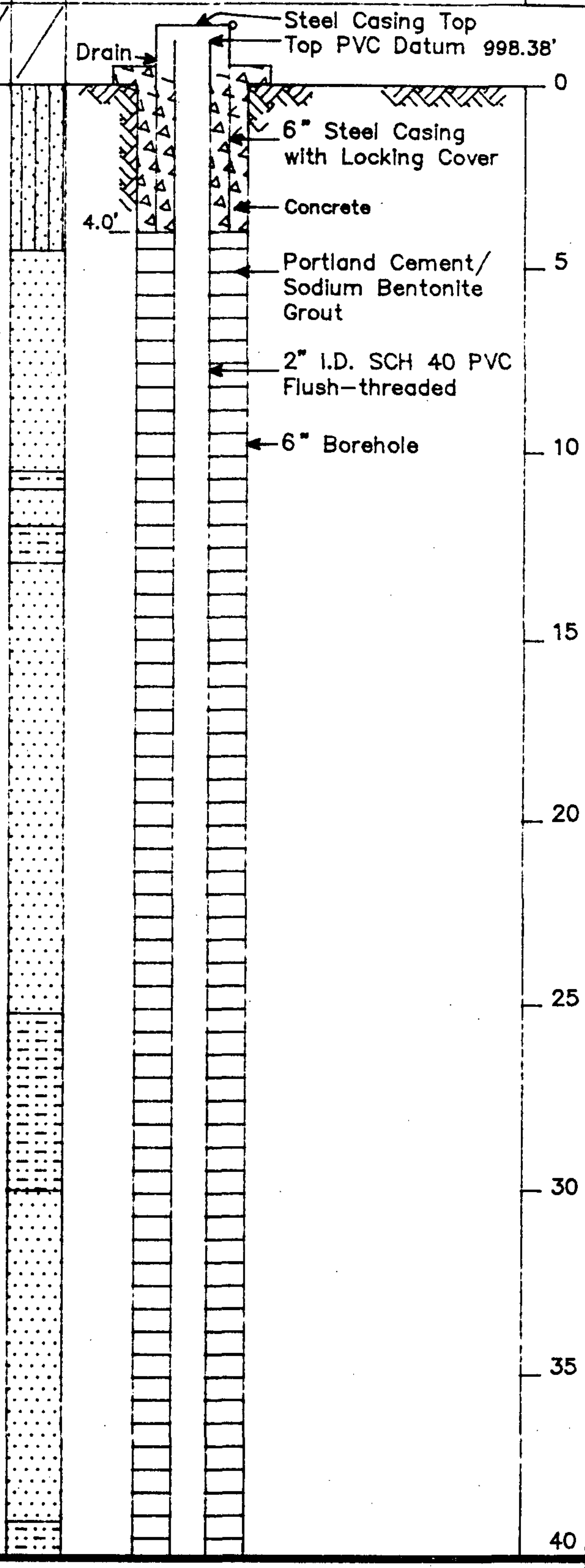
Drilled By KERR–MCGEE Drilling Method AIR ROTARY

Logged By PFB Checked By SLW

Installation Date January 20,1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 996.0'			
	0 – 4.5	Stiff to hard, reddish brown SILT and very fine SAND, calcareous, low plasticity, moist	SM–ML		38
					180
	4.5	SANDSTONE: brownish red, fine to very fine grained, well sorted, rounded to subrounded grains, weak calcite and hematite cement		Run 1 NX	55% / 45
	10	... thin, very fine grained Sandy MUDSTONE beds at 10.5' to 11.0' and 12.0' to 13.0'	SS	Run 2 NX	100% / 88
	20			Run 3 NX	100% / 75
	25.5	MUDSTONE: very fine grained, sandy, with bluish–gray reduction spots and laminae	MS		
	30.0	SANDSTONE: brownish red, very fine grained, silty, well sorted, rounded, weak to moderate calcite, hematite cement, silt content about 20%, cross bedding, medium grains appear at 35'	SS	Run 4 NX	100% / 99
	39.5 – 40	see pg. 2	MS		

Well Completion Detail



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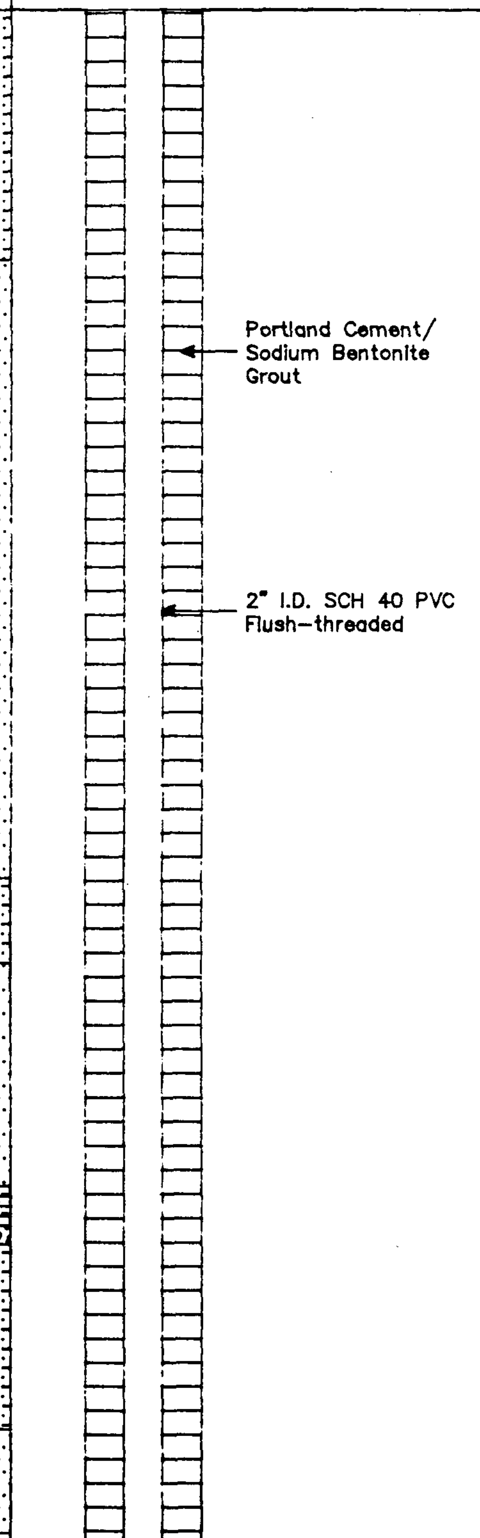
Monitoring Well Record 1321
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 11,261.76 N 11,743.26 E
Drilled By KERR–MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date January 25, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD	Graphic Log
	40 – 46.5	MUDSTONE: very fine grained, sandy, occasionally conglomeratic with lithic clasts, slightly calcareous, sand content variable, 15 – 50%. Contacts are bluish gray reduction zones	MS	Run 5 NX	100% / 100	
	46.5 – 71.5	SANDSTONE: brownish red, very fine to fine grained, silty, grains sub-rounded, well sorted. Moderately cemented. Silt content variable, 5 – 30%	SS			
	51	... very clean and porous 51' to 60'		Run 6 NX	96% / 95	
	60	... cross bedded 60' to 62.5'		Run 7 NX		
	62.5	... becomes conglomeratic at 62.5' to 64.7' with mudstone clasts. Matrix 50% sand, 50% silt, irregular vuggy porosity with some vugs lined with calcite, gypsum. Patches of M_n O_2 (?)			100% / 100	
	70.5	... becomes interbedded with mud-stone at 70.5' to 71.5'		Run 8 NX		
	71.5 – 76.8	MUDSTONE: very fine grained, sandy. Sand up to 30%, conglomeratic at 71.5' to 72.0'. Occasional reduction spots, sharp bottom contact.	MS		100% / 92	
	76.8 – 79.5	SANDSTONE: very fine to fine grained, silty, well sorted, rounded.	SS			
	79.5 – 80	see pg. 3	MS			

Well Completion Detail



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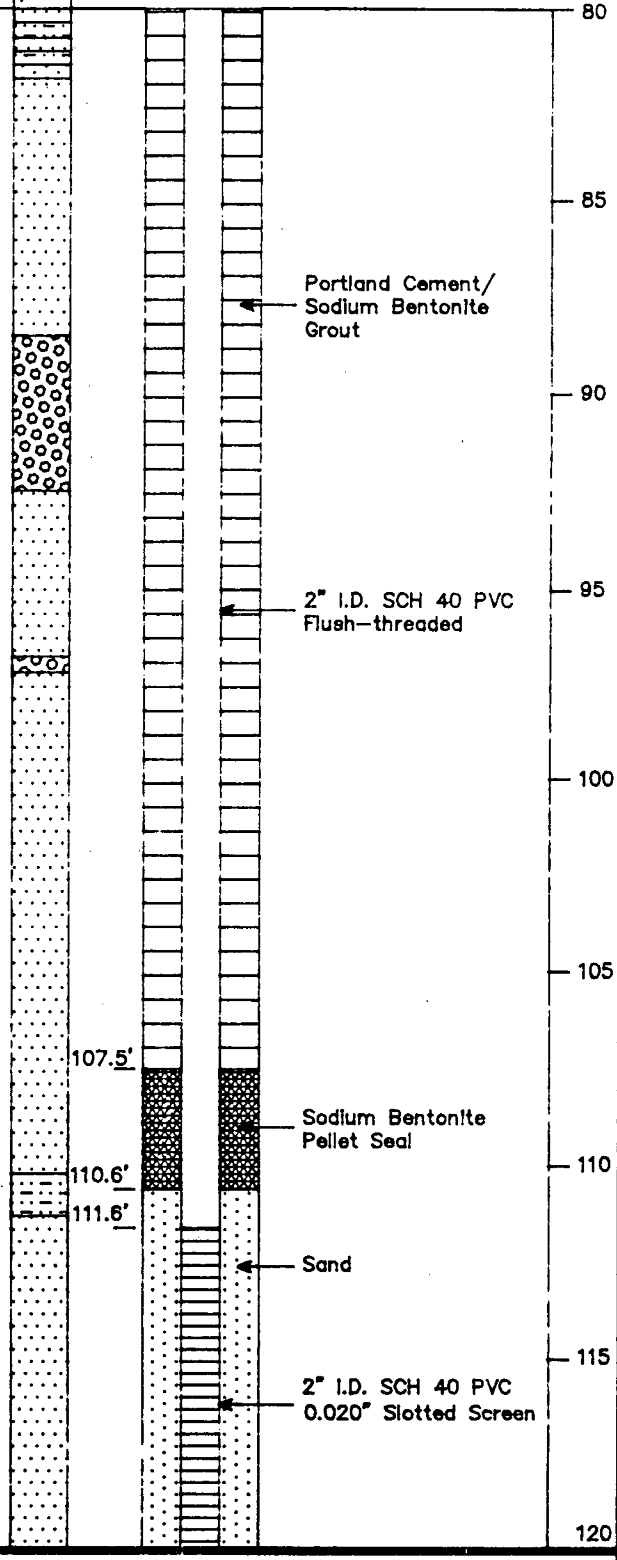
Monitoring Well Record 1321
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 11,261.76 N 11,743.26 E
Drilled By KERR-MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date January 25, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	80	MUDSTONE: very fine grained, sandy interbedded with silty sandstone	MS	Run 9 NX	
	81.8	SANDSTONE: very fine grained, silty, rounded, well sorted grains, faint cross bedding, moderate calcite, iron cement, silt decreases to about 10% below 85'	SS		100% / 100
	88.5	MUDSTONE: conglomerate, lithic clasts up to 1/2", calcite, gypsum filling fractures and vugs, clasts of yellow-green sandstone	MS	Run 10 NX	
	92.5	SANDSTONE: brownish red, fine grained to very fine grained, silty. Silt content about 20% to 30%, increases to up to 40% below 126.5'. Sand grains rounded, well sorted, rock parts along thin laminations and bedding planes. Weak to moderate calcite and iron cement. Rip-up clasts present at 96.8' to 97.2', blue-gray reduction zone at 110' to 110.2'. Thin mudstone beds occur from 110.2' to 111.3' and 125.7' to 126.5'.	SS		100% / 95
	100			Run 11 NX	
	105		SS		100% / 97
	110			Run 12 NX	
	115				100% / 100
	120				

Graphic Log / Well Completion Detail



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Monitoring Well Record 1321

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

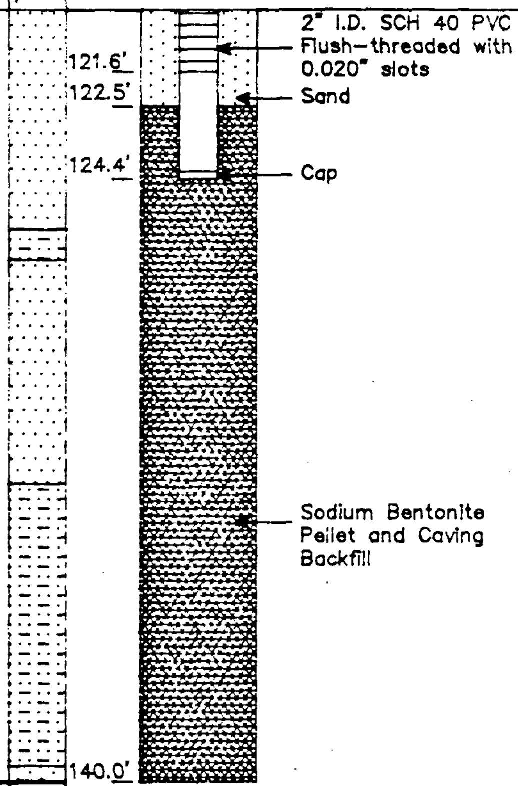
Coordinates 11,261.76 N 11,743.26 E

Drilled By KERR-MCGEE Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date January 25, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	120	Same as 92.5' to 120.0'		Run 13 NX					120
	125		SS		100% / 90				125
	130			Run 14 NX					130
	132.3	MUDSTONE: sandy, very fine grained, parts readily at 132.3' to 133.0' along grayish-blue laminae							
	135		MS		100% / 89				135
	139.6								
	140.0	SANDSTONE: very fine grained, silty	SS						140
		B.T. @ 140.0'							
	145								145
	150								150
	155								155
	160								160



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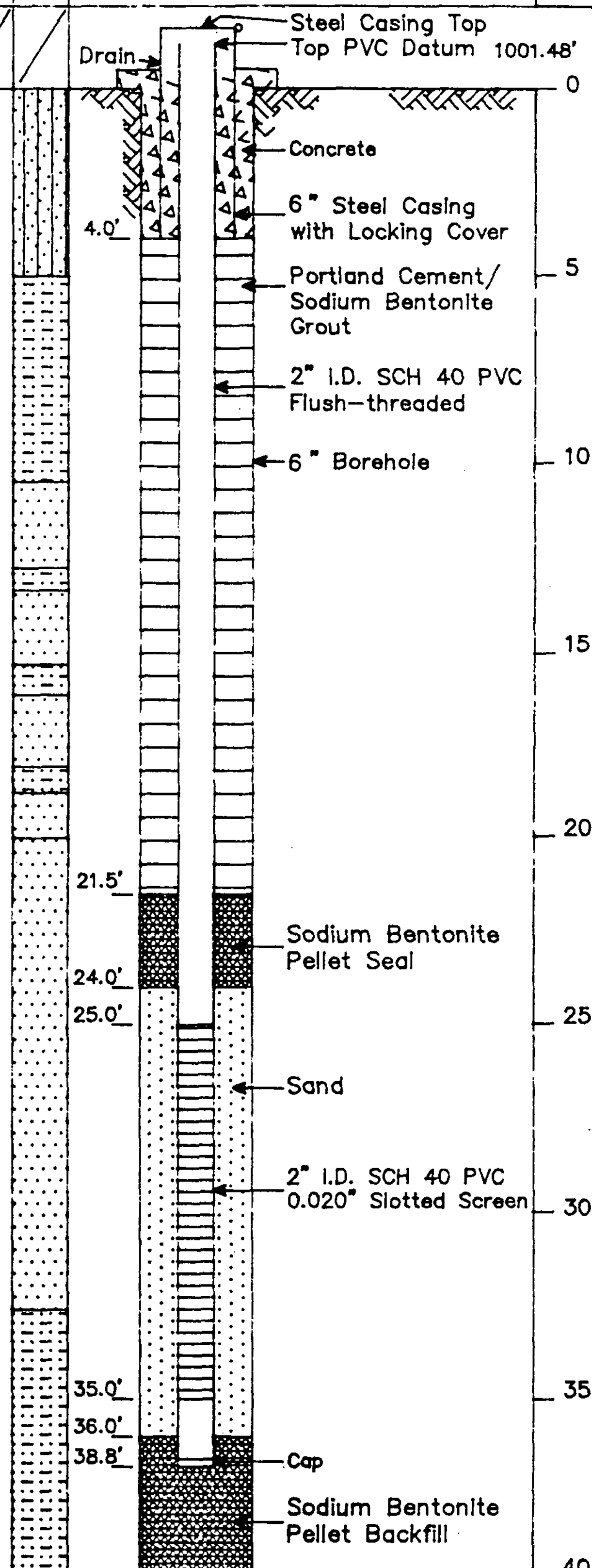
Monitoring Well Record 1321
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 11,261.76 N 11,743.26 E
Drilled By KERR-MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date January 25, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log
	0	Ground Surface 998.6'					
		Firm to hard Silty SAND and Sandy SILT, damp	SM-ML				
	5.0	MUDSTONE: sandy, very fine grained with grayish blue reduction laminae	MS				
	10						
	10.5	SANDSTONE and MUDSTONE: Interbedded, silty fine grained sandstone and very fine sandy mudstone. Considerable weathering and drilling fluid loss	SS MS	NO SAMPLES COLLECTED			
	15						
	20.0	SANDSTONE: very fine grained, silty, sand grains well sorted, rounded, ... several thin mudstone interbeds and occasional reduction spots 20.0' to 21.0'	SS				
	25	... becomes fine grained below 25'					
	30	... cross bedded at 29.9' to 32.4'					
		... becomes medium grained with mudstone clasts at 32.3' to 32.6', well cemented					
	32.6	MUDSTONE: sandy, very fine grained, with several 1-2" reduction zones	MS				
	35						
	40						

Well Completion Detail



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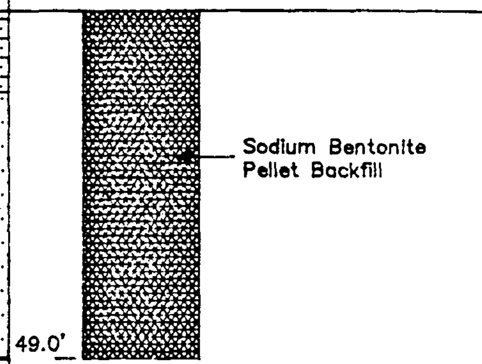
Monitoring Well Record 1322

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,386.13 N 10,238.93 E
Drilled By KERR-MCGEE Drilling Method AIR ROTARY
Logged By PFB Checked By SLW
Installation Date January 26, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run Size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	Same as 32.6' to 40.0'	MS						40
	42.1	SANDSTONE: brownish red, fine grained with 30% to 40% silt content, grains well sorted, sub-rounded to rounded							
	45		SS						45
		... becomes clean below 46.5'							
		... thin mudstone interbeds at 48.2' to boring termination depth							
	49.0							49.0'	
	50	B.T. @ 49.0'							50
	55	NOTE: descriptions are taken from Well 1323, which is located 14' West							55
	60								60
	65								65
	70								70
	75								75
	80								80



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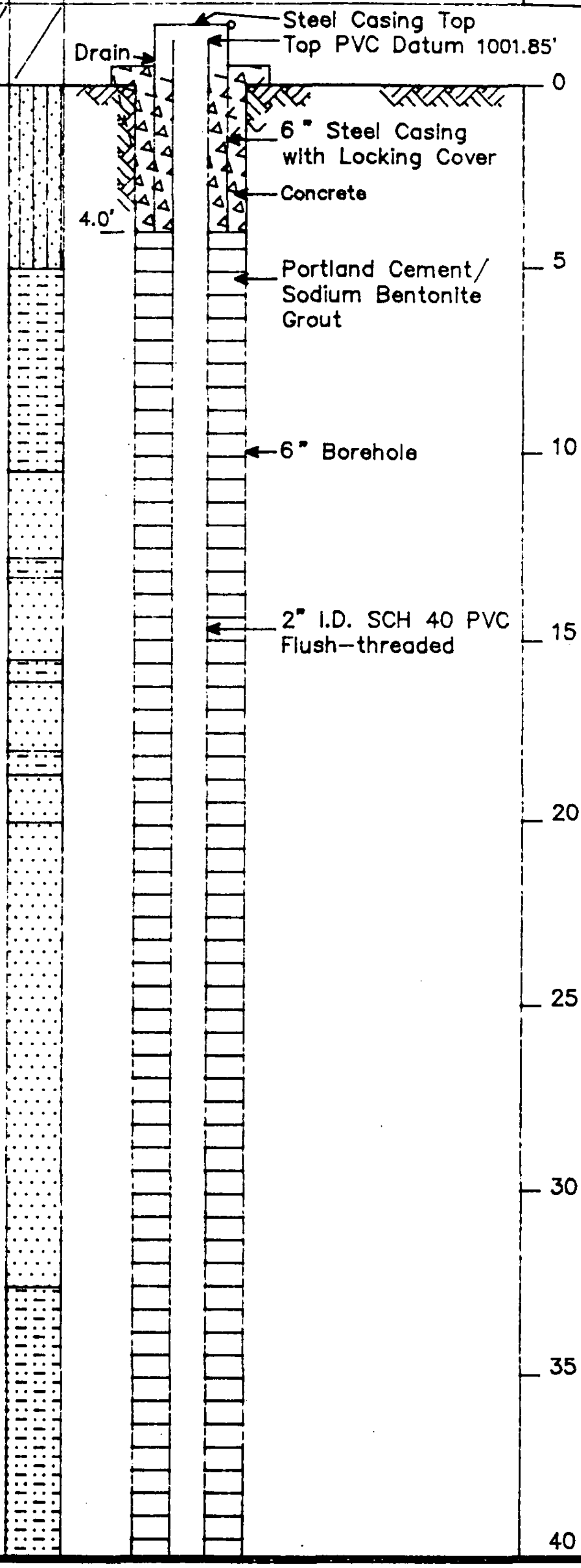
Monitoring Well Record 1322

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,386.13 N 10,238.93 E
Drilled By KERR-MCGEE Drilling Method AIR ROTARY
Logged By PFB Checked By SLW
Installation Date January 26, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 998.9'			
	0–5.0	Firm to hard Silty SAND and Sandy SILT, damp	SM-ML		
	5.0	MUDSTONE: sandy, very fine grained, with grayish blue reduction laminae	MS	Run 1 NX	36% / 29
	10.5	SANDSTONE and MUDSTONE: interbedded, silty fine grained sandstone and very fine sandy mudstone. Considerable weathering and drilling fluid loss	SS MS	Run 2 NX	37% / 8
	20.0	SANDSTONE: very fine grained, silty, sand grains well sorted, rounded, ... several thin mudstone interbeds and occasional reduction spots 20.0' to 21.0'	SS	Run 3 NX	
	25	... becomes fine grained below 25.0'			100% / 95
	30	... cross bedded at 29.9' to 32.4' ... becomes medium grained with mudstone clasts 32.3' to 32.6', well cemented		Run 4 NX	
	32.6	MUDSTONE: sandy, very fine grained, with several 1–2" reduction zones	MS		100% / 100
	40				

Well Completion Detail



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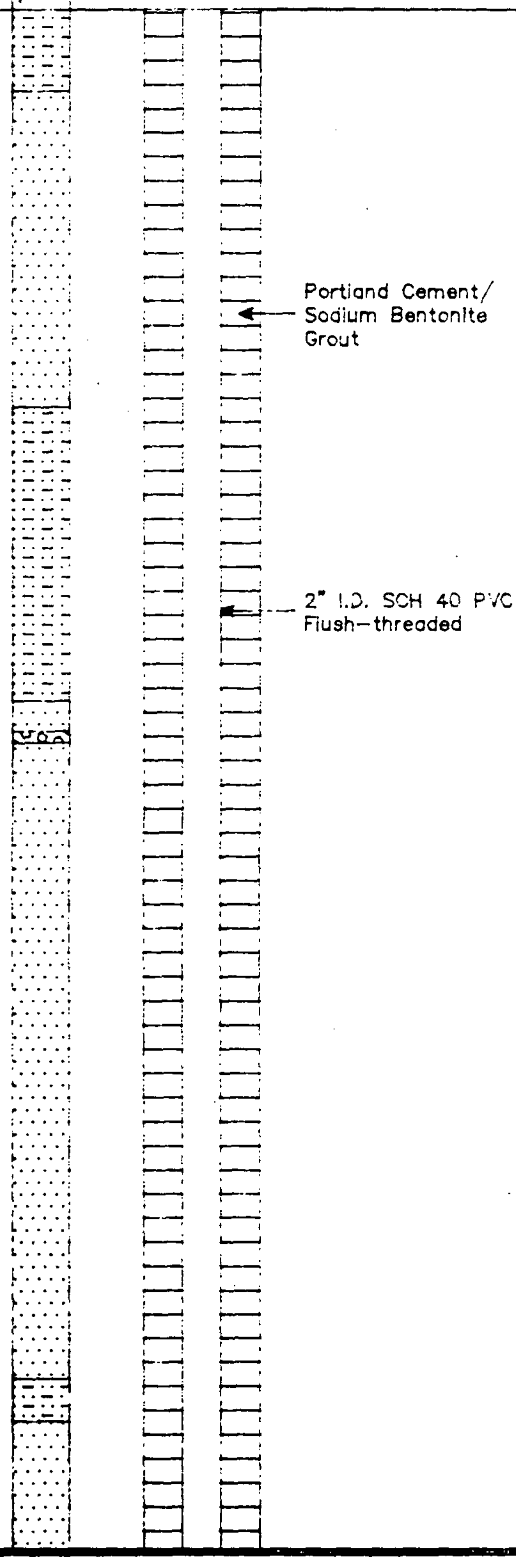
Monitoring Well Record 1323

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,387.37 N 10,224.06 E
Drilled By KERR-MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date February 14, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	40 – 42.1	Same as 32.6' to 40.0'	MS	Run 5 NX	
	42.1 – 50.3	SANDSTONE: brownish red, fine grained with 30% to 40% silt content, grains well sorted, sub-rounded to rounded ... becomes clean below 46.5' ... thin mudstone interbeds 48.2' to 50.0'	SS		100% / 100
	50.3 – 57.9	MUDSTONE: sandy, very fine grained with occasional reduction spots and sand clasts	MS	Run 6 NX	100% / 100
	57.9 – 80	SANDSTONE: fine grained, silty, well sorted, subrounded to rounded, weakly to moderately cemented, conglomeratic with sandstone, mudstone clasts and vug-like porosity 60.8' to 61.1' ... sandstone becomes mostly clean below 61.1' ... becomes crossbedded below 70.0' with occasional thin, shaley laminations ... thin mudstone bed at 75.5' to 76.6' with gray laminae	SS	Run 7 NX (from 60) Run 8 NX (from 70)	100% / 100 97% / 97

Graphic Log / Well Completion Detail (Depth 40 – 80 Feet):



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Monitoring Well Record 1323

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,387.37 N 10,224.06 E

Drilled By KERR-MCGEE Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date February 14, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	N Value / Rec. RQD	Graphic Log	Well Completion Detail	DEPTH (Feet)
	80	SANDSTONE: fine to very fine grained, silty, well sorted, sub-rounded to rounded, moderately cemented. Occasional patches of yellow-green minerals and shaley laminae	SS	Run 9 NX				80
	83.8	MUDSTONE: sandy, very fine grained, reddish brown, occasional reduction spots ... conglomeratic at 83.8' to 84.3'	MS		97% / 95			
	85							85
	90	... becomes very sandy below 90.0'		Run 10 NX			Portland Cement/ Sodium Bentonite Grout	90
	94.4	SANDSTONE: fine to very fine grained, silty, moderately cemented ... becomes fairly clean below 96.0'	SS		100% / 100		2" I.D. SCH 40 PVC Flush-threaded	
	95							95
	100			Run 11 NX				100
	105	... conglomeratic at 105.8' to 106.0'			100% / 100			105
	110	... becomes crossbedded below 110.0'		Run 12 NX			112.2'	110
	112.6	MUDSTONE: sandy, very fine grained, occasional gray reduction spots, occasionally conglomeratic	MS		99% / 99		Sodium Bentonite Pellet Seal	
	115						115.1' Sand; 116.8' 2" I.D. SCH 40 PVC 0.020" Slotted Screen	115
	117.9	SANDSTONE: fine to very fine grained, silty with horizontal laminations, moderately cemented	SS					
	120							120

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Monitoring Well Record 1323

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

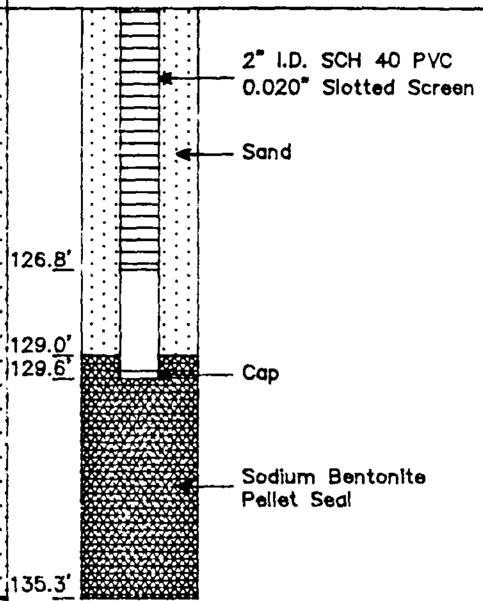
Coordinates 10,387.37 N 10,224.06 E

Drilled By KERR-MCGEE Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date February 14, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	120	SANDSTONE: fine to very fine grained, silty, brownish red, moderately cemented		Run 13 NX					120
	125				93% / 93				125
			SS						
	130	... silt content increases to about 50% at 130.0' to 131.5'		Run 14 NX					130
					100% / 100				
	135 / 135.3								135
		B.T. @ 135.3'							
	140								140
	145								145
	150								150
	155								155
	160								160



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Monitoring Well Record 1323

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,387.37 N 10,224.06 E

Drilled By KERR-MCGEE Drilling Method CORE

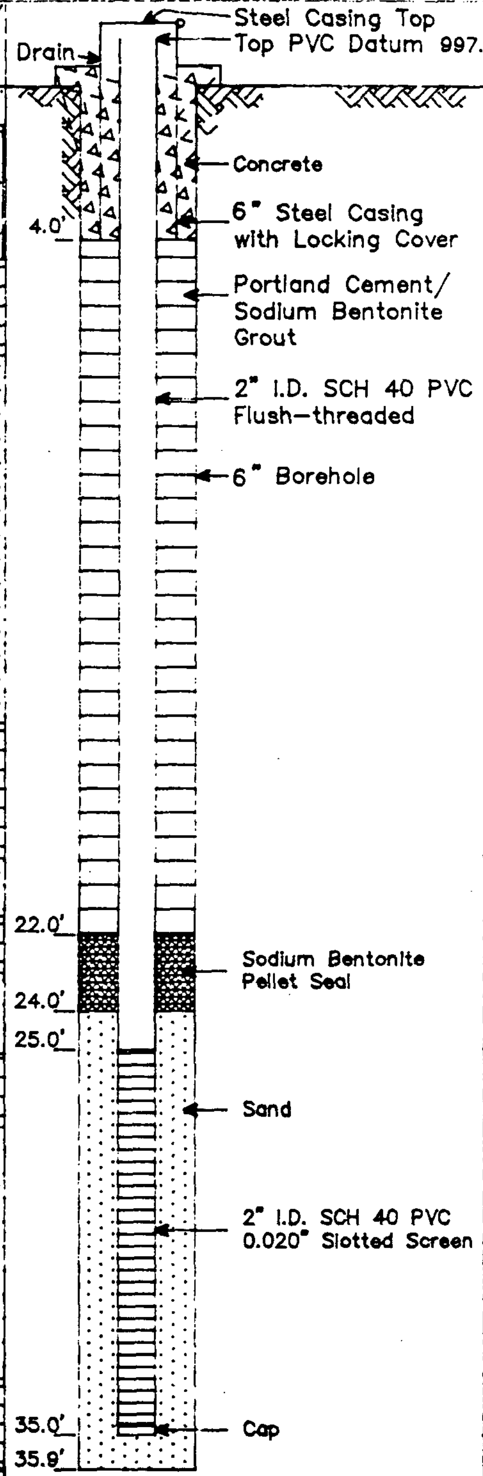
Logged By PFB Checked By SLW

Installation Date February 14, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC
	0	Ground Surface 995.2'	
	0–1.0	Firm, reddish brown, Silty SAND, damp	SM
	1.0–4.5	Hard, reddish brown Sandy SILT, almost dry, some black organic material	ML
	4.5–7.0	MUDSTONE: reddish brown, sandy, gray reduction spots, dry	MS
	7.0–16.5	SANDSTONE: brownish red, fine grained, silty, moderate cement, slightly calcareous, dry	SS
	16.5–20.0	MUDSTONE: reddish brown, very sandy, gray reduction spots, dry	MS
	20.0–21.5	SANDSTONE: brownish red, fine grained, silty, moderate cement, slightly calcareous, dry	SS
	21.5–23.0	MUDSTONE: reddish brown, very sandy, gray reduction spots, dry	MS
	23.0–25.1	SANDSTONE: brownish red, fine grained, silty, moist	SS
	25.1–27.0	MUDSTONE: reddish brown, sandy	MS
	27.0–33.5	SANDSTONE: brownish red, fine grained, silty, wet	SS
	33.5–35.9	MUDSTONE: reddish brown, sandy	MS
	35.9	B.T. @ 35.9'	

Sample Interval / Core Run Size; "N" Value / Rec. RQD; Graphic Log

Well Completion Detail



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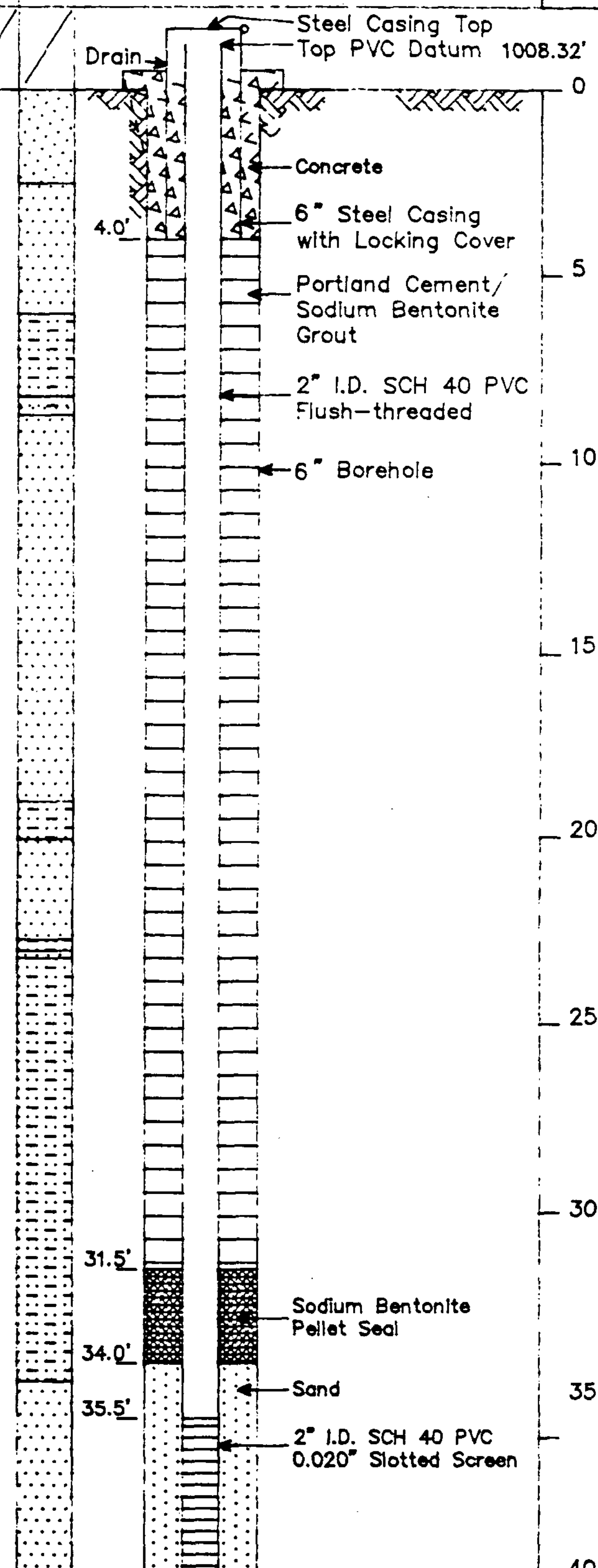
Monitoring Well Record 1324

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,972.36 N 12,075.48 E
Drilled By KERR-MCGEE Drilling Method AIR ROTARY
Logged By PFB Checked By SLW
Installation Date February 8, 1989 Page 1 of 1

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 1005.9'			
		Hard, fine SAND, brownish red	SP		72
	2.5				94
		SANDSTONE: brownish red, fine grained, silty, slightly calcareous	SS		
	5				
	6.0	MUDSTONE: reddish brown, sandy	MS		
	8.2	Interbedded sandstone, mudstone	SS-MS		
	9.3	SANDSTONE: brownish red, fine grained, silty, slightly calcareous			
	10				
	15		SS		
		... mudstone layers at 19.0' to 20.0' and 22.3' to 22.7', dry			
	20				
		... yellow-brown sandstone at 23.0' to 23.2', damp			
	23.2	MUDSTONE: reddish brown, sandy, damp			
	25				
			MS		
	30				
	34.4				
	35	SANDSTONE: brownish red, fine grained, silty, slightly calcareous, damp ... moist below 37.0'	SS		
	40				

Graphic Log / Well Completion Detail



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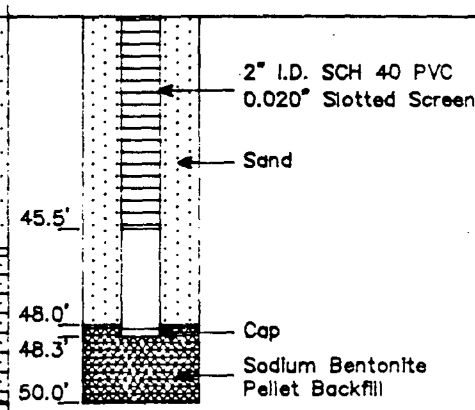
Monitoring Well Record 1325

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,494.65 N 11,951.47 E
Drilled By KERR-MCGEE Drilling Method AIR ROTARY
Logged By PFB Checked By SLW
Installation Date February 9, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	SANDSTONE: brownish red, fine grained, silty, wet	SS						40
	45								45
	46.0	MUDSTONE: reddish brown, sandy, wet	MS						
	50.0	B.T. @ 50.0'							50
	55								55
	60								60
	65								65
	70								70
	75								75
	80								80



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Monitoring Well Record 1325

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,494.65 N 11,951.47 E

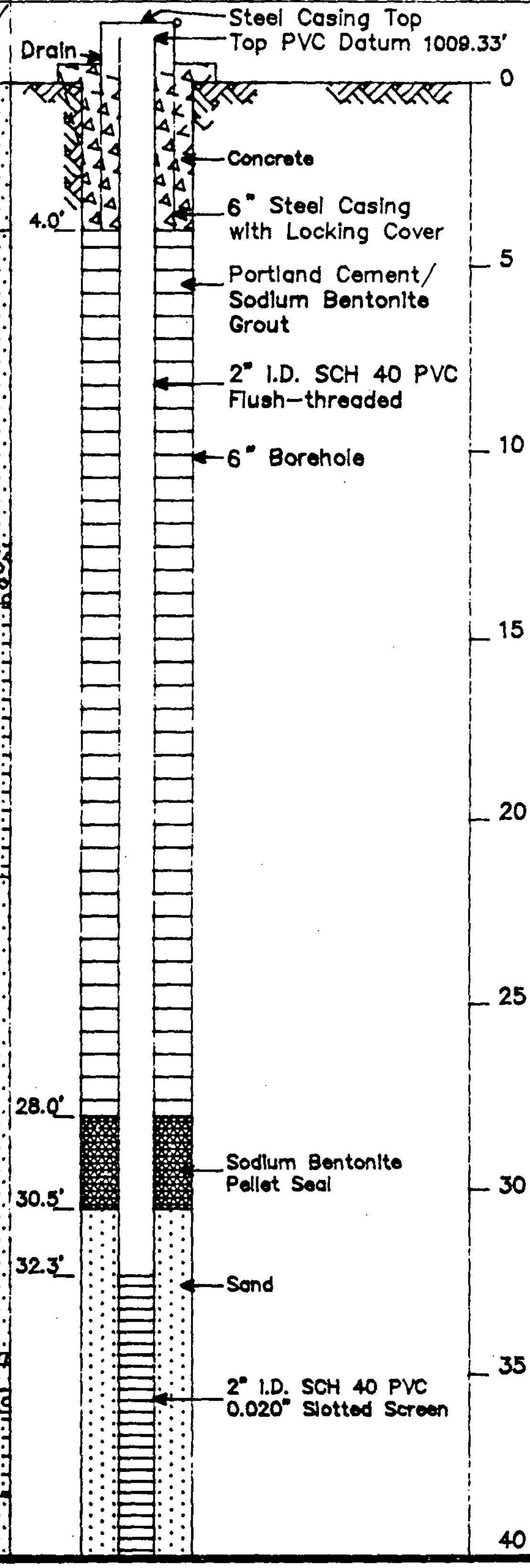
Drilled By KERR-MCGEE Drilling Method AIR ROTARY

Logged By PFB Checked By SLW

Installation Date February 9, 1989 Page 2 of 2

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 1006.5'			
		Loose to very dense, slightly Silty SAND, a few roots	SP		10
	4.0	SANDSTONE: brownish red, fine grained, well sorted, subrounded to rounded, weakly cemented		Run 1 NX	
	5				
	10		SS		66% / 66
		... becomes medium grained and conglomeratic at 12.5' to 14.1'			
	14.1	MUDSTONE: reddish brown, sandy, very fine grained,		Run 2 NX	
	15		MS		91% / 91
	20	... reduction zone at 21.2' to 21.5'		Run 3 NX	
	21.5	SANDSTONE: brownish red, fine grained, well sorted, subrounded to rounded, weakly cemented, very silty to 26.2'			100% / 100
	25	... crossbedded at 26.2' to 30.0'	SS		
	30			Run 4 NX	
	35	... conglomeratic with mudstone clasts at 34.4' to 34.7' and 35.4' to 36.0'			100% / 100
	36.0	MUDSTONE: reddish brown, sandy, very fine grained, with filled dessication cracks	MS		
	38.3	SANDSTONE: fine grained, well sorted, rounded, clean	SS		
	40				

Well Completion Detail



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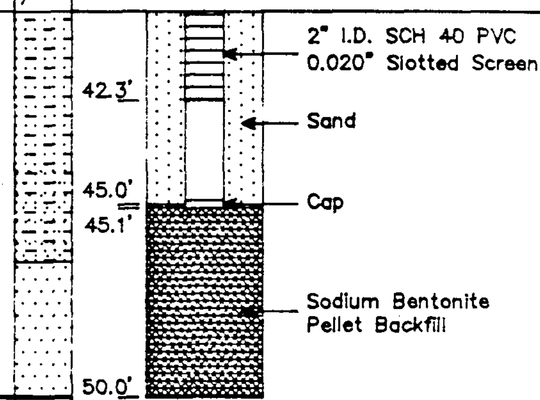
Monitoring Well Record 1326

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,112.93 N 10,719.85 E
Drilled By KERR-MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date February 16, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	MUDSTONE: sandy, very fine grained, with thin reduction laminae and spots	MS	Run 5 NX	100% / 100				40
	45								45
	46.5	SANDSTONE: fine to very fine grained, silty	SS						
	50.0	B.T. @ 50.0'							50
	55								55
	60								60
	65								65
	70								70
	75								75
	80								80



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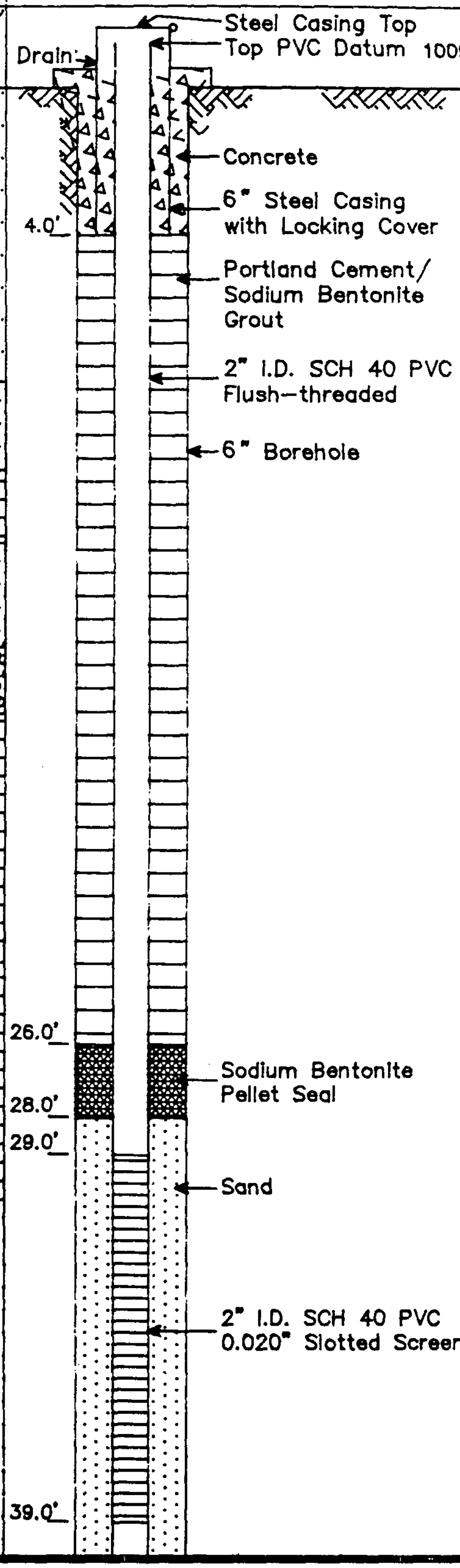
Monitoring Well Record 1326
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,112.93 N 10,719.85 E
Drilled By KERR-MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date February 16,1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 1006.2'			
	0–8.0	Loose to dense, reddish brown, Silty SAND	SM		10, 15, 41
	8.0–10.4	SANDSTONE: brownish red, fine grained, well sorted, rounded, weak to moderate cement	SS	Run 1 NX	
	10.4–12.4	MUDSTONE: reddish brown, sandy	MS		84% / 84
	12.4–17.0	SANDSTONE: brownish red, fine grained, well sorted, rounded, weak to moderate cement ... conglomeratic with sandstone, mudstone clasts at 15.1' to 17.0'; calcite and gypsum filling vugs, grain boundaries	SS		
	17.0–30.2	MUDSTONE: sandy, very fine grained, with hard sandstone layer at 23.2' to 23.8'. Occasional reduction spots, laminae	MS	Run 2 NX	60% / 60
				Run 3 NX	100% / 78
				Run 4 NX	78% / 72
	30.2–40	SANDSTONE: brownish red, fine grained, well sorted, rounded, weak to moderate cement, silty to 34.0', clean below that ... grayish-blue reduction zone at 30.2' to 31.1'	SS	Run 5 NX	100% / 100

Well Completion Detail



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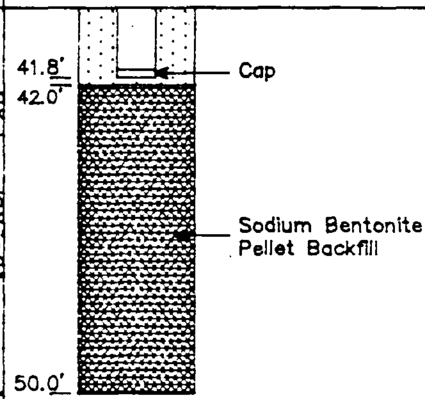
Monitoring Well Record 1327 A

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,103.73 N 10,100.10 E
Drilled By KERR-MCGEE Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 1, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	SANDSTONE: brownish red, fine grained, well sorted, subrounded to rounded, clean. Patchy yellow-green minerals appearing below 41.2'. Conglomeratic at 42.1' to 43.2' and 44.8' to 46.9' with lithic clasts, vug-like porosity, calcite and gypsum cementing clasts lining vugs. Crossbedded at 43.2' to 44.8' with abundant gypsum ... becomes silty below 46.9'	SS	Run 6 NX	100% / 100				40
	45								45
	50.0	B.T. @ 50.0'							50
	55								55
	60								60
	65								65
	70								70
	75								75
	80								80



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Monitoring Well Record 1327 A

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,103.73 N 10,100.10 E

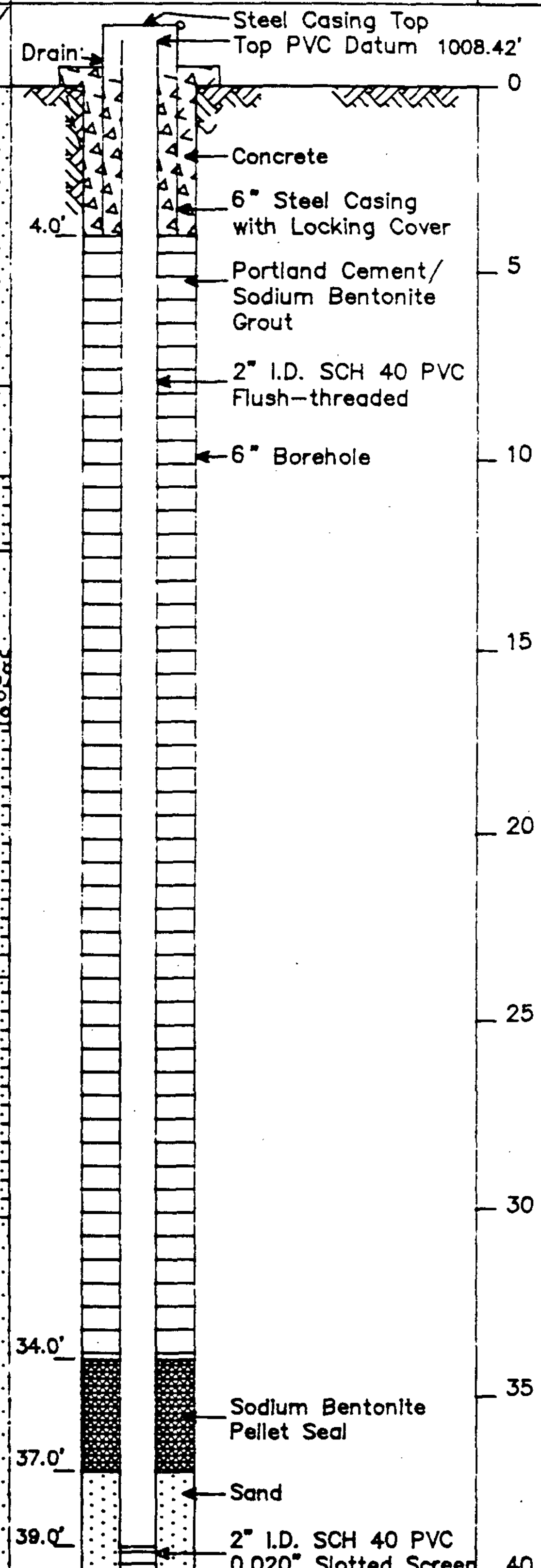
Drilled By KERR-MCGEE Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 1, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core run size	"N" Value / Rec. RQD	Graphic Log
	0	Ground Surface 1006.2'				
		Loose to dense, reddish brown, Silty SAND	SM			
	5					
	8.0	SANDSTONE: brownish red, fine grained, well sorted, rounded, weak to moderate cement	SS			
	10					
	10.4	MUDSTONE: reddish brown, sandy	MS			
	12.4	SANDSTONE: brownish red, fine grained, well sorted, rounded, weak to moderate cement ... conglomeratic with sandstone, mudstone clasts at 15.1' to 17.0'; calcite and gypsum filling vugs, grain boundaries	SS			
	15					
	17.0	MUDSTONE: sandy, very fine grained, with hard sandstone layer at 23.2' to 23.8'. Occasional reduction spots, laminae	MS			
	20					
	25					
	30					
	30.2	SANDSTONE: brownish red, fine grained, well sorted, rounded, weak to moderate cement, silty to 34.0', clean below that ... grayish-blue reduction zone at 30.2' to 31.1'	SS			
	35					
	40					

Well Completion Detail



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Monitoring Well Record 1327 B

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

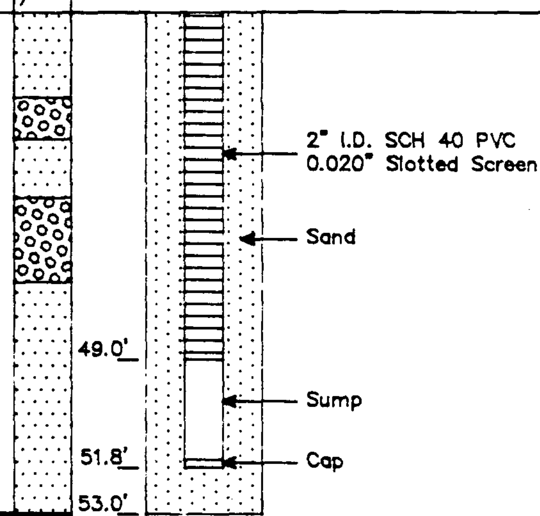
Coordinates 10,090.43 N 10,100.10 E

Drilled By KERR-MCGEE Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 20, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40 – 53.0	SANDSTONE: brownish red, fine grained, well sorted, subrounded to rounded, clean. Patchy yellow-green minerals appearing below 41.2'. Conglomeratic at 42.1' to 43.2' and 44.8' to 46.9' with lithic clasts, vug-like porosity, calcite and gypsum cementing clasts lining vugs. Crossbedded at 43.2' to 44.8' with abundant gypsum ... becomes silty below 46.9'	SS						40 – 53.0
	53.0	B.T. @ 53.0'							



Depth scale (Feet): 40, 45, 50, 55, 60, 65, 70, 75, 80

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Monitoring Well Record 1327 B

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,090.43 N 10,100.10 E

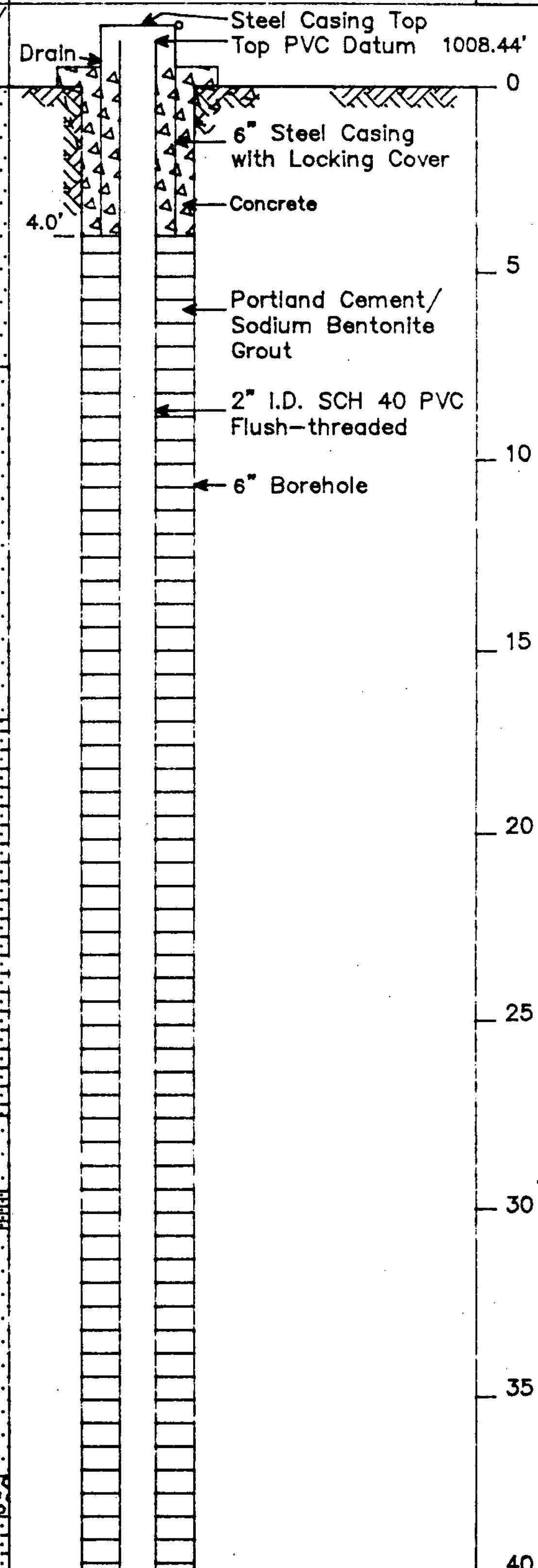
Drilled By KERR-MCGEE Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 20, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD	Graphic Log
	0	Ground Surface 1006.0'				
		Loose to very dense, brownish-red, Silty SAND	SM		8	
					7	
	5				11	
					90	
	7.5	SANDSTONE: brownish-red, fine grained, silty to 12'				
	10					
		... then becoming clean, medium grained, hard, crossbedded	SS	Run 1 NX		
	15				100% / 100	
	16.9	MUDSTONE: reddish-brown, slightly sandy, occassional reduction spots				
	20					
			MS	Run 2 NX		
	25				95% / 92	
	27.5	SANDSTONE: fine to very fine grained, silty, weakly cemented, with several very thin mudstone layers 29.5' to 30.5'				
	30					
		... becomes clean below 32.8'	SS	Run 3 NX		
	35				75% / 75	
		...becomes medium grained, conglomeratic 37.2' to 38.3' with patchy yellow-green and black minerals				
	40	... thin mudstone 38.3' to 41.0'				

Well Completion Detail



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Monitoring Well Record 1328

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 9830.36 N 10,411.70 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 9, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD	Graphic Log	DEPTH (Feet)
	40	Same as 27.5' to 40.0'	MS	Run 3 NX			40
	41.0	SANDSTONE: Brownish-red, fine grained, well sorted, subrounded-rounded, silty to 42.4, then clean. Weakly cemented. Cross bedded to 53'	SS	Run 4 NX			
	45	... Thin mudstone layers 44.3' to 44.4' and 46.8' to 47'			97% / 97		45
	50			Run 5 NX			50
	55	... becomes hard, medium grained, slightly conglomeratic 56.4' to 57.7' with calcite, gypsum cement			75% / 75		55
	57.7	MUDSTONE: sandy, very fine to fine grained with reduction spots	MS				
	60						60
	61.0	SANDSTONE: brownish-red, fine grained, well sorted, rounded, moderately cemented, clean to slightly silty	SS	Run 6 NX			
	65	... mudstone layer 65.1' to 67.0'			79% / 79		65
	70			Run 7 NX			70
	75				79% / 79		75
	80						80

Well Completion Detail

Portland Cement/ Sodium Bentonite Grout

2" I.D. SCH 40 PVC Flush-threaded

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Monitoring Well Record 1328

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 9830.36 N 10,411.70 E

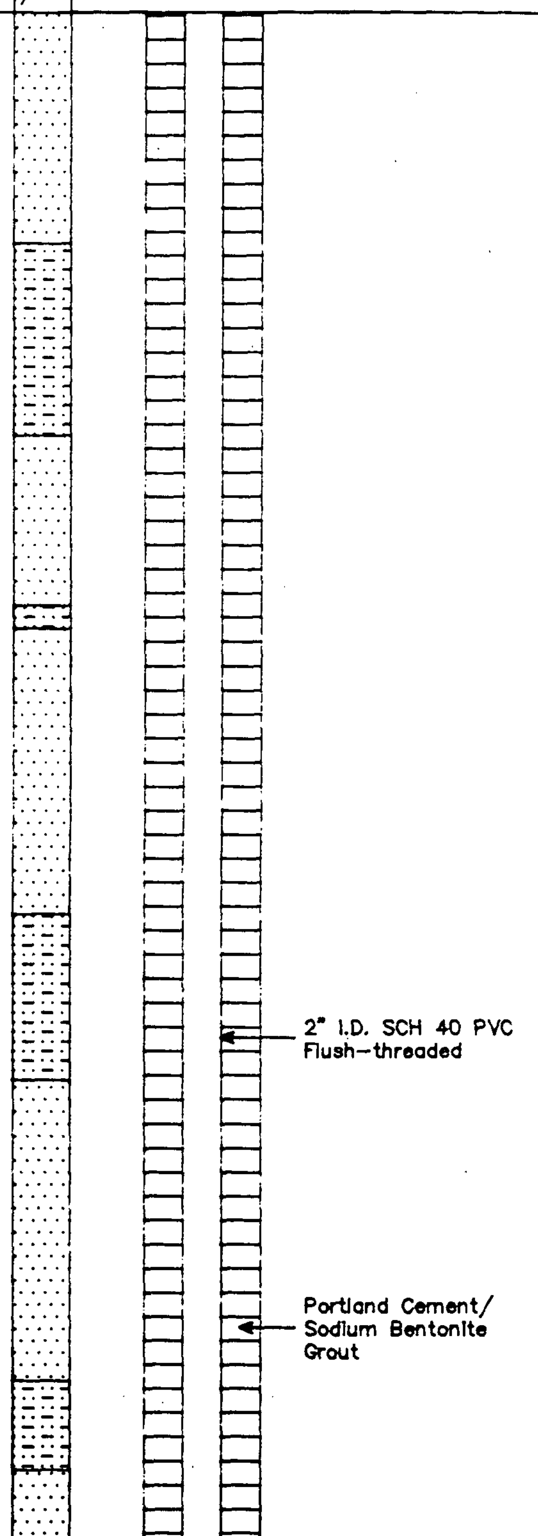
Drilled By WINNEK, INC. Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 9, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	80	SANDSTONE: fine grained, well sorted, rounded, slightly silty ... becomes fine to medium grained 81' to 84.1', well sorted, subangular to subrounded, moderate to well cemented with calcite and gypsum, vug-like porosity, salt and pepper with dark minerals and bitumen ... becomes siltier, finer grained, more weakly cemented below 84.1'	SS	Run 8 NX	95% / 95
	86.0	MUDSTONE: reddish-brown, slightly sandy	MS		
	91.0	SANDSTONE: fine grained, silty, well sorted, rounded ... Hard, well cemented layer 94.5' to 95.4' ... Mudstone layer 95.4' to 96.0'	SS	Run 9 NX Run 10 NX	49% / 49
	103.4	MUDSTONE: reddish-brown, slightly sandy	MS		76% / 75
	107.7	SANDSTONE: brownish-red, fine grained, well sorted, rounded to subrounded, fairly clean.	SS	Run 11 NX	
	115.5	MUDSTONE: reddish-brown, slightly sandy	MS		90% / 90
	117.8	SANDSTONE: brownish-red, fine grained, well sorted, rounded to subrounded, fairly clean.	SS		
	120				

Well Completion Detail



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Monitoring Well Record 1328

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 9830.36 N 10,411.70 E

Drilled By WINNEK, INC. Drilling Method CORE

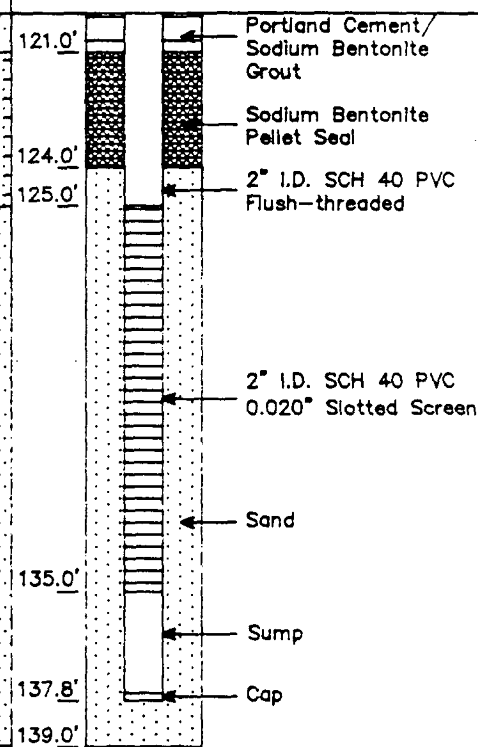
Logged By PFB Checked By SLW

Installation Date March 9, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log
	120 – 121.0	Same as 117.8' to 120.0'	SS				
	121.0 – 125.0	MUDSTONE: reddish-brown, slightly sandy with occasional reduction spots ... becomes sandier below 123.5'	MS	Run 12 NX			
	125.0 – 139.0	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, slightly silty, moderately cemented	SS	Run 13	75% / 75; 98% / 98		
	139.0	B.T. @ 139.0'					

Depth scale (Feet): 120, 125, 130, 135, 140, 145, 150, 155, 160

Well Completion Detail



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Monitoring Well Record 1328

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 9830.36 N 10,411.70 E

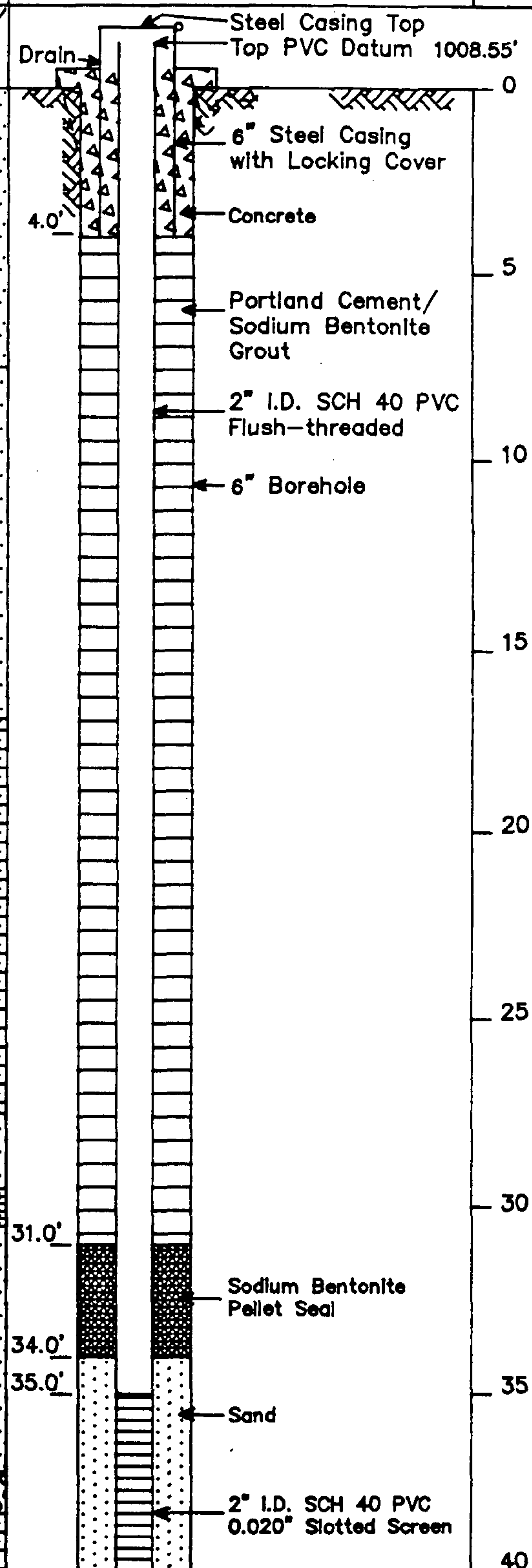
Drilled By WINNEK, INC. Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 9, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log
	0	Ground Surface 1005.9'					
		Loose to very dense, brownish-red, Silty SAND	SM				
	7.5	SANDSTONE: brownish-red, fine grained, silty to 12'	SS				
		... then becoming clean, medium grained, hard, crossbedded					
	16.9	MUDSTONE: reddish-brown, slightly sandy, occasional reduction spots	MS				
	27.5	SANDSTONE: fine to very fine grained, silty, weakly cemented, with several very thin mudstone layers 29.5' to 30.5'	SS				
		... becomes clean below 32.8'					
		...becomes medium grained, conglomeratic 37.2' to 38.3' with patchy yellow-green and black minerals					
	40	...thin mudstone 38.3' to 41.0'					

Well Completion Detail



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Monitoring Well Record 1329

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

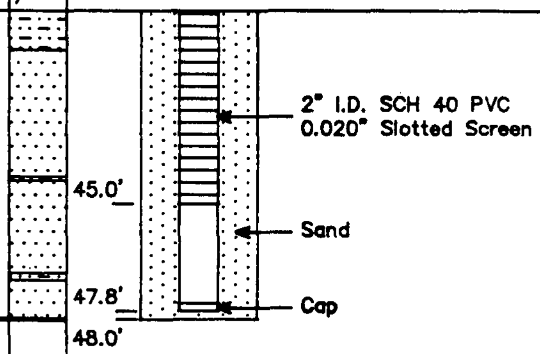
Coordinates 9835.39 N 10,405.36 E

Drilled By WINNEK, INC. Drilling Method WET ROTARY

Logged By PFB Checked By SLW

Installation Date March 10, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40								40
	41.0	Same as 27.5' to 40.0'	MS						
		SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, silty to 42.4', then clean. Weakly cemented. Cross bedded to B.T. depth. Thin mudstone layers 44.3' to 44.4' and 46.8' to 47'	SS						
	45								45
	48.0								
	50	B.T. @ 48.0'							50
	55								55
	60	NOTE: Descriptions taken from Well 1328 located 8' NW of this location.							60
	65								65
	70								70
	75								75
	80								80



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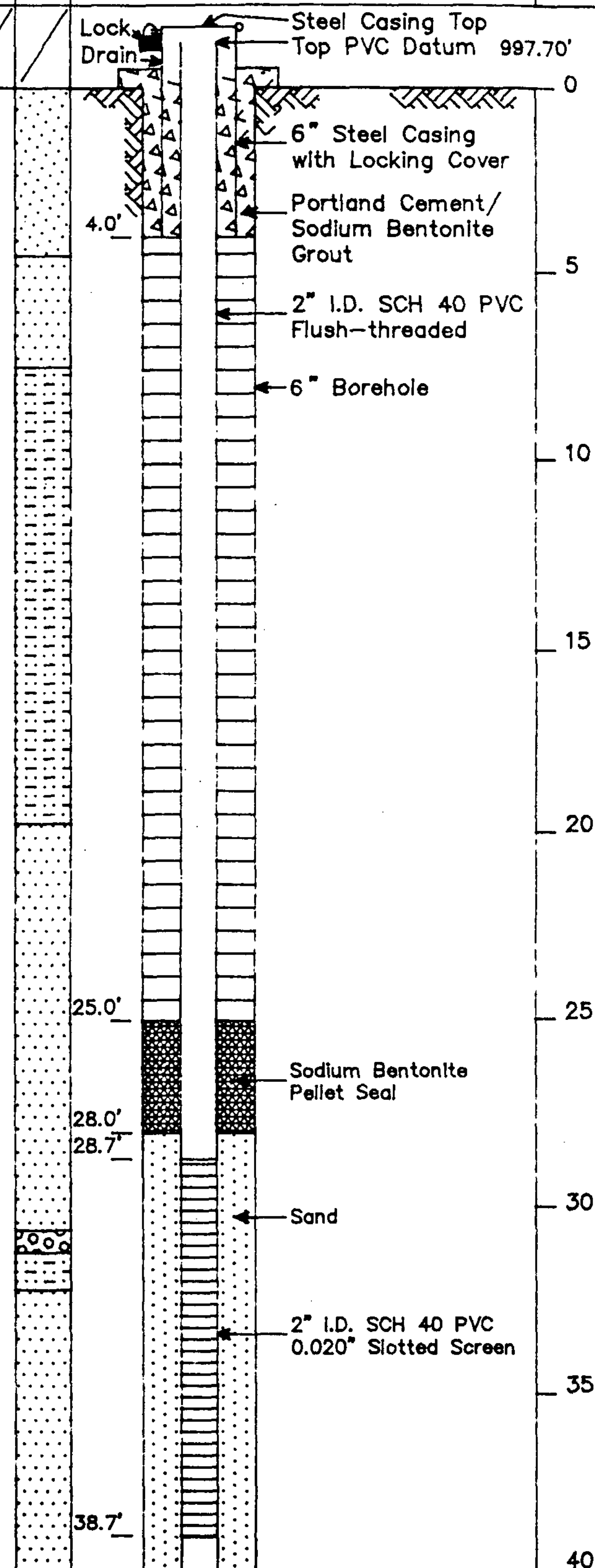
Monitoring Well Record 1329

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 9835.39 N 10,405.36 E
Drilled By WINNEK, INC. **Drilling Method** WET ROTARY
Logged By PFB **Checked By** SLW
Installation Date March 10, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Core run size	Rec. RQD	Graphic Log
	0	Ground Surface 995.3'				
	0–4.5	Loose to very dense, fine to very fine, Silty SAND, some roots and organic material	SM		4	
	4.5–7.5	SANDSTONE: brownish-red, fine grained, well sorted, rounded. Becomes medium grained, pinkish gray, with black tarry spots	SS			
	7.5–19.7	MUDSTONE: reddish brown, occasional reduction spots	MS	Run 1 NX	20% / 20	
		... becomes sandy below 17.5'		Run 2 NX	95% / 95	
	19.7–40	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, moderately cemented, slightly silty, calcareous	SS	Run 3 NX	73% / 73	
		... becomes clean below 24.5'				
		... becomes cross bedded below 29'				
		... becomes fine to medium grained, conglomeratic 30.6' to 31.2' with mudstone clasts, patchy yellow-green minerals thin mudstone layer 31.2' to 32.2'		Run 4 NX	90% / 90	
		... cross bedded 34.5' to 40.0'		Run 5 NX	96% / 96	
	40					

Well Completion Detail



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Monitoring Well Record 1330

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

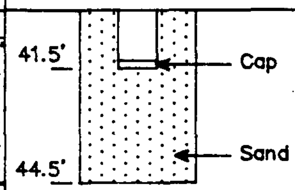
Coordinates 9657.06 N 10,231.32 E

Drilled By WINNEK,INC. Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 10, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Core run size	Rec. / RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	SANDSTONE: fine grained, well sorted, subrounded, weakly to moderately cemented. Thin mudstone layer 40.7' to 40.9'	SS	Run 6 NX	76% / 76				40
	44.5	B.T. @ 44.5'							
	45								45
	50								50
	55								55
	60								60
	65								65
	70								70
	75								75
	80								80



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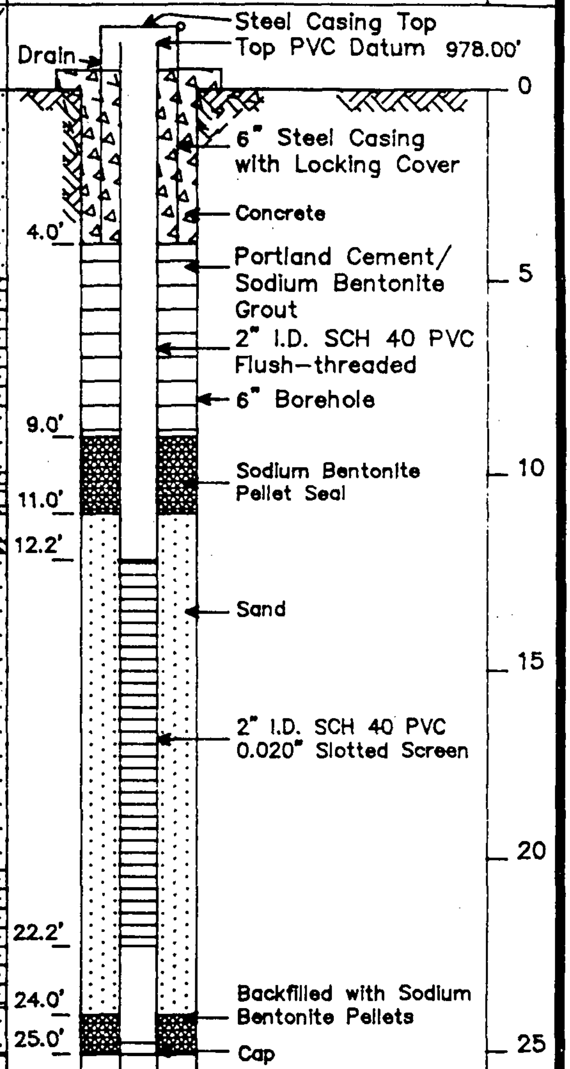
Monitoring Well Record 1330

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 9657.06 N 10,231.32 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 10, 1989

Monitoring Well Record 1331

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD	Graphic Log
		Ground Surface 975.3'				
	0	Firm to very dense, brown to reddish-brown, Silty fine SAND	SM		13	
					43	
	4.9				78+	
	5	MUDSTONE: reddish-brown, sandy, very fine grained with occasional reduction spots	MS	Run 1 NX		
	8.2	SANDSTONE: Brownish-red, fine grained, well sorted, subrounded to rounded, weakly cemented, slightly calcareous. ...Thin mudstone layers at 9.9' to 10.4', 10.8' to 11.0', 20.2' to 23.8' ...Fine to medium grained and conglomeratic 11.7' to 12.0'	SS		94% / 94	
	10					
				Run 2 NX	36% / 36	
	15	...cross bedded below 15'		Run 3 NX	98% / 98	
	20			Run 4 NX	100% / 100	
				Run 5 NX	100% / 100	
	25.0	B.T. @ 25.0'				
	30					
	35					
	40					

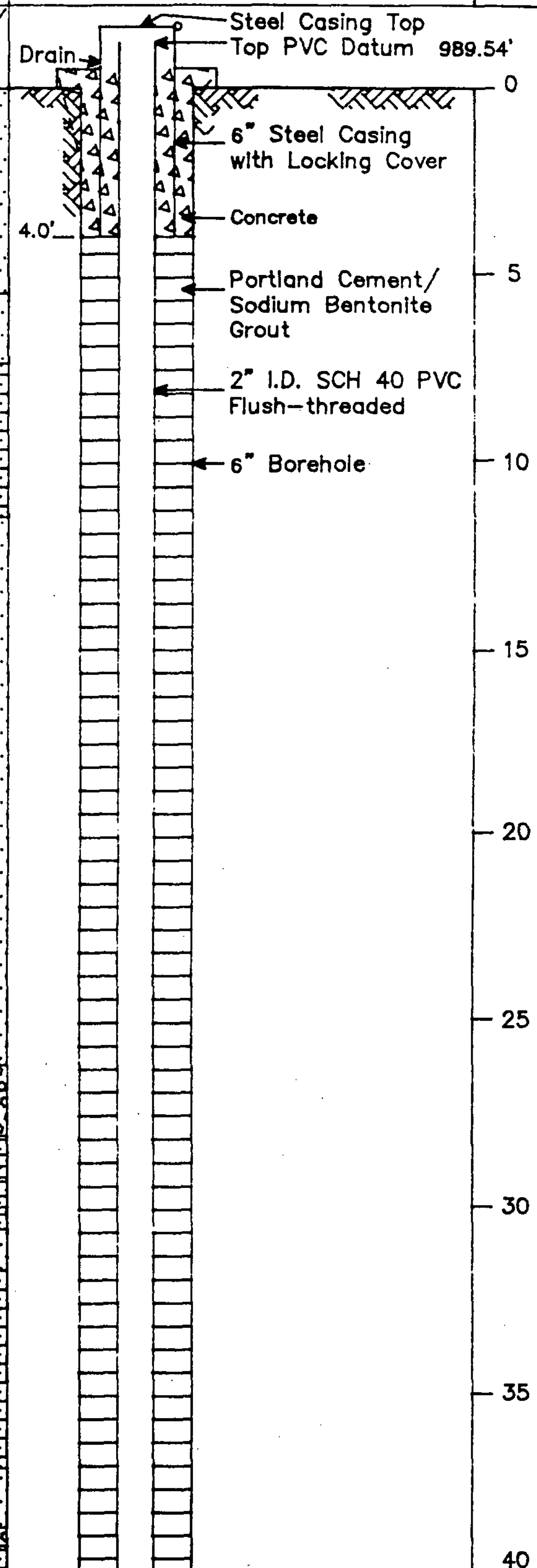
Well Completion Detail



JAMES L. GRANT & ASSOCIATES geotechnical engineering • management • computer science DENVER, COLORADO	Monitoring Well Record 1331 Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA Coordinates 10,751.13 N 10,202.71 E Drilled By WINNEK, INC. Drilling Method CORE Logged By PFB Checked By SLW Installation Date March 11, 1989 Page 1 of 1

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 987.1'			
	0–5.5	Firm to very dense, reddish-brown, Silty fine SAND grading to Sandy SILT	SM-ML		14; 50
	5.5	SANDSTONE: fine to very fine grained, well sorted, subrounded, silty, weakly cemented	SS	Run 1 NX	
	7.4	MUDSTONE: reddish-brown, sandy, very fine grained	MS		76% / 76
	11.5	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, slightly silty	SS	Run 2 NX	80% / 80
		... becomes clean, cross bedded below 17.0'		Run 3 NX	70% / 70
				Run 4 NX	70% / 70
		... becomes fine to medium grained, conglomeratic 26.2' to 28.1' with sandstone and mudstone clasts, calcite and gypsum cement ... thin mudstone layers 28.1' to 28.6', 28.9' to 29.3', 29.7' to 30.0', 30.2' to 30.6'		Run 5 NX	79% / 79
	31.7	MUDSTONE: reddish-brown, sandy, very fine grained	MS	Run 6 NX	90% / 90
	37.0	SANDSTONE: fine to very fine grained, silty ... becomes conglomeratic 38.6 to 39.1, bluish-gray	SS		
	39.1	MUDSTONE: reddish-brown, sandy, very fine grained	MS		
	40				

Well Completion Detail



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Monitoring Well Record 1332

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,686.36 N 10,457.35 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 13, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Core run size	Rec. / RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	MUDSTONE: reddish-brown, sandy, very fine grained, weakly cemented. Reduction zone 44.0' to 44.4'	MS	Run 7 NX	64% / 64				40
	44.4 / 45	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, weak to moderate cement, slightly calcareous, silty, occasional cross bedded intervals		Run 8 NX	44% / 44				45
	50			Run 9 NX	50% / 50			Portland Cement/ Sodium Bentonite Grout	50
	55		SS	Run 10 NX	100% / 100			2" I.D. SCH 40 PVC Flush-threaded	55
	60			Run 11 NX	100% / 100				60
	65	... conglomeratic with sandstone, mudstone clasts, patchy yellow-green minerals and vug-like porosity 63.5' to 64.1', 65.8' to 66.8', 68.4' to 69.0'		Run 12 NX	96% / 96				65
	69.7 / 70	MUDSTONE: reddish-brown, sandy, very fine grained, weakly cemented.							70
	75	--							75
	80	... mudstone conglomerate 77.8' to 78.6'		Run 13 NX					80

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Monitoring Well Record 1332

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,686.36 N 10,457.35 E

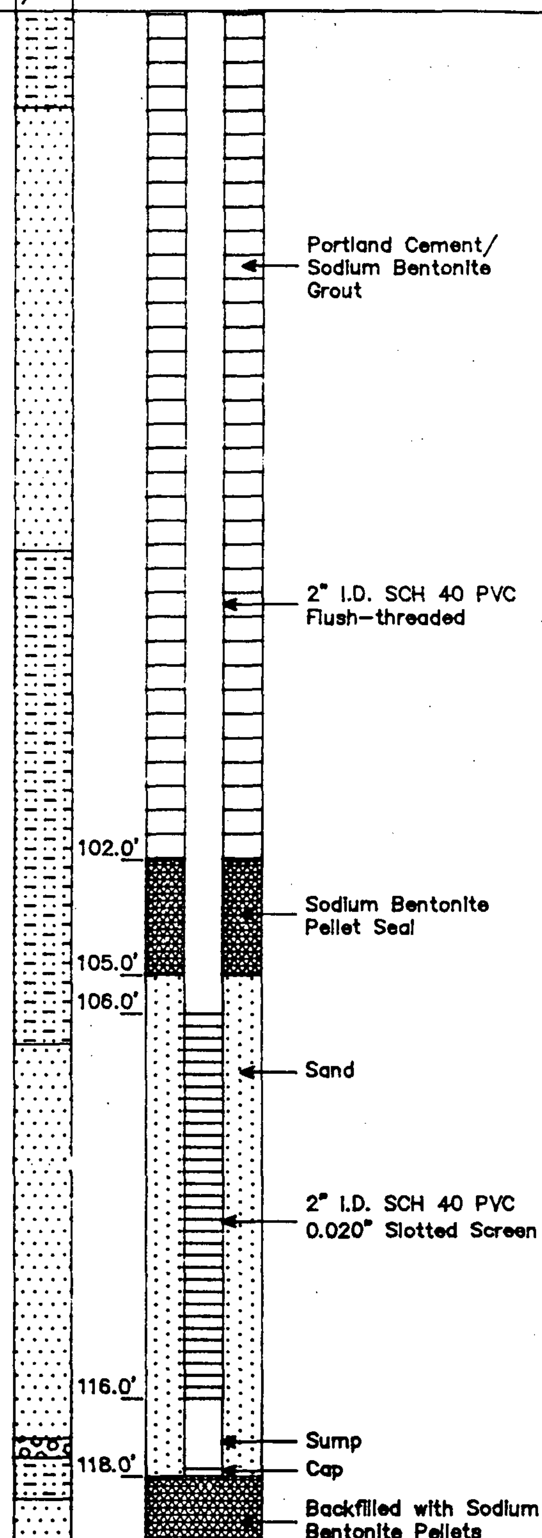
Drilled By WINNEK, INC. Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 13, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Core run size	Rec. / RQD
	80–82.5	MUDSTONE: reddish-brown, sandy, very fine grained	MS	Run 13 NX	95% / 95
	82.5–94.0	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, slightly silty, cross bedded, slightly calcareous ... color becomes red and white 89' to 94'	SS	Run 14 NX	85% / 85
	94.0–106.8	MUDSTONE: reddish-brown, sandy, very fine grained	MS	Run 15 NX	57% / 57
	106.8–120	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, slightly silty, cross bedded, slightly calcareous -- ... becomes siltier and conglomeratic 117.0' to 117.5' thin mudstone layer 117.5' to 118.6'	SS	Run 16 NX Run 17 NX	93% / 93 88% / 88

Graphic Log / Well Completion Detail



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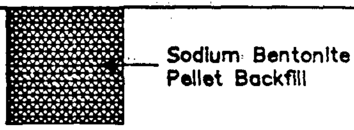
Monitoring Well Record 1332
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,686.36 N 10,457.35 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 13, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	120	Same as 106.8' to 120.0'	SS	Run 17	88% / 88				120
	121.0	MUDSTONE: sandy, very fine grained	MS					123.0'	
	123.0	B.T. @ 123.0'							
	125								125
	130								130
	135								135
	140								140
	145								145
	150								150
	155								155
	160								160



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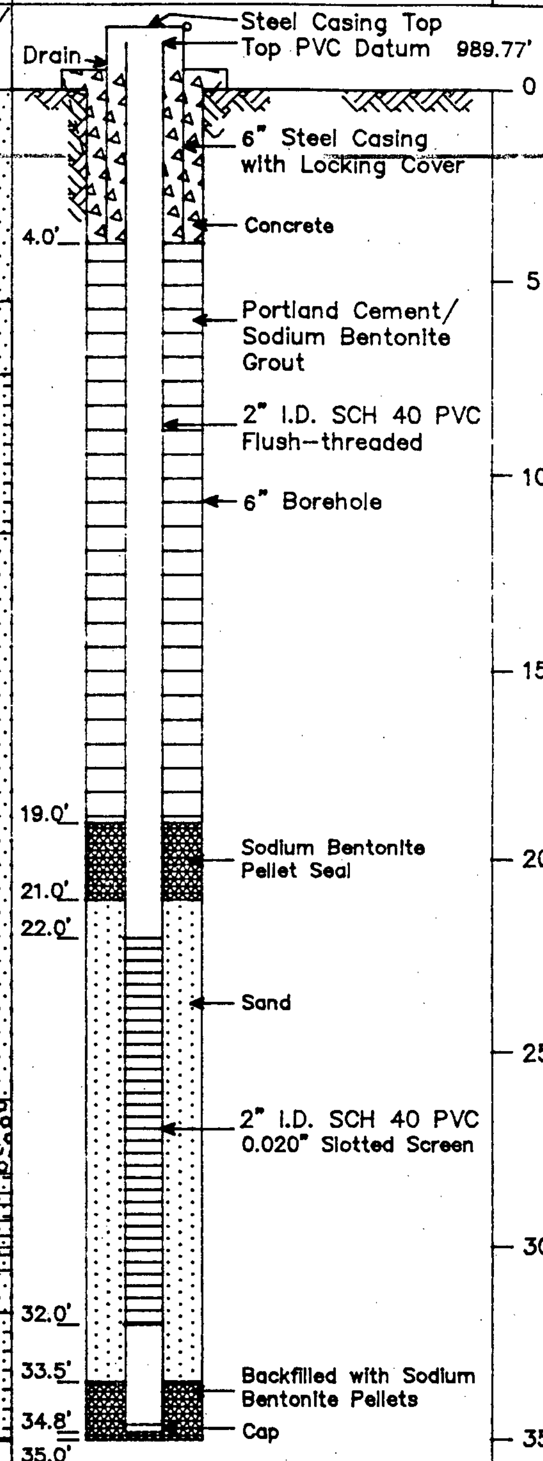
Monitoring Well Record 1332
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,686.35 N 10,457.35 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 13, 1989 Page 4 of 4

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log
	0	Ground Surface 986.8'					
	0–5.5	Firm to very dense, reddish-brown, Silty fine SAND grading to Sandy SILT	SM–ML				
	5.5–7.4	SANDSTONE: fine to very fine grained, well sorted, subrounded, silty, weakly cemented	SS				
	7.4–11.5	MUDSTONE: reddish-brown, sandy, very fine grained	MS				
	11.5–31.7	SANDSTONE: brownish-red, fine grained, well sorted, subrounded to rounded, slightly silty ... becomes clean, cross bedded below 17.0' ... becomes fine to medium grained, conglomeratic 26.2' to 28.1' with sandstone and mudstone clasts, calcite and gypsum cement ... thin mudstone layers 28.1' to 28.6', 28.9' to 29.3', 29.7' to 30.0', 30.2' to 30.6'	SS				
	31.7–35.0	MUDSTONE: reddish-brown, sandy, very fine grained	MS				
	35.0	B.T. @ 35.0'					
	40	NOTE: Descriptions taken from Well 1332 which offsets this location 14' E–NE					

Well Completion Detail



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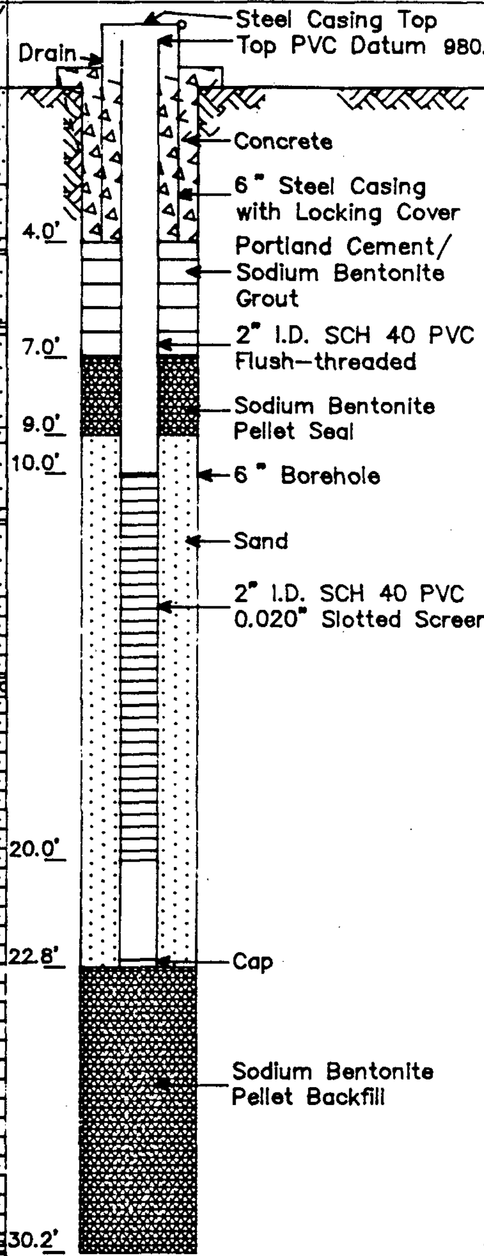
Monitoring Well Record 1333

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,662.97 N 10,442.73 E
Drilled By WINNEK, INC. Drilling Method WET ROTARY
Logged By PFB Checked By SLW
Installation Date March 12 1989 Page 1 of 1

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD
	0	Ground Surface 977.6'			
	0–2.5	Brownish red, Silty, fine SAND, grading to red fine SAND	SP		36; 50
	2.5–7.6	SANDSTONE: fine grained, silty, interbedded with MUDSTONE, sandy, very fine grained	SS	Run 1 NX	94% / 94
	7.6–13.2	SANDSTONE: fine to very fine grained, weakly cemented, cross-bedded, grains subrounded. Silt content about 10% to 20% to 11.0', ... clean below 11.0'	SS	Run 2 NX	44% / 44
	13.2–29.9	MUDSTONE: slightly sandy, reddish brown, occasional grayish-blue reduction spots ... sandy, gray-blue reduction zone at 16.1' to 16.7' ... numerous closely spaced conjugate fractures at 21.0' to 25.2'. Spacing about 2". Some open with black mineral coating surfaces	MS	Run 3 NX; Run 4 NX; Run 5 NX; Run 6 NX	78% / 78; 100% / 100; 98% / 71; 100% / 90
	29.9–30.2	SANDSTONE: conglomeratic with SANDSTONE and MUDSTONE clasts, patchy gray-blue reduction spots	SS		

B.T. @ 30.2'



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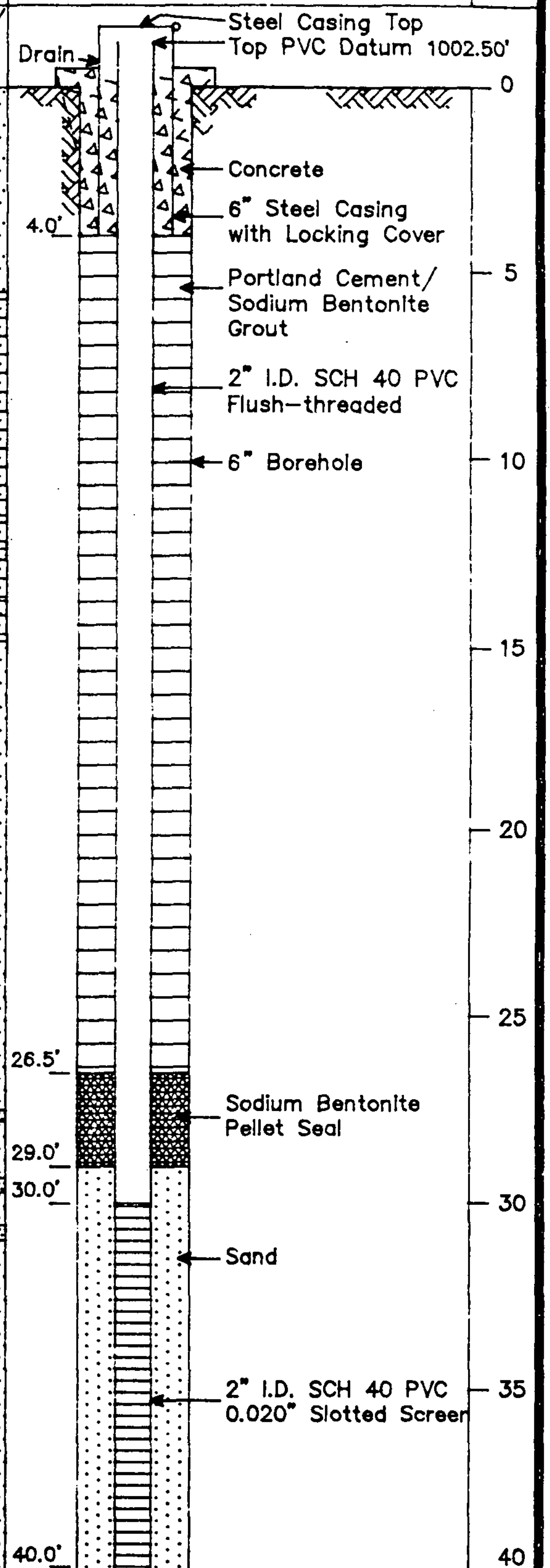
Monitoring Well Record 1334
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 10,688.14 N 10,776.31 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 12, 1989 Page 1 of 1

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD	Graphic Log
	0	Ground Surface 1000.2'				
	0–5.5	Very dense, brownish red slightly Silty SAND	SP		53 57 90	
	5.5–14.9	MUDSTONE: reddish brown, sandy, very fine grained with gray reduction spots and laminae ... becomes interbedded with sandstone at 11.0' to 14.9'	MS	Run 1 NX Run 2 NX	92% / 92	
	14.9–40	SANDSTONE: brownish red, fine grained, well sorted, subrounded to rounded, slightly silty, slightly calcareous, weakly cemented ... becomes very silty at 17.2' to 18.0' ... clean and crossbedded at 18.0' to 27.5' ... becomes interbedded with very sandy siltstone at 27.5' to 31.0'	SS	Run 3 NX Run 4 NX	91% / 91 90% / 90 100% / 100	



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Monitoring Well Record 1335

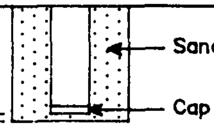
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,944.05 N 11,758.09 E

Drilled By WINNEK, INC. Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 13, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log	Well Completion Detail	DEPTH (Feet)
	40	SANDSTONE: fine to medium grained, well sorted, subrounded to rounded, crossbedded, weakly cemented	SS	Run 4 / NX	100% / 100			42.8' / 43.0' 	40
	43.0	B.T. @ 43.0'							
	45								45
	50								50
	55								55
	60								60
	65								65
	70								70
	75								75
	80								80

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Monitoring Well Record 1335

Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA

Coordinates 10,944.05 N 11,758.09 E

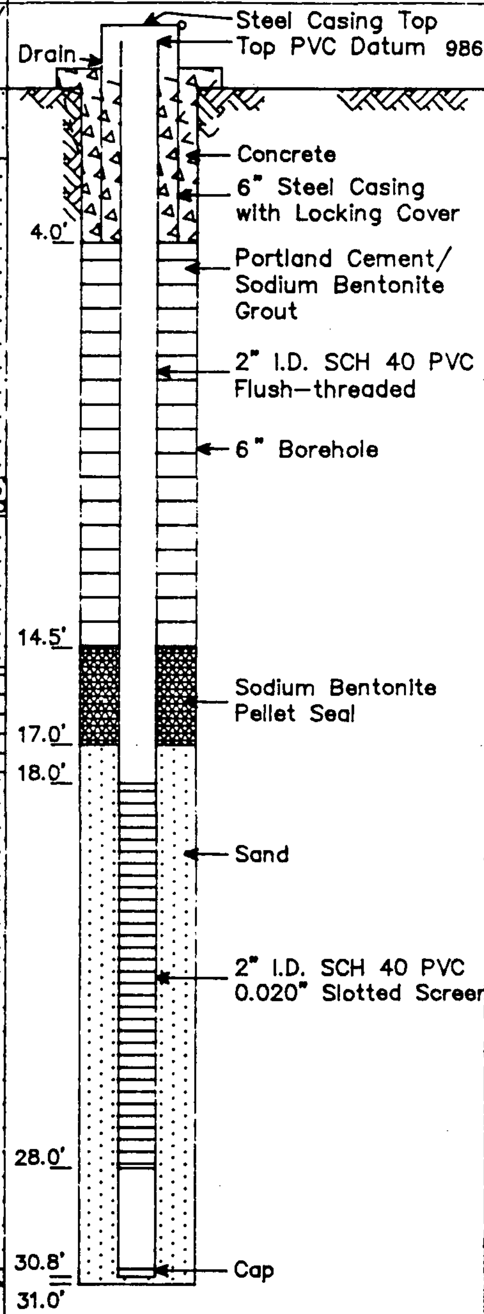
Drilled By WINNEK, INC. Drilling Method CORE

Logged By PFB Checked By SLW

Installation Date March 13, 1989

ELEV. (Feet)	DEPTH (Feet)	Description	USC	Sample Interval / Core Run size	"N" Value / Rec. RQD		Graphic Log
		Ground Surface 984.0'					
	0	Very dense, reddish brown SAND	SP		77		
	1.8	SANDSTONE: brownish red, fine grained, well sorted, subrounded, slightly silty, weakly cemented	SS				
	10	... thin sand mudstone, conglomeratic at 9.9' to 10.9' ... sandstone becomes clean below 11.0'					
	15.0	MUDSTONE: reddish brown, sandy, very fine grained	MS				
	17.7	SANDSTONE: brownish red, fine grained, well sorted, subrounded, slightly silty, weakly cemented ... crossbedded at 24.0' to 26.0' ... conglomeratic at 30.6' to 31.0' with sandstone and mudstone clasts	SS				
	31.0	B.T. @ 31.0'					

Well Completion Detail



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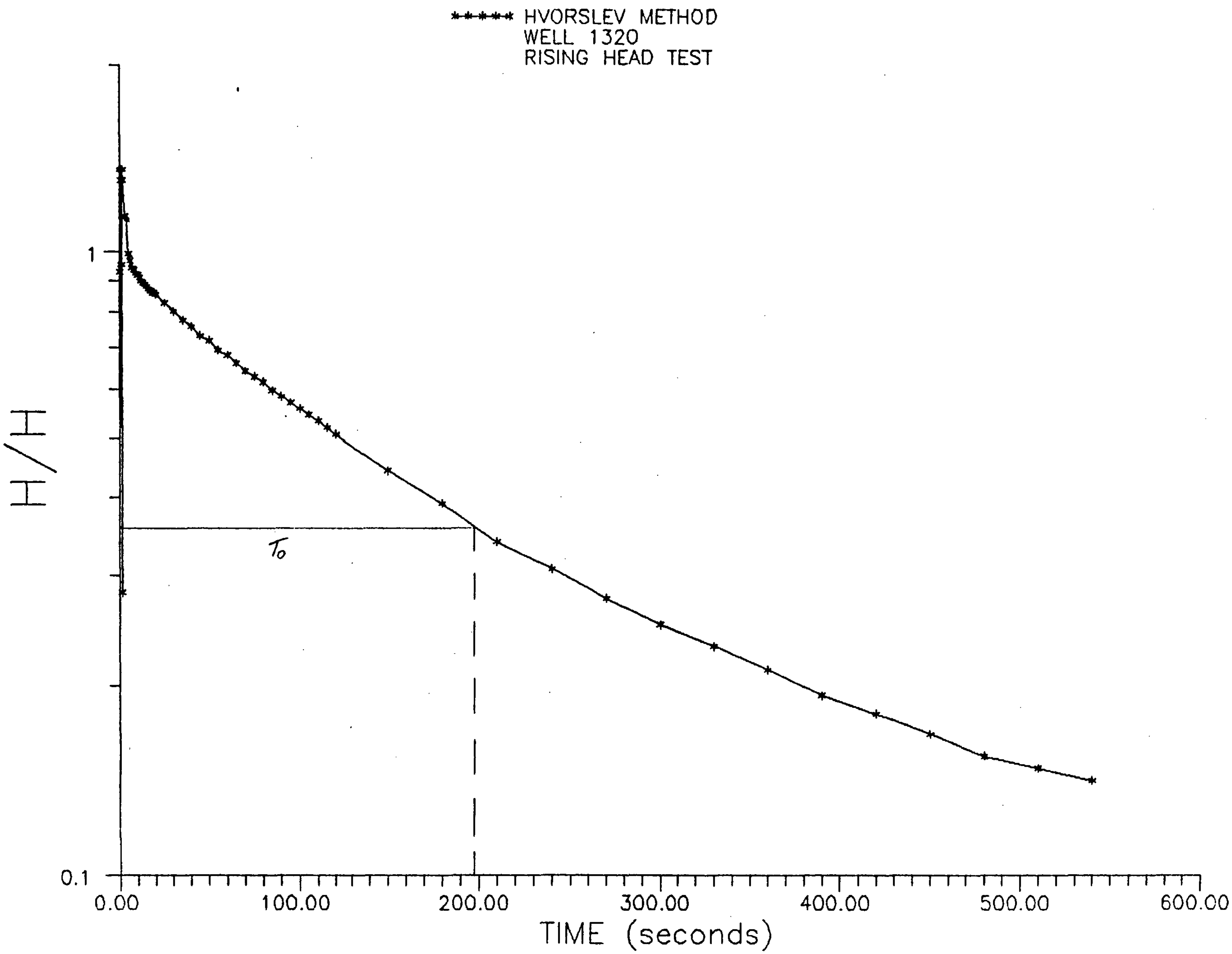
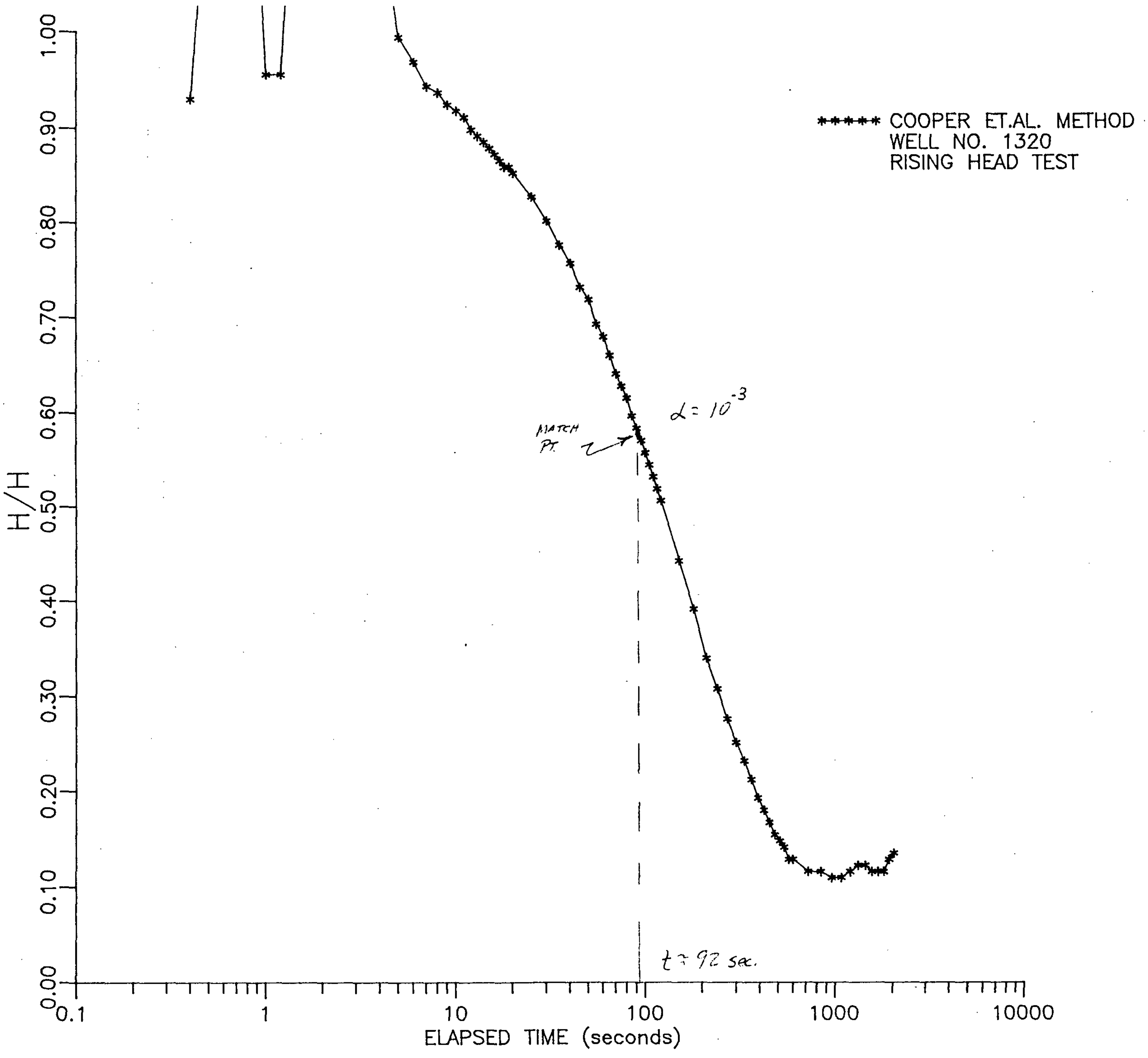
Monitoring Well Record 1336
Location CIMARRON FACILITY, LOGAN COUNTY, OKLAHOMA
Coordinates 11,738.39 N 11,722.31 E
Drilled By WINNEK, INC. Drilling Method CORE
Logged By PFB Checked By SLW
Installation Date March 14, 1989 Page 1 of 1

APPENDIX C

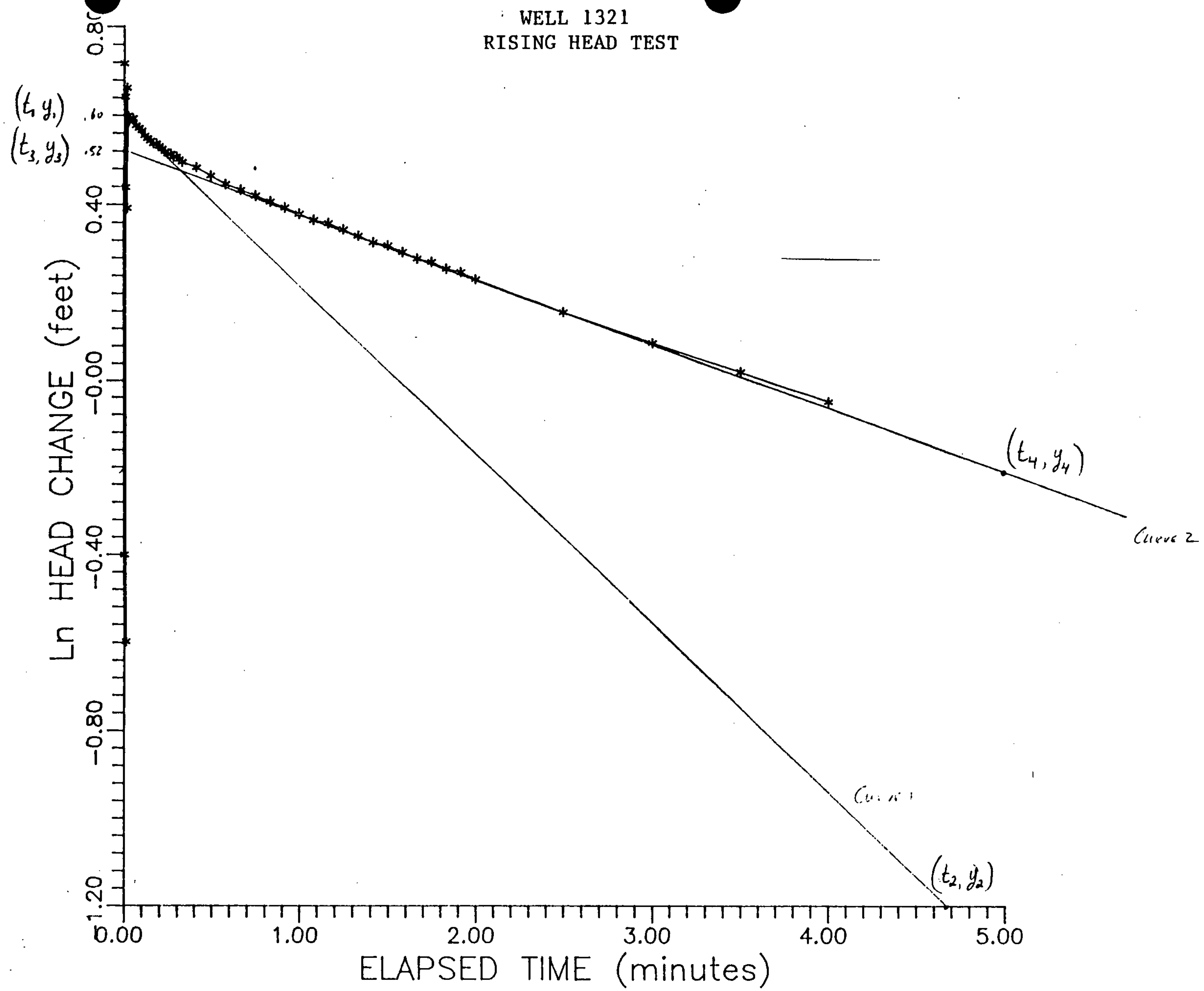
SLUG TEST DATA

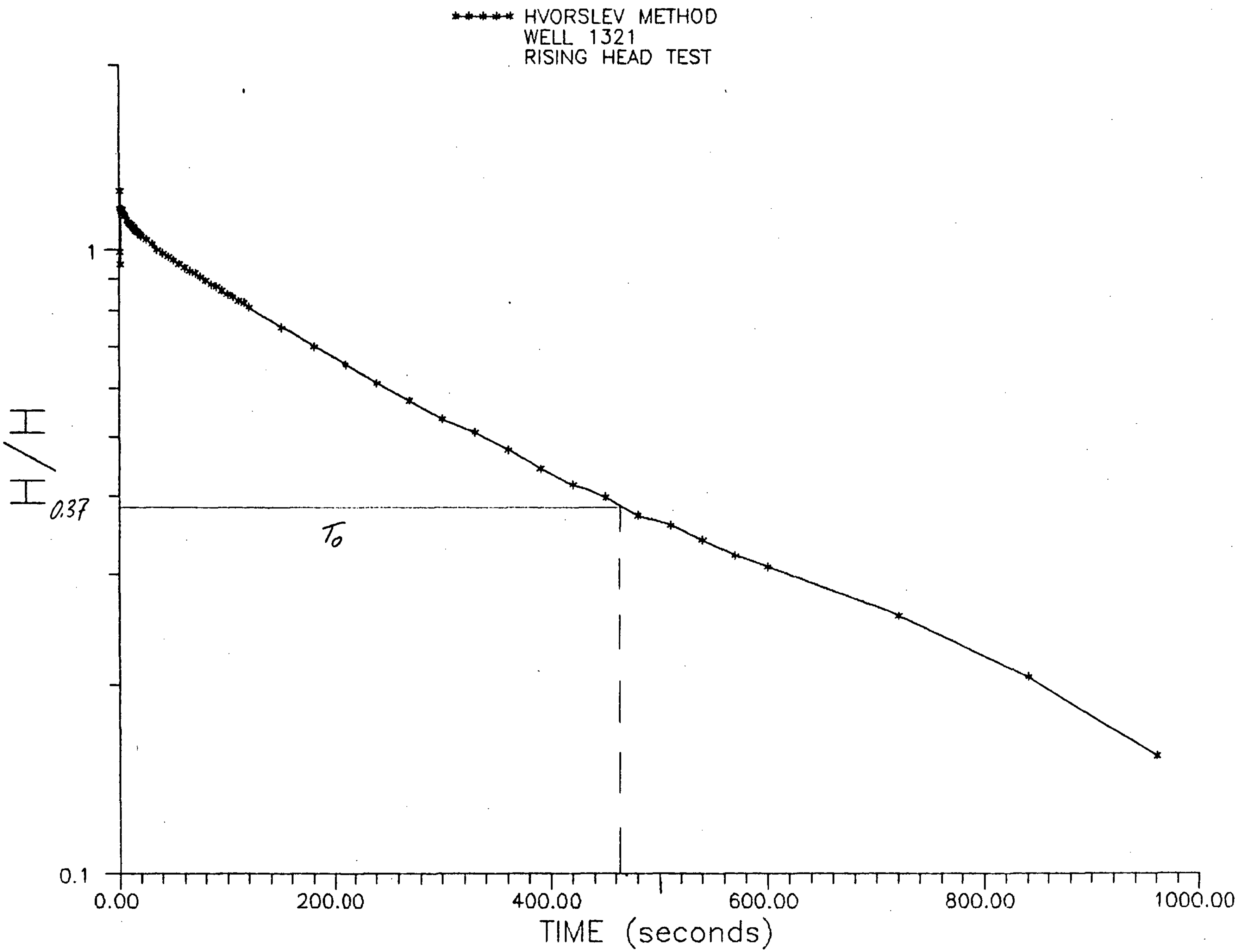


HVORSLEV METHOD
WELL 1320
RISING HEAD TEST
H/H
1
0.1
To
0.00
100.00
200.00
300.00
400.00
500.00
600.00
TIME (seconds)

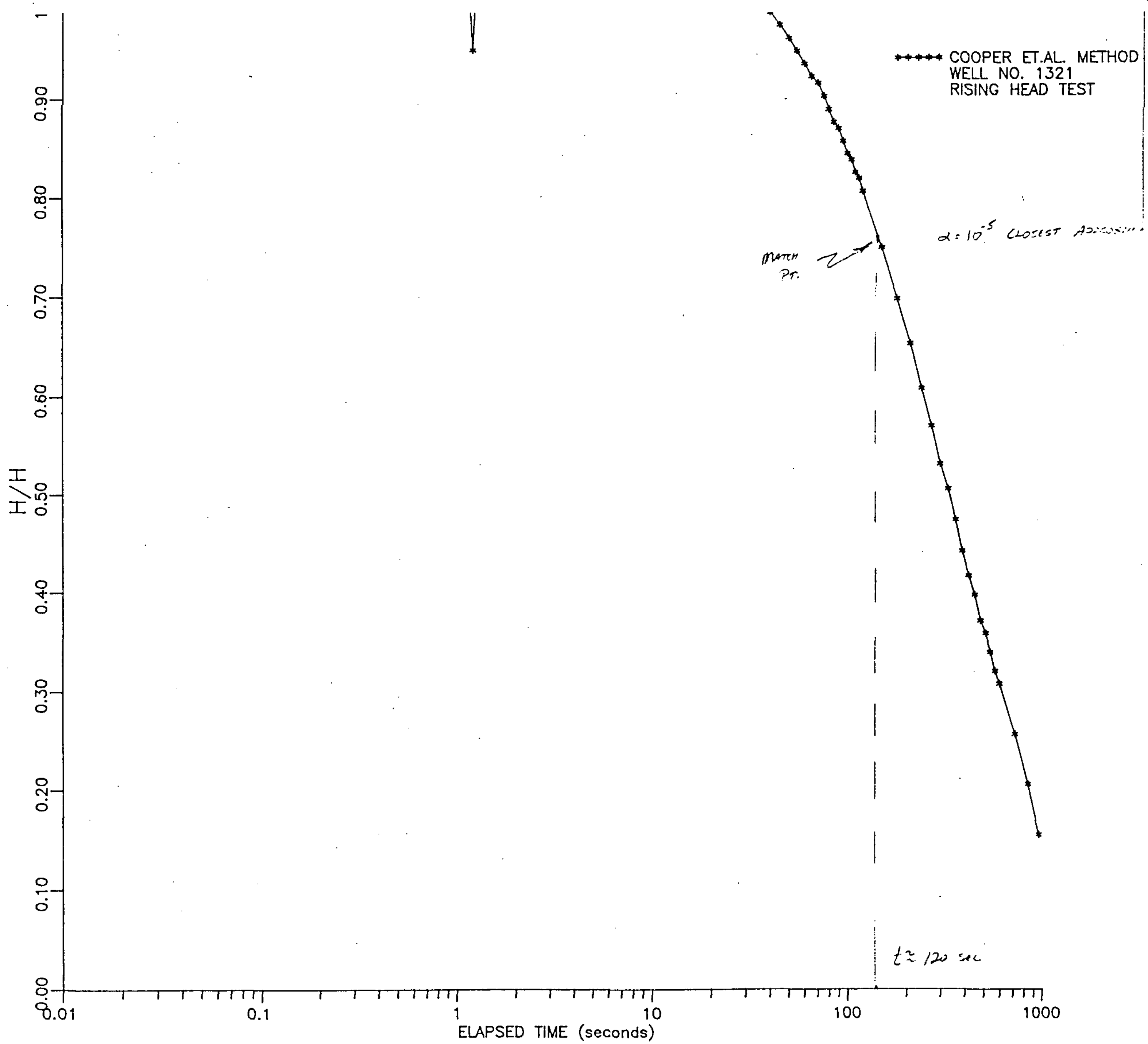


COOPER ET.AL. METHOD
WELL NO. 1320
RISING HEAD TEST
H/H
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.1
1
10
100
1000
10000
ELAPSED TIME (seconds)
MATCH PT.
α = 10^-3
t = 92 sec.

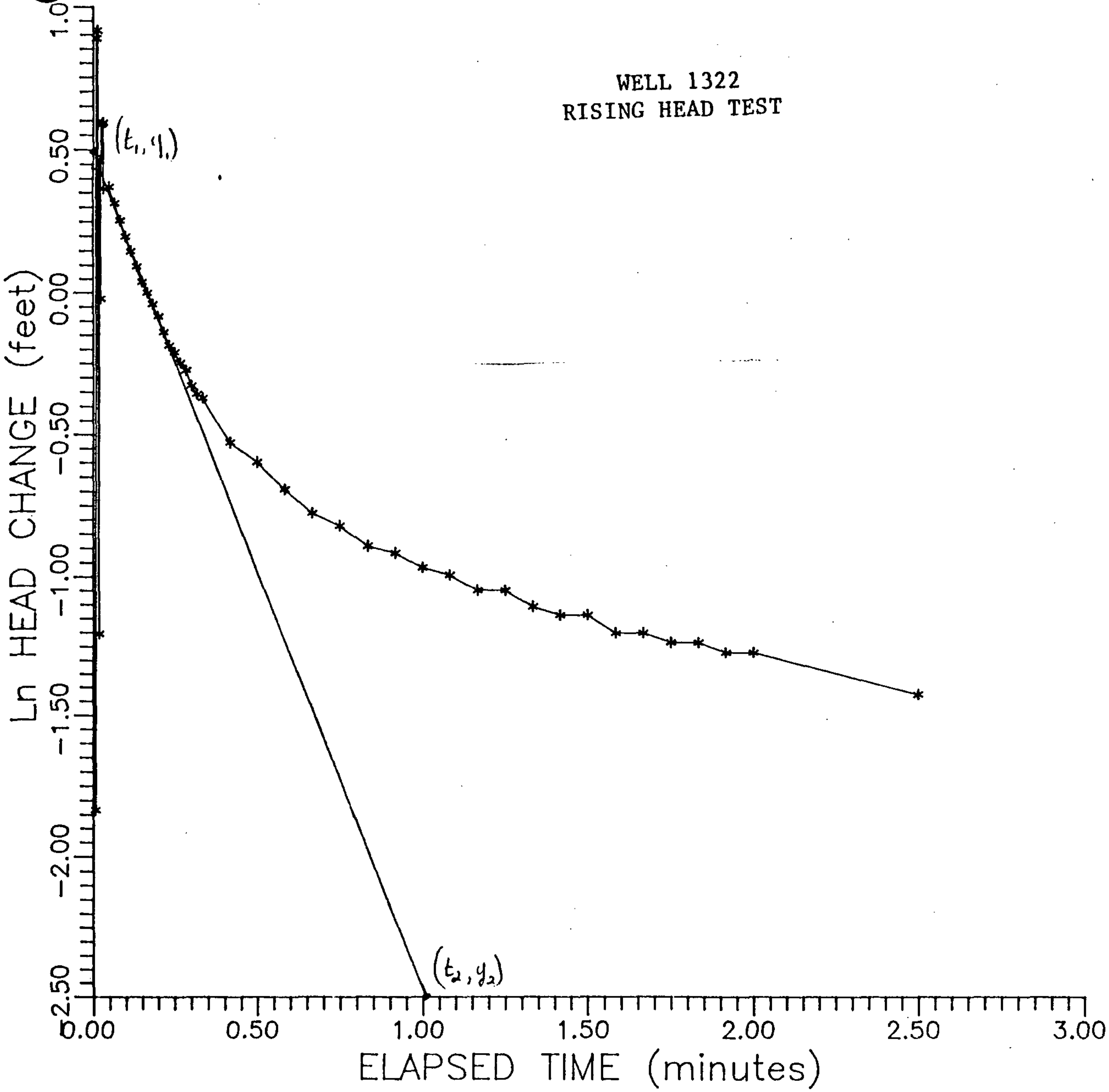

WELL 1321
RISING HEAD TEST
Ln HEAD CHANGE (feet)
0.80
0.40
-0.00
-0.40
-0.80
-1.20
0.00
1.00
2.00
3.00
4.00
5.00
ELAPSED TIME (minutes)
(t_1, y_1)
(t_3, y_3)
.60
.52
(t_4, y_4)
Curve 2
(t_2, y_2)

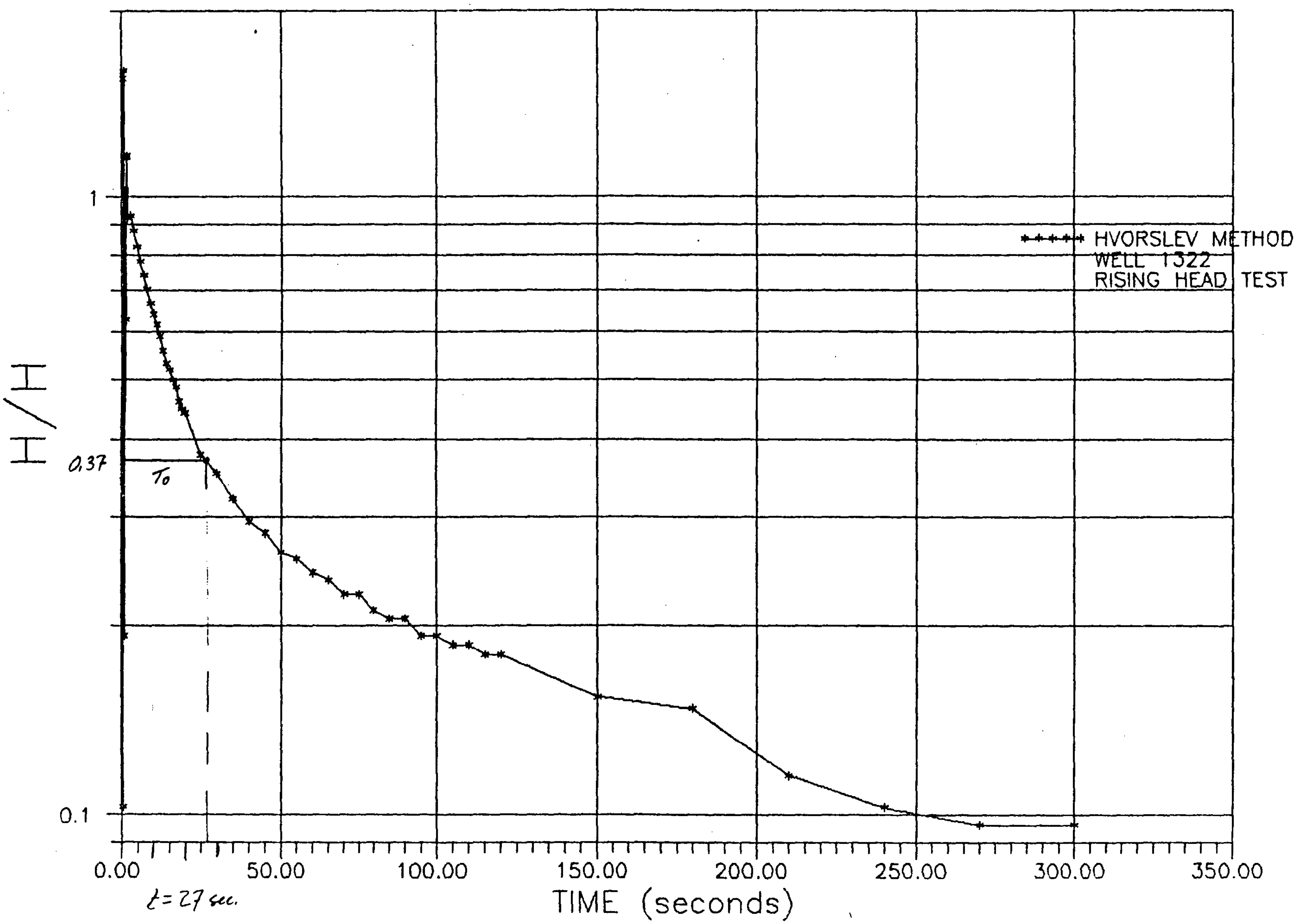


HVORSLEV METHOD
WELL 1321
RISING HEAD TEST
H/H
1
0.37
0.1
To
0.00
200.00
400.00
600.00
800.00
1000.00
TIME (seconds)

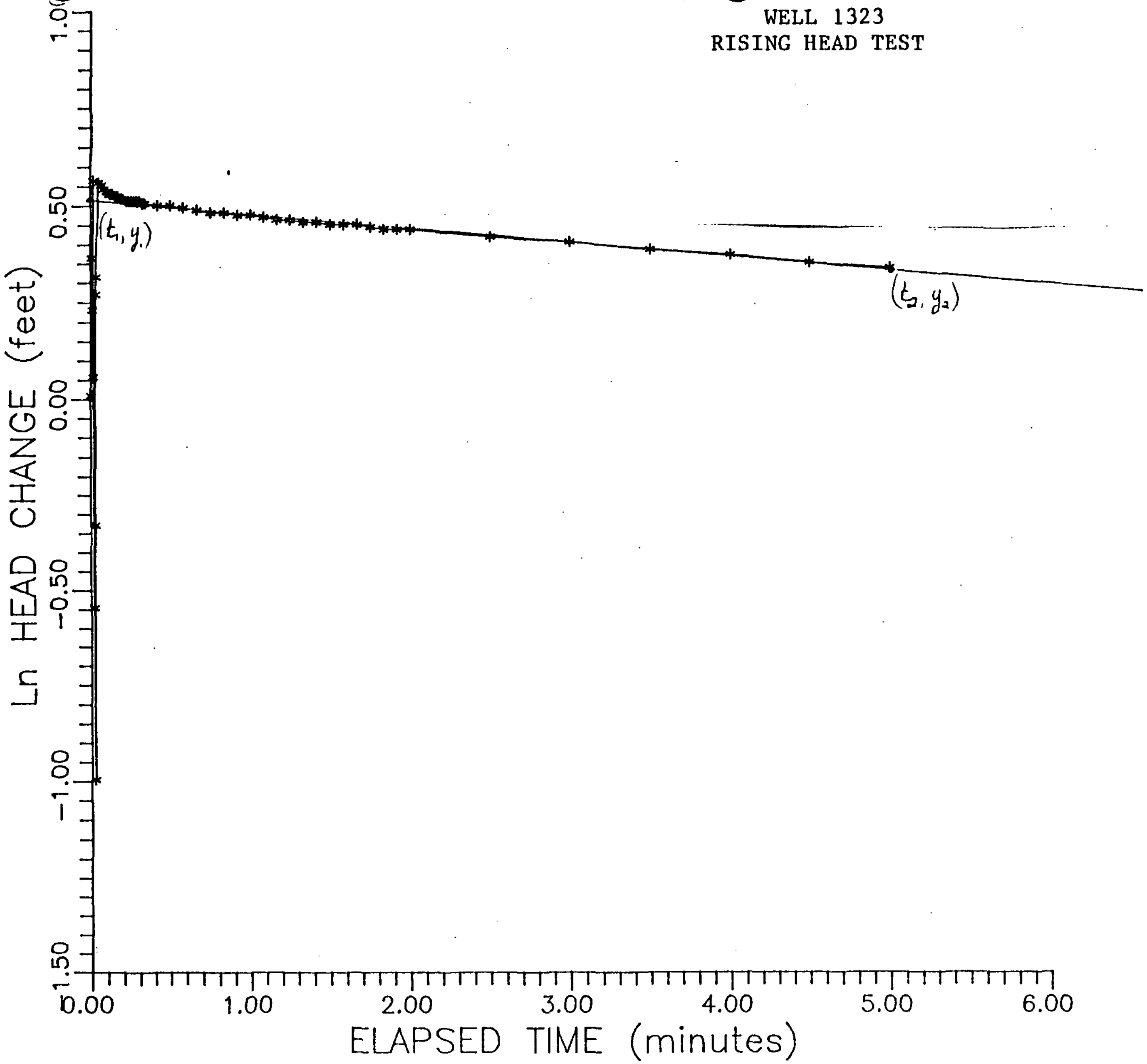


COOPER ET.AL. METHOD
WELL NO. 1321
RISING HEAD TEST
H/H
ELAPSED TIME (seconds)
0.01
0.1
1
10
100
1000
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1

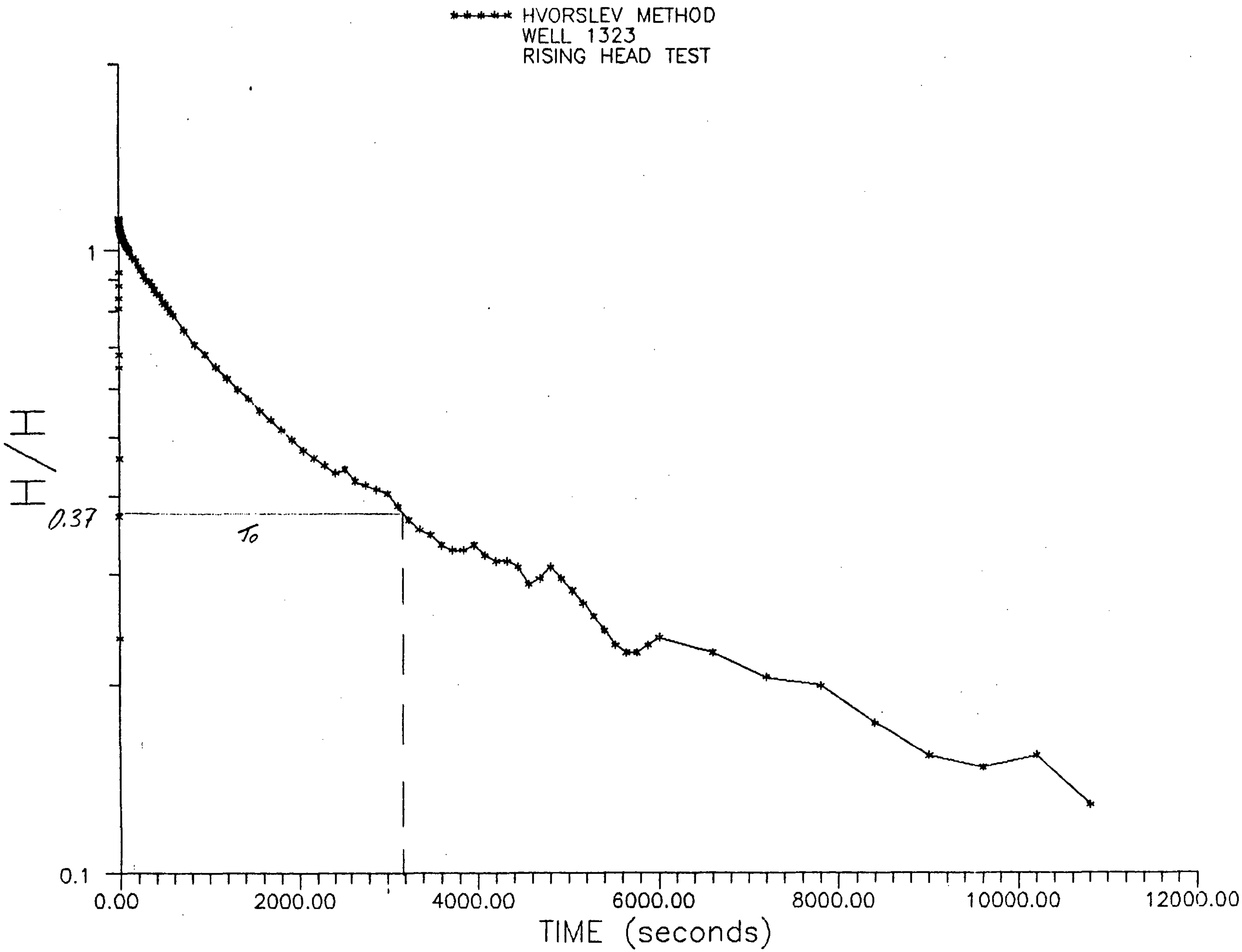

WELL 1322
RISING HEAD TEST
(t_1, y_1)
(t_2, y_2)
Ln HEAD CHANGE (feet)
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
0.00
0.50
1.00
1.50
2.00
2.50
3.00
ELAPSED TIME (minutes)



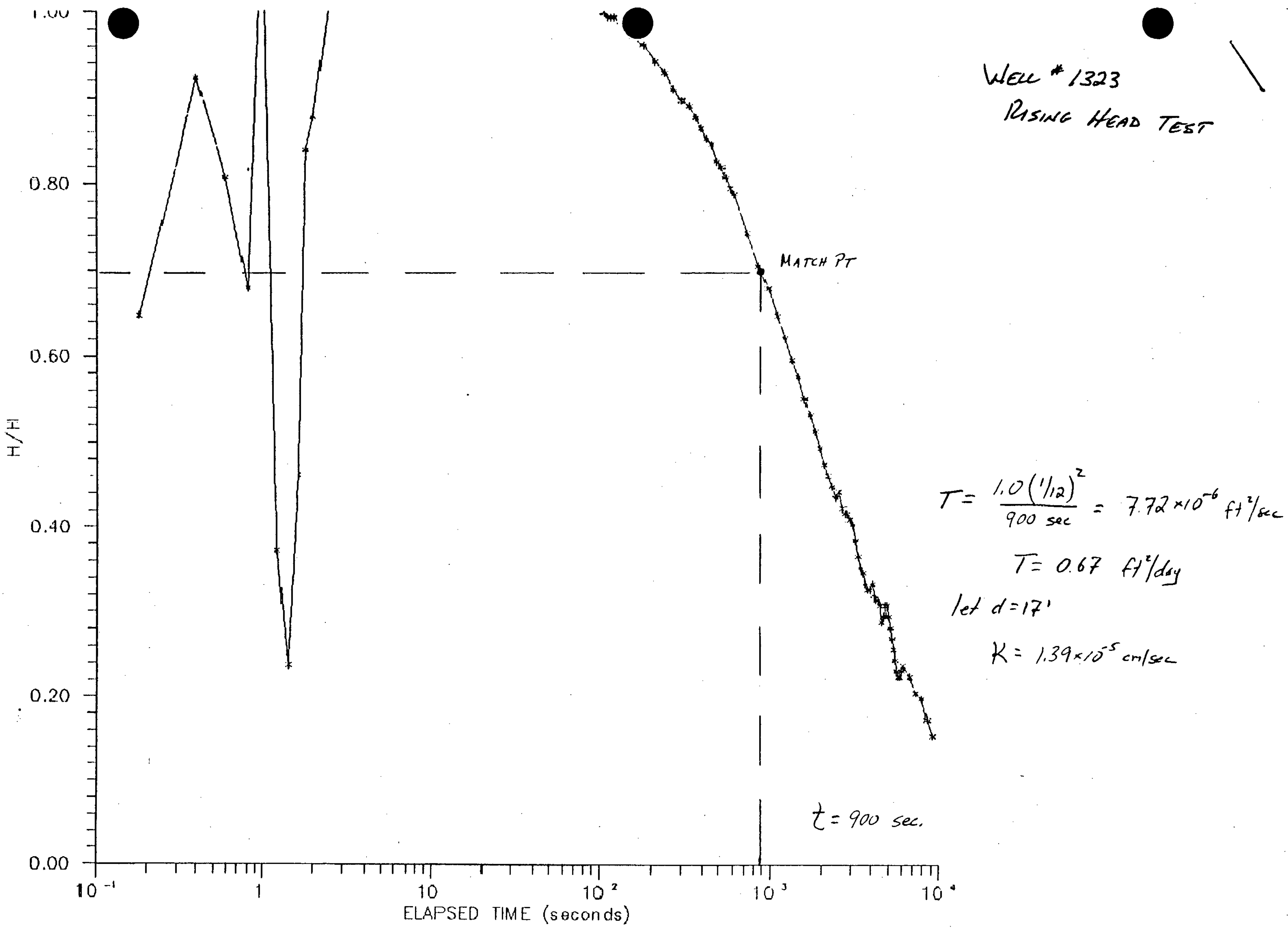
H/H
1
0.37
To
0.1
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
t = 27 sec.
TIME (seconds)
HVORSLEV METHOD
WELL 1322
RISING HEAD TEST



WELL 1323
RISING HEAD TEST
Ln HEAD CHANGE (feet)
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.00
1.00
2.00
3.00
4.00
5.00
6.00
ELAPSED TIME (minutes)
(t1, y1)
(t2, y2)

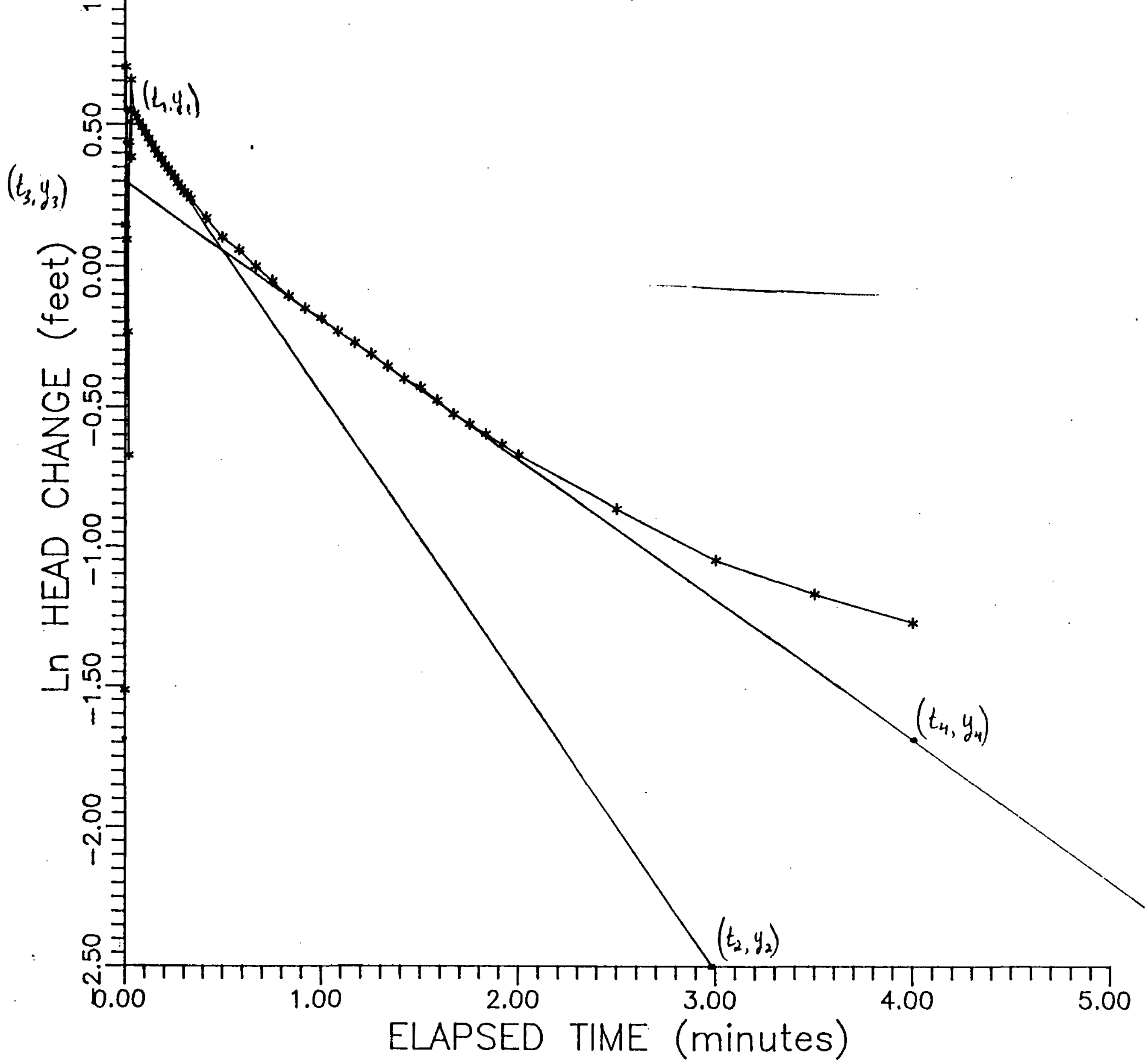


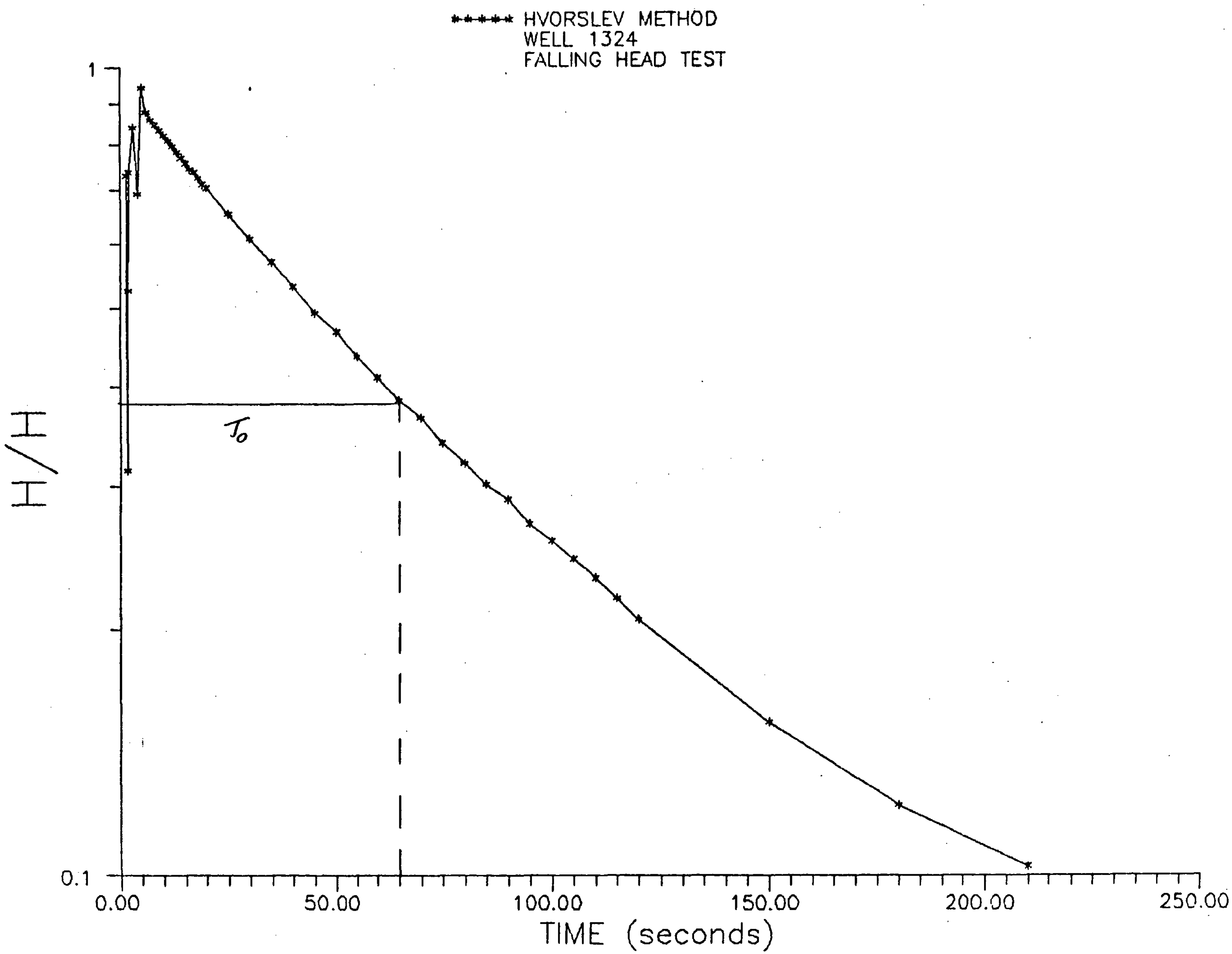
HVORSLEV METHOD
WELL 1323
RISING HEAD TEST
H/H
1
0.37
To
0.1
0.00
2000.00
4000.00
6000.00
8000.00
10000.00
12000.00
TIME (seconds)



WELL # 1323
RISING HEAD TEST
MATCH PT
t = 900 sec.
T = 1.0 (1/12)^2 / 900 sec = 7.72×10^-6 ft²/sec
T = 0.67 ft²/day
let d = 17'
K = 1.39×10^-5 cm/sec
H/H
0.00
0.20
0.40
0.60
0.80
ELAPSED TIME (seconds)
10^-1
1
10
10^2
10^3
10^4

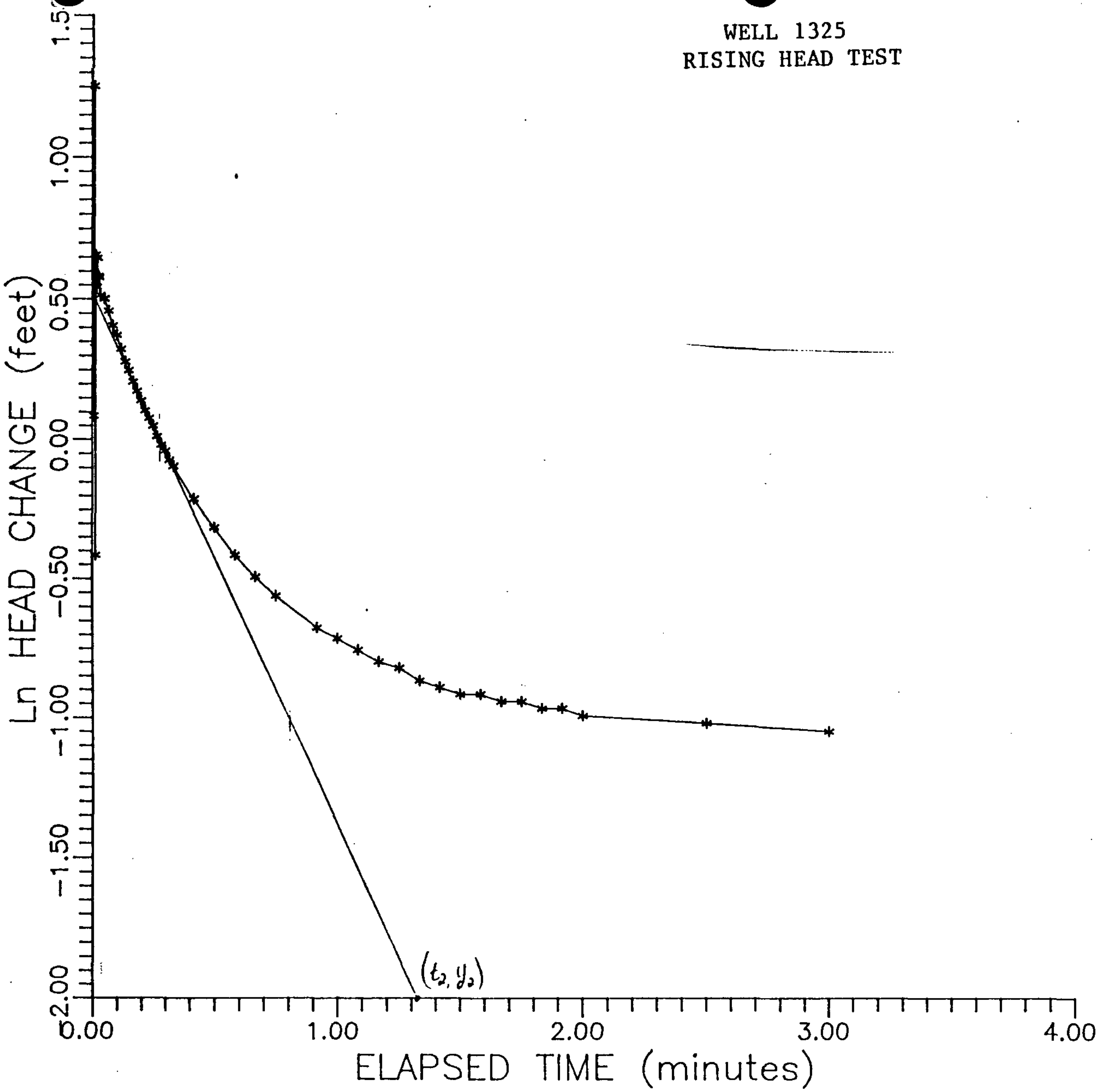
WEL 324
RISING HEAD TEST

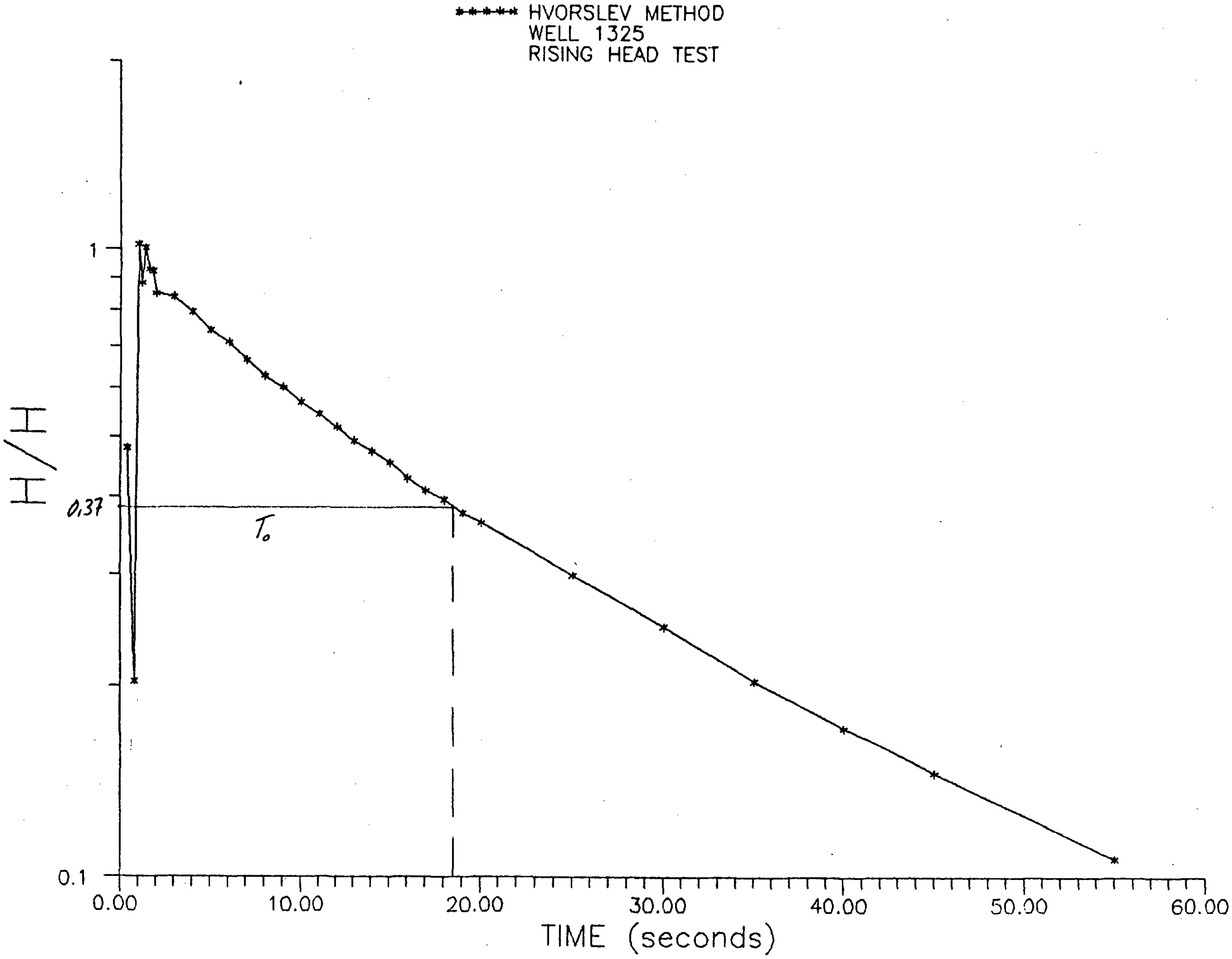




HVORSLEV METHOD
WELL 1324
FALLING HEAD TEST
1
0.1
H/H
T_o
0.00
50.00
100.00
150.00
200.00
250.00
TIME (seconds)

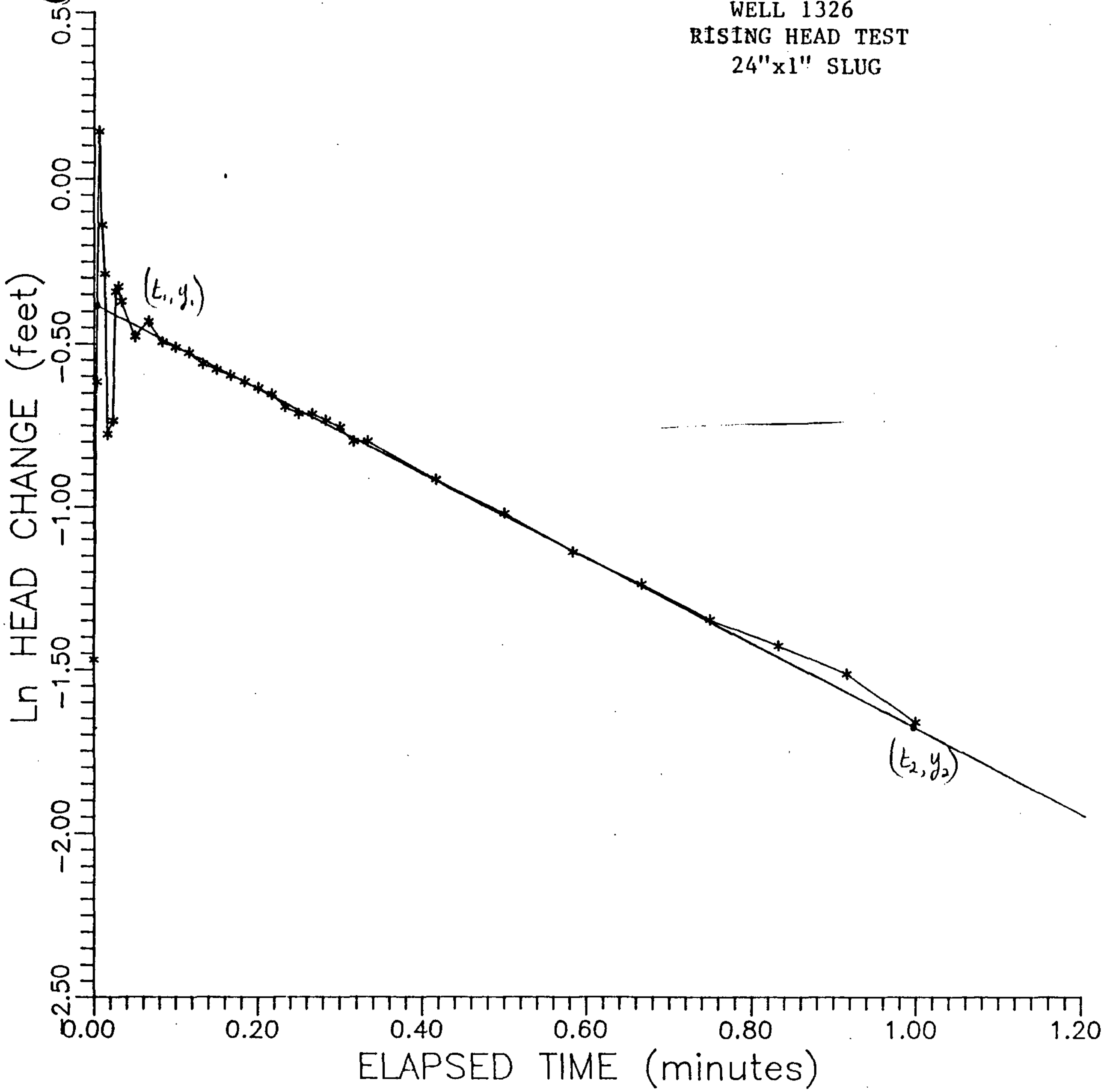
WELL 1325
RISING HEAD TEST

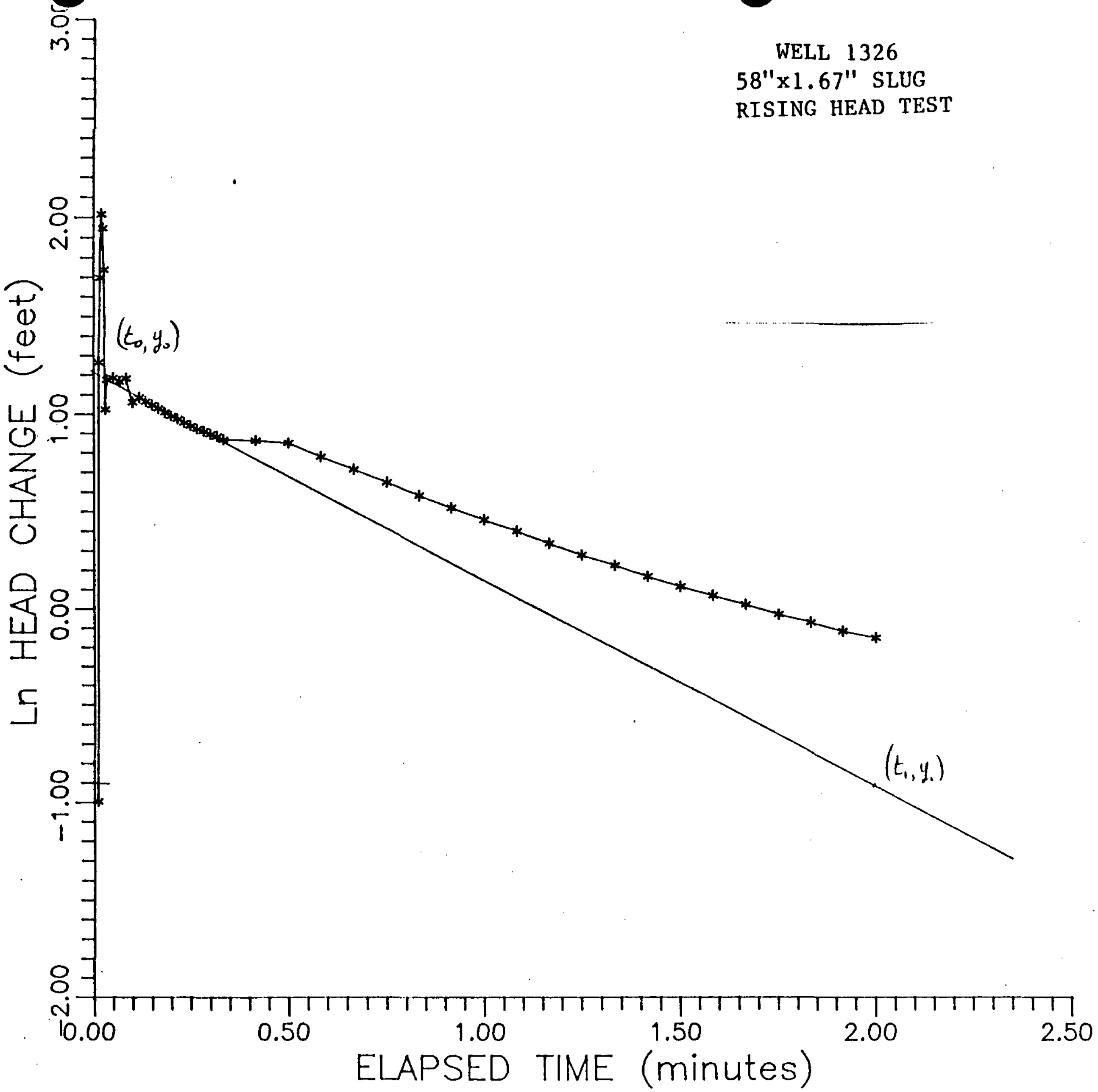


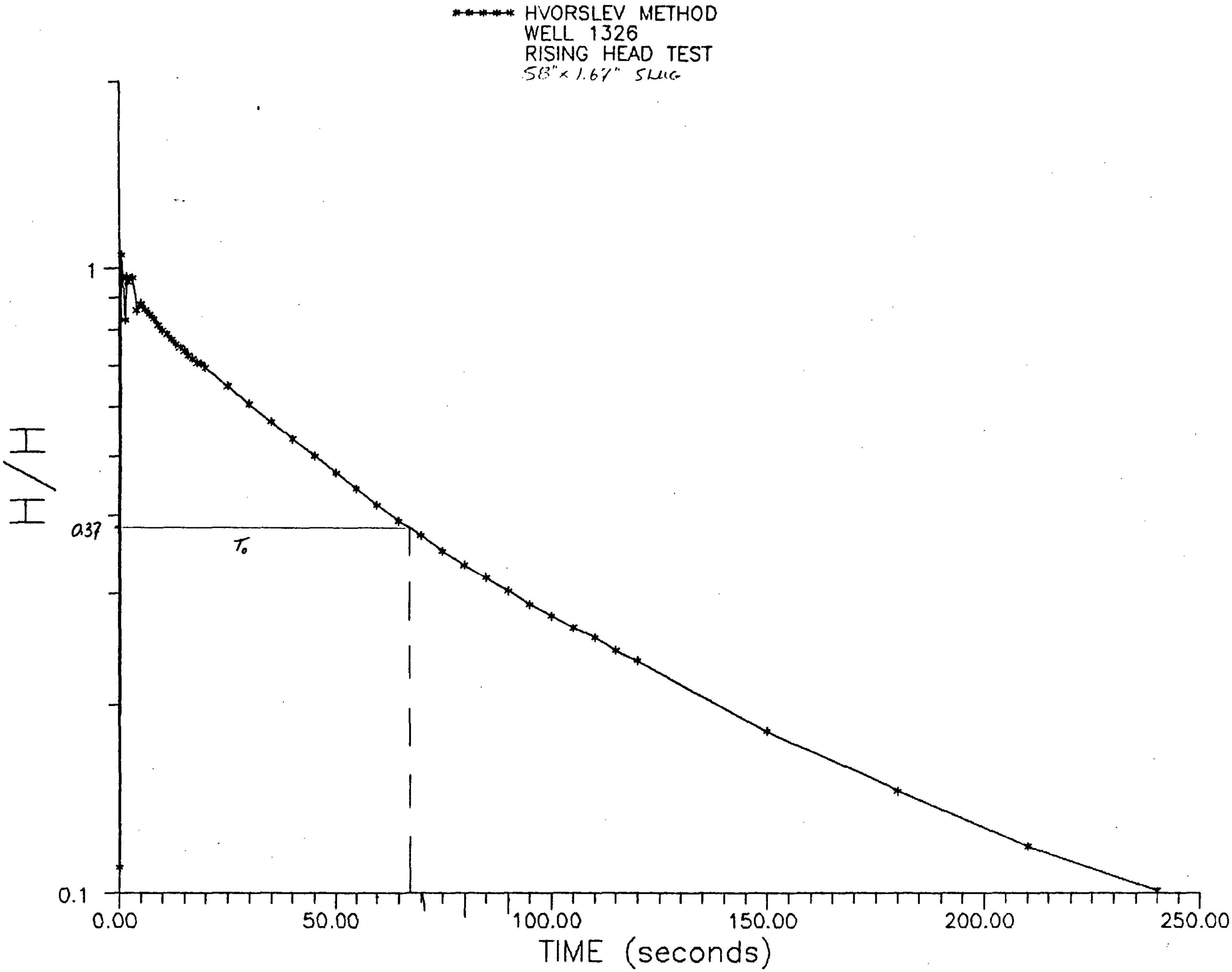


HVORSLEV METHOD
WELL 1325
RISING HEAD TEST
H/H
1
0,37
0.1
T_o
0.00
10.00
20.00
30.00
40.00
50.00
60.00
TIME (seconds)

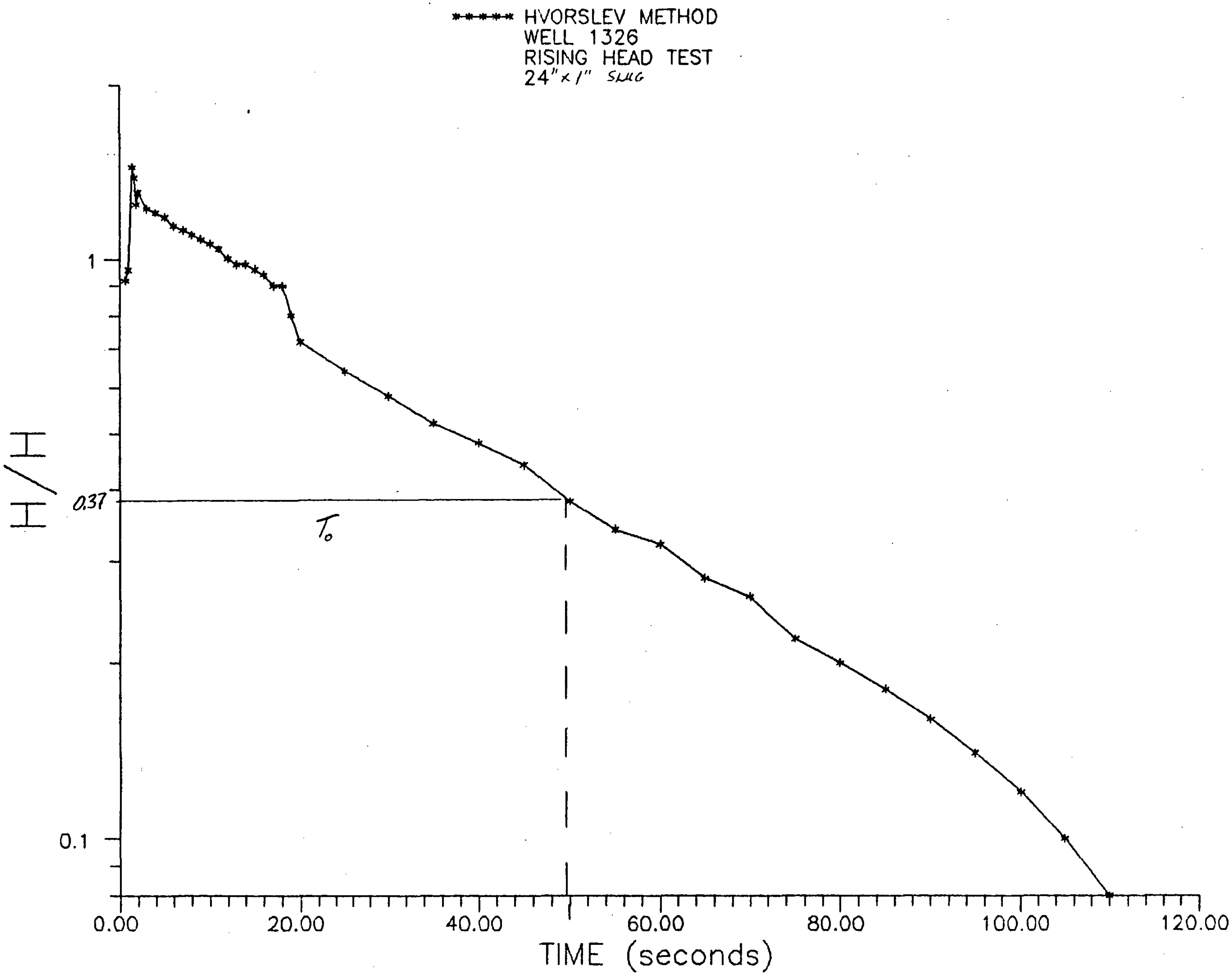
WELL 1326
RISING HEAD TEST
24"x1" SLUG



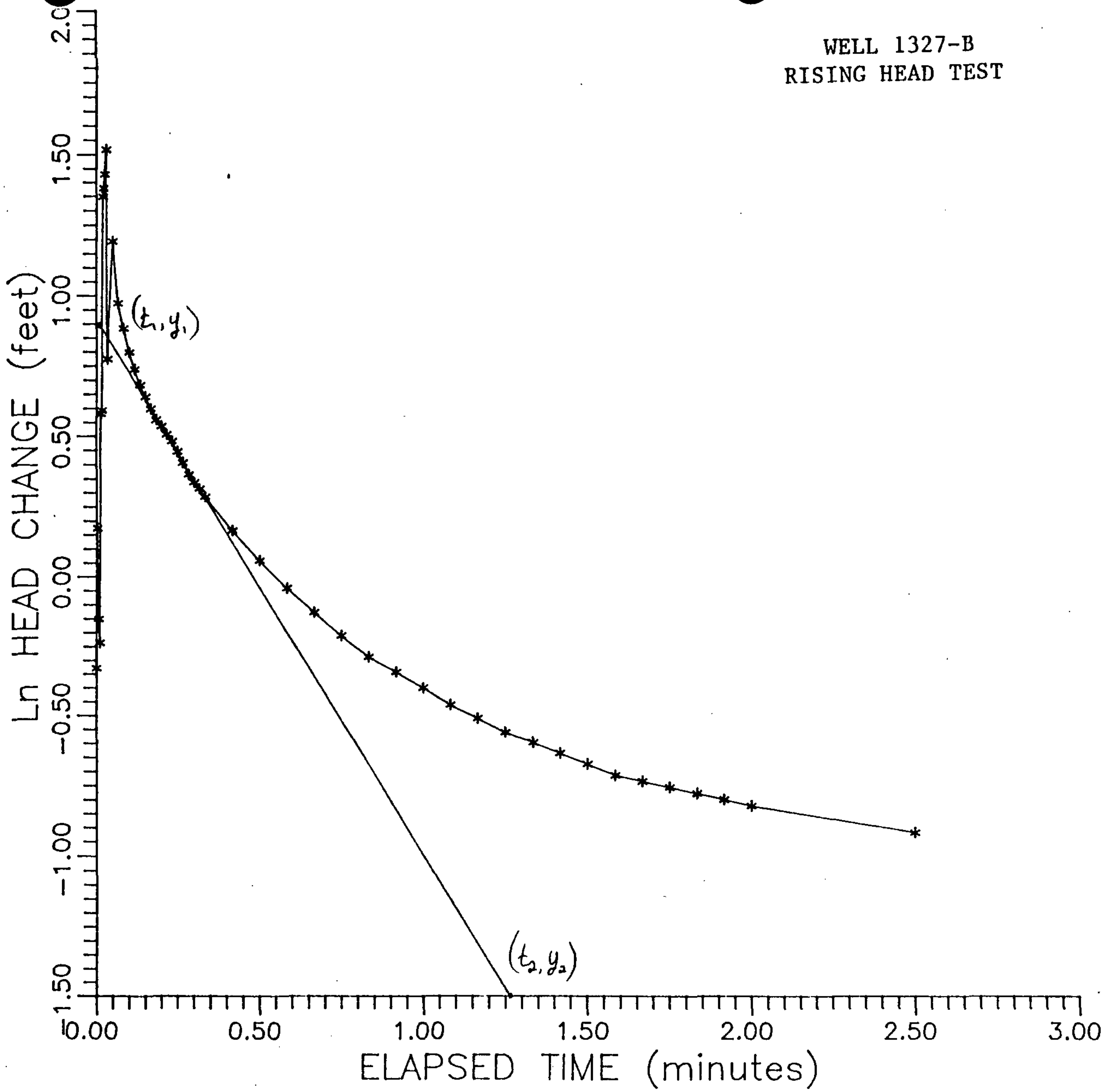

WELL 1326
58"x1.67" SLUG
RISING HEAD TEST
(t₀, y₀)
(t₁, y₁)
Ln HEAD CHANGE (feet)
3.00
2.00
1.00
0.00
-1.00
-2.00
0.00
0.50
1.00
1.50
2.00
2.50
ELAPSED TIME (minutes)



HVORSLEV METHOD
WELL 1326
RISING HEAD TEST
1
0.37
T_0
0.1
H/H
0.00
50.00
100.00
150.00
200.00
250.00
TIME (seconds)

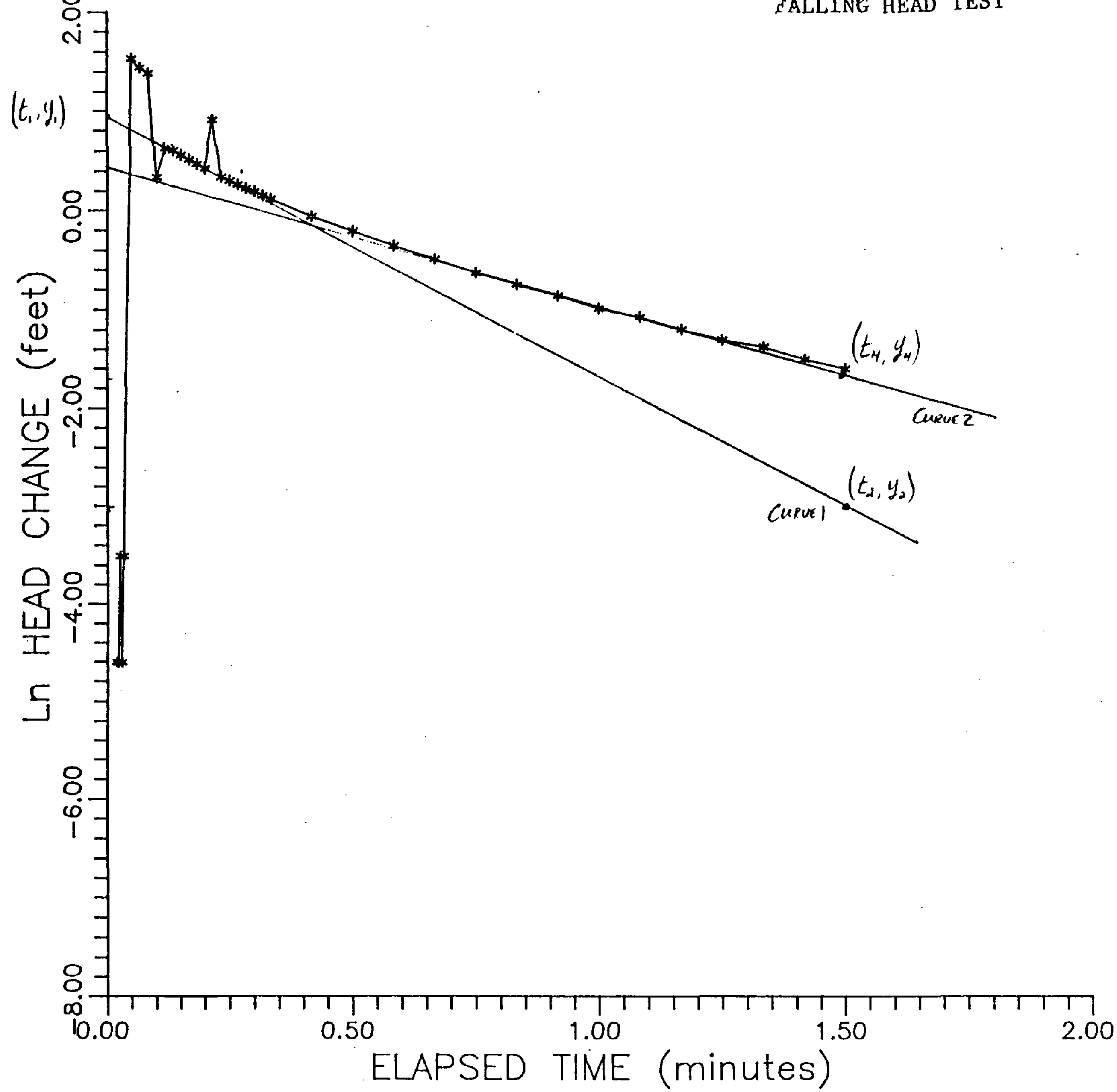


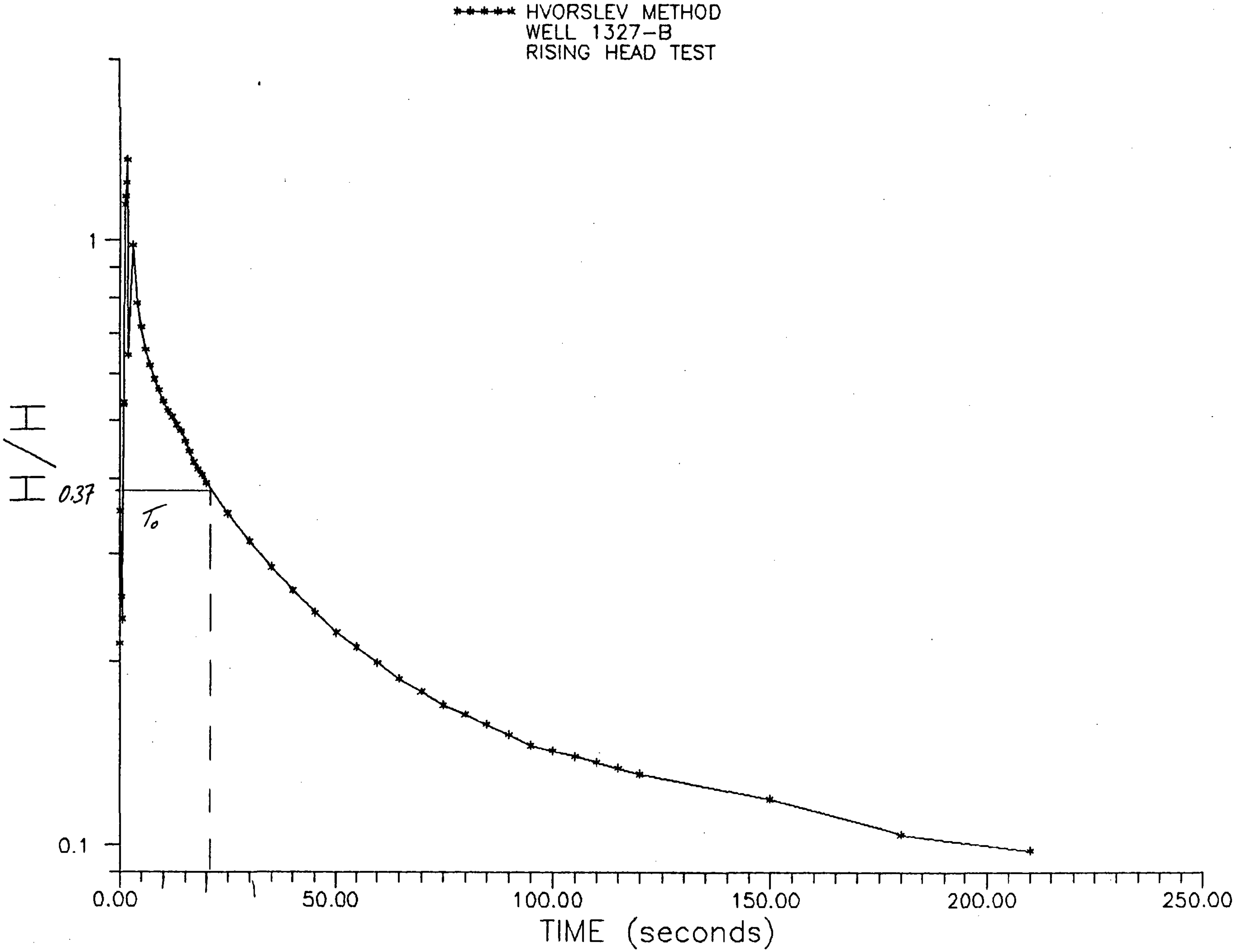
HVORSLEV METHOD
WELL 1326
RISING HEAD TEST
24" x 1" SLUG
H/H
1
0.37
0.1
T_o
0.00
20.00
40.00
60.00
80.00
100.00
120.00
TIME (seconds)



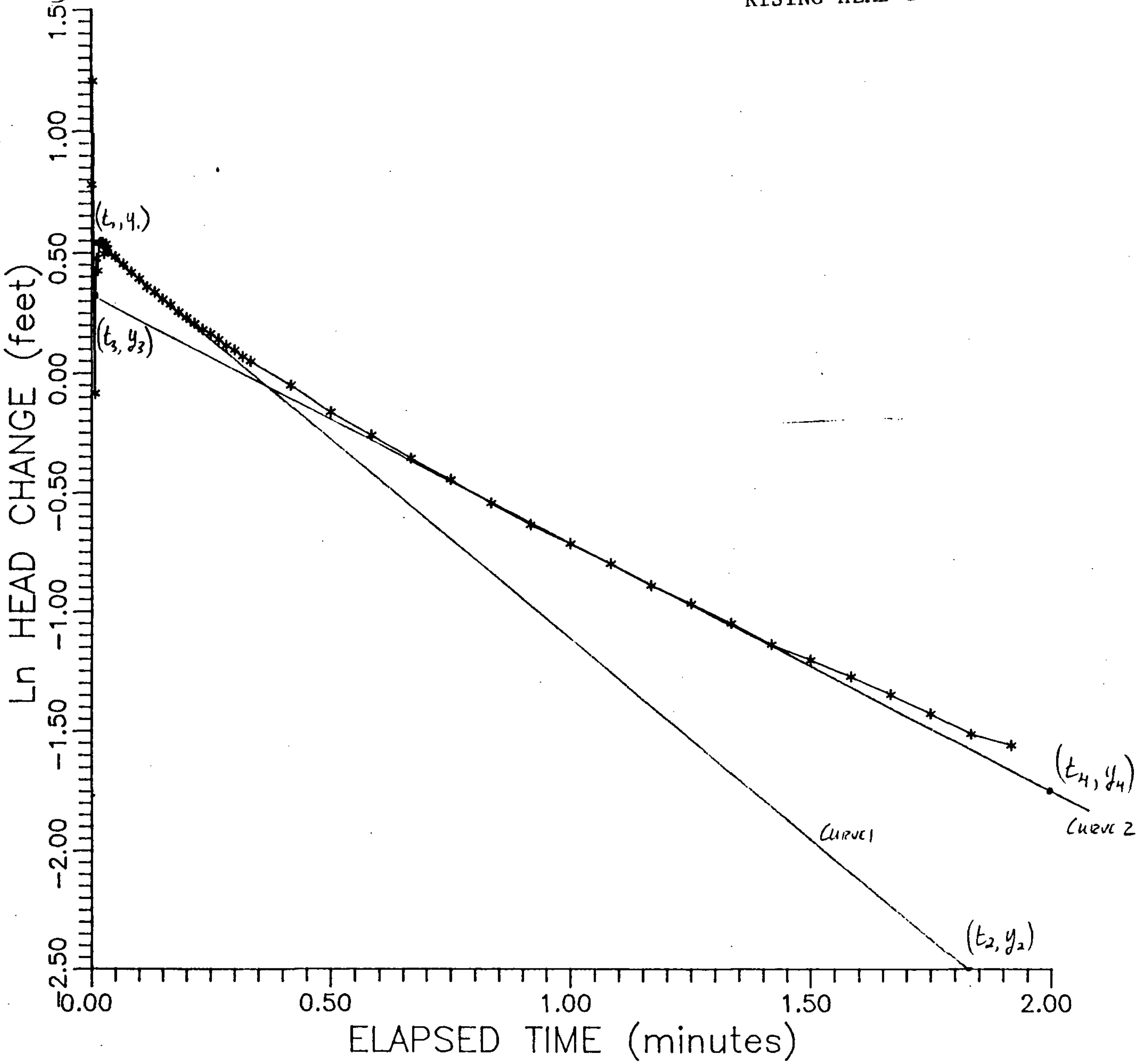
WELL 1327-B
RISING HEAD TEST
Ln HEAD CHANGE (feet)
2.0
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
(t1,y1)
(t2,y2)
0.00
0.50
1.00
1.50
2.00
2.50
3.00
ELAPSED TIME (minutes)

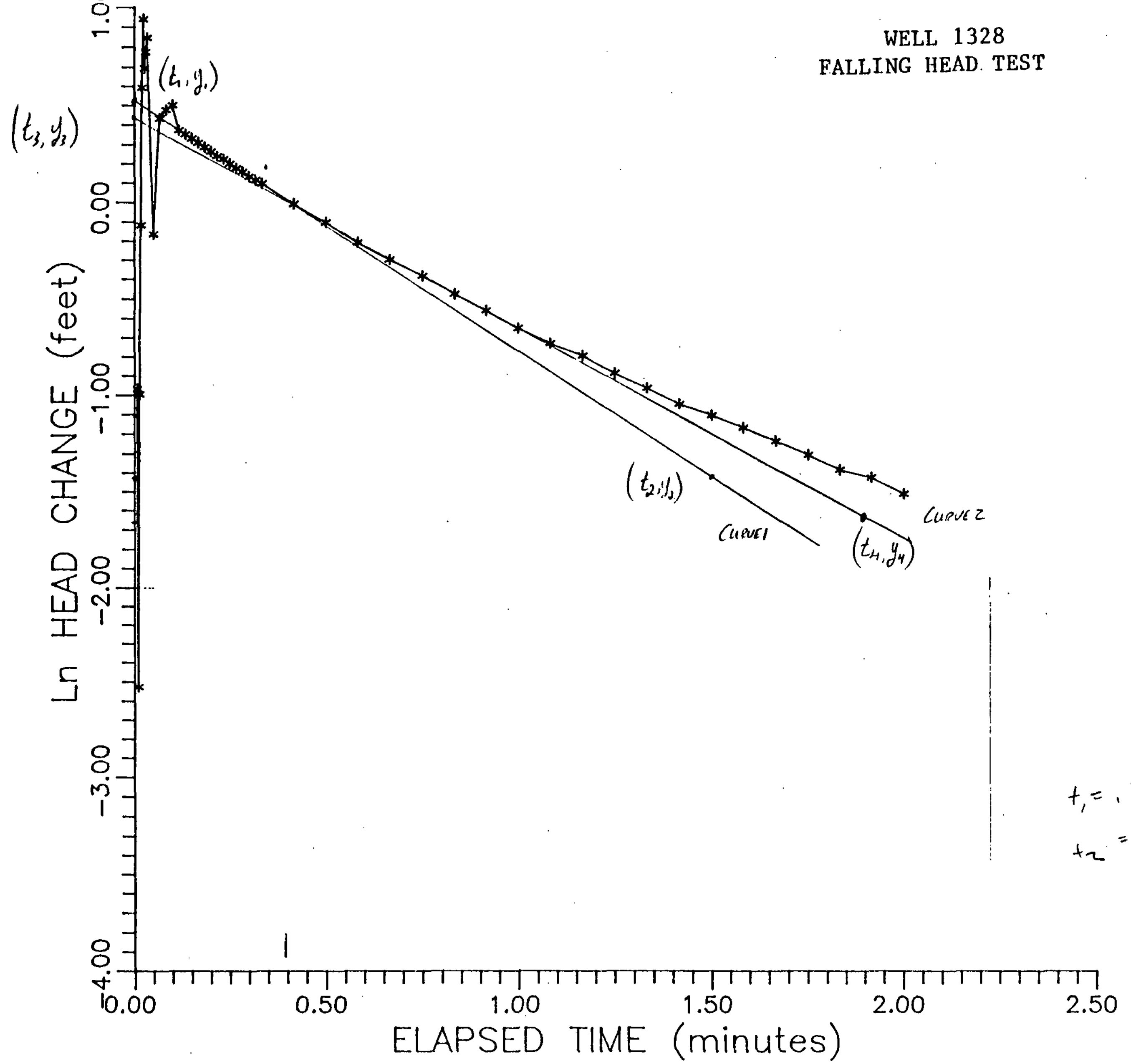
WELL 1327-B
FALLING HEAD TEST




HVORSLEV METHOD
WELL 1327-B
RISING HEAD TEST
H/H
1
0.37
0.1
T_o
0.00
50.00
100.00
150.00
200.00
250.00
TIME (seconds)

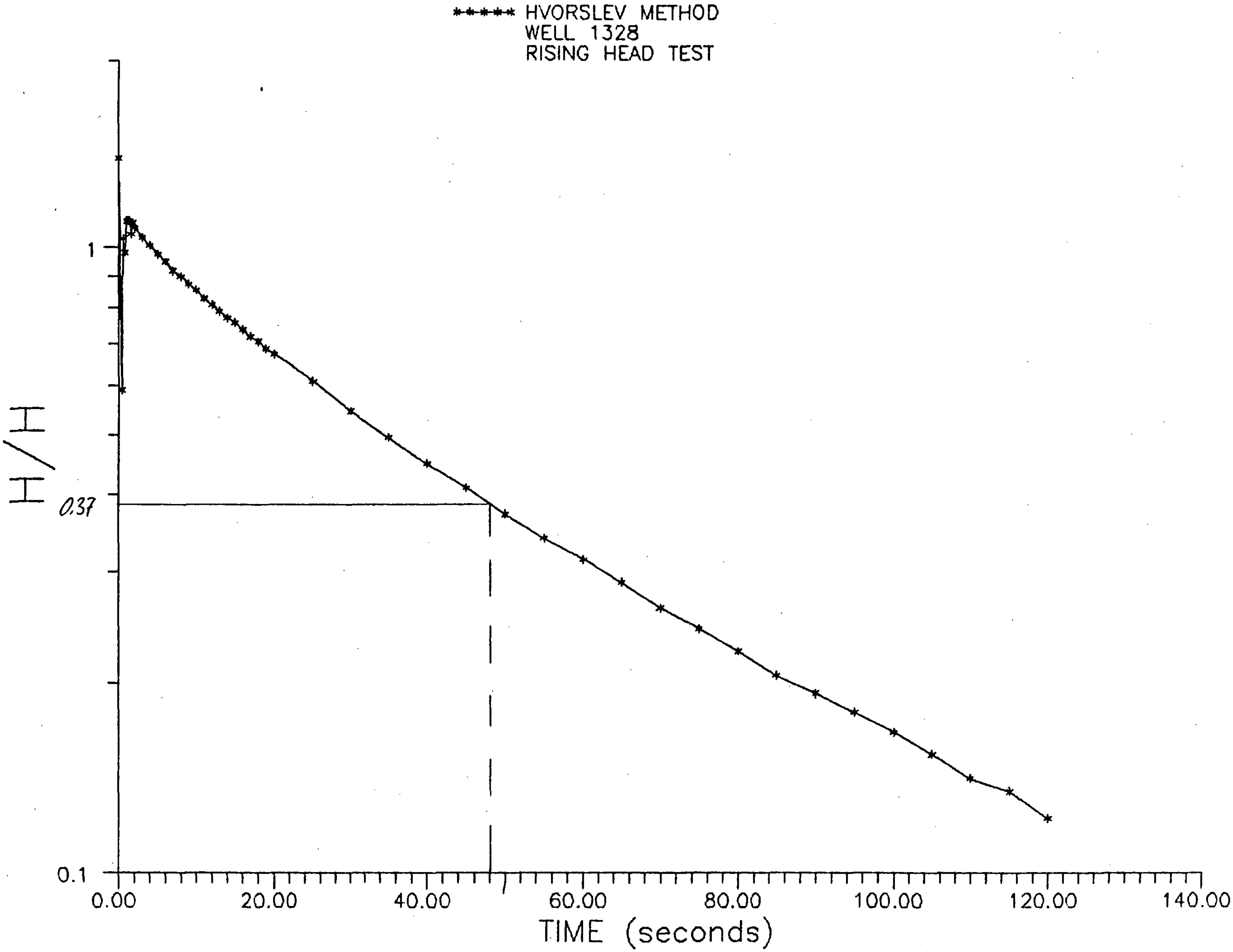
WELL 1328
RISING HEAD TEST



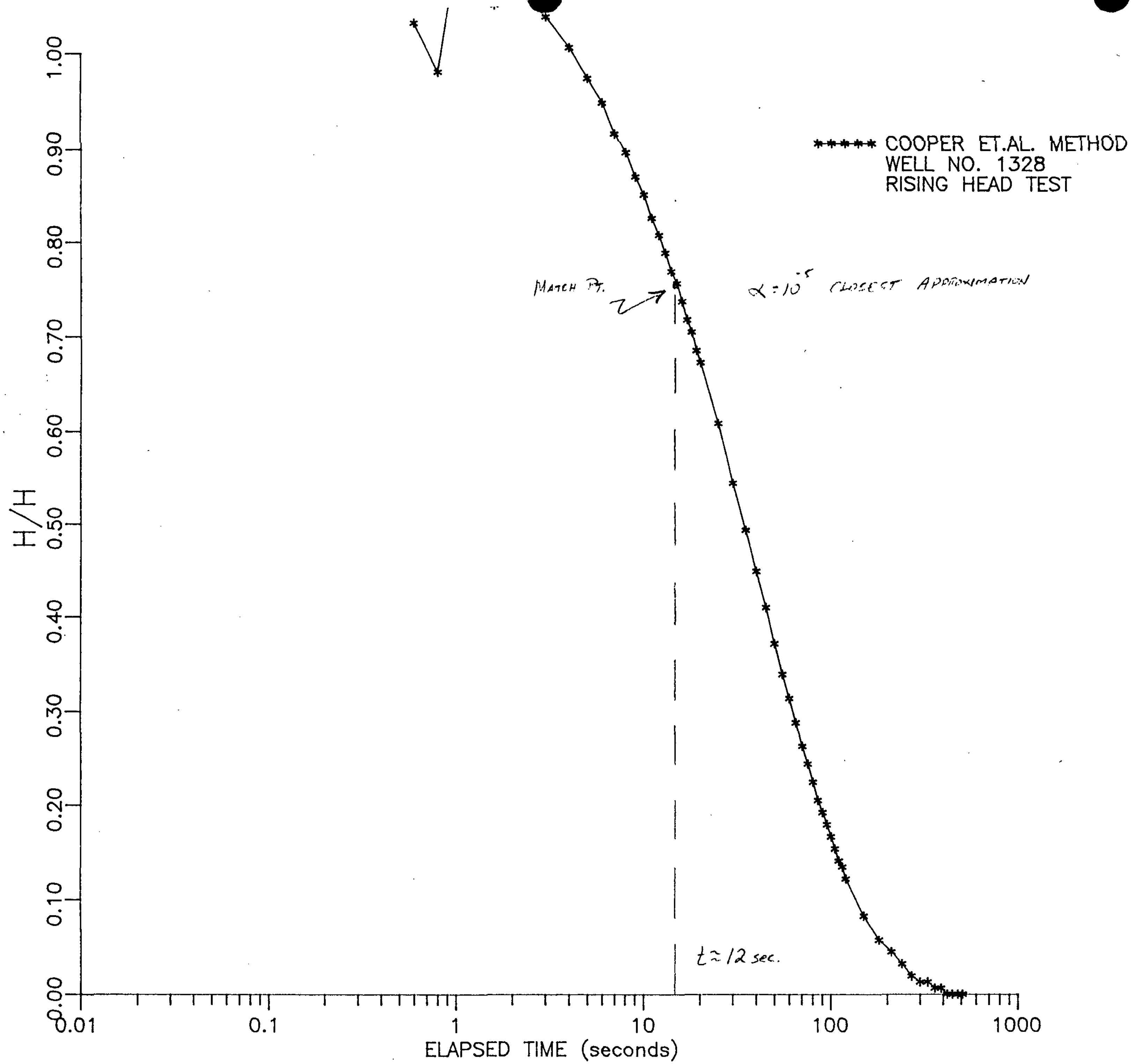


$t_1 = .39$ $y_1 = 1$

$t_2 = 2.22$ $Y_2 = .135$

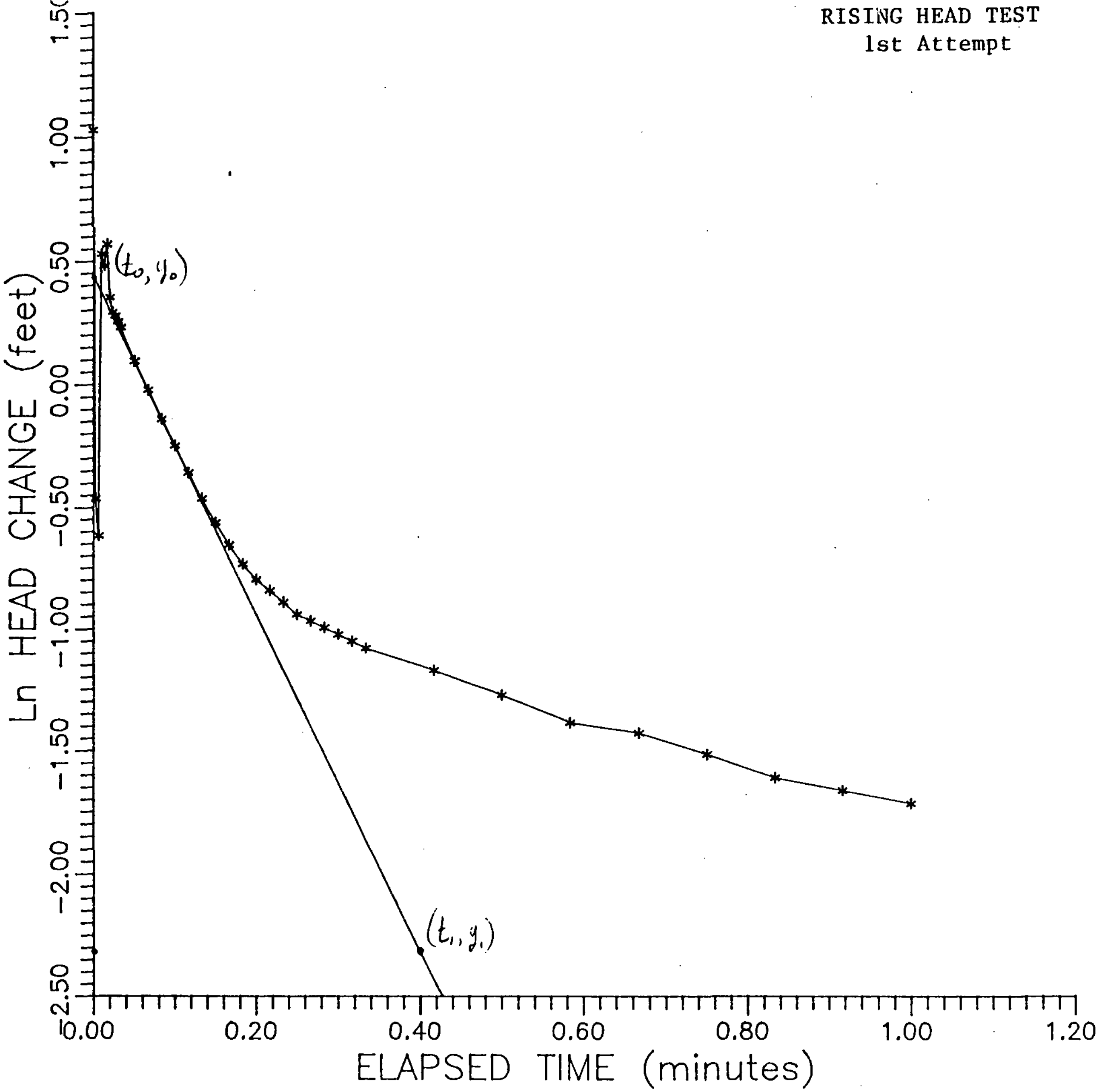


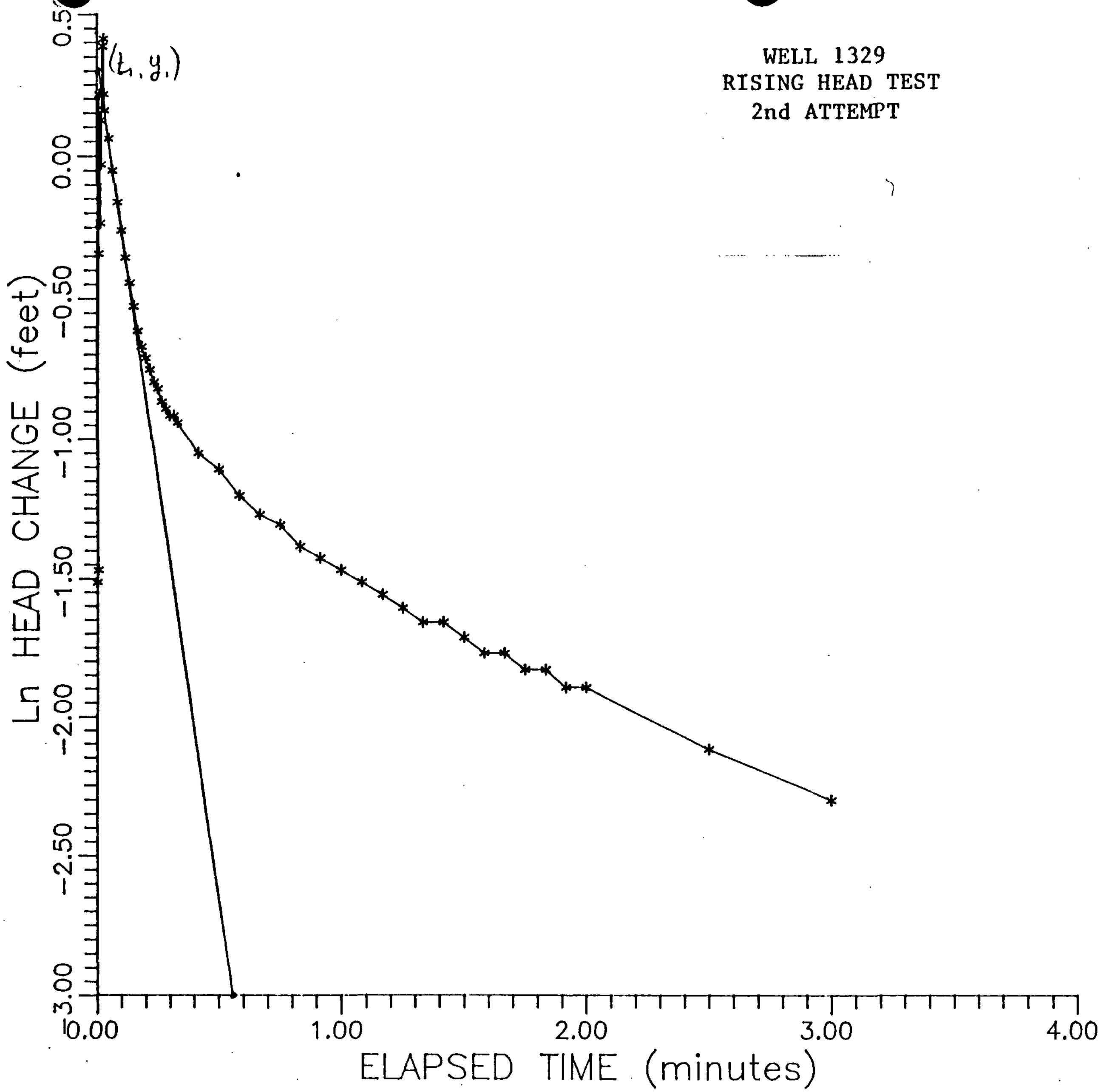
HVORSLEV METHOD
WELL 1328
RISING HEAD TEST
H/H
1
0.37
0.1
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
TIME (seconds)



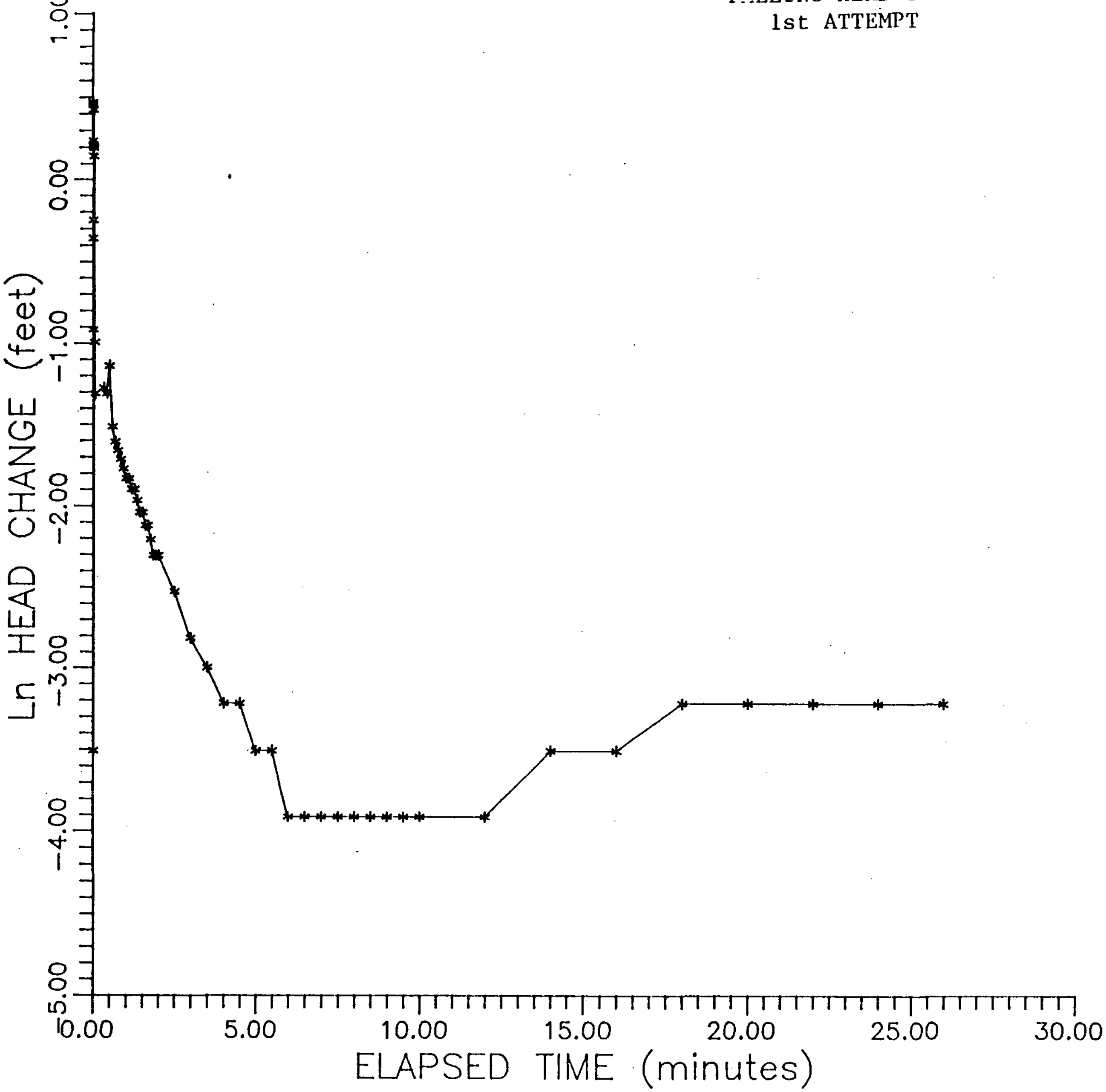
COOPER ET.AL. METHOD
WELL NO. 1328
RISING HEAD TEST
MATCH PT.
α = 10^-5 CLOSEST APPROXIMATION
t ≈ 12 sec.
H/H
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.01
0.1
1
10
100
1000
ELAPSED TIME (seconds)

WELL 1329
RISING HEAD TEST
1st Attempt

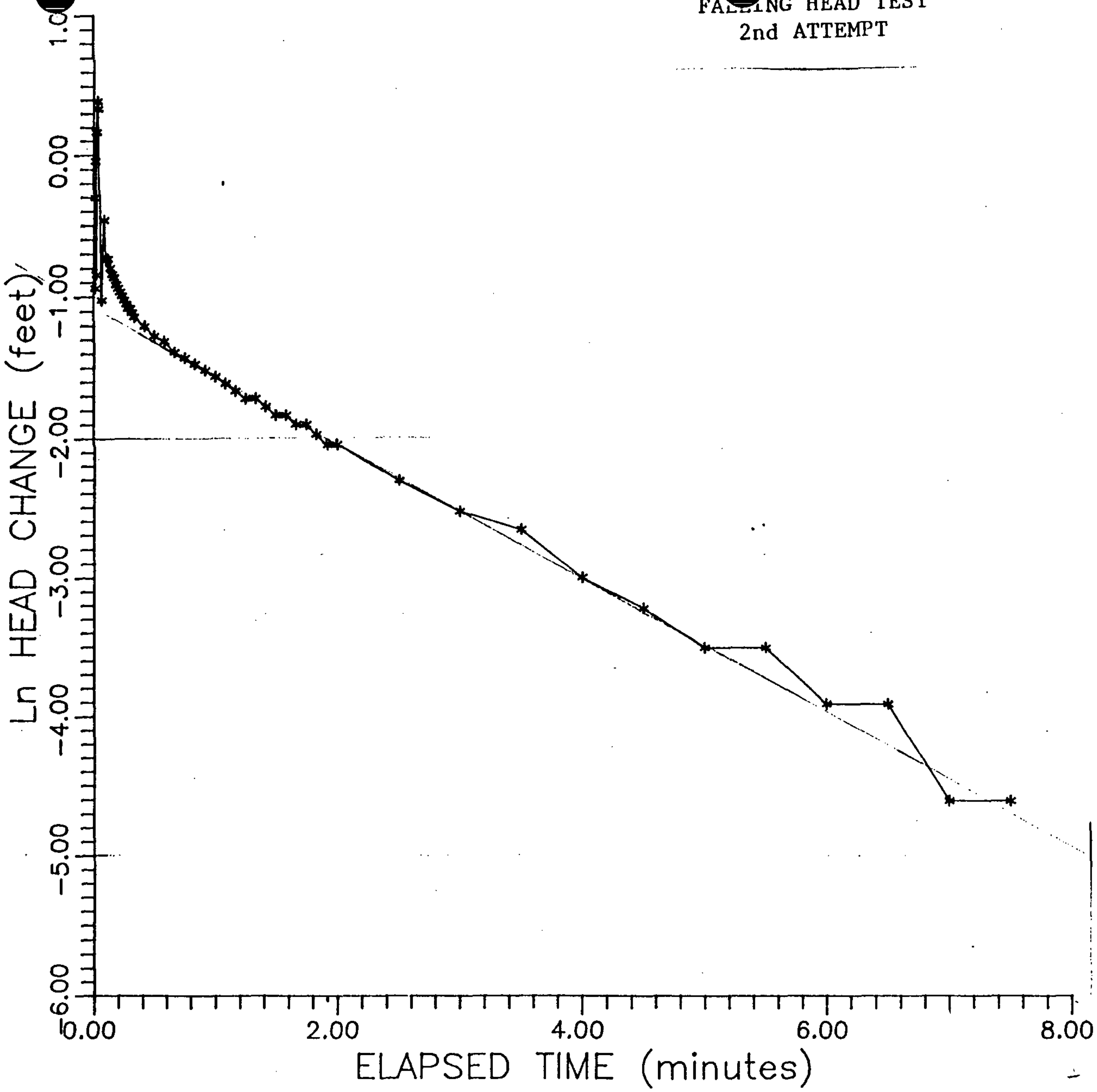


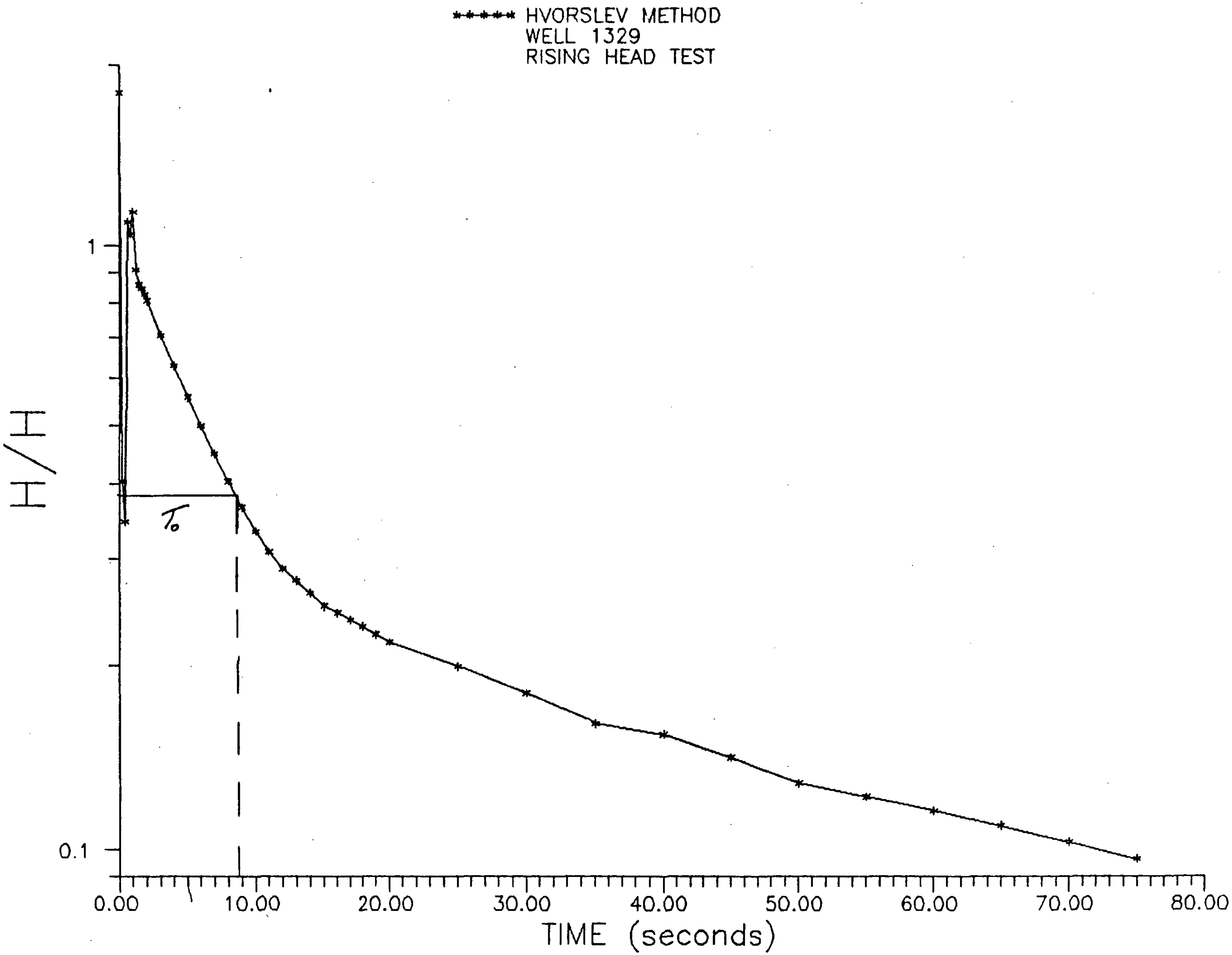

WELL 1329
RISING HEAD TEST
2nd ATTEMPT
(t1, y1)
Ln HEAD CHANGE (feet)
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
0.00
1.00
2.00
3.00
4.00
ELAPSED TIME (minutes)

WELL 1329
FALLING HEAD TEST
1st ATTEMPT



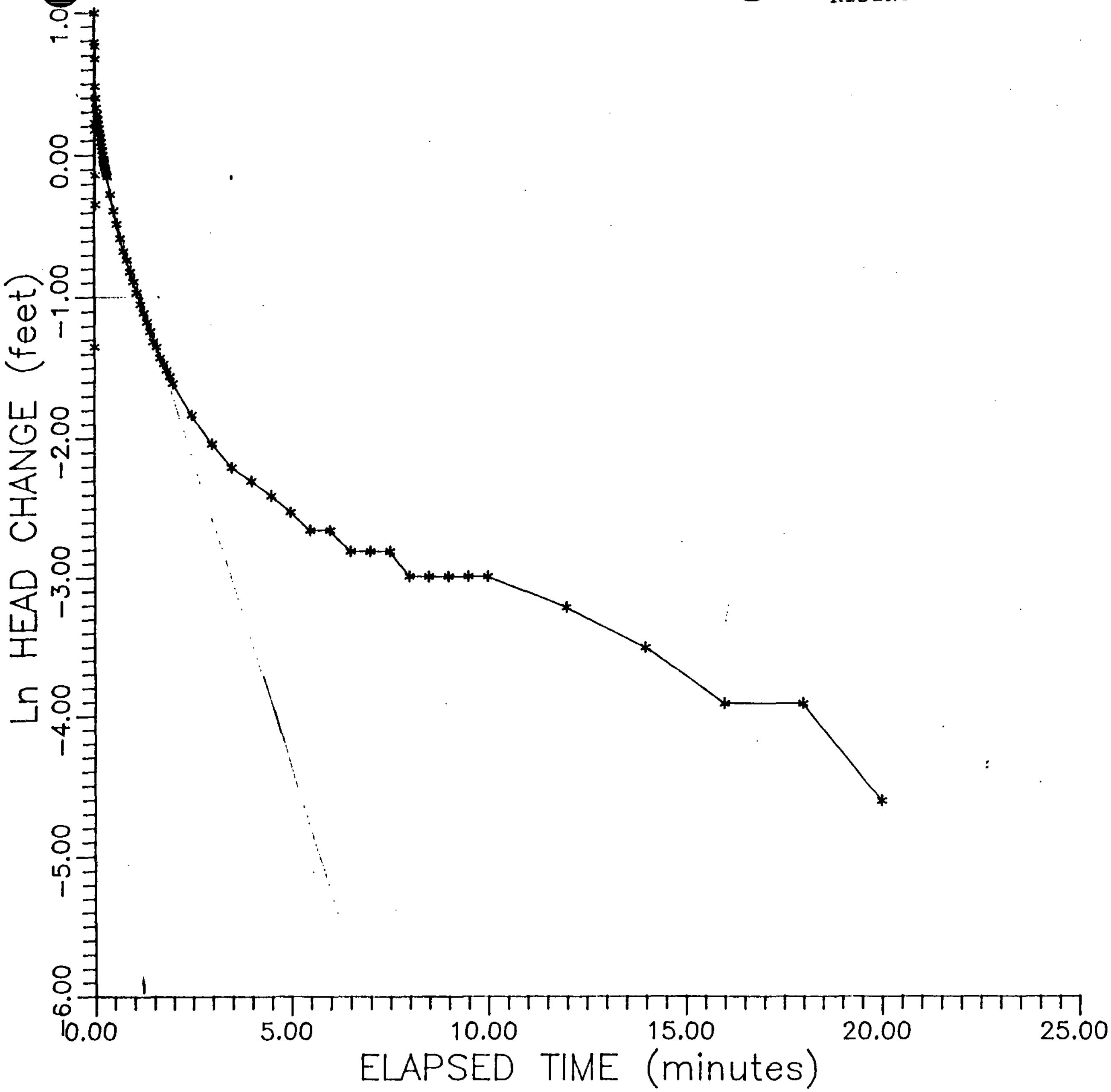
WELL 1329
FALLING HEAD TEST
2nd ATTEMPT



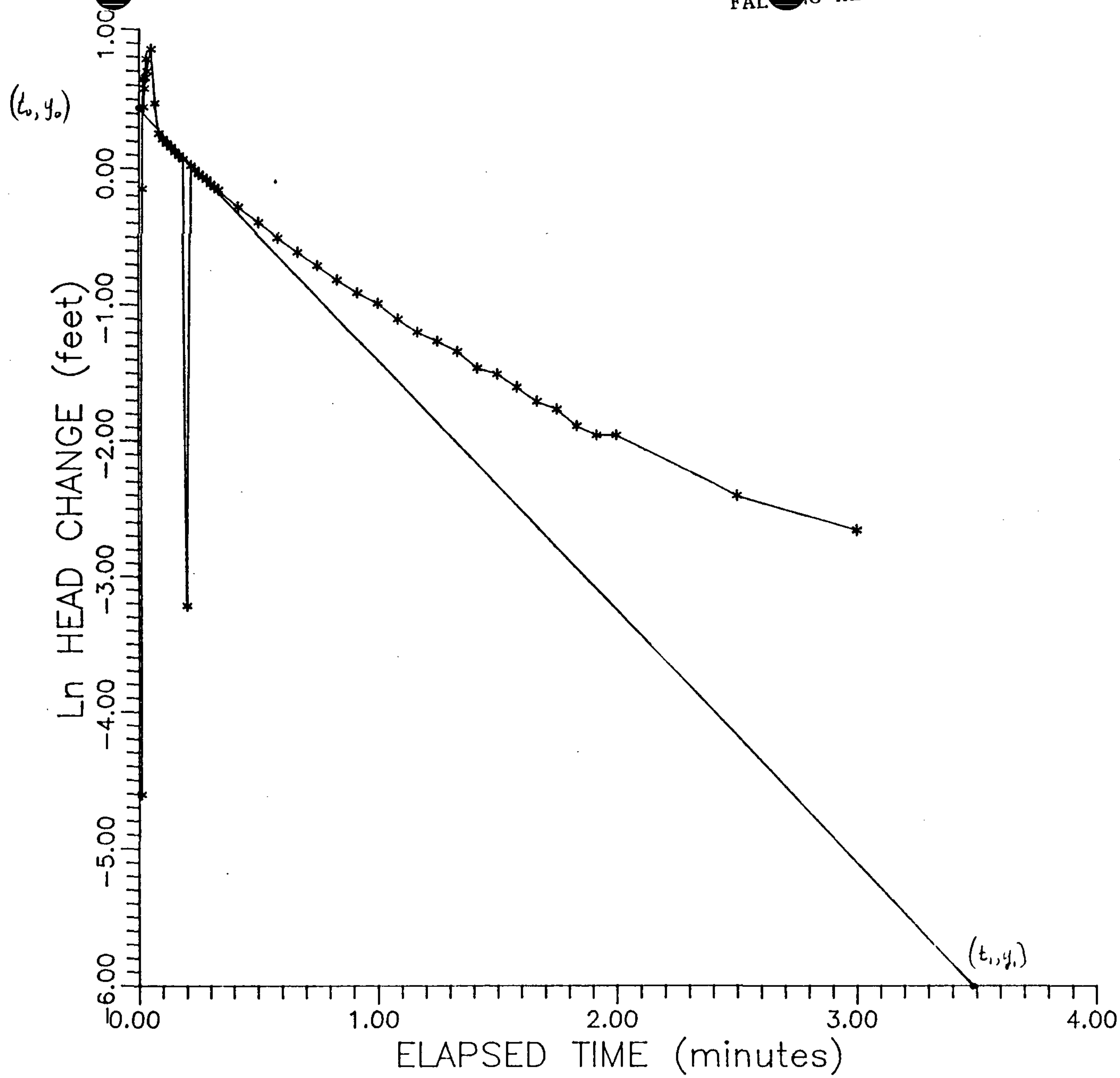


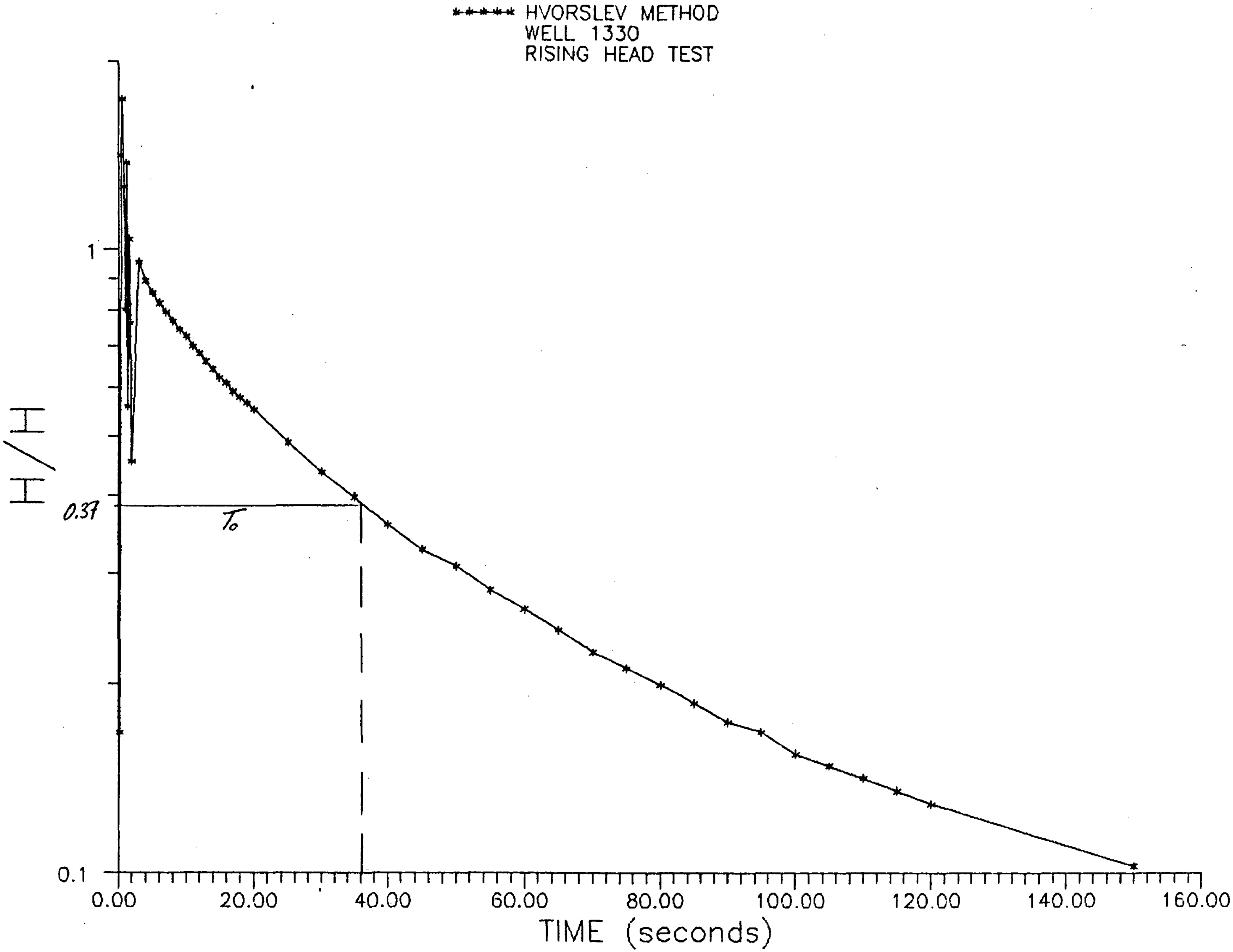
HVORSLEV METHOD
WELL 1329
RISING HEAD TEST
H/H
1
0.1
T_0
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
TIME (seconds)

WELL 1330
RISING HEAD TEST

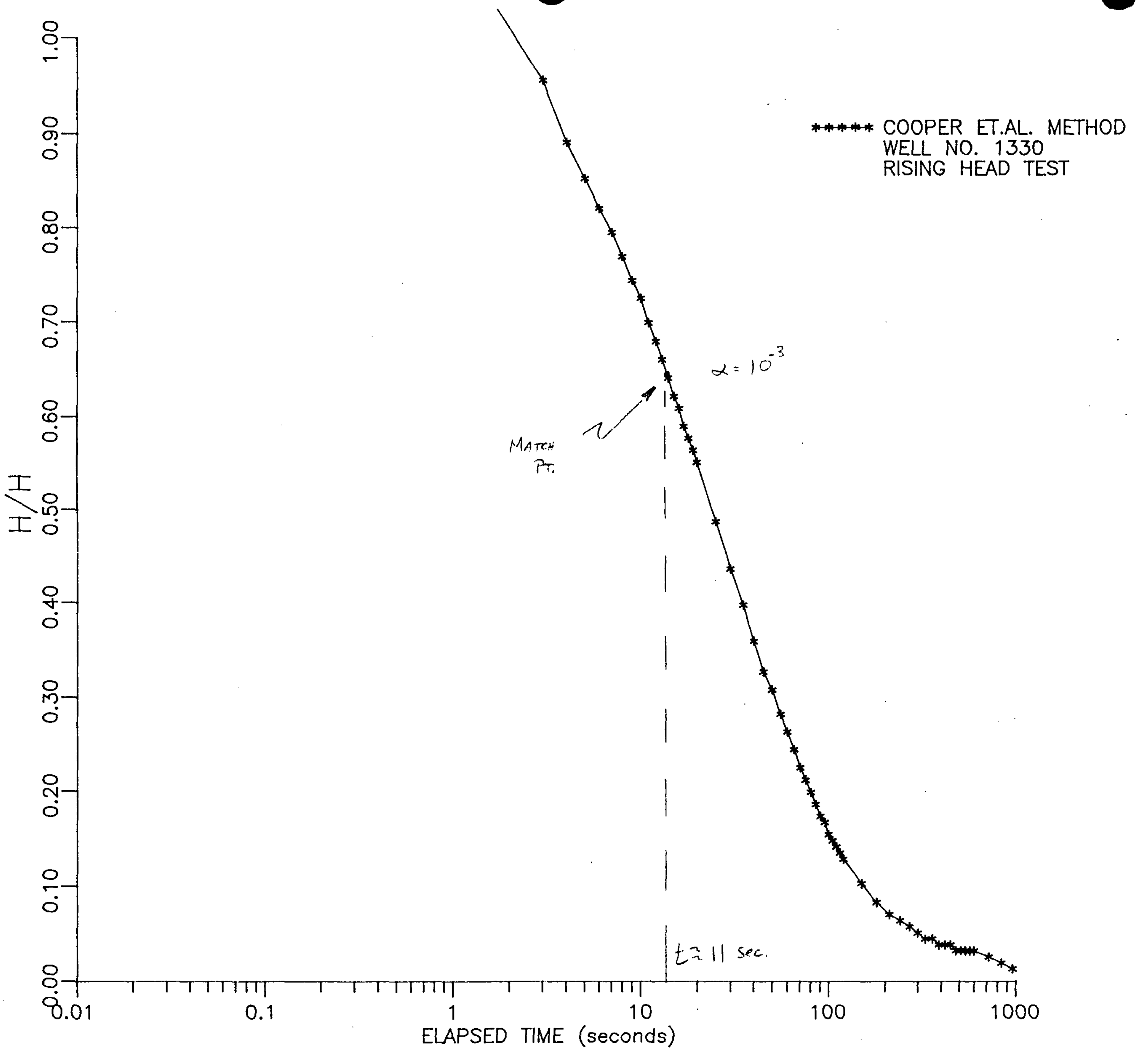


WELL 1330
FALLING HEAD TEST



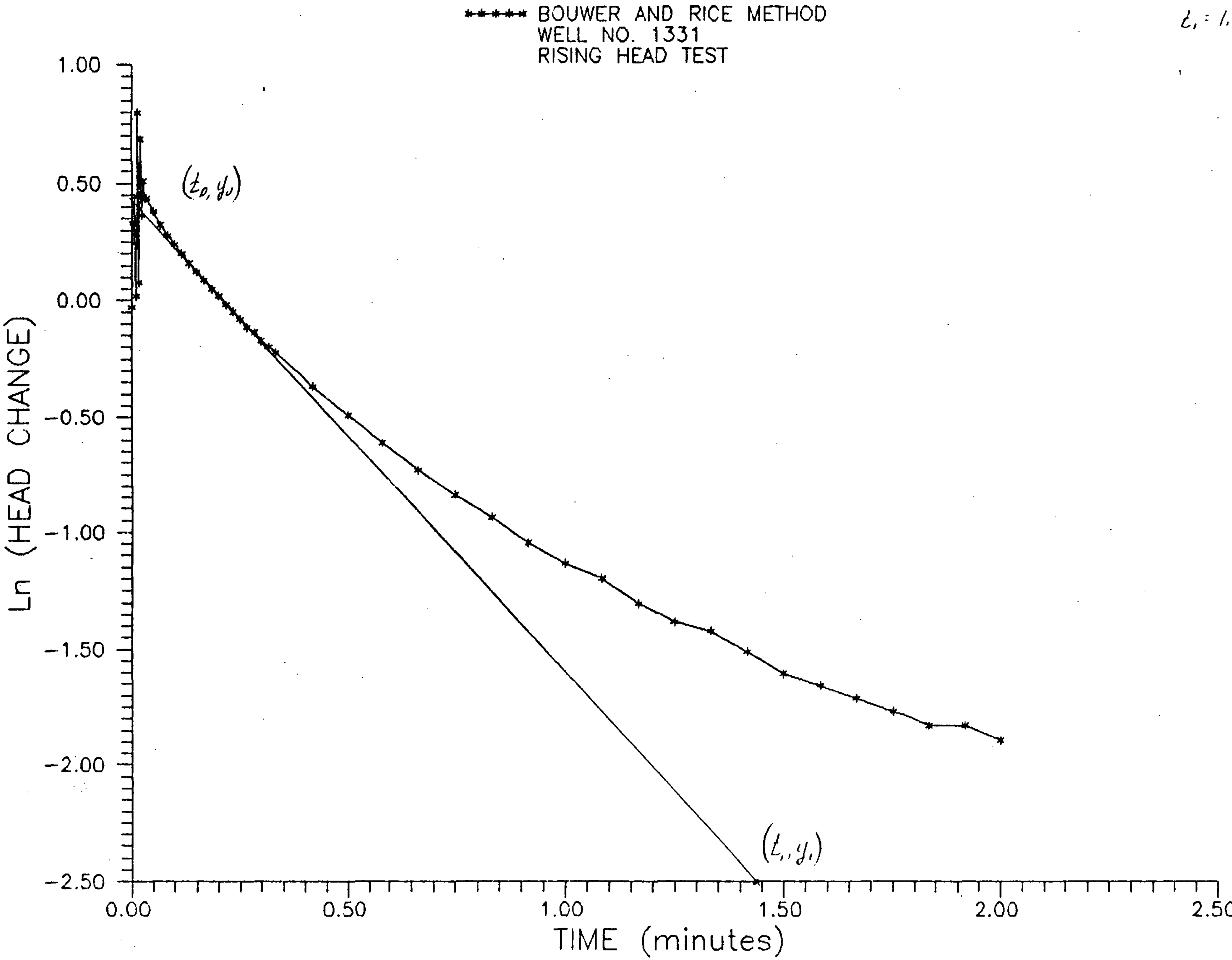


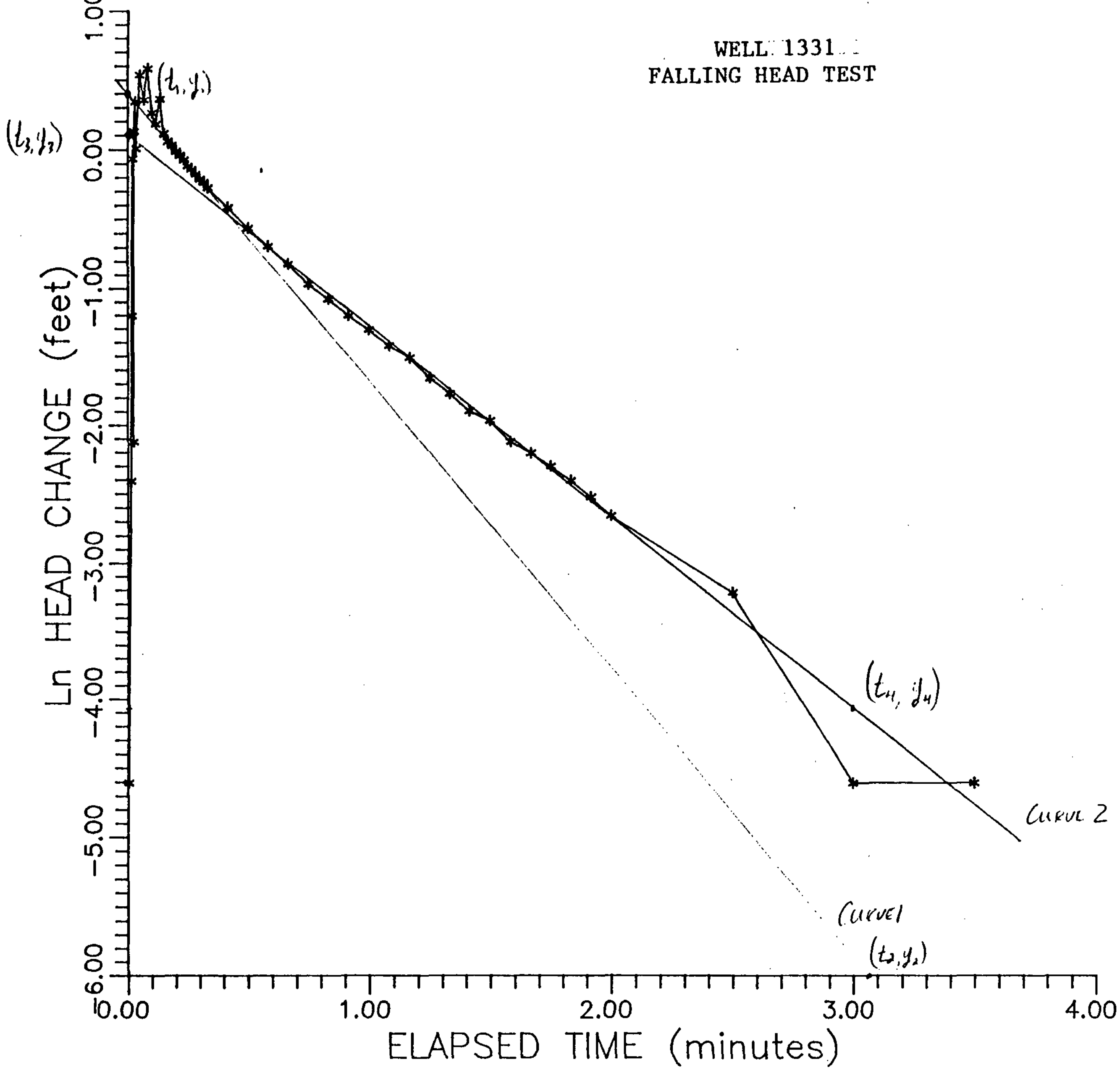
HVORSLEV METHOD
WELL 1330
RISING HEAD TEST
H/H
1
0.37
0.1
To
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME (seconds)



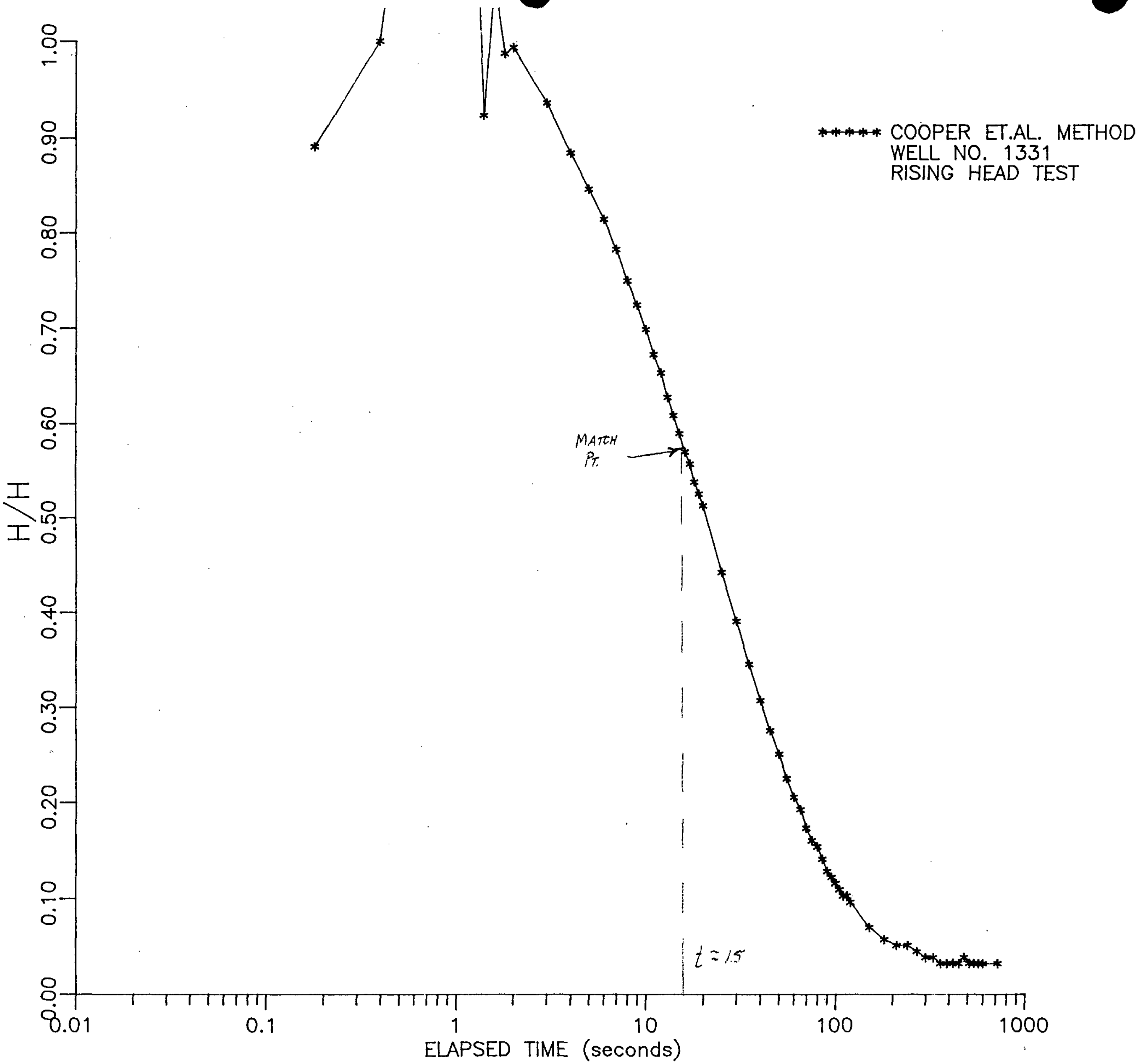
***** COOPER ET.AL. METHOD
WELL NO. 1330
RISING HEAD TEST
H/H
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.01
0.1
1
10
100
1000
ELAPSED TIME (seconds)
MATCH PT.
α = 10⁻³
t ≈ 11 sec.

t_0 = 0.00 y_0 = 1.56'
t_1 = 1.44 y_1 = [illegible]

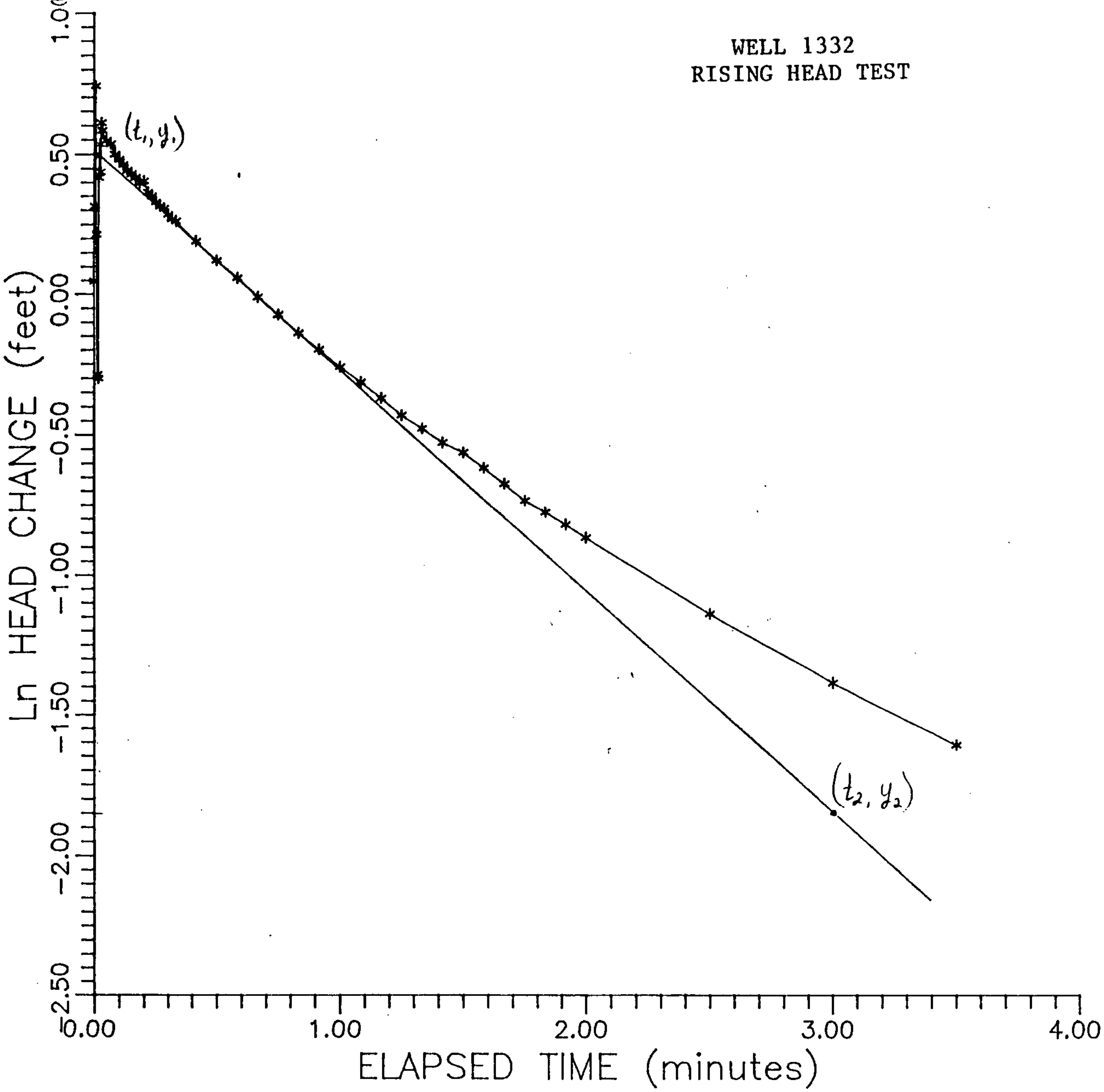




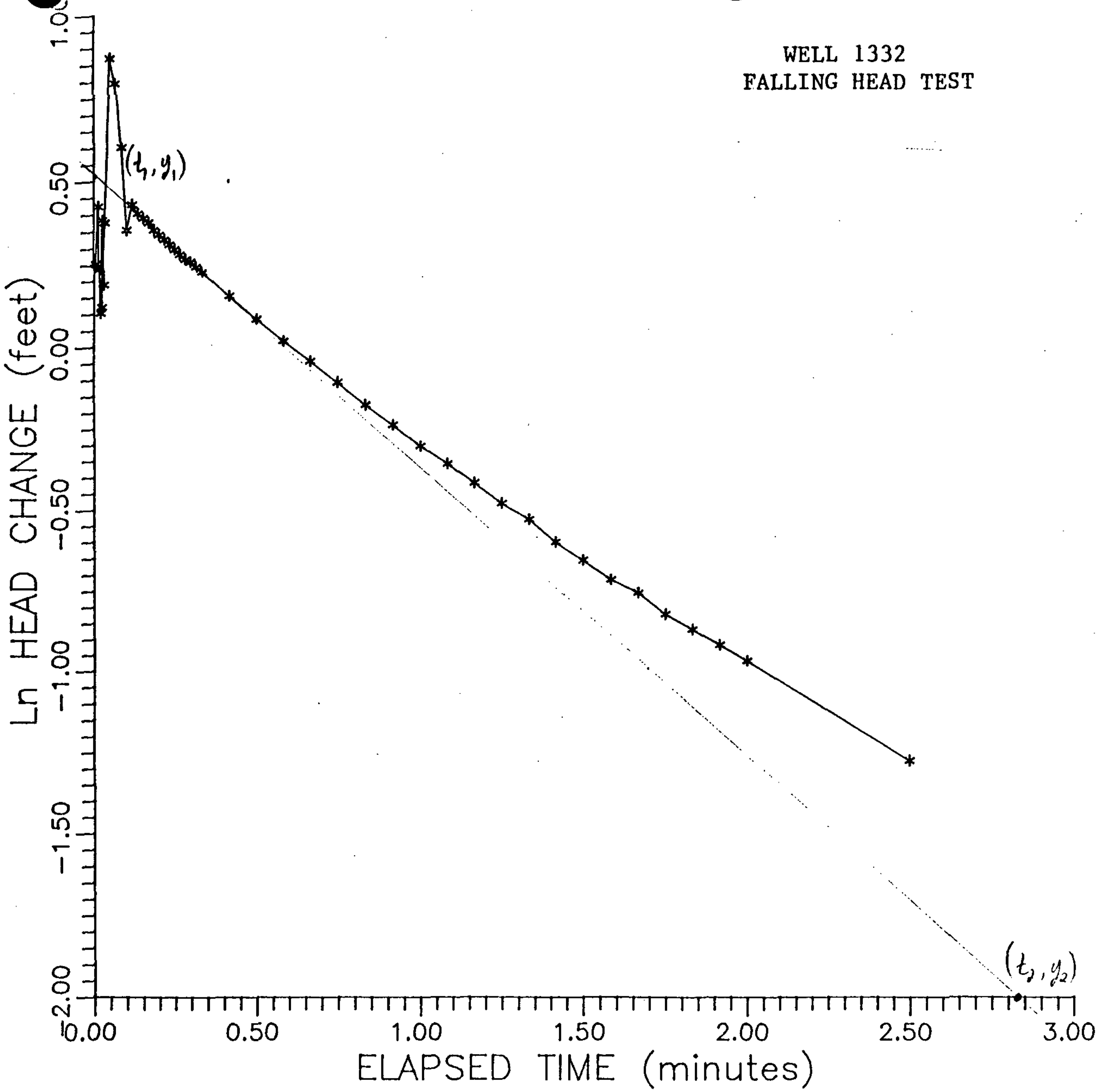
WELL 1331
FALLING HEAD TEST
Ln HEAD CHANGE (feet)
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
0.00
1.00
2.00
3.00
4.00
ELAPSED TIME (minutes)
(t1, y1)
(t3, y3)
(t4, y4)
(t2, y2)
Curve 2
Curve 1



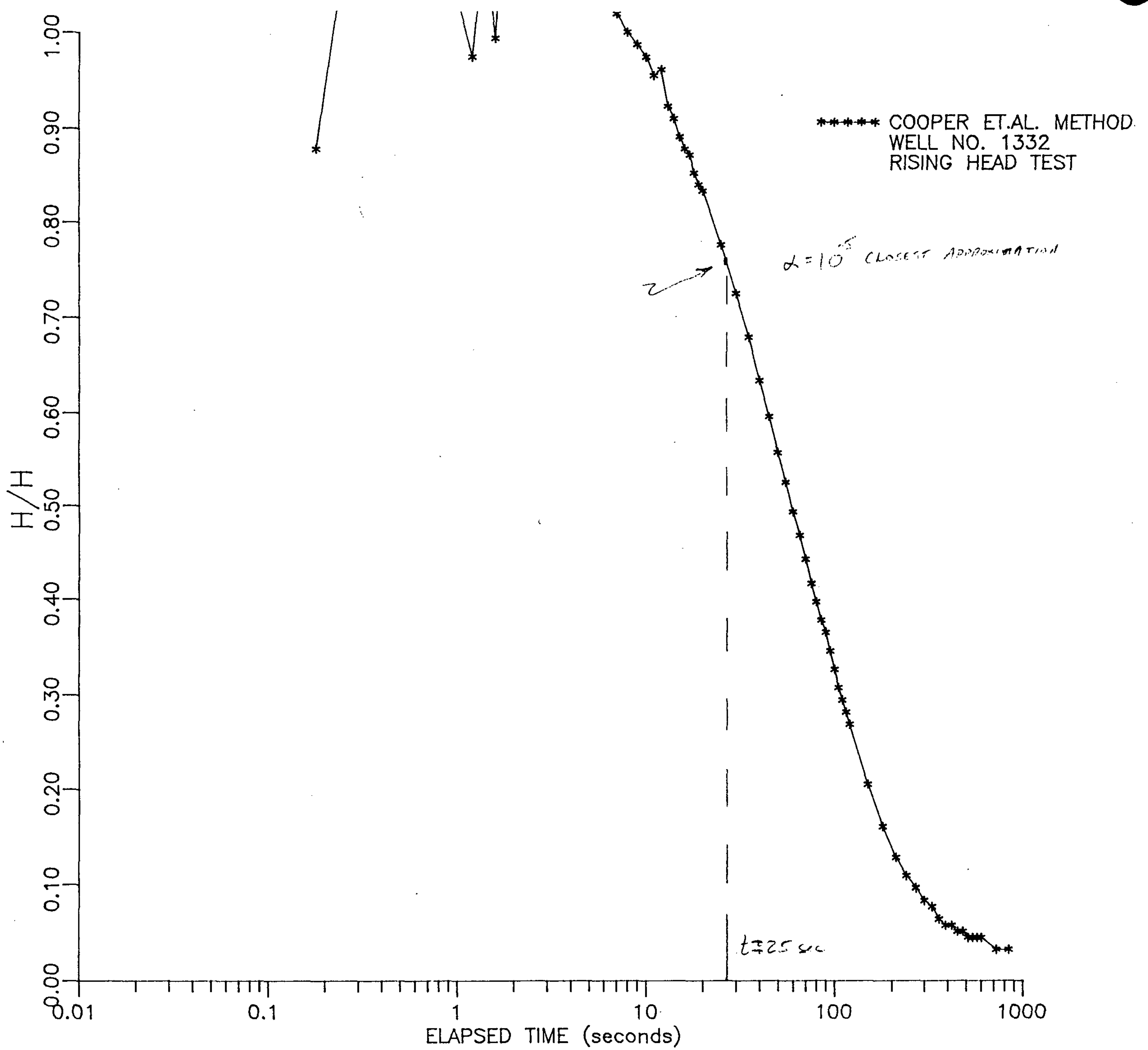
COOPER ET.AL. METHOD
WELL NO. 1331
RISING HEAD TEST
H/H
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.01
0.1
1
10
100
1000
ELAPSED TIME (seconds)
MATCH PT.
t ≈ 15



WELL 1332
RISING HEAD TEST
(t₁, y₁)
(t₂, y₂)
Ln HEAD CHANGE (feet)
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
0.00
1.00
2.00
3.00
4.00
ELAPSED TIME (minutes)

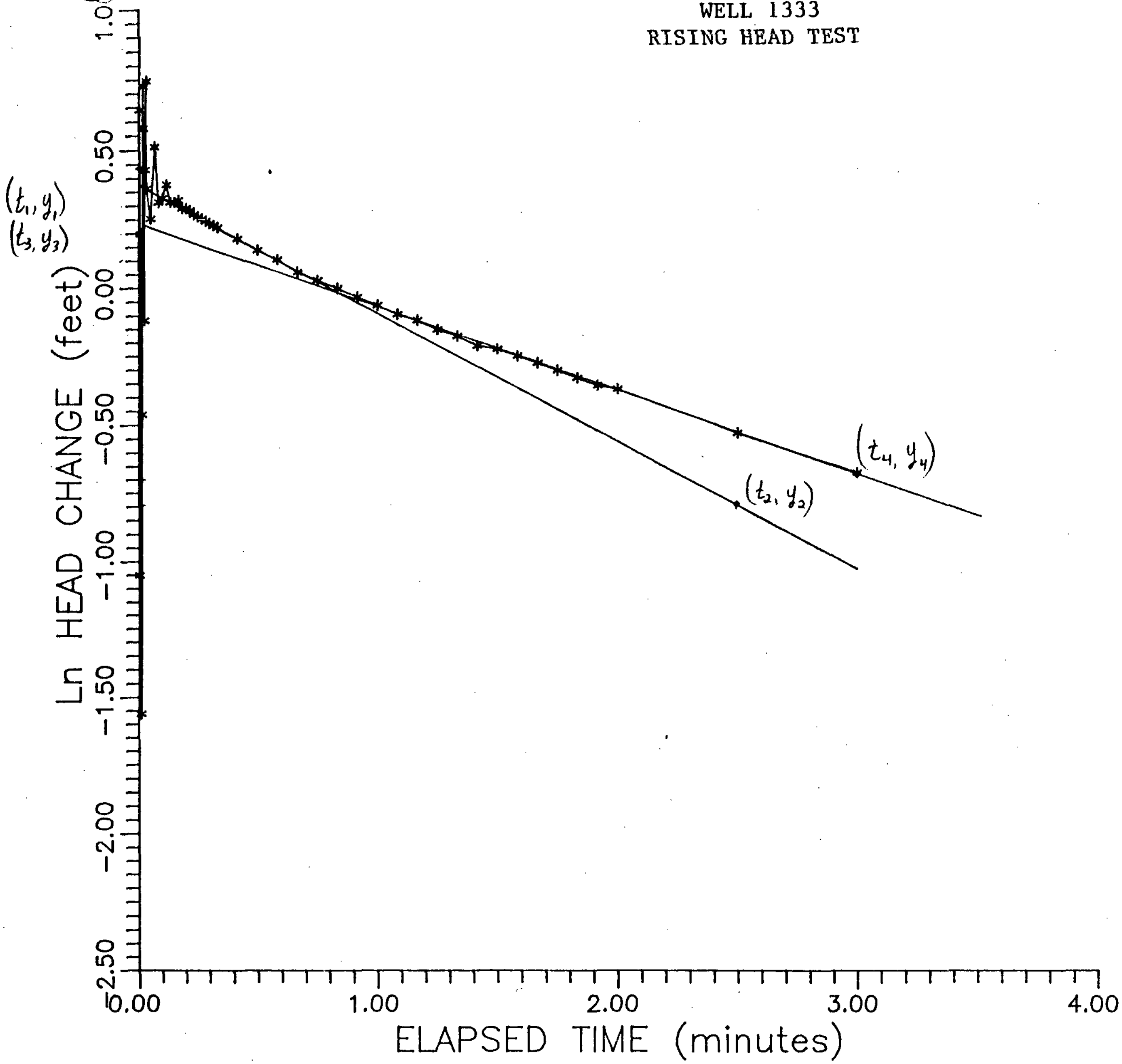


WELL 1332
FALLING HEAD TEST
Ln HEAD CHANGE (feet)
ELAPSED TIME (minutes)
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
(t_1, y_1)
(t_2, y_2)

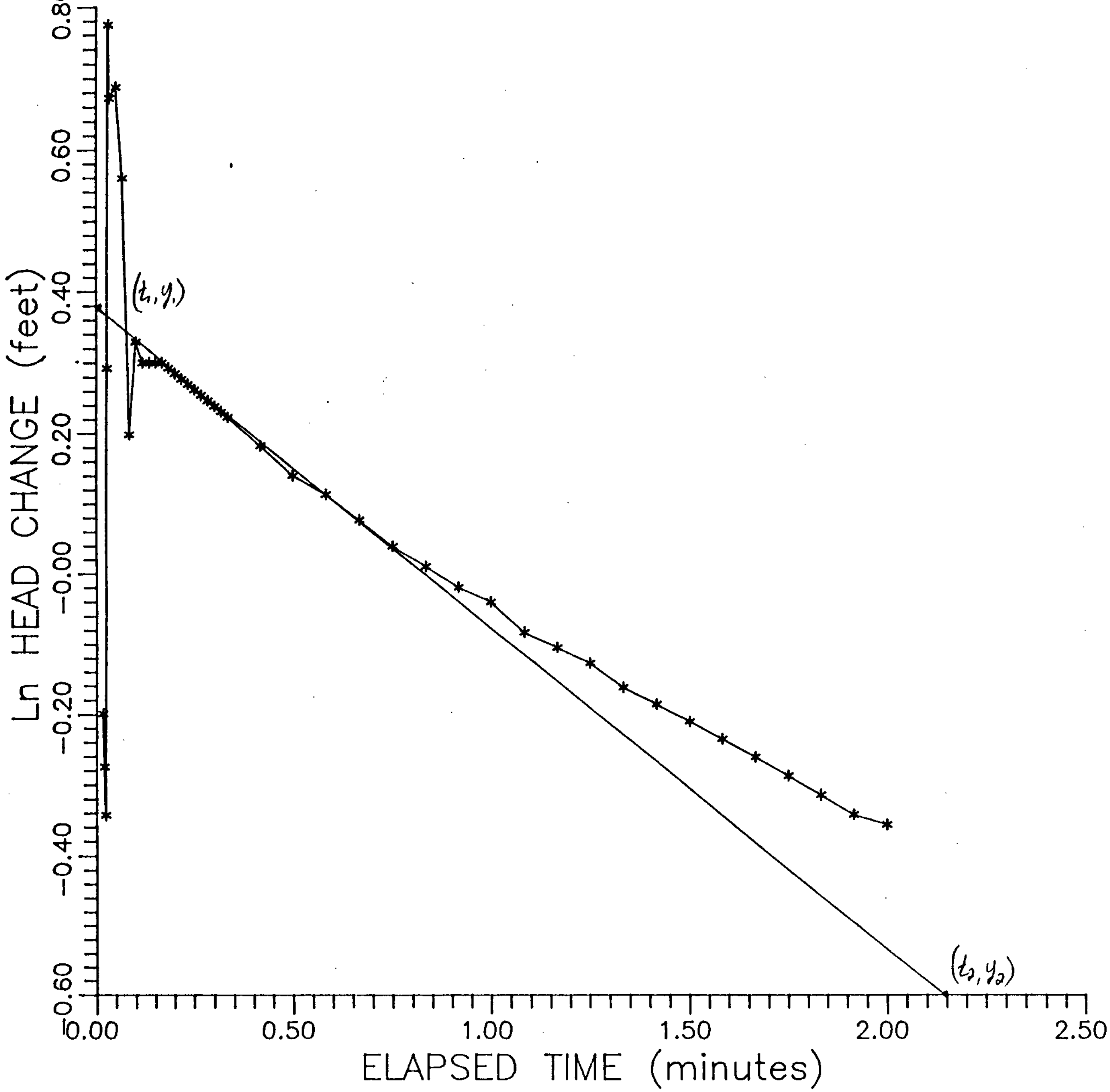


COOPER ET.AL. METHOD
WELL NO. 1332
RISING HEAD TEST
α=10^-5 CLOSEST APPROXIMATION
t=25 sec
H/H
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.01
0.1
1
10
100
1000
ELAPSED TIME (seconds)

WELL 1333
RISING HEAD TEST

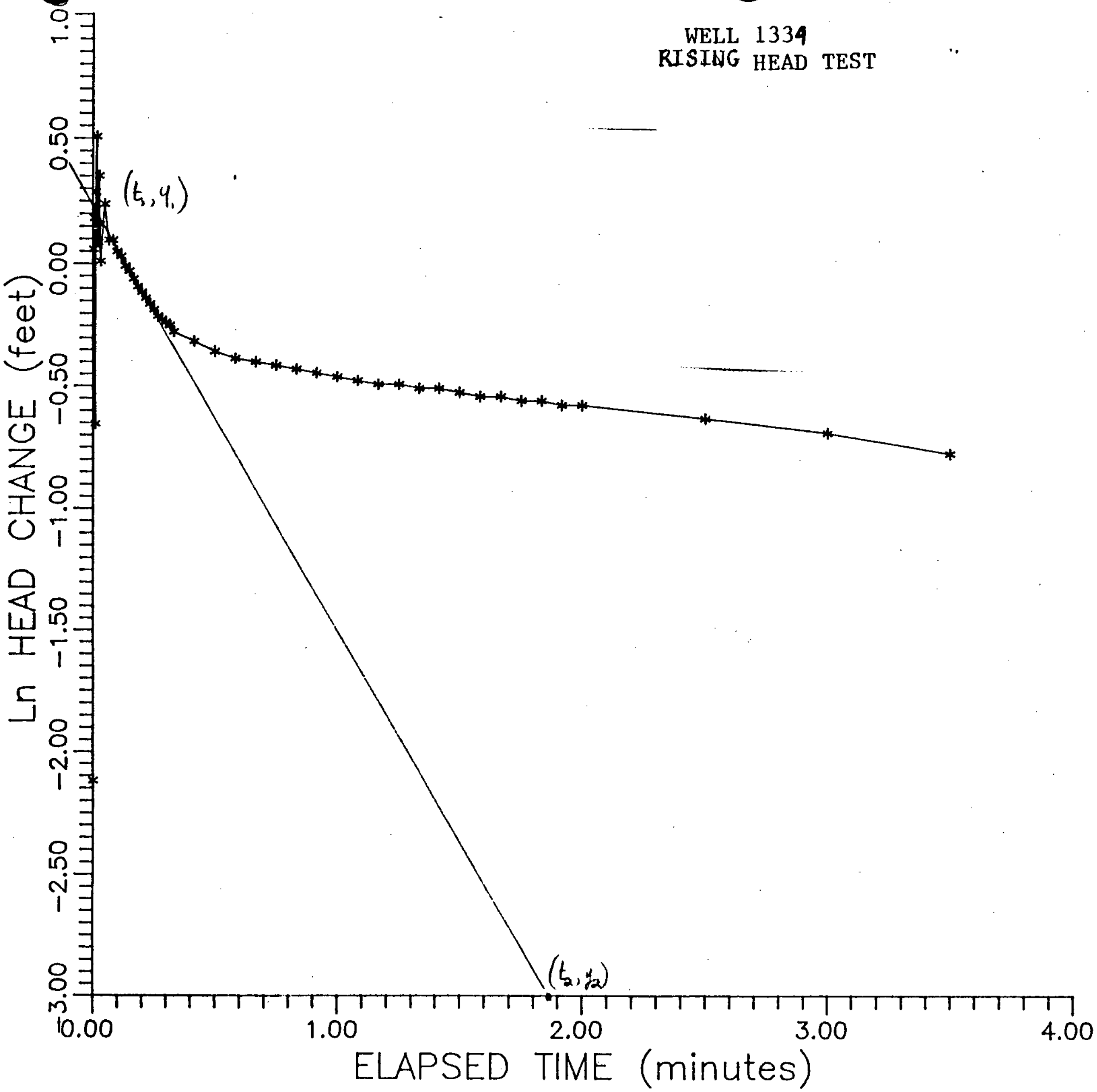


WELL 1333
FALLING HEAD TEST

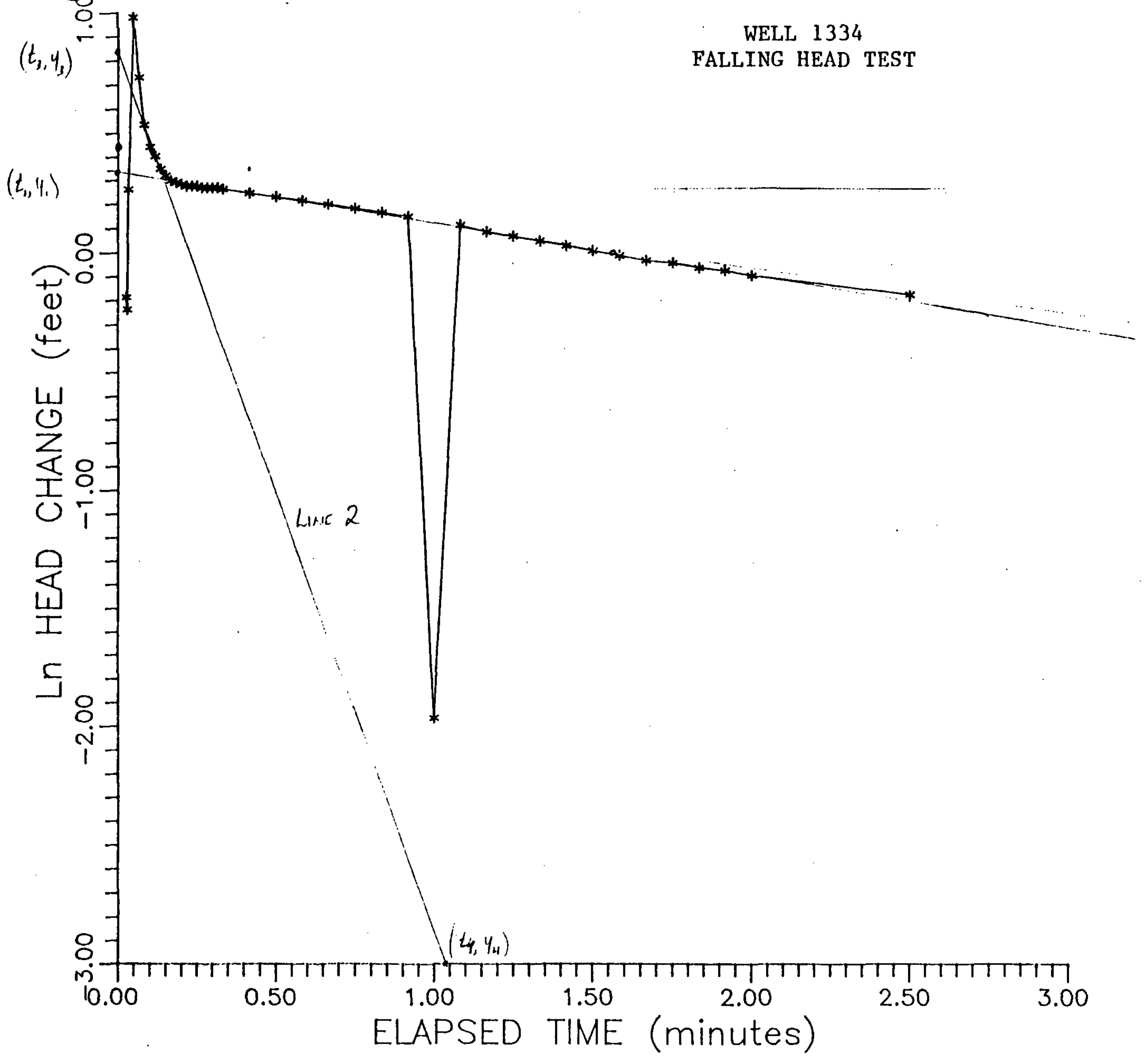


$t_1 = .01$ $y_1 = 1.45$

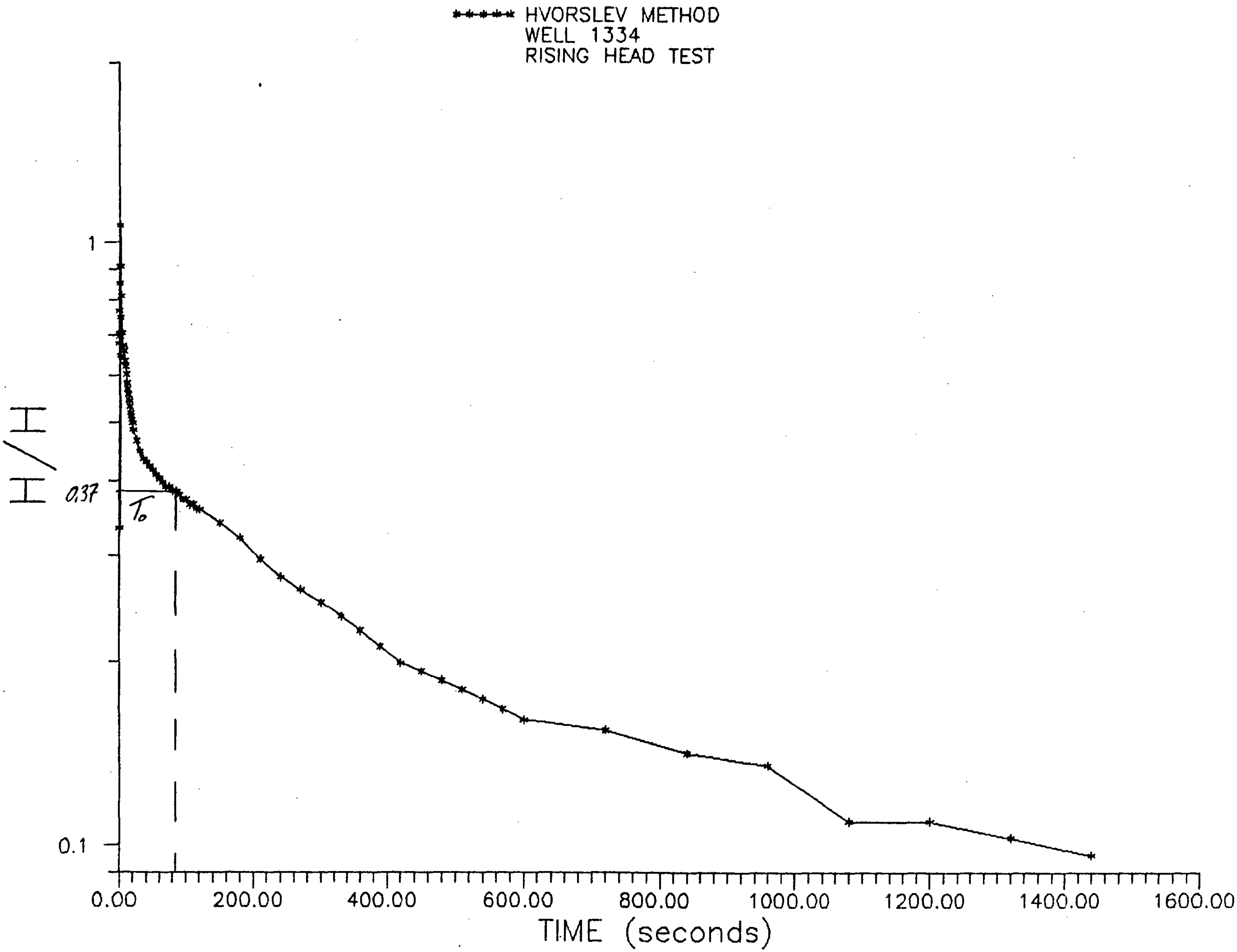
$t_2 = 2.14$ $y_2 = 0.55$



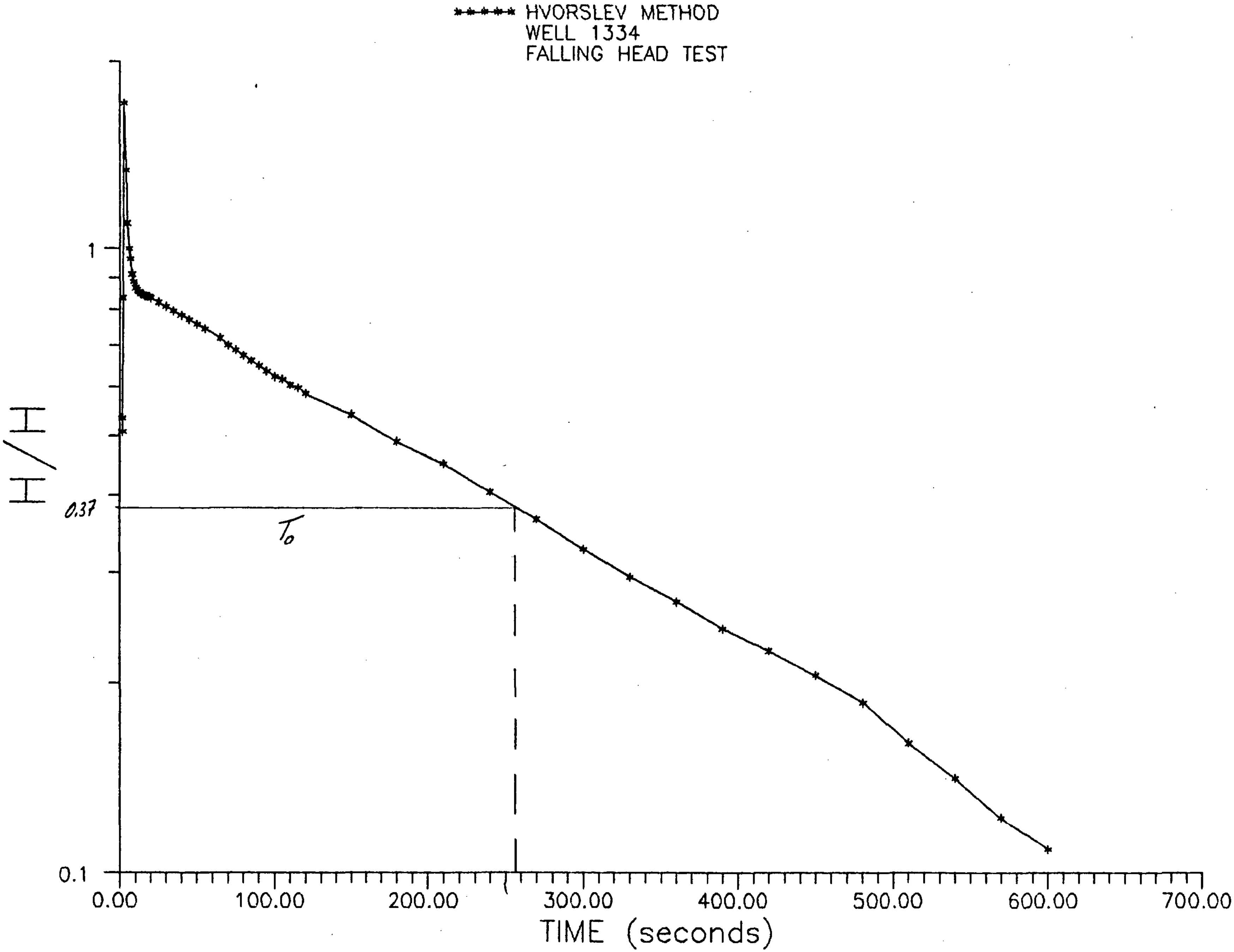
WELL 1334
RISING HEAD TEST
Ln HEAD CHANGE (feet)
1.00
0.50
0.00
-0.50
-1.00
-1.50
-2.00
-2.50
-3.00
0.00
1.00
2.00
3.00
4.00
ELAPSED TIME (minutes)
(t_1, y_1)
(t_2, y_2)



WELL 1334
FALLING HEAD TEST
Ln HEAD CHANGE (feet)
ELAPSED TIME (minutes)
1.00
0.00
-1.00
-2.00
-3.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
(t_3, y_3)
(t_1, y_1)
Line 2
(t_4, y_4)

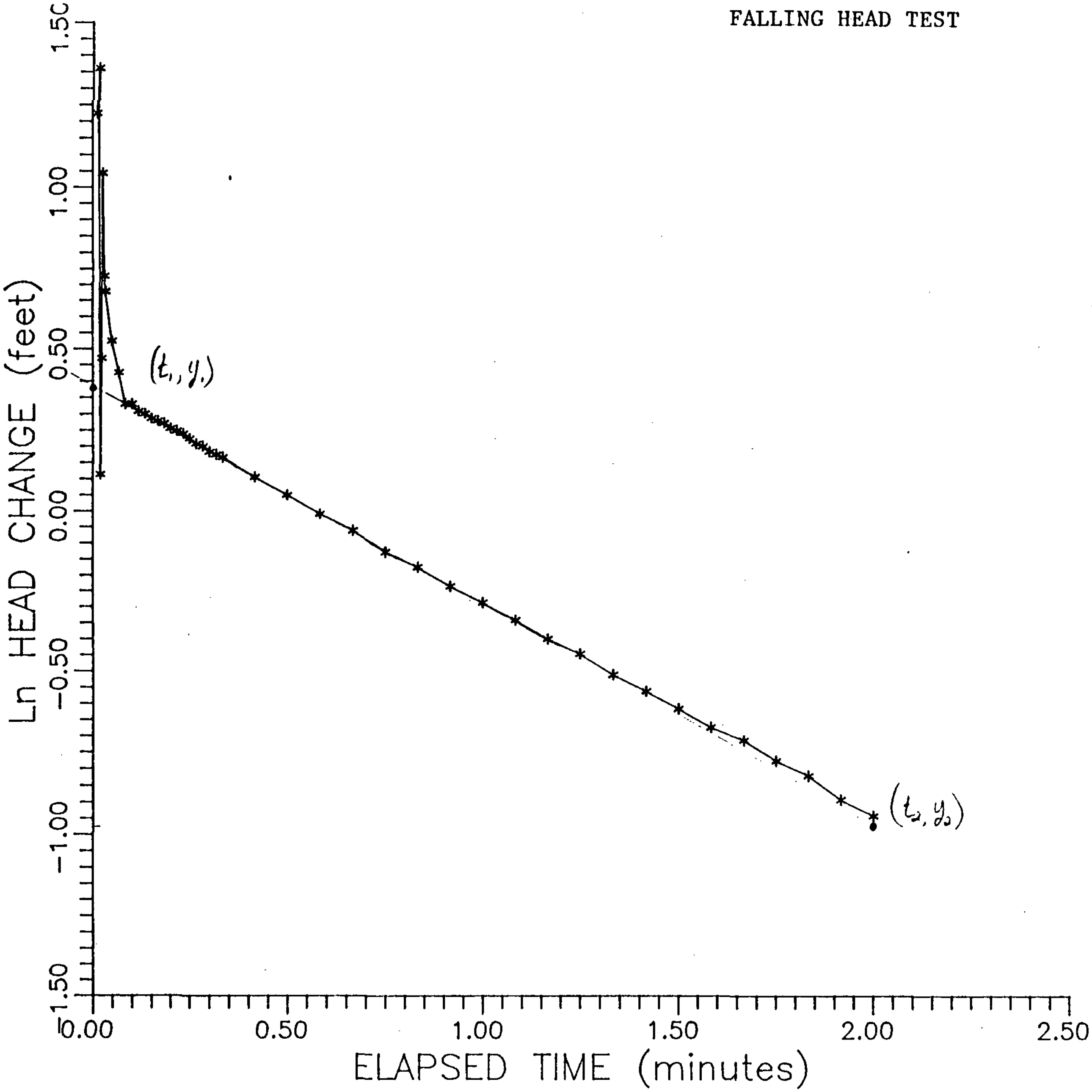


HVORSLEV METHOD
WELL 1334
RISING HEAD TEST
H/H
1
0.37
0.1
T₀
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
1400.00
1600.00
TIME (seconds)

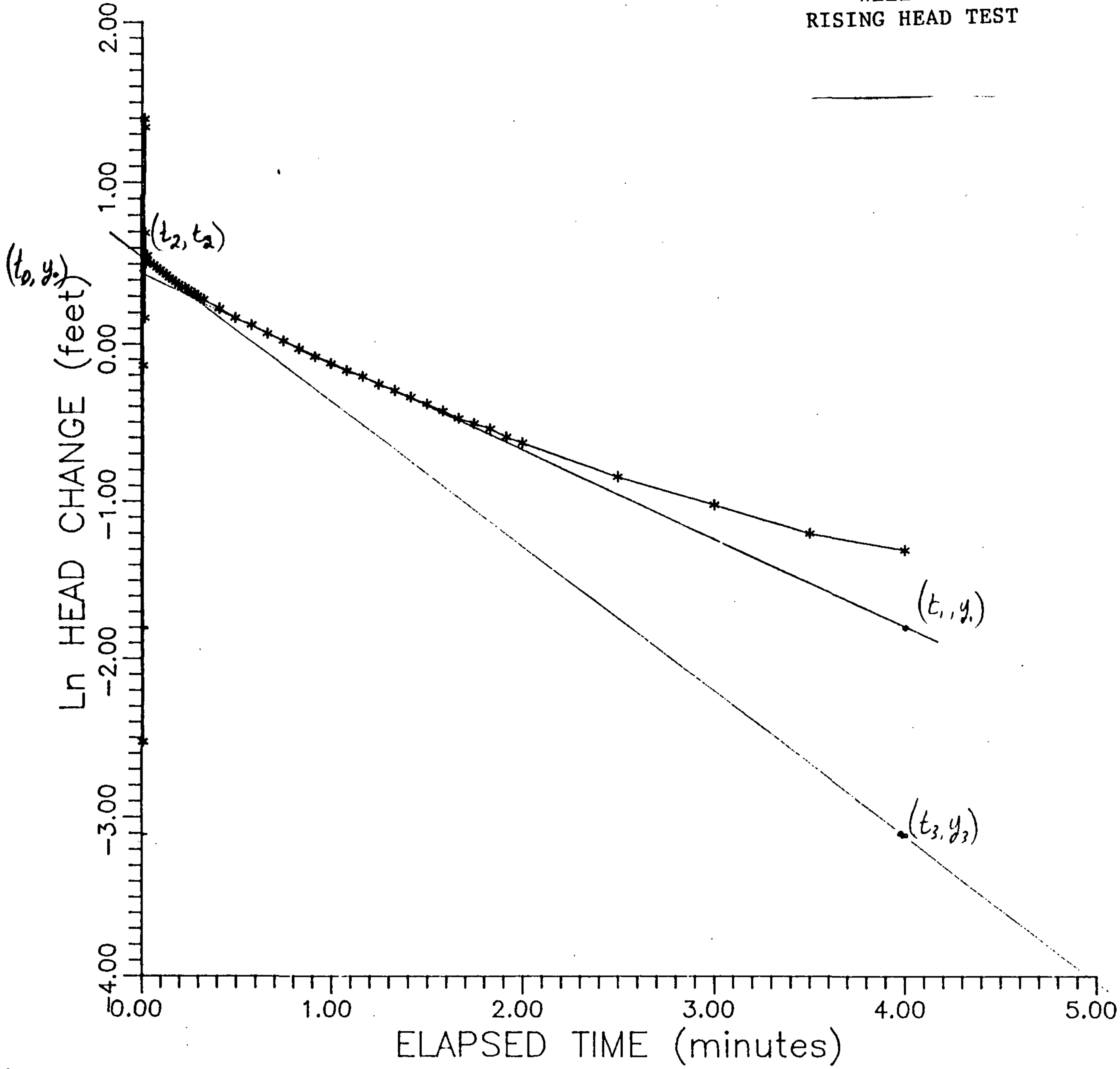


HVORSLEV METHOD
WELL 1334
FALLING HEAD TEST
H/H
1
0.37
0.1
T_o
0.00
100.00
200.00
300.00
400.00
500.00
600.00
700.00
TIME (seconds)

WELL 1335
FALLING HEAD TEST



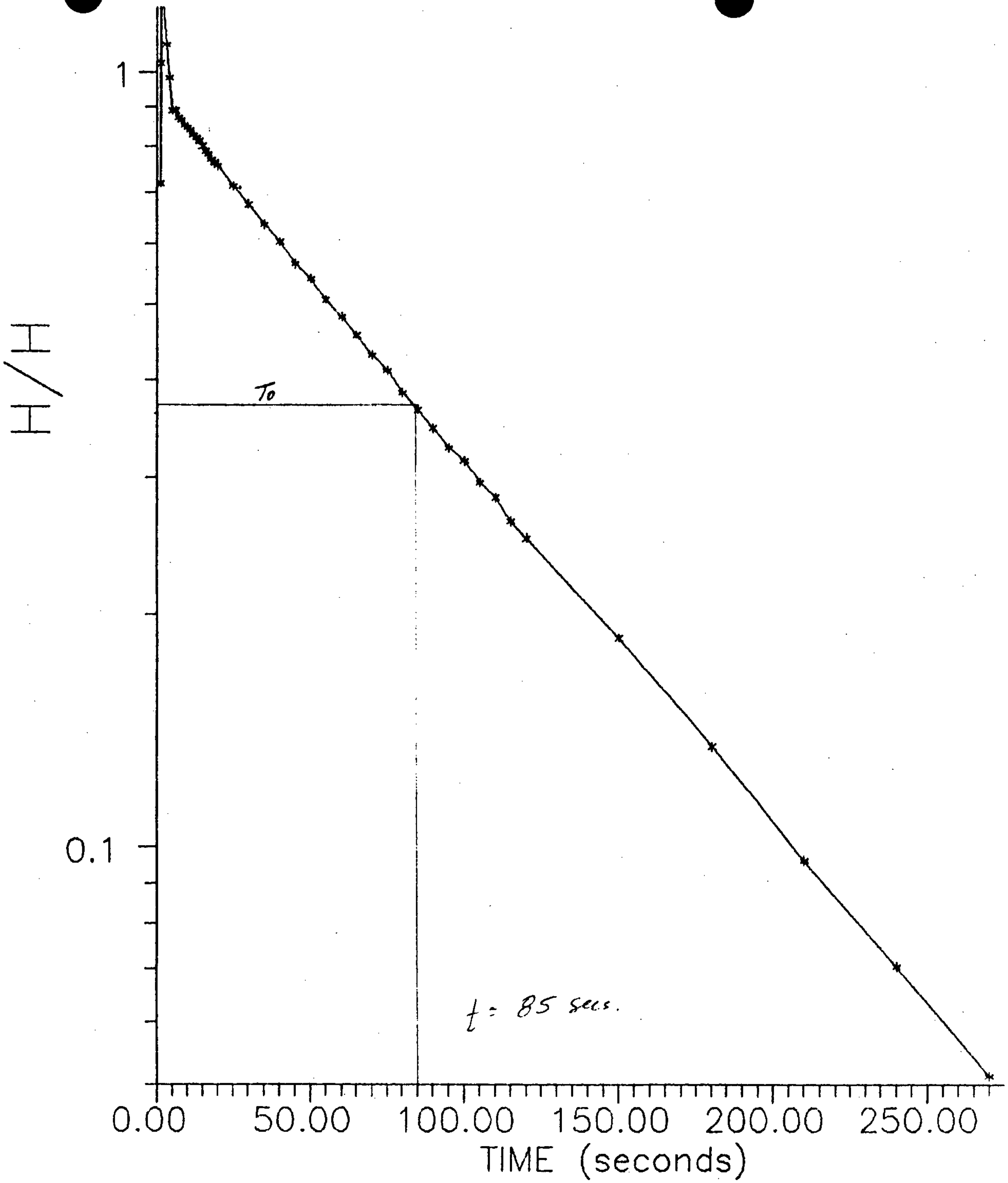
WELL 1335
RISING HEAD TEST



Curve 1 $t_0 = 0.00$ $y_0 = 1.56$
$t_1 = 4.00$ $y_1 = 0.17$

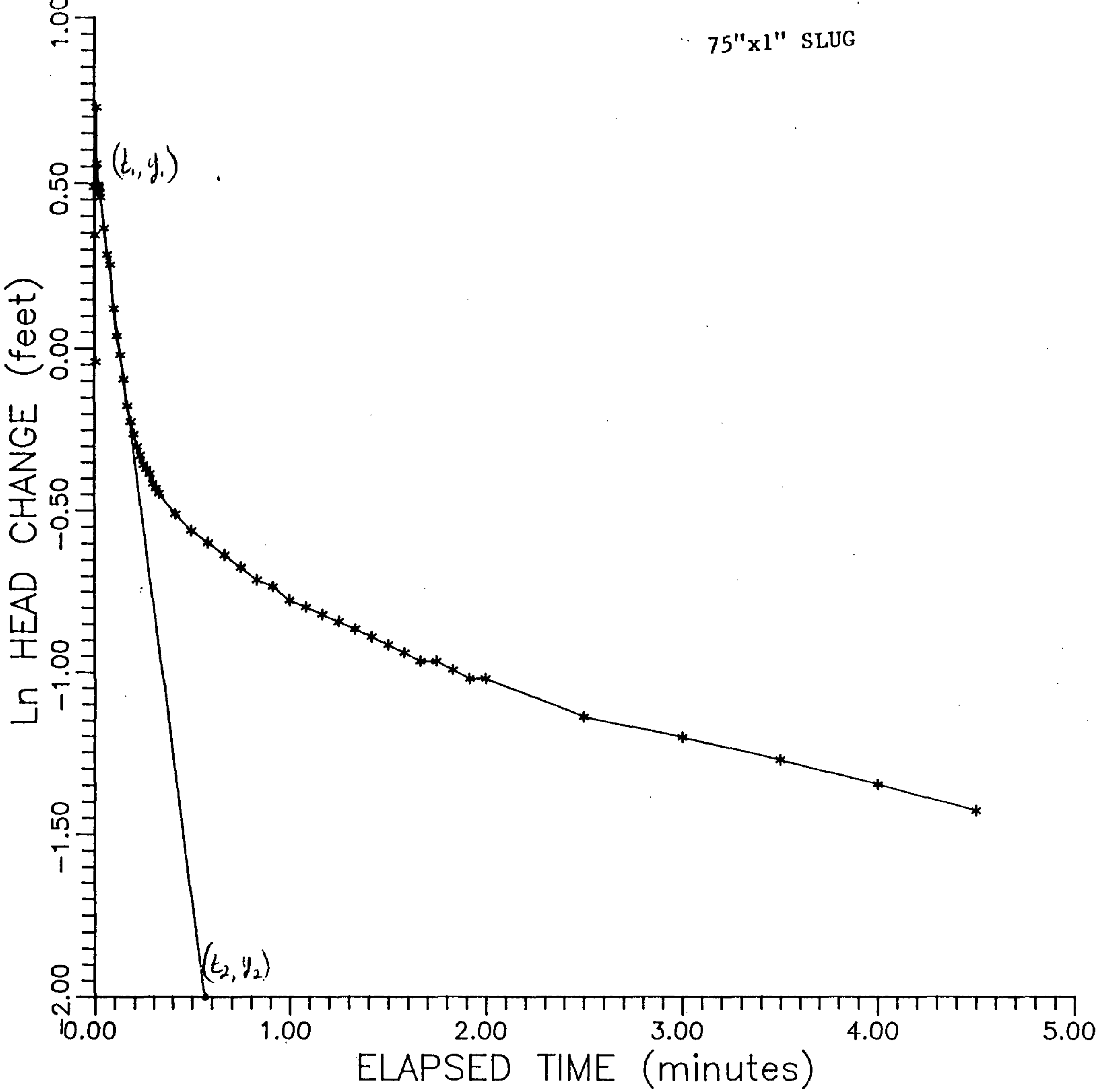
Curve 2 $t_2 = 0.01$ $y_2 = 1.73$
$t_3 = 4.00$ $y_3 = 0.05$

Well 1335
Falling Head Test



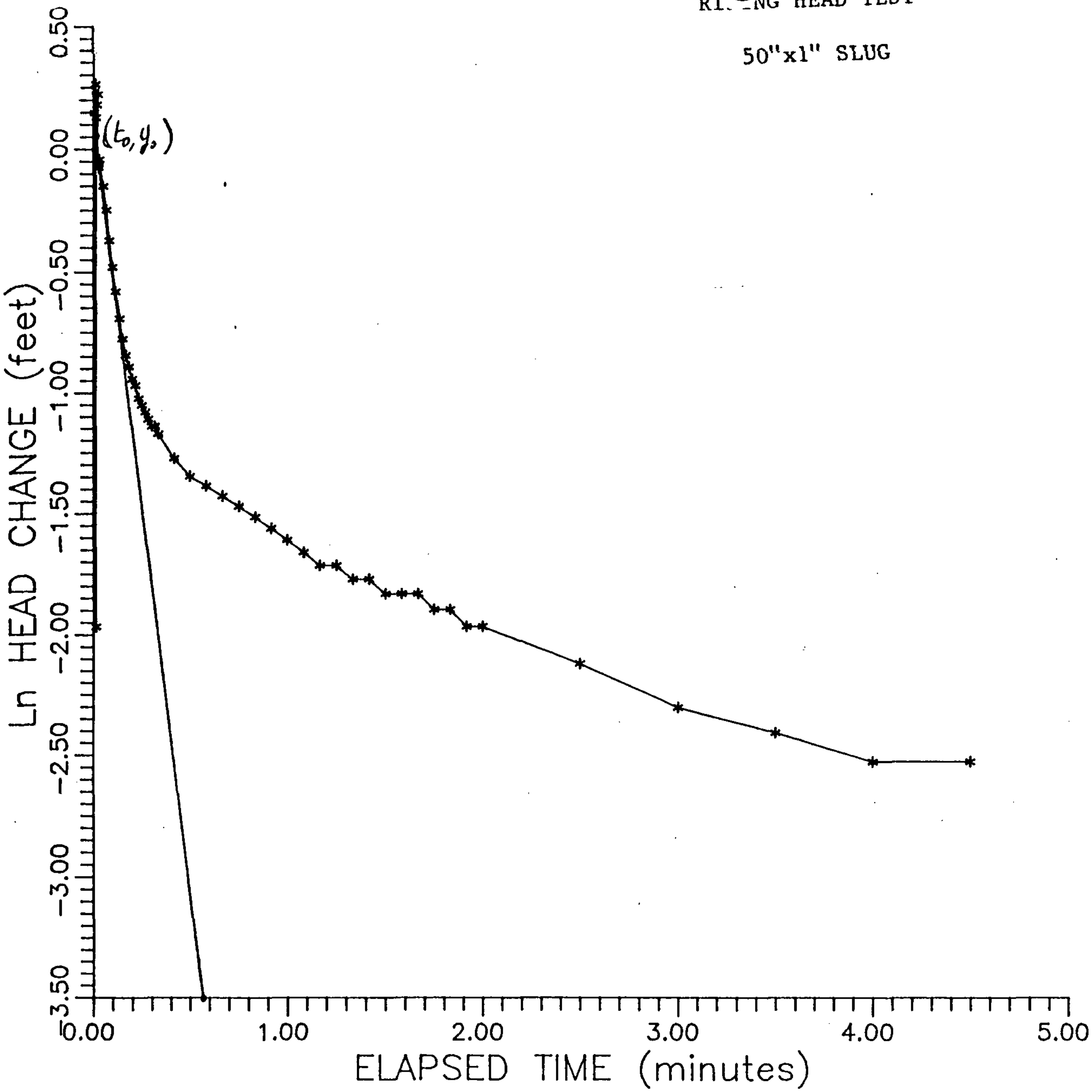
LL 1336
RIS HEAD TEST

75"x1" SLUG



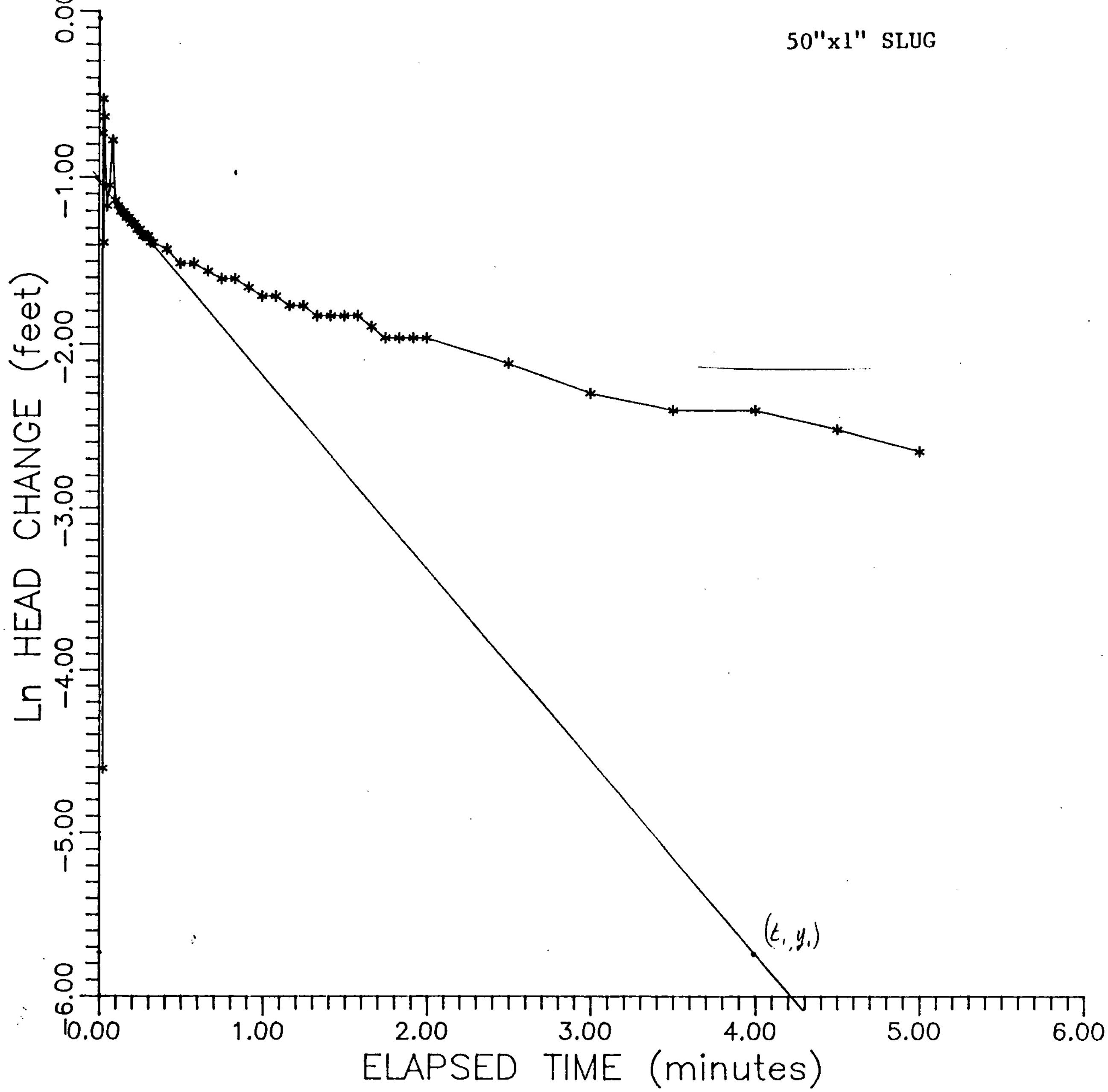
WELL 1336
RISING HEAD TEST

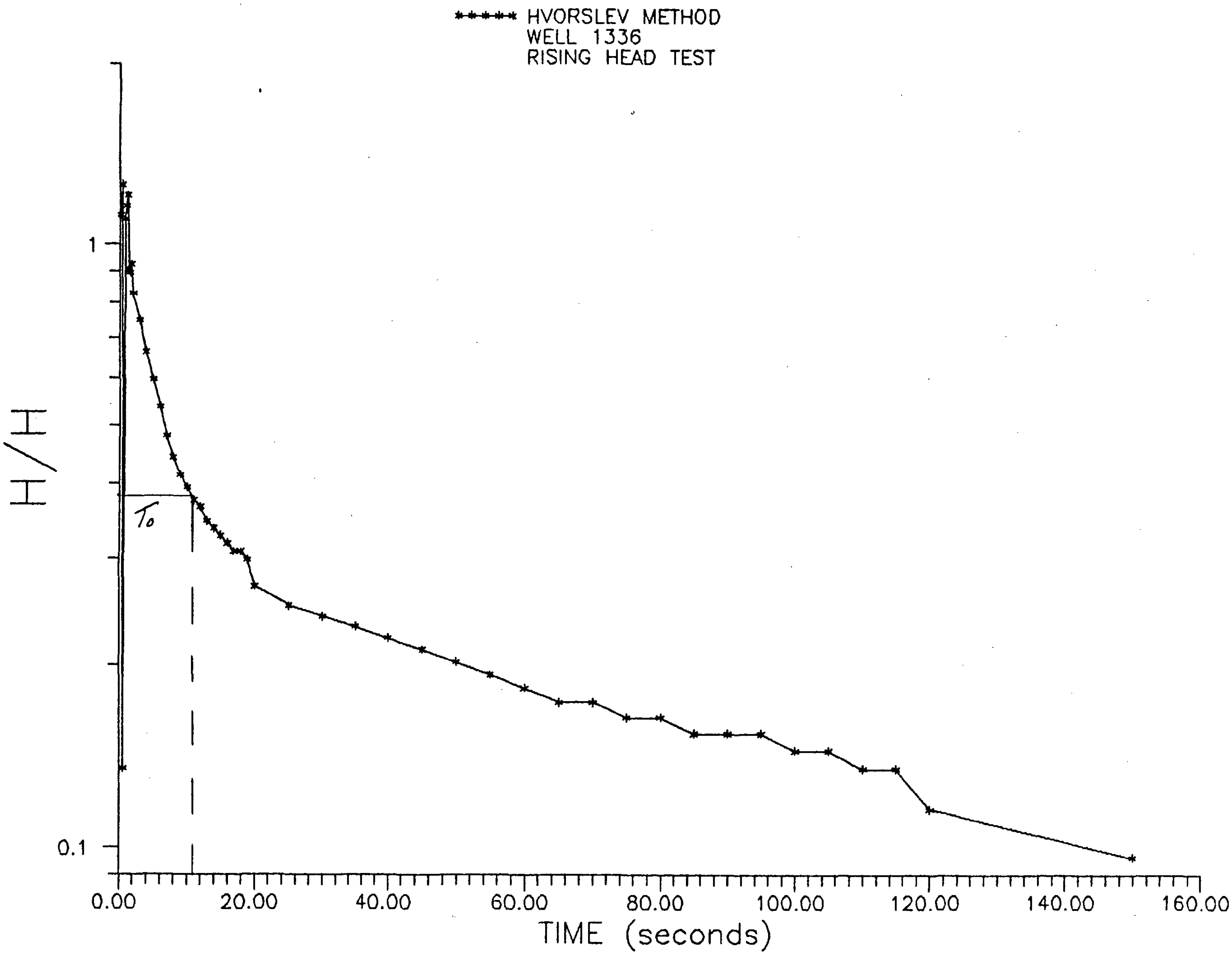
50"x1" SLUG



WELL 1336
FALLING HEAD TEST

50"x1" SLUG





HVORSLEV METHOD
WELL 1336
RISING HEAD TEST
H/H
1
0.1
To
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
TIME (seconds)

APPENDIX D

GROUND-WATER ANALYSES

17-Apr-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932941
COMPLETION DATE: 4-17-89

JLCA
RECEIVED
APR 24 1989

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1311
SAMPLE DESCRIPTION: Ground Water

NOTES: 1607-LRW-10P81,82

F	<0.20 mg/l	Ra-228	0.082+-0.19 pCi/l
NO3(N)	66.0 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	23 pCi/l	U238	0.77+-0.11 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	0.99+-0.13 pCi/l
Ra-226	0.18+-0.21 pCi/l	U-235	0.018+-0.018 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: D. Keck 4/17/89

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KERR-MCGEE CORPORATION Technology Division
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17-Apr-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932942
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1312
SAMPLE DESCRIPTION: Ground Water

APR 24 19..

NOTES: NBR same as 932941

F	50 mg/l	Ra-228	1.38+-0.54 pCi/l
NO3(N)	1020 mg/l	Th-228	0.007+-0.005 pCi/l
Alpha	59 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	2370 pCi/l	U238	15.3+-1.9 pCi/l
Pu-239	0.003+-0.002 pCi/l	U-234	41.6+-3.2 pCi/l
Ra-226	0.45+-0.34 pCi/l	U-235	1.23+-0.55 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: D. Keck 4/17/89 [signatures]

DISTRIBUTION: J.C. STAUTER, D.M. KECK,

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17-Apr-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932943
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

RECEIVED

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1313
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932941

APR 24 1989

F	140 mg/l	Ra-228	2.34+-0.91 pCi/l
NO3(N)	720 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	260 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	2200 pCi/l	U238	30+-2 pCi/l
Pu-239	0.003+-0.002 pCi/l	U-234	84+-4 pCi/l
Ra-226	0.49+-0.49 pCi/l	U-235	2.7+-0.7 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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17-Apr-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932944
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

RECEIVED

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1314
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932941

APR 24 1989

F	<0.20 mg/l	Ra-228	0+-0.27 pCi/l
NO3(N)	0.36 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	0.31+-0.08 pCi/l
Pu-239	0.003+-0.002 pCi/l	U-234	0.77+-0.12 pCi/l
Ra-226	0.11+-0.23 pCi/l	U-235	0.039+-0.027 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

****

APPROVED: D.Keck 4/17/89 JRG [signatures]

DISTRIBUTION: J.C. STAUTER, D.M. KECK,

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17-Apr-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932945
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

RECEIVED
APR 24 1989

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1315
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932941

F	0.22 mg/l	Ra-228	1.61+-0.77 pCi/l
NO3(N)	13 mg/l	Th-228	0.013+-0.007 pCi/l
Alpha	6440 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	660 pCi/l	U238	1550+-190 pCi/l
Pu-239	0.003+-0.002 pCi/l	U-234	3570+-285 pCi/l
Ra-226	0+-0.22 pCi/l	U-235	110+-51 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: D. Keck 4/17/89 JRQ [signatures]

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17-Apr-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932946
COMPLETION DATE: 4-17-89

JLGA RECEIVED

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1316
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932941

APR 24 1989

F	<0.20 mg/l	Ra-228	0.47+-0.58 pCi/l
NO3(N)	16 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	331 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	100 pCi/l	U238	67+-10 pCi/l
Pu-239	0.003+-0.002 pCi/l	U-234	210+-17 pCi/l
Ra-226	0+-0.30 pCi/l	U-235	10.0+-3.8 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: D. Keck 4/17/89 [signatures]

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8-May-198…

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932926
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1320
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	0.42 mg/l	Ra-228	0.25+-0.30 pCi/l
NO3(N)	20 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	3.1+-0.28 pCi/l
Pu-239	0.005+-0.003 pCi/l	U-234	5.58+-0.57 pCi/l
Ra-226	0.15+-0.22 pCi/l	U-235	0.17+_0.10 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: JAH 5-8-89

DISTRIBUTION: J.C. STAUTER, D.M. KECK,

KERR-MCGEE CORPORATION Technology Division

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932928
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1321
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	<0.2 mg/l	Ra-228	0.021+-0.14 pCi/l
NO3(N)	9.1 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	18 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	26 pCi/l	U238	2.75+-0.4 pCi/l
Pu-239	0.004+-0.003 pCi/l	U-234	8.1+-0.7 pCi/l
Ra-226	0+-0.14 pCi/l	U-235	0.12+-0.08 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: 5-8-89

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9-Aug-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932936
COMPLETION DATE: 5-08-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1322
SAMPLE DESCRIPTION: Ground Water

NOTES: 1688-JAH-22P33
1607-LRW-10P81,82

F	<0.20 mg/l	Ra-226	0.22+-0.29 pCi/l
NO3(N)	9.2 mg/l	Ra-228	0.038+-0.30 pCi/l
TOC	<10 mg/l	Th-228	0.004+-0.004 pCi/l
TOX	77 ug/l	Th-232	0.004+-0.004 pCi/l
Alpha	15 pCi/l	U238	3.9+-0.65 pCi/l
Beta	<20 pCi/l	U-234	8.2+-0.09 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-235	0.13+-0.011 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: D. Keck 8/9/89

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8-May-198

AFE/PROJECT NUMBER: 84007 SAMPLE ID: 932938
DATE RECEIVED: 3-22-89 COMPLETION DATE: 0-00-00

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1323
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932936

F	<0.20 mg/l	Ra-228	0.012+-0.24 pCi/l
NO3(N)	1.7 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	51 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	9.8+-1.0 pCi/l
Pu-239	0.004+-0.003 pCi/l	U-234	17+-1.3 pCi/l
Ra-226	0.046+-0.20 pCi/l	U-235	0.42+-0.21 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED:

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932927
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1324
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	0.26 mg/l	Ra-228	0.059+-0.27 pCi/l
NO3(N)	18 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	0.20+-0.07 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	0.44+-0.10 pCi/l
Ra-226	0+-0.27 pCi/l	U-235	0.022+-0.022 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

****

APPROVED: JAH 5-8-89

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10-Aug-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967473
11:46 a.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ 1324A
SAMPLE DESCRIPTION: Water

NOTES: Results needed by 6-21-89
1665-ADP-1P173;1663-MTM-6P116
1559-DAW-26P190

Ca	71.5 mg/l	Cl	3.8 mg/l
Mg	37.2 mg/l	HCO3	394 mg/l
F	0.6 mg/l	NO3(N)	20 mg/l
K	0.36 mg/l	SO4	72 mg/l
Na	40.1 mg/l		

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

****
*
* APPROVED: D. Keck 8/10/89
*
****

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This/these samples are being returned to you.

9-Aug-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932922
COMPLETION DATE: 5-08-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1325
SAMPLE DESCRIPTION: Ground Water

NOTES: 1688-JAH-22P33
1607-LRW-10P81,82

F	0.35	mg/l	Ra-226	0.086+-0.26	pCi/l
NO3(N)	13	mg/l	Ra-228	0.26+-0.26	pCi/l
TOC	12/12	mg/l	Th-228	0.004+-0.004	pCi/l
TOX	130	ug/l	Th-232	0.004+-0.004	pCi/l
Alpha	<10	pCi/l	U238	1.00+-0.12	pCi/l
Beta	<20	pCi/l	U-234	1.49+-0.015	pCi/l
Pu-239	0.006+-0.003	pCi/l	U-235	0.046+-0.026	pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

****

APPROVED: D.Keck 8/9/89

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9-Aug-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932923
COMPLETION DATE: 5-08-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1326
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	<0.20 mg/l	Ra-226	0+-0.16 pCi/l
NO3(N)	14 mg/l	Ra-228	0.15+-0.20 pCi/l
TOC	<10 mg/l	Th-228	0.008+-0.005 pCi/l
TOX	98 ug/l	Th-232	0.004+-0.004 pCi/l
Alpha	14 pCi/l	U238	1.48+-0.15 pCi/l
Beta	25 pCi/l	U-234	4.43+-0.25 pCi/l
Pu-239	0.002+-0.001 pCi/l	U-235	0.058+-0.029 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

****
APPROVED: D. Keck 8/9/89 [signature]

DISTRIBUTION: J.C. STAUTER, D.M. KECK,
****

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932934
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1327
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	0.20 mg/l	Ra-228	0.009+-0.10 pCi/l
NO3(N)	8.2 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	1.52+-0.20 pCi/l
Pu-239	0.006+-0.003 pCi/l	U-234	2.8+-0.28 pCi/l
Ra-226	0.052+-0.082 pCi/l	U-235	0.14+-0.06 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

****

* APPROVED: ________ 5-8-89 ________ *

* DISTRIBUTION: J.C. STAUTER, D.M. KECK, ________ *

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If you want the samples retained or returned, please advise.

8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932939
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1328
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932936

F	(0.2 mg/l	Ra-228	0+-0.19 pCi/l
NO3(N)	2.2 mg/l	Th-228	0.011+-0.007 pCi/l
Alpha	29 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	(20 pCi/l	U238	9+-0.9 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	18+-1.3 pCi/l
Ra-226	0.054+-0.13 pCi/l	U-235	0.66+-0.25 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

****

APPROVED: 5-8-89

DISTRIBUTION: J.C. STAUTER, D.M. KECK, ____________

****

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9-Aug-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932937
COMPLETION DATE: 5-08-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1329
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932936

F	<0.20 mg/l	Ra-226	0.030+-0.13 pCi/l
NO3(N)	0.40 mg/l	Ra-228	0+-0.17 pCi/l
TOC	<10 mg/l	Th-228	0.008+-0.006 pCi/l
TOX	62 ug/l	Th-232	0.004+-0.004 pCi/l
Alpha	12 pCi/l	U238	2.04+-0.18 pCi/l
Beta	<20 pCi/l	U-234	5.3+-0.29 pCi/l
Pu-239	0.006+-0.003 pCi/l	U-235	0.093+-0.037 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

****

APPROVED: D. Keck 8/9/89 [illegible]

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17-Apr-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932935
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1330
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	<0.2 mg/l	Ra-228	0+-0.31 pCi/l
NO3(N)	172 mg/l	Th-228	0.008+-0.008 pCi/l
Alpha	16 pCi/l	Th-232	0.008+-0.008 pCi/l
Beta	62 pCi/l	U238	2.4+-0.22 pCi/l
Pu-239	0.006+-0.003 pCi/l	U-234	5.17+-0.33 pCi/l
Ra-226	0.088+-0.22 pCi/l	U-235	0.10+-0.05 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: ____________________

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932929
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1331
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	<0.2 mg/l	Ra-228	0+-0.23 pCi/l
NO3(N)	5.7 mg/l	Th-228	0.008+-0.005 pCi/l
Alpha	190 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	23 pCi/l	U238	35+-6.1 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	126+-12 pCi/l
Ra-226	0+-0.23 pCi/l	U-235	3.7+-1.8 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: 5-8-89

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932932
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1332
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	1.3 mg/l	Ra-228	1.00+-0.46 pCi/l
NO3(N)	3.4 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	23 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	6.4+-0.6 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	13.9+-0.9 pCi/l
Ra-226	0.18+-0.36 pCi/l	U-235	0.12+-0.08 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932930
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1333
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	<0.20 mg/l	Ra-228	0.12+-0.32 pCi/l
NO3(N)	6.3 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	47 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	6.2+-0.5 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	18+-0.6 pCi/l
Ra-226	0.12+-0.39 pCi/l	U-235	0.71+-0.12 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932933
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1334
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	0.26 mg/l	Ra-228	0.20+-0.14 pCi/l
NO3(N)	6.1 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	30 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	5.0+-0.33 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	13.2+-0.5 pCi/l
Ra-226	0.029+-0.13 pCi/l	U-235	0.23+-0.07 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: JGH 5-8-89 [signatures]

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9-May-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932924
COMPLETION DATE: 5-60-98

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1335
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	0.24/0.20 mg/l	Ra-228	0+-0.32 pCi/l
NO3(N)	22/22 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	1.25+-0.15 pCi/l
Pu-239	0.006+-0.004 pCi/l	U-234	1.64+-0.17 pCi/l
Ra-226	0+-0.32 pCi/l	U-235	0.10+-0.042 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: JRQ 5-8-89 JAH [signature]

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932925
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1336
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	17 mg/l	Ra-228	7.83+-1.63 pCi/l
NO3(N)	1260 mg/l	Th-228	0.085+-0.018 pCi/l
Alpha	140 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	4970 pCi/l	U238	23+-2.4 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	76+-4 pCi/l
Ra-226	1.95+-1.02 pCi/l	U-235	2.4+-0.8 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-21-89

SAMPLE ID: 932931
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\21-MAR-89\ \ \ \ \1337
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932922

F	<0.2 mg/l	Ra-228	1.2+-0.41 pCi/l
NO3(N)	5.7 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	33 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	5.1+-0.54 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	18.7+-1.04 pCi/l
Ra-226	0.20+-0.21 pCi/l	U-235	0.17+-0.10 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: 5-8-89

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8-May-198

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 3-22-89

SAMPLE ID: 932940
COMPLETION DATE: 4-17-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\22-MAR-89\ \ \ \ \1338
SAMPLE DESCRIPTION: Ground Water

NOTES: NBR same as 932936

F	0.32/0.33 mg/l	Ra-228	0.028+-0.089 pCi/l
NO3(N)	<0.23/<0.23 mg/l	Th-228	0.004+-0.004 pCi/l
Alpha	<10 pCi/l	Th-232	0.004+-0.004 pCi/l
Beta	<20 pCi/l	U238	0.036+-0.025 pCi/l
Pu-239	0.002+-0.002 pCi/l	U-234	0.071+-0.036 pCi/l
Ra-226	0+-0.061 pCi/l	U-235	0.017+-0.017 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

****

APPROVED: JRD JCH 5-8-89

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KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD — ENVIRONMENTAL SAMPLES

FACILITY	SAMPLING FIRM	SAMPLE
NAME: Cimarron Facility	NAME: James L. Grant & Assoc.	☐ Effluent ☒ Groundwater
ADDRESS: Highway 74	ADDRESS: 8301 E. Prentice #402, Englewood, Co. 80111	☐ Solid ☐ Surface Water
Crescent, OK	SIGNATURE: [signature]	☐

NO.	LOCATION	DATE	TIME	WEATHER TEMP	WEATHER PREC.	SAMPLE TYPE AND METHOD COMP.	GRAB	MECH	MAN	TIMES CASING CLEARED	NO. OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
1325	Cimarron Facility	3/20/89	08:45	30°F 45°F	Mod. None		X		932922		3	NO_3 as N, F, Gross Alpha Beta, Th-232, Th-228, U-238, U-235, Ra-228, Ra-226, Pu-239, TOC, TOX	
1326	" "	"	10:35	"	"		"		932923		3	Same	
1335	" "	"	0915	"	"		"		932924		2	Same without TOC, TOX	
1336	" "	"	10:10	"	"		"		932925		2	" " " "	
1320	" "	"	0755	"	"		"		932926		2	" " " "	
1324	" "	"	0820	"	"		"		932927		2	" " " "	
1321	" "	"	07:25	"	"		"		932928		2	" " " "	

RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME	ADDITIONAL REMARKS
[signature]				
RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME	
RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME	

DISPATCHED BY (SIGNATURE)	DATE	TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME
			D M Keck	3/24/89	11:30a

CARRIER: Delivered Personally

LABORATORY:

ADDRESS:

ADDRESS:

METHOD OF SHIPMENT:

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES

☒ Yes ☐ No, explain above

KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD — ENVIRONMENTAL SAMPLES

FACILITY	SAMPLING FIRM	SAMPLE
NAME: CIMARRON FACILITY	NAME: JAMES L. GRANT & ASSOC.	☐ Effluent ☒ Groundwater
ADDRESS: HIGHWAY 74	ADDRESS: 8301 E. PRENTICE #402 ENGLEWOOD, CO. 80111	☐ Soil ☐ Surface Water
CRESCENT, OK 73028	SIGNATURE: Patrick F. Brown	☐

NO.	LOCATION	DATE	TIME	WEATHER TEMP	WEATHER PREC	SAMPLE TYPE AND METHOD COMP.	GRAB	MECH	MAN	TIMES CASING CLEARED	NO. OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
1331	CIMARRON FACILITY	3/21/89	11:25	50°	None		X		932929		2	NO_3 as N, F, Gross Alpha, Beta, Th-232, Th-228, U-238, U-235, Ra-228, Ra-226, Pu-239	
1333	" "	"	11:50	"	"		"		932930		2	SAME	
1337	" "	"	17:00	"	"		"		932931		2	SAME	
1332	" "	"	17:25	"	"		"		932932		2	SAME	
1334	" "	"	17:50	"	"		"		932933		2	SAME	
1327	" "	"	19:35	"	"		"		932934		2	SAME	
1330 ~~1940~~	" "	"	19:10	"	"		"		932935		2	SAME	

RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME	ADDITIONAL REMARKS
Patrick F. Brown	E. D. Endert	3-21-89	20:15	

DISPATCHED BY (SIGNATURE)	DATE	TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME
			[signature]	3/22/89	7:00

CARRIER

LABORATORY

ADDRESS

ADDRESS

METHOD OF SHIPMENT

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES

☒ Yes ☐ No, explain above

KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD — ENVIRONMENTAL SAMPLES KM 4775

FACILITY	SAMPLING FIRM	SAMPLE
NAME: Cimarron Facility	NAME: James L. Grant & Assoc.	☐ Effluent ☒ Groundwater
ADDRESS: Highway 74	ADDRESS: 8301 E. Prentice #402 Englewood Co. 80111	☐ Solid ☐ Surface Water
Crescent OK 73028	SIGNATURE: Patrick [signature] (Brown)	☐

NO.	LOCATION	DATE	TIME	WEATHER TEMP	WEATHER PREC	COMP.	GRAB	MECH	MAN	TIMES CASING CLEARED	NO. OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
1322	Cimarron	3/22/89	12:00	60	ϕ		X		932936		3	NO3 as N, F, Gross Alpha, U-238, U-235, Ra-228	Beta, Th-232, Th-228, Ra-226, Pu-239, TOC, TOX
1329	"	"	1:15	60	ϕ		"		932937		3	SAME	
1323	"	"	11:35	50	ϕ		"		932938		2	SAME WITHOUT	TOC, TOX
1328	"	"	12:40	60	ϕ		"		932939		2	SAME "	" "
1338	"	"	1:35	60	ϕ		"		932940		2	SAME "	" "
							"						

RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME	ADDITIONAL REMARKS
Patrick [signature]				

DISPATCHED BY (SIGNATURE)	DATE	TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME
			D. Keck	3/22/89	3:25p

CARRIER:

LABORATORY:

ADDRESS:

ADDRESS:

METHOD OF SHIPMENT:

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES

☒ Yes ☐ No, explain above

APPENDIX E

SOIL AND ROCK SITE-SPECIFIC PARAMETER ANALYSES

21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943087
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\24-JAN-89\ \ \ \ \CS-101 WELL 1321
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	560 ppm	Ra-226	0.51+-0.28 pCi/g
NO3(N)	3 ppm	Ra-228	1.84+-0.39 pCi/g
TOC	<10 ppm	Th-228	1.37+-0.07 pCi/g
Alpha	34 pCi/g	Th-232	1.37+-0.07 pCi/g
Beta	<20 pCi/g	U-234	0.57+-0.07 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.66+-0.07 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: D. Keck 7/21/89 JRG

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21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943098
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\20-JAN-89\ \ \ \ \CS-112 WELL 1321
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	55 ppm	Ra-226	0.10+-0.30 pCi/g
NO3(N)	2 ppm	Ra-228	0.07+-0.27 pCi/g
TOC	160 ppm	Th-228	0.41+-0.03 pCi/g
Alpha	<10 pCi/g	Th-232	0.34+-0.03 pCi/g
Beta	<20 pCi/g	U-234	0.33+-0.03 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.29+-0.03 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: D. Keck 7/21/89

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21-Jul-1989

AFE/PROJECT NUMBER: 84007 | SAMPLE ID: 943099
DATE RECEIVED: 4-11-89 | COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\20-JAN-89\ \ \ \ \CS-113 WELL 1321
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	65 ppm	Ra-226	0.12+-0.20 pCi/g
NO3(N)	130 ppm	Ra-228	0.08+-0.18 pCi/g
TOC	170 ppm	Th-228	0.33+-0.03 pCi/g
Alpha	<10 pCi/g	Th-232	0.32+-0.03 pCi/g
Beta	<20 pCi/g	U-234	0.18+-0.03 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.23+-0.03 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: D. Keck 7/21/89

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21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943112
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\20-JAN-89\ \ \ \ \CS-126 WELL 1321
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	18 ppm	Ra-226	0.01+-0.13 pCi/g
NO3(N)	4 ppm	Ra-228	0+-0.09 pCi/g
TOC	130 ppm	Th-228	0.41+-0.04 pCi/g
Alpha	<10 pCi/g	Th-232	0.41+-0.04 pCi/g
Beta	<20 pCi/g	U-234	0.21+-0.03 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.16+-0.02 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943088
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\13-FEB-89\ \ \ \ C\S-102 WELL 1323
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	640 ppm	Ra-226	0.21+-0.21 pCi/g
NO3(N)	2 ppm	Ra-228	0.29+-0.20 pCi/g
TOC	190 ppm	Th-228	1.42+-0.06 pCi/g
Alpha	30 pCi/g	Th-232	1.39+-0.06 pCi/g
Beta	<20 pCi/g	U-234	0.63+-0.08 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.67+-0.08 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943089
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\13-FEB-89\ \ \ \ \CS-103 WELL 1323
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	440	ppm	Ra-226	0.28+-0.95	pCi/g
NO3(N)	3	ppm	Ra-228	0.27+-0.85	pCi/g
TOC	23	ppm	Th-228	1.28+-0.10	pCi/g
Alpha	30	pCi/g	Th-232	1.17+-0.10	pCi/g
Beta	<20	pCi/g	U-234	0.60+-0.06	pCi/g
Pu-239	0.001+-0.001	pCi/g	U-238	0.51+-0.06	pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943105
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-FEB-89\ \ \ \ \CS-119 WELL 1323
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	330 ppm	Ra-226	0.38+-0.33 pCi/g
NO3(N)	3 ppm	Ra-228	0.30+-0.27 pCi/g
TOC	130 ppm	Th-228	0.93+-0.06 pCi/g
Alpha	18 pCi/g	Th-232	0.96+-0.06 pCi/g
Beta	<20 pCi/g	U-234	0.59+-0.05 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.63+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007 SAMPLE ID: 943106
DATE RECEIVED: 4-11-89 COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-FEB-89\ \ \ \ \CS-120 WELL 1323
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	59 ppm	Ra-226	0.03+-0.20 pCi/g
NO3(N)	3 ppm	Ra-228	0+-0.14 pCi/g
TOC	140 ppm	Th-228	0.42+-0.05 pCi/g
Alpha	<10 pCi/g	Th-232	0.42+-0.05 pCi/g
Beta	<20 pCi/g	U-234	0.27+-0.04 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.27+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943097
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\08-FEB-89\ \ \ \ \CS-111 WELL 1324
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	39 ppm	Ra-226	0.11+-0.26 pCi/g
NO3(N)	4 ppm	Ra-228	0+-0.16 pCi/g
TOC	27 ppm	Th-228	0.41+-0.02 pCi/g
Alpha	<10 pCi/g	Th-232	0.45+-0.02 pCi/g
Beta	<20 pCi/g	U-234	0.19+-0.05 pCi/g
Pu-239	0.006+-0.001 pCi/g	U-238	0.19+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943086
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\09-FEB-89\ \ \ \ \CS-100 WELL 1325
SAMPLE DESCRIPTION: Soils

NOTES: 1705-JAE-18P36-50;1660-JRJ-23P183-190
1663-MTM-6P108,109;1717-JRJ-24P20-46
1717-JRJ-24P1-10;1660-JRJ-23P182-192

F	170 ppm	Ra-226	0.55+-0.36 pCi/g
NO3(N)	14 ppm	Ra-228	0.07+-0.18 pCi/g
TOC	45 ppm	Th-228	0.70+-0.03 pCi/g
Alpha	16 pCi/g	Th-232	0.70+-0.03 pCi/g
Beta	<20 pCi/g	U-234	0.51+-0.05 pCi/g
Pu-239	0.003+-0.001 pCi/g	U-238	0.34+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943090
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\16-FEB-89\ \ \ \ \CS-104 WELL 1326
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	600 ppm	Ra-226	0.77+-0.21 pCi/g
NO3(N)	4 ppm	Ra-228	1.17+-0.24 pCi/g
TOC	<10 ppm	Th-228	1.15+-0.06 pCi/g
Alpha	35 pCi/g	Th-232	1.15+-0.06 pCi/g
Beta	<20 pCi/g	U-234	0.77+-0.07 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.69+-0.07 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943107
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\15-FEB-89\ \ \ \ \CS-121 WELL 1326
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	170 ppm	Ra-226	0.42+-0.32 pCi/g
NO3(N)	5 ppm	Ra-228	0+-0.25 pCi/g
TOC	3110 ppm	Th-228	0.59+-0.05 pCi/g
Alpha	<10 pCi/g	Th-232	0.49+-0.04 pCi/g
Beta	<20 pCi/g	U-234	0.68+-0.05 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.44+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943091
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\28-FEB-89\ \ \ \ \CS-105 WELL 1327
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	470 ppm	Ra-226	0.65+-0.34 pCi/g
NO3(N)	3 ppm	Ra-228	0.77+-0.35 pCi/g
TOC	<10 ppm	Th-228	1.2+-0.08 pCi/g
Alpha	31 pCi/g	Th-232	1.0+-0.08 pCi/g
Beta	<20 pCi/g	U-234	0.68+-0.04 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.68+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943092
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\09-MAR-89\ \ \ \ \CS-106 WELL 1328
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	600 ppm	Ra-226	0.66+-0.39 pCi/g
NO3(N)	15 ppm	Ra-228	0.99+-0.42 pCi/g
TOC	<10 ppm	Th-228	1.18+-0.07 pCi/g
Alpha	36 pCi/g	Th-232	1.14+-0.07 pCi/g
Beta	<20 pCi/g	U-234	0.72+-0.07 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.71+-0.07 pCi/l

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007 SAMPLE ID: 943108
DATE RECEIVED: 4-11-89 COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\08-MAR-89\ \ \ \ \CS-122 WELL 1328
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	72 ppm	Ra-226	0.12+-0.25 pCi/g
NO3(N)	5 ppm	Ra-228	0.01+-0.19 pCi/g
TOC	47 ppm	Th-228	0.33+-0.03 pCi/g
Alpha	<10 pCi/g	Th-232	0.33+_0.03 pCi/g
Beta	<20 pCi/g	U-234	0.36+-0.03 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.26+-0.03 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943109
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\08-MAR-89\ \ \ \ \CS-123 WELL 1328
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	180 ppm	Ra-226	0.37+-0.22 pCi/g
NO3(N)	2 ppm	Ra-228	0.30+-0.21 pCi/g
TOC	320 ppm	Th-228	0.68+-0.06 pCi/g
Alpha	11 pCi/g	Th-232	0.50+-0.06 pCi/g
Beta	<20 pCi/g	U-234	0.45+-0.04 pCi/g
Pu-239	0.003+-0.001 pCi/g	U-238	0.45+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943110
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\08-MAR-89\ \ \ \ \CS-124 WELL 1328
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	23 ppm	Ra-226	0+-0.06 pCi/g
NO3(N)	6 ppm	Ra-228	1.90+-0.54 pCi/g
TOC	1180 ppm	Th-228	0.47+-0.04 pCi/g
Alpha	<10 pCi/g	Th-232	0.27+-0.04 pCi/g
Beta	<20 pCi/g	U-234	0.19+-0.03 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.19+-0.03 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943093
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\10-MAR-89\ \ \ \ \CS-107 WELL 1330
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	560 ppm	Ra-226	0.29+-0.22 pCi/g
NO3(N)	16 ppm	Ra-228	0.62+-0.21 pCi/g
TOC	420 ppm	Th-228	0.87+-0.05 pCi/g
Alpha	19 pCi/g	Th-232	0.69+-0.05 pCi/g
Beta	<20 pCi/g	U-234	0.73+-0.08 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.84+-0.08 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943111
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\10-MAR-89\ \ \ \ \CS-125 WELL 1330
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	88 ppm	Ra-226	0.11+-0.32 pCi/g
NO3(N)	12 ppm	Ra-228	0+-0.25 pCi/g
TOC	240 ppm	Th-228	0.26+-0.03 pCi/g
Alpha	<10 pCi/g	Th-232	0.26+-0.03 pCi/g
Beta	<20 pCi/g	U-234	0.23+-0.03 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.22+-0.03 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943104
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\10-MAR-89\ \ \ \ \CS-118 WELL 1331
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	210 ppm	Ra-226	0.40+-0.57 pCi/g
NO3(N)	3 ppm	Ra-228	0.02+-0.24 pCi/g
TOC	250 ppm	Th-228	0.63+-0.05 pCi/g
Alpha	12 pCi/g	Th-232	0.56+-0.04 pCi/g
Beta	<20 pCi/g	U-234	0.30+-0.04 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.34+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943101
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\11-MAR-89\ \ \ \ \CS-115 WELL 1332
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	150 ppm	Ra-226	0.26+-0.26 pCi/g
NO3(N)	5 ppm	Ra-228	0.02+-0.16 pCi/g
TOC	440 ppm	Th-228	0.65+-0.05 pCi/g
Alpha	<10 pCi/g	Th-232	0.61+-0.05 pCi/g
Beta	<20 pCi/g	U-234	0.36+-0.04 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.38+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943102
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\11-MAR-89\ \ \ \ \CS-116 WELL 1332
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	65 ppm	Ra-226	0.30+-0.22 pCi/g
NO3(N)	3 ppm	Ra-228	0+-0.44 pCi/g
TOC	110 ppm	Th-228	0.56+-0.04 pCi/g
Alpha	<10 pCi/g	Th-232	0.56+-0.04 pCi/g
Beta	<20 pCi/g	U-234	0.45+-0.04 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.38+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943103
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\11-MAR-89\ \ \ \ \CS-117 WELL 1332
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	450 ppm	Ra-226	0.32+-0.36 pCi/g
NO3(N)	3 ppm	Ra-228	0.54+-0.36 pCi/g
TOC	<10 ppm	Th-228	0.96+-0.04 pCi/g
Alpha	25 pCi/g	Th-232	0.89+-0.04 pCi/g
Beta	<20 pCi/g	U-234	0.63+-0.05 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.70+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: D. Keck 7/21/89 JRG

DISTRIBUTION: J.C. STAUTER, D.M. KECK,

KERR-MCGEE CORPORATION Technology Division

This/these samples are scheduled for disposal after 30 days.
If you want the samples retained or returned, please advise.

21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943100
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\11-MAR-89\ \ \ \ \CS-114 WELL 1334
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	51 ppm	Ra-226	0.33+-0.17 pCi/g
NO3(N)	4 ppm	Ra-228	0+-0.09 pCi/g
TOC	18 ppm	Th-228	0.28+-0.03 pCi/g
Alpha	11 pCi/g	Th-232	0.27+-0.03 pCi/g
Beta	<20 pCi/g	U-234	0.61+-0.05 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.38+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

APPROVED: D. Keck 7/21/89

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21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943096
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\13-MAR-89\ \ \ \ \CS-110 WELL 1335
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	40 ppm	Ra-226	0.08+-0.11 pCi/g
NO3(N)	3 ppm	Ra-228	0.10+-0.14 pCi/g
TOC	840 ppm	Th-228	0.27+-0.03 pCi/g
Alpha	<10 pCi/g	Th-232	0.27+-0.03 pCi/g
Beta	<20 pCi/g	U-234	0.24+-0.04 pCi/g
Pu-239	0.001+-0.001 pCi/g	U-238	0.24+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

APPROVED: D. Keck 7/21/89

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21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943094
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\14-MAR-89\ \ \ \ \CS-108 WELL 1336
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	140 ppm	Ra-226	0.19+-0.34 pCi/g
NO3(N)	9 ppm	Ra-228	0.04+-0.17 pCi/g
TOC	1180 ppm	Th-228	0.52+-0.07 pCi/g
Alpha	<10 pCi/g	Th-232	0.53+-0.07 pCi/g
Beta	<20 pCi/g	U-234	0.21+-0.04 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.23+-0.04 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric analyses will be run and the results reported later.

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21-Jul-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 4-11-89

SAMPLE ID: 943095
COMPLETION DATE: 7-21-89

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\14-MAR-89\ \ \ \ \CS-109 WELL 1336
SAMPLE DESCRIPTION: Soils

NOTES: NBR same as 943086

F	190 ppm	Ra-226	0.26+-0.25 pCi/g
NO3(N)	27 ppm	Ra-228	0.37+-0.31 pCi/g
TOC	<10 ppm	Th-228	0.52+-0.05 pCi/g
Alpha	<10 pCi/g	Th-232	0.52+-0.05 pCi/g
Beta	<20 pCi/g	U-234	0.42+-0.05 pCi/g
Pu-239	0.002+-0.001 pCi/g	U-238	0.38+-0.05 pCi/g

All constituents soluble unless otherwise specified:
i=insoluble constitutent, t=total constitutent
* Gross Alpha greater than 15 pCi/l. Radiometric
analyses will be run and the results reported later.

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APPENDIX F

PHYSICAL PROPERTY ANALYSES

STANDARD TESTING AND ENGINEERING COMPANY

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3400 N. Lincoln Okla. City, OK 73105 (405) 528-0541

Field Offices

902 Trails West Loop Enid, OK 73703 (405) 237-3130
900 S.E. 2nd Lawton, OK 73501 (405) 353-0872
208 Eastside Blvd. Muskogee, OK 74403 (918) 682-7853
660 Distributors Row Suite C, Harahan, LA 70123 (504) 734-8378

REPORT: Permeability Tests Date: 4/3/89

Structure Project: Cimarron Corporation Site Assessment Specification: ASTM DG98 & ASTM STP 479

Station Location: Sample PP-1 Quantity Represented: See Below

Architect Engineer: James L. Grant and Associates, Inc. Sampled by: Client

Contractor: (Kerr McGee) by Order of: Wyndal Goodman

Reported To: James Grant Date: 4/25/89 Order Number:

TEST RESULTS

Laboratory Number G109

Soil Sample: PP-1

Standard Proctor Test:

Percent Moisture	Dry Density, pcf
11.0	118.8
13.1	119.7
14.7	118.3
13.1 Optimum	119.7 Maximum

Permeability Results:

Percent Moisture	Percent Compaction	Coefficient of Permeability k,cm/sec.
13.4	80.8	1.02×10^{-4}
12.8	89.6	1.18×10^{-5}
14.3	96.1	3.0×10^{-7}

Charge: Kerr McGee
Orig. & 1cc To James Grant
1cc To Kerr McGee
1cc to Lab

REGISTERED PROFESSIONAL ENGINEER RICHARD W. MUDD 11537 OKLAHOMA

Respectfully Submitted
STANDARD TESTING AND ENGINEERING CO.
(Original Signed By)

By Richard W. Mudd, P.E.

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES, INC.

STANDARD TESTING AND ENGINEERING COMPANY

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660 Distributors Row	Suite C, Harahan, LA 70123	(504) 734-8378

REPORT Permeability Tests Date 4/3/89

Structure Project Cimarron Corporation Site Assessment Specification ASTM DG98 & ASTM STP 479

Station Location Sample PP-2 Quantity Represented See Below

Architect Engineer James L. Grant and Associates, Inc. Sampled by Client

Contractor (Kerr McGee) by Order of Wyndal Goodman

Reported To James Grant Date 4/25/89 Order Number

TEST RESULTS

Laboratory Number G109

Soil Sample: PP-2

Standard Proctor Test:

Percent Moisture	Dry Density, pcf
11.9	119.4
13.7	120.2
15.9	116.0
13.0 Optimum	120.5 Maximum

Permeability Results:

Percent Moisture	Percent Compaction	Coefficient of Permeability, k, cm/sec
15.3	77.9	1.98×10^{-5}
14.7	88.2	2.99×10^{-6}
14.6	97.4	3.08×10^{-8}

Charge: Kerr McGee
Orig. & 1cc To James Grant
1cc to Kerr McGee
1cc To Lab

Respectfully Submitted
STANDARD TESTING AND ENGINEERING CO.
(Original Signed By)

REGISTERED PROFESSIONAL ENGINEER RICHARD W. MUDD 11567 OKLAHOMA

By Richard W. Mudd, P.E.

Construction Materials, Testing & Inspections
Fabrications Weldment & Erection Inspections
Geo-technical Investigations
Chemical & Bacteriological Analysis

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES, INC.

"TEST FOR ASSURANCE"

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REPORT Permeability Date 4/3/89

Structure Project Cimarron Corporation Site Assessment Specification ASTM DG98 & ASTM STP 479

Station Location Sample PB. 3 Quantity Represented See Below

Architect Engineer James L. Grant and Associates, Inc. Sampled by Client

Contractor (Kerr McGee) by Order of Wyndal Goodman

Reported To James Grant Date 4/25/89 Order Number

TEST RESULTS

Laboratory Number G109

Soil Sample: PP-3

Standard Proctor Test:

Percent Mixture	Dry Density, pcf
12.7	116.4
14.2	117.8
15.8	116.1
14.0 Optimum	117.8 Maximum

Permeability Results:

Percent Moisture	Percent Compaction:	Coefficient of Permeability, k, cm/sec.
16.9	77.1	1.38×10^{-4}
15.5	87.7	1.60×10^{-5}
16.0	97.1	2.48×10^{-8}

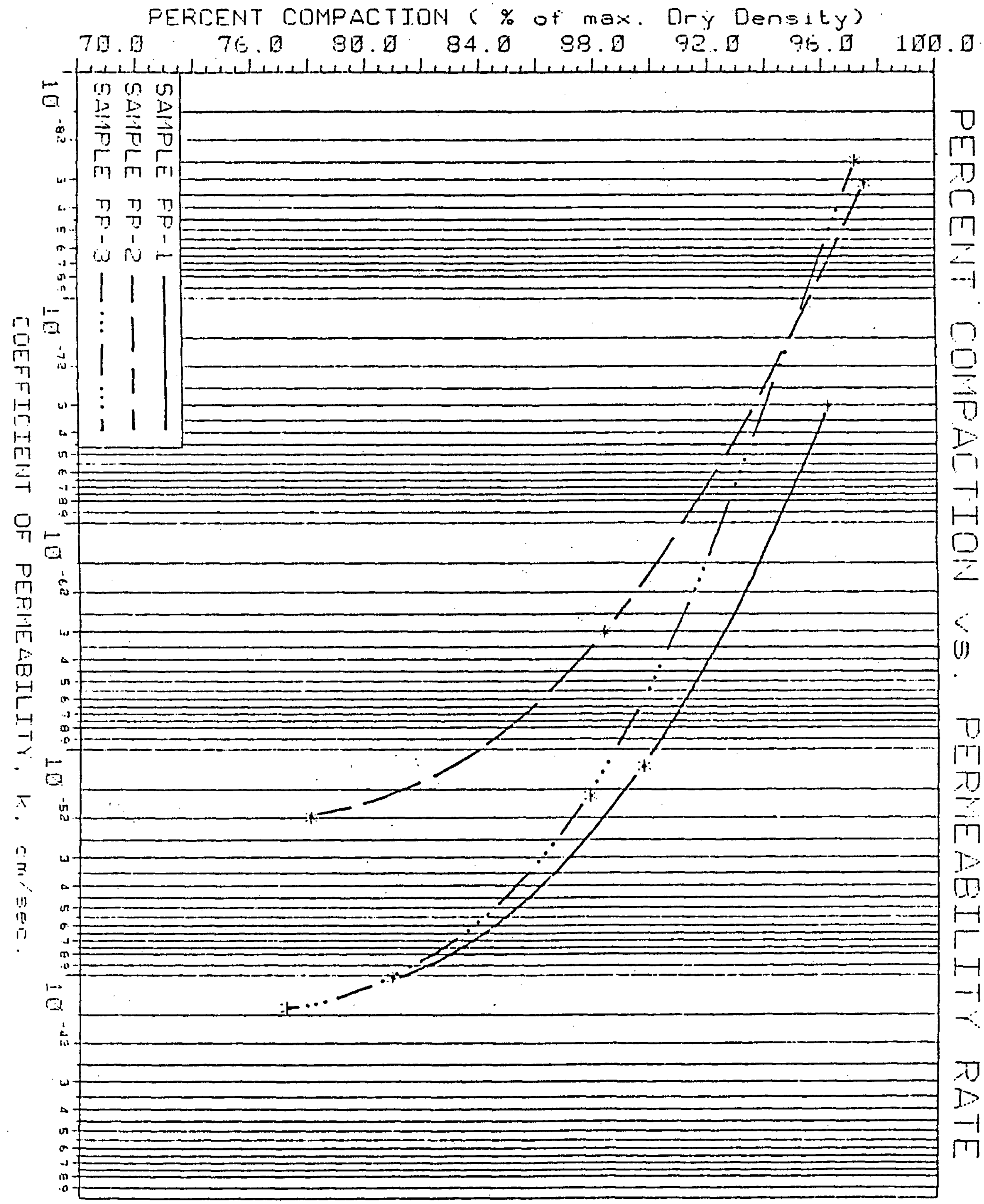
Charge: Kerr McGee
Orig. & 1cc To James Grant
1cc to Kerr McGee
1cc to Lab

REGISTERED PROFESSIONAL ENGINEER RICHARD W. MUDD 12537 OKLAHOMA

Respectfully Submitted
STANDARD TESTING AND ENGINEERING CO.
(Original Signed By)

By Richard W. Mudd, P.E.

STANDARD TESTING and ENGINEERING COMPANY



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2KE22
KE22

REPORT SOIL CLASSIFICATION **Date** 4-3-89

Structure Project Cimarron Corporation Site Assessment **Specification** AASHTO M-145

Station Location Crescent, Okla. - See Below **Quantity Represented**

Architect Engineer James L. Grant & Associates **Sampled by** Client

Contractor Kerr McGee **by Order of** Wyndal Goodman

Reported To Kerr McGee **Date** 4-25-89 **Order Number**

TEST RESULTS

Laboratory Number	5885	5886	5887	5888	5889
Field Number	PP-1	PP-2	PP-3	PP-4	PP-5
% Passing #10 Sieve	93.8	98.3	97.3	100.0	100.0
" " #40 "	90.0	95.4	93.5	94.8	95.6
" " #200 "	70.5	73.3	72.9	62.8	87.7
Liquid Limit	24	23	23	26	34
Plasticity Index	10	9	8	8	9
AASHTO Classification	A-4(4)	A-4(3)	A-4(3)	A-4(3)	A-4(8)

Charge: Kerr McGee
Orig. & 1cc To James L. Grant
1-cc Kerr McGee
1-cc Laboratory

AMERICAN COUNCIL OF INDEPENDENT LABORATORIES, INC.

Respectfully Submitted
STANDARD TESTING AND ENGINEERING CO.
(Original Signed By)

REGISTERED PROFESSIONAL ENGINEER RICHARD W. MUDD 12527 OKLAHOMA

By Richard W. Mudd, P.E.

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2KE22
KE22

REPORT SOIL CLASSIFICATION Date 4-3-89
Structure Project Cimarron Corporation Site Assessment Specification AASHTO M-145
Station Location Crescent, Okla. (See Below) Quantity Represented
Architect Engineer James L. Grant & Associates Sampled by Client
Contractor Kerr McGee by Order of Wyndal Goodman
Reported To Kerr McGee Date 4-25-89 Order Number

TEST RESULTS

Laboratory Number	5890	5891	5892	5893
Field Number	PP-6	PP-7	PP-8	PP-9
% Passing #10 Sieve	100.0	100.0	100.0	100.0
" " #40 "	99.9	99.2	99.9	98.5
" " #200 "	39.2	89.2	94.6	94.1
Liquid Limit	NP	NP	25	36
Plasticity Index	NP	NP	8	13
AASHTO Classification	A-4(0)	A-4(0)	A-4(6)	A-6(13)

(PP-10?)

Charge: Kerr McGee
Orig. & 1cc To J.Grant
1-cc Kerr McGee
1-cc Laboratory

Respectfully Submitted,
STANDARD TESTING AND ENGINEERING CO.
(Original Signed By)

REGISTERED PROFESSIONAL ENGINEER RICHARD W. MUDD 12537 OKLAHOMA

By Richard W. Mudd, P.E.

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660 Distributors Row	Harahan, LA 70123	(504) 734-8378

2KE22
KE22

REPORT SOIL CLASSIFICATION **Date** 4-28-89

Structure Project Cimarron Corporation Site Assessment **Specification** AASHTO M-145

Station Location Crescent, Oklahoma **Quantity Represented**

Architect Engineer James L. Grant & Associates **Sampled by** Client

Contractor Kerr McGee **by Order of** Wyndal Goodman

Reported To James L. Grant **Date** 5-1-89 **Order Number**

TEST RESULTS

Laboratory Number 5894 PP#10

SIEVES	% PASSING
#4	100.0
#10	95.9
#40	71.8
#200	44.7
Liquid Limit	NP
Plasticity Index	NP
AASHTO Classification	A-4(0)

Charge: Kerr McGee
Orig. & 1cc **To** James L. Grant
1-cc Kerr McGee
1-cc Laboratory

Respectfully Submitted
STANDARD TESTING AND ENGINEERING CO.
(Original Signed By)

By Thomas J. Kelly, P.E.

"TEST FOR ASSURANCE"

APPENDIX G

SOIL AND ROCK MINERALOGICAL ANALYSES

GEOLOGIC DESCRIPTION

CH-1 Red (2.5YR 4/8) clay-silt mudstone, with greenish-white clasts and/or bioturbations. Moderately fissiled, fine visible mica grains.

CH-2 Light gray (10YR 7/2) clay-silt mudstone, interlayered with a few thin red layers, moderate fissility, with some low angle cross bedding

CH-5 Dark reddish brown (2.5YR 3/4) weakly consolidated sand cemented with iron oxides and calcite.

CH-6 Massive red (10R 4/6) mudstone, poor fissility, some evidence of bioturbation with light greenish gray silty material in burrows.

CH-8 Red (10R 4/8) with orange-white mottles poorly cemented mudstone, poorly layered. Visible quartz grains are well rounded.

CH-9 Massive red (2.5YR 4/6) sandy mudstone, mottled with light greenish gray. Gray material is up to 3/8 in. long, includes moderately cemented bedded quartz sand.

CH-12 Light gray (2.5Y 7/2) very fine sand - silt mudstone, poorly cemented with no layering. Includes clay clasts

CH-14 Light olive gray (5Y 6/2) and pinkish gray (10YR 7/2) conglomerate of soft sediment clasts, some layering, calcite in isolated grains.

CH-15 Red (10R 4/8) very fine sand and silt mudstone, massive, moderately consolidated. Few isolated calcite and quartz clusters. Some evidence of slickensides or pressure faces.

Table 1. Grain size distribution
Less than 2mm fraction

Sample	Size Distribution		
	Sand	Silt	Clay
	%		
CH-1	0.70	78.74	20.56
CH-2	15.50	64.94	19.56
CH-3	57.70	27.82	14.48
CH-4	18.70	47.22	34.08
CH-5	82.40	10.48	7.12
CH-6	2.50	58.18	39.32
CH-7	39.60	45.56	14.84
CH-8	80.00	13.08	6.92
CH-9	37.50	39.66	22.84
CH-10	74.20	16.12	9.68
CH-11	56.40	25.56	18.04
CH-12	47.00	43.44	9.56
CH-13	25.50	55.34	19.16
CH-14	59.20	24.16	16.64
CH-15	21.90	51.94	26.16

Table 2. Sand-size distribution (percent of sand)

Sample	Sand Size Distribution (mm)				
	2-1	1-.5	.5-.25	.25-.1	.1-.05
	%				
CH-1	0.00	0.00	0.00	0.00	100.00
CH-2	5.88	8.50	7.84	14.38	63.40
CH-3	0.00	0.17	0.17	29.34	70.31
CH-4	6.95	14.97	12.83	19.25	45.99
CH-5	28.68	15.31	15.07	32.81	8.14
CH-6	20.83	12.50	4.17	41.67	20.83
CH-7	2.78	2.28	1.01	2.78	91.14
CH-8	3.51	5.89	6.14	68.30	16.17
CH-9	3.73	6.40	6.67	31.47	51.73
CH-10	0.14	0.27	3.51	78.38	17.70
CH-11	7.09	14.01	16.31	39.72	22.87
CH-12	2.77	2.13	5.74	15.11	74.26
CH-13	1.19	2.37	1.98	13.04	81.42
CH-14	20.88	21.90	18.00	19.52	19.69
CH-15	5.02	4.11	3.65	14.16	73.06

Table 3. Exchangeable cations, pH and Cation Exchange Capacity

Sample	Exchangeable Cations				CEC	pH
	Ca	Mg	K	Na		1:1
	meq/100g					
CH-1	6.96	3.29	0.32	0.30	10.83	8.43
CH-2	17.25	2.78	0.23	0.28	7.96	8.72
CH-3	5.01	1.61	0.16	0.11	7.71	6.87
CH-4	27.37	6.62	0.47	0.30	18.56	8.53
CH-5	18.84	1.14	0.08	0.21	2.55	9.18
CH-6	26.26	5.97	0.48	0.35	22.75	8.18
CH-7	8.35	1.62	0.11	0.33	4.59	7.91
CH-8	10.93	1.43	0.07	0.33	3.37	8.30
CH-9	21.14	2.94	0.25	0.21	9.93	8.76
CH-10	10.50	1.36	0.10	0.17	2.96	5.99
CH-11	17.82	5.71	0.22	0.29	6.00	8.86
CH-12	9.29	4.03	0.50	0.27	6.20	8.69
CH-13	20.24	4.95	0.34	0.47	8.02	8.89
CH-14	17.71	4.20	0.50	0.21	6.87	8.95
CH-15	12.35	5.18	0.58	0.15	11.32	8.62

Table 4. Mineralogical Composition of Whole Soils

Sample	Kaolin	Fe-Oxyhy	2:1 Exp *	Feldspars & Mica	Calcite	Quartz	Ads.H2O
	%						
CH-1	15	4	12	17	<1	48	1.63
CH-2	12	2	8	17	<1	56	2.25
CH-5	1	3	3	5	29	58	0.50
CH-6	27	8	23	27	<1	12	3.63
CH-8	1	<1	3	3	1	90	0.38
CH-9	8	3	10	14	3	59	1.63
CH-12	7	1	6	9	3	72	1.00
CH-14	7	1	7	11	12	59	1.25
CH-15	10	4	11	17	3	52	1.88

* 2:1 Exp Expanding layer silicates
Feldspars and mica are given as mica equivalent (10% K_2O = 100%)

ELEMENTAL COMPOSITION (OXIDES)

Sample	CaO	Al_2O_3	Fe_2O_3	K_2O	MgO	SiO_2	MnO
	%						
CH-1	0.59	11.42	3.87	1.70	1.12	66.84	0.04
Ch-2	0.45	10.90	1.73	1.72	1.14	74.92	0.01
CH-5	22.38	3.47	3.03	0.54	2.67	62.50	0.22
CH-6	1.69	18.26	7.52	2.66	2.67	51.57	0.07
CH-8	1.06	1.42	0.46	0.28	0.13	93.51	0.00
CH-9	2.91	8.50	3.49	1.38	1.23	75.86	0.05
CH-12	2.16	6.47	0.78	0.94	1.14	83.41	0.03
CH-14	7.11	6.44	1.23	1.13	3.28	72.36	0.09
CH-15	2.11	10.05	4.44	1.72	1.49	72.03	0.04

James Grant Samples
Material Description of Air-Dried Samples

CH-1	Strongly cemented, fine-grained, massive soil material
CH-2	Light gray, moderately to strongly cemented, fine-grained soil material
CH-3	Unconsolidated fine-grained soil material
CH-4	Weakly consolidated fines in thin platy layers soil material
CH-5	Moderately consolidated, calcareous, sandstone coarse-grained soil material
CH-6	Weakly consolidated fines in thin platy layers soil material
CH-7	Moderately consolidated, fine-grained, massive soil material
CH-8	Weakly cemented sandstone with some fines soil material
CH-9	Unconsolidated sand and clay with about 5% small fragments less than one inch in diameter
CH-10	Unconsolidated loose sand and fines
CH-11	Unconsolidated loose sand and fines, very f?
CH-12	Light gray, weakly cemented to unconsolidated fine-grained soil material, few very hard rock fragments and gravels.
CH-13	Weakly cemented to unconsolidated sand and clay
CH-14	Light gray, weakly to moderately consolidated, fine-grained soil material
CH-15	Moderately consolidated, fine-grained, massive soil material

Determination of soil water retention curves

Soil water retention curves (Table 1) were determined following standard procedures as outlined by Klute (Klute, A. 1986. Water Retention: Laboratory Methods. In A. Klute (ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9:635-662). Tempe pressure cells were used for soil water pressure head values ranging from 0 to -300 cm of water, while a pressure cooker was used in the range from -1,000 to -4,000 cm of water.

The soil samples were first air dried, passed through a 2-mm sieve, and then packed into cylinders to bulk density values similar to those determined on two undisturbed clods (Blake G.R. and K.H. Hartge. 1986. Bulk density. In A. Klute (ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agronomy 9:371-373).

The reported bulk density values (Table 2) were calculated from the final amount of oven dry soil packed into each cylinder. The corresponding porosity values (Table 2) are based on these bulk density values and an assumed particle density of 2.65 g/cm^3.

Table 1. Volumetric water content as a function of soil water pressure head.

Soil water pressure head	Volumetric water content cm^3/cm^3			
cm of water	Sample			
	CH-16	CH-17	CH-18	CH-19
0	0.327	0.332	0.331	0.320
-10	0.327	0.332	0.331	0.320
-20	0.327	0.332	0.331	0.320
-40	0.327	0.332	0.331	0.320
-80	0.327	0.332	0.331	0.305
-100	0.316	0.332	0.331	0.273
-150	0.274	0.332	0.331	0.248
-300	0.239	0.305	0.282	0.214
-1,000	0.207	0.254	0.233	0.180
-4,000	0.177	0.206	0.200	0.147

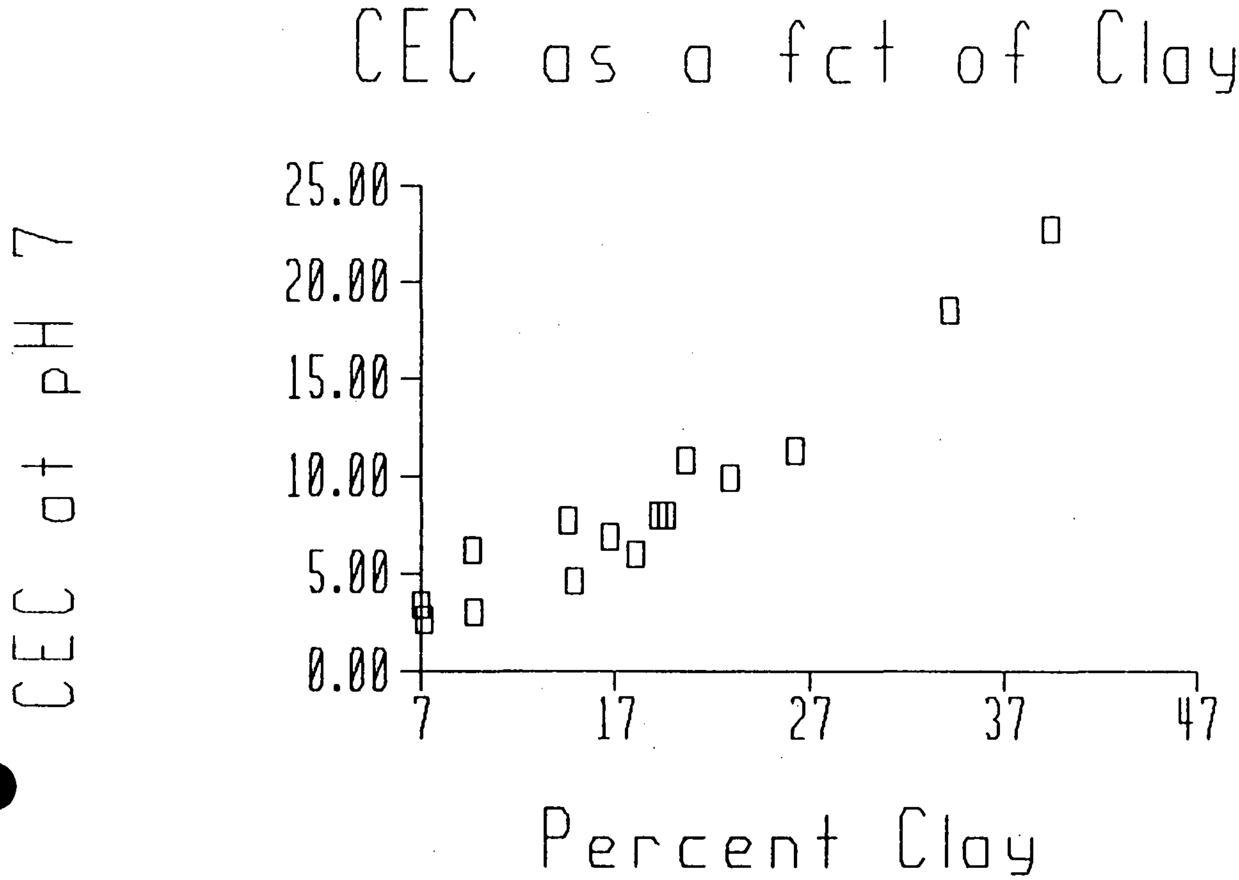
Table 2. Bulk density and porosity.

Sample	Bulk density g/cm^3	Porosity cm^3/cm^3
CH-16	1.78	0.328
CH-17	1.78	0.328
CH-18	1.76	0.336
CH-19	1.79	0.325

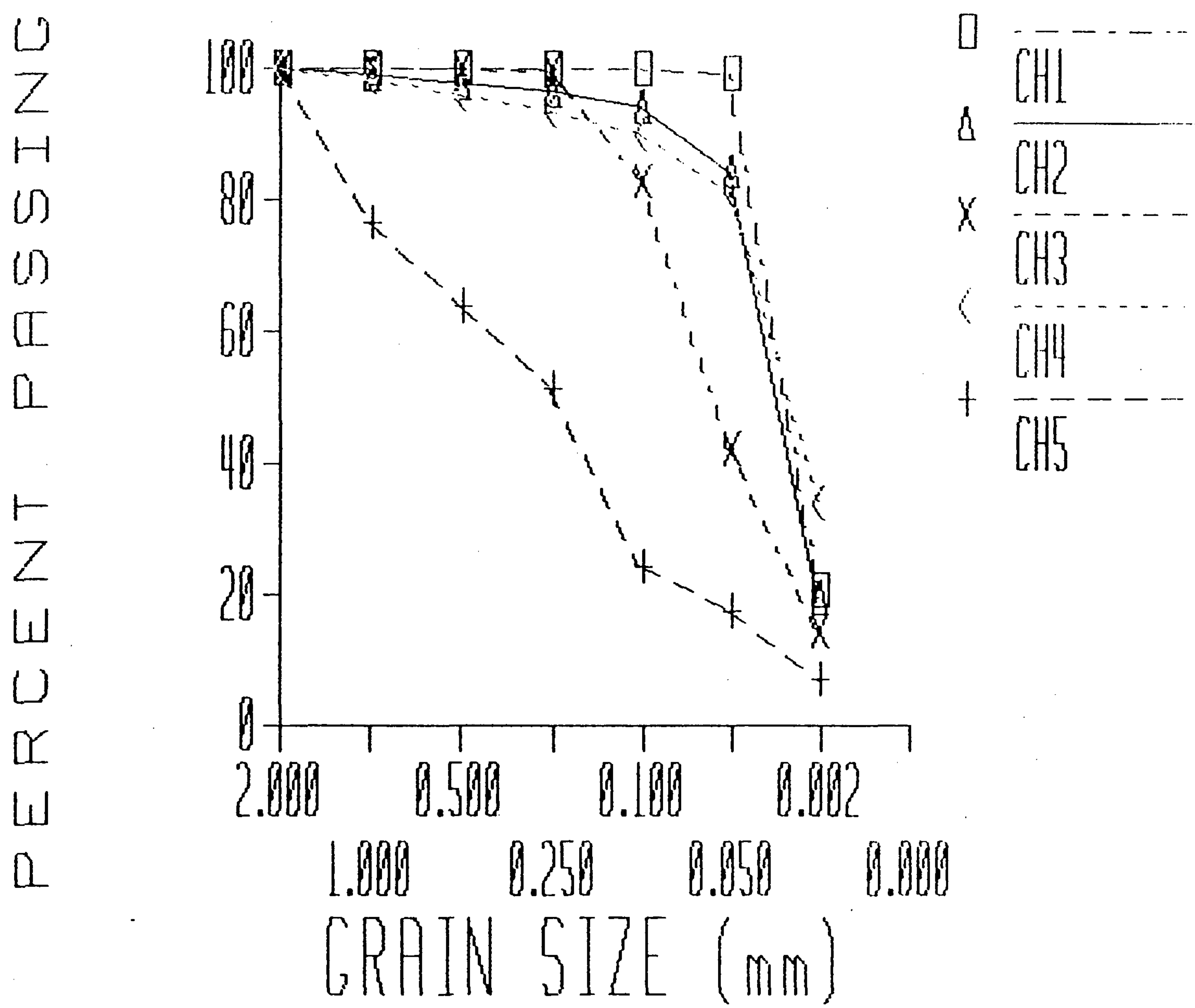
Classification for K_d Analysis

Color		Calcite	Clay	Typical K_d Analysis	Comp
Red Soil Material					
	CH-1		X	X	A
	CH-3				E
	CH-4		XX		D
	CH-5	XX		X	B
	CH-6		XX	X	D
	CH-7				E
	CH-8			X	E
	CH-9	X	X		F
	CH-10				E
	CH-11		X		A
	CH-13		X		A
	CH-15	X	X		F
Gray Soil Material					
	CH-2		X	X	G
	CH-12	X			C
	CH-14	XX		X	C

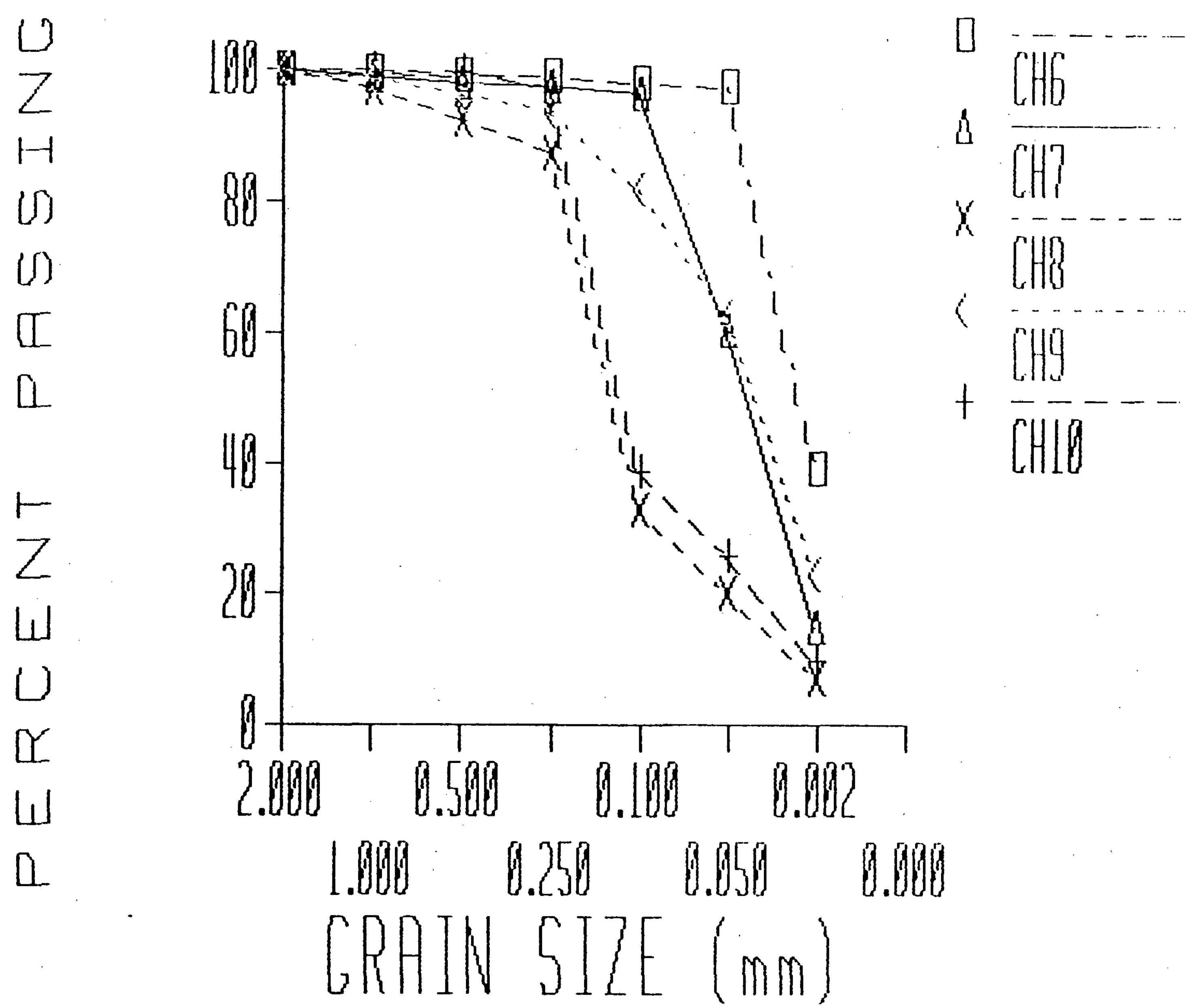
%Calcite _<3, X 3, XX>3
%Clay _ < 18, X 18-30, XX >30%

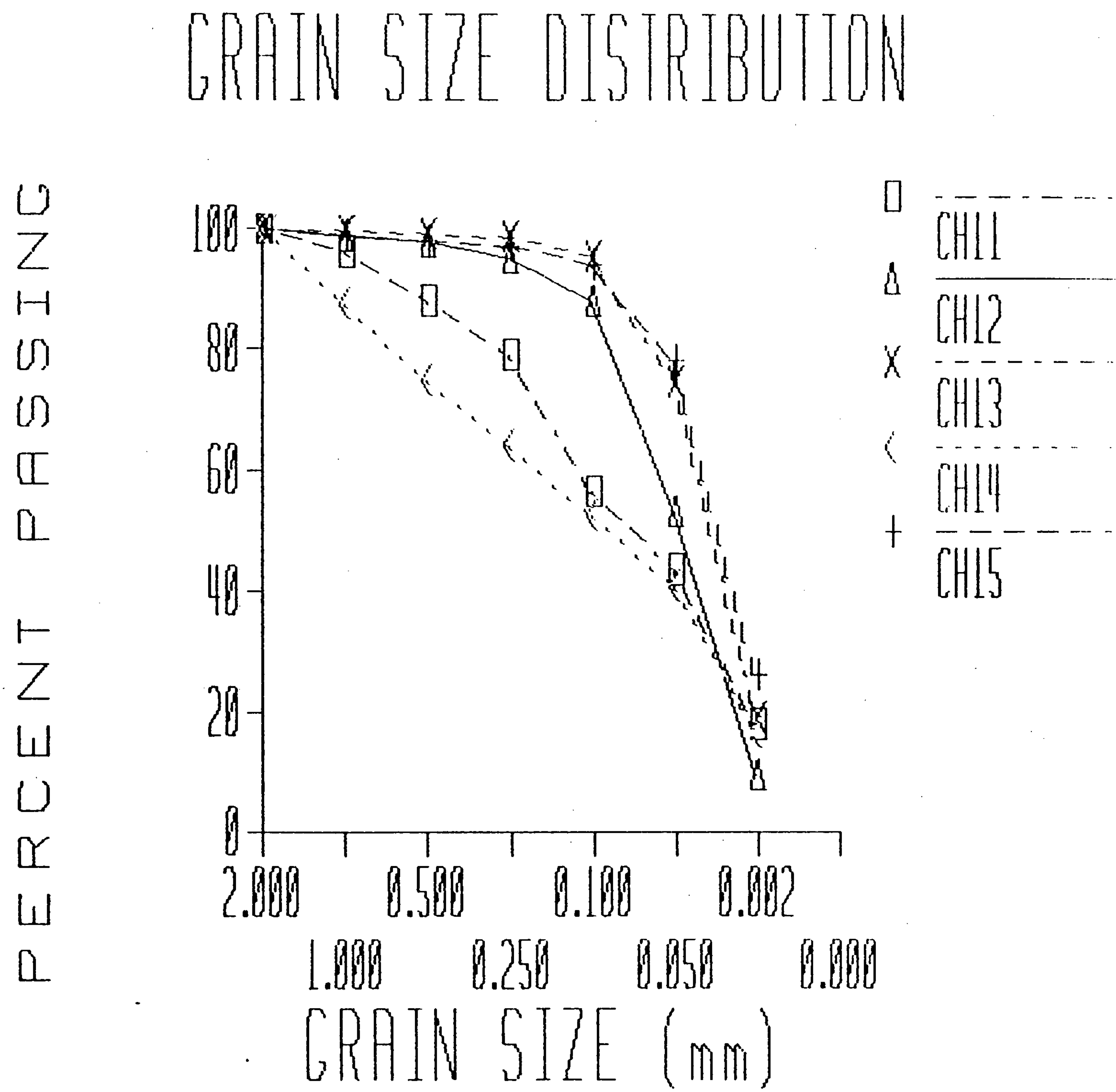

CEC as a fct of Clay
CEC at pH 7
25.00
20.00
15.00
10.00
5.00
0.00
7
17
27
37
47
Percent Clay

GRAIN SIZE DISTRIBUTION



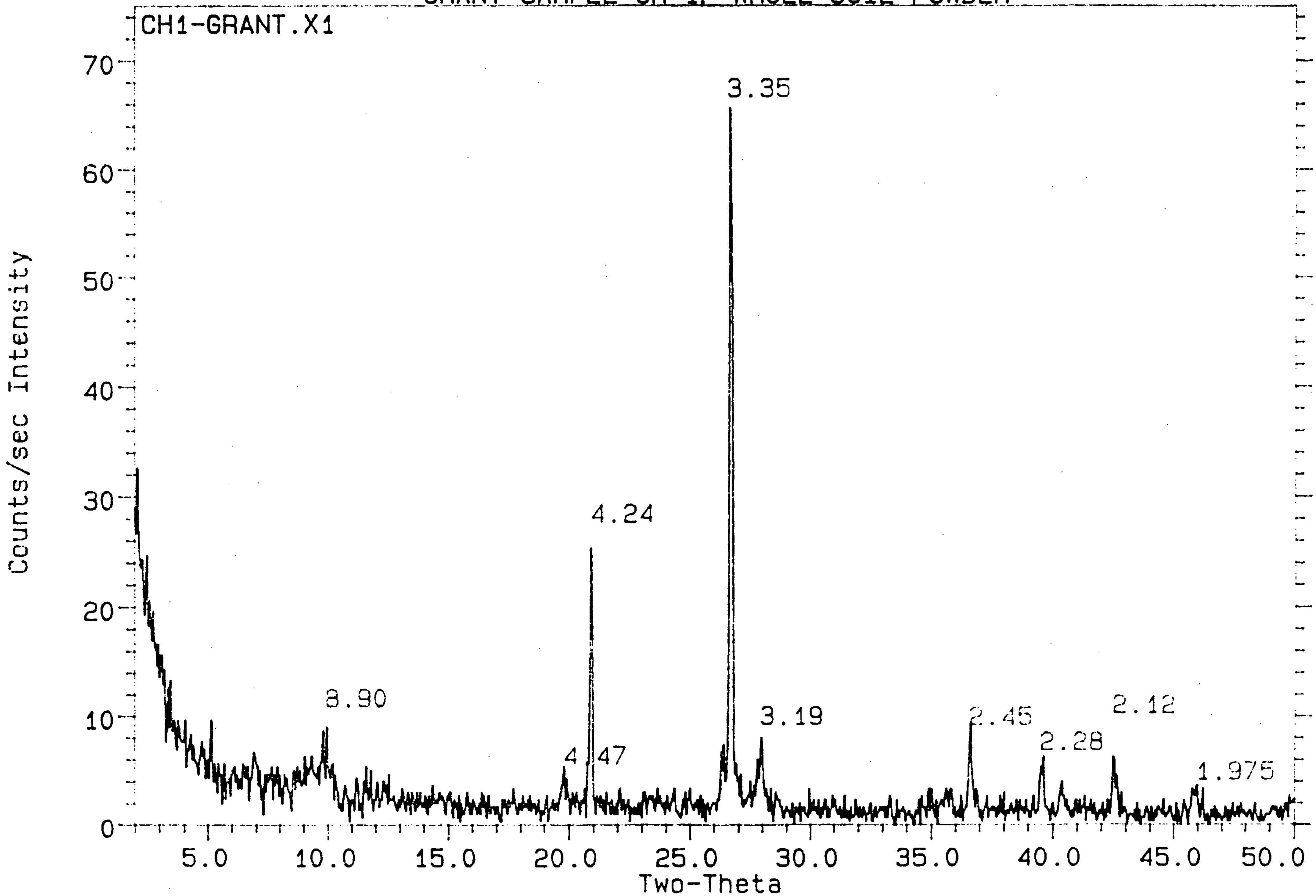
GRAIN SIZE DISTRIBUTION



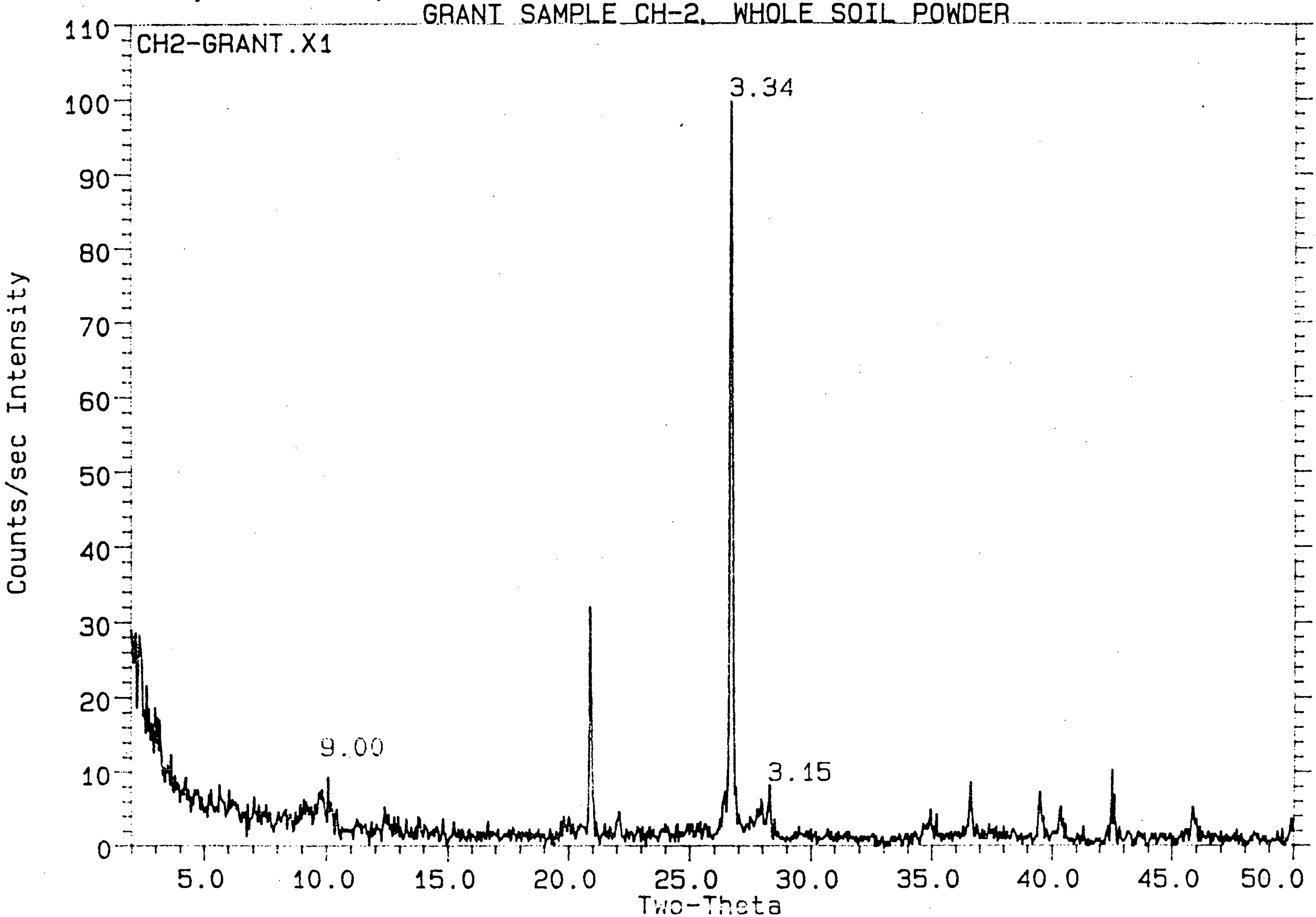

GRAIN SIZE DISTRIBUTION
PERCENT PASSING
100
80
60
40
20
0
2.000
1.000
0.500
0.250
0.100
0.050
0.002
0.000
GRAIN SIZE (mm)
CH11
CH12
CH13
CH14
CH15

Siemens Analytical X-Ray Instruments Inc. 2-MAY-89

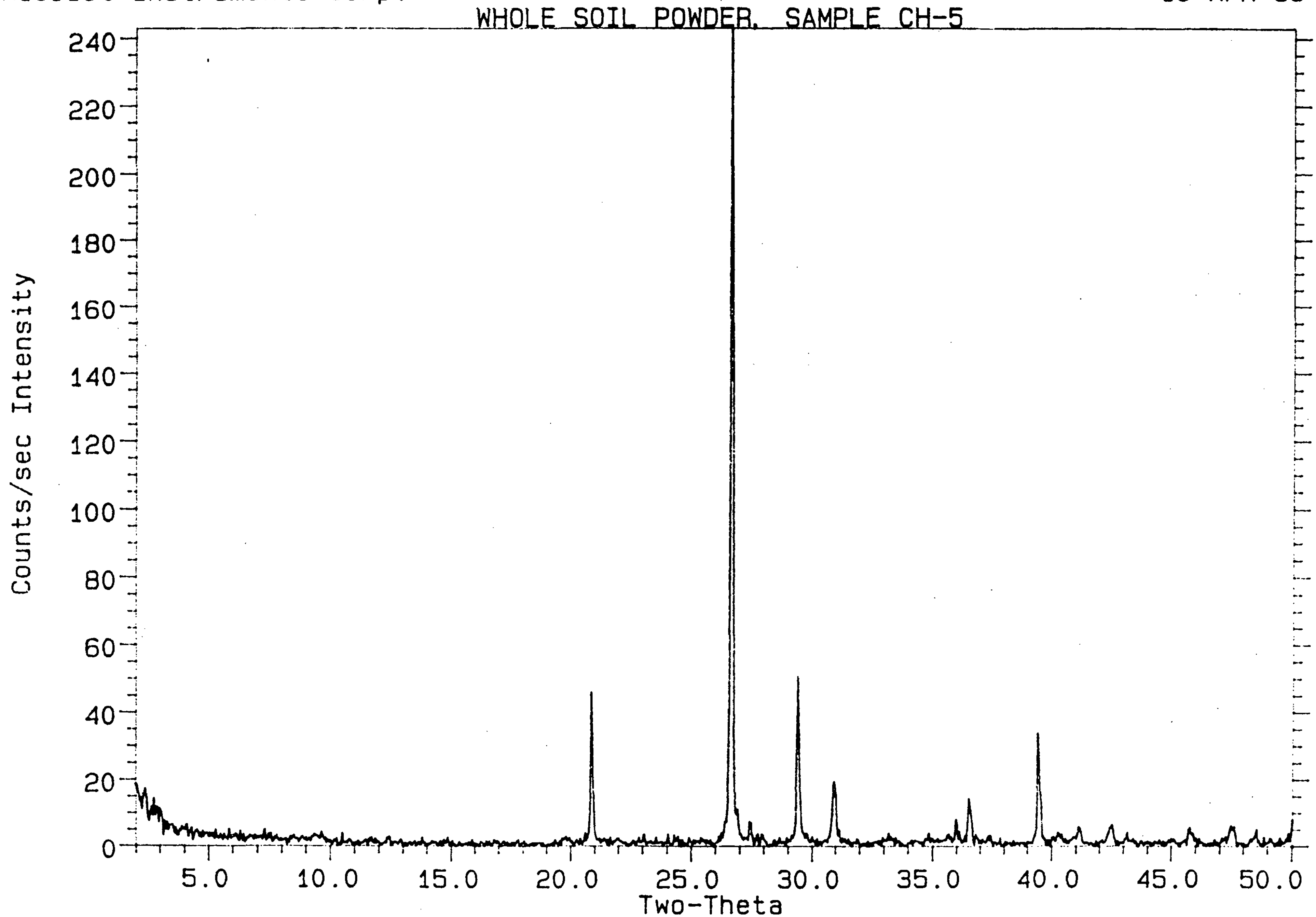
GRANT SAMPLE CH-1, WHOLE SOIL POWDER



Siemens Analytical X-Ray Instruments Inc. 2-MAY-89

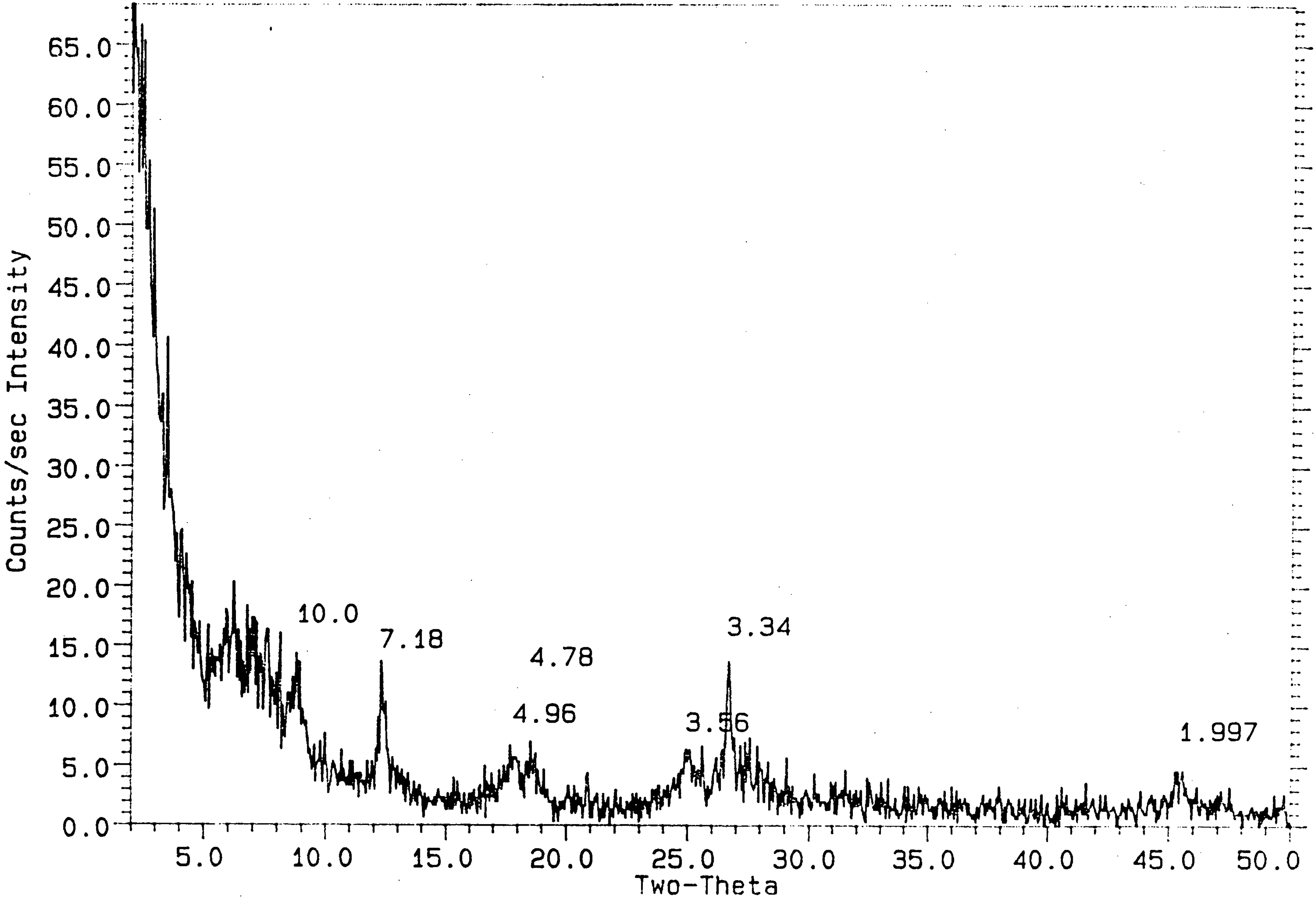


Nicolet Instruments Corp. 18-APR-89



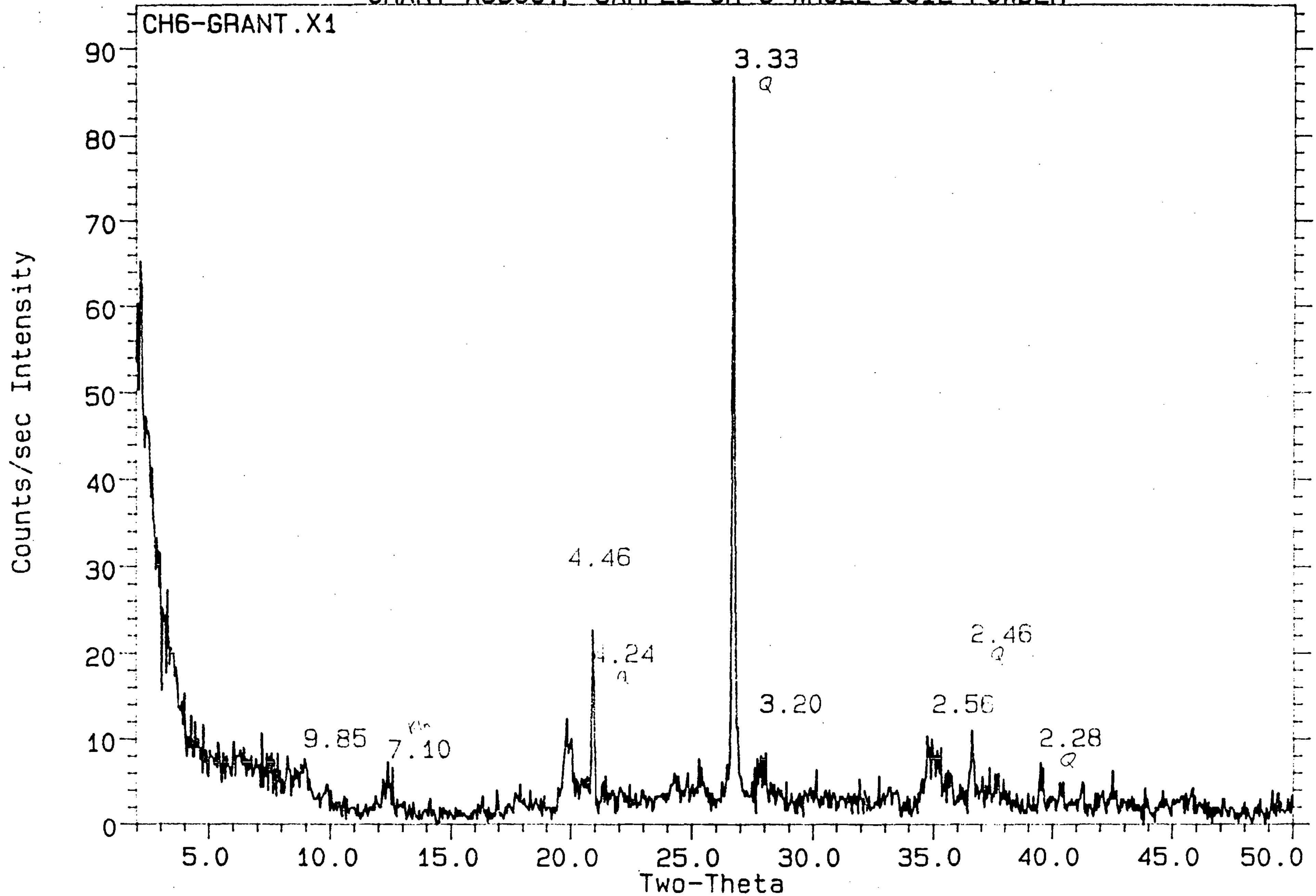
CH-6

Siemens Analytical X-Ray Instruments Inc. Clay 5-MAY-89



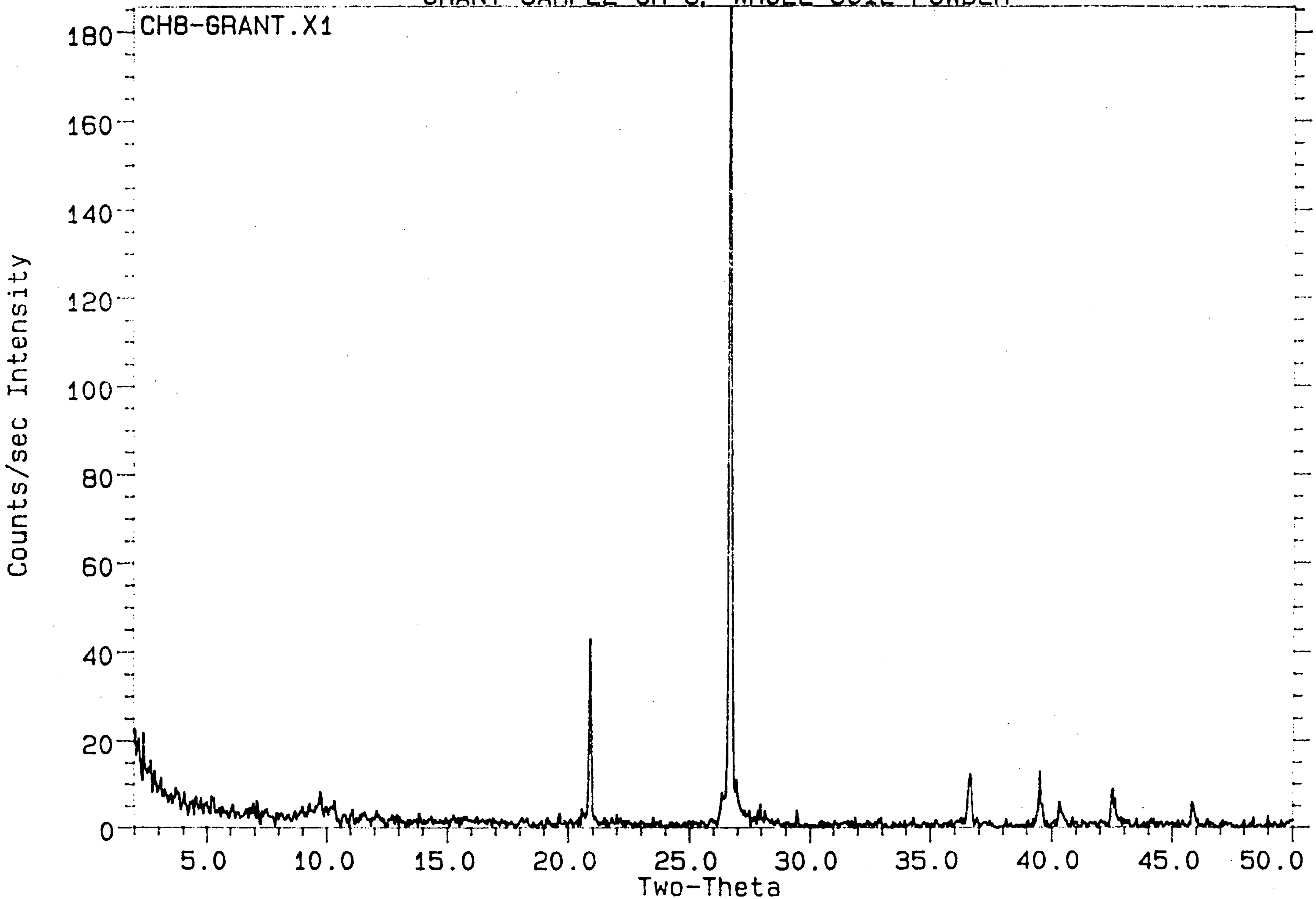
Nicolet Instruments Corp. 18-APR-89

GRANT ASSOC., SAMPLE CH-6 WHOLE SOIL POWDER



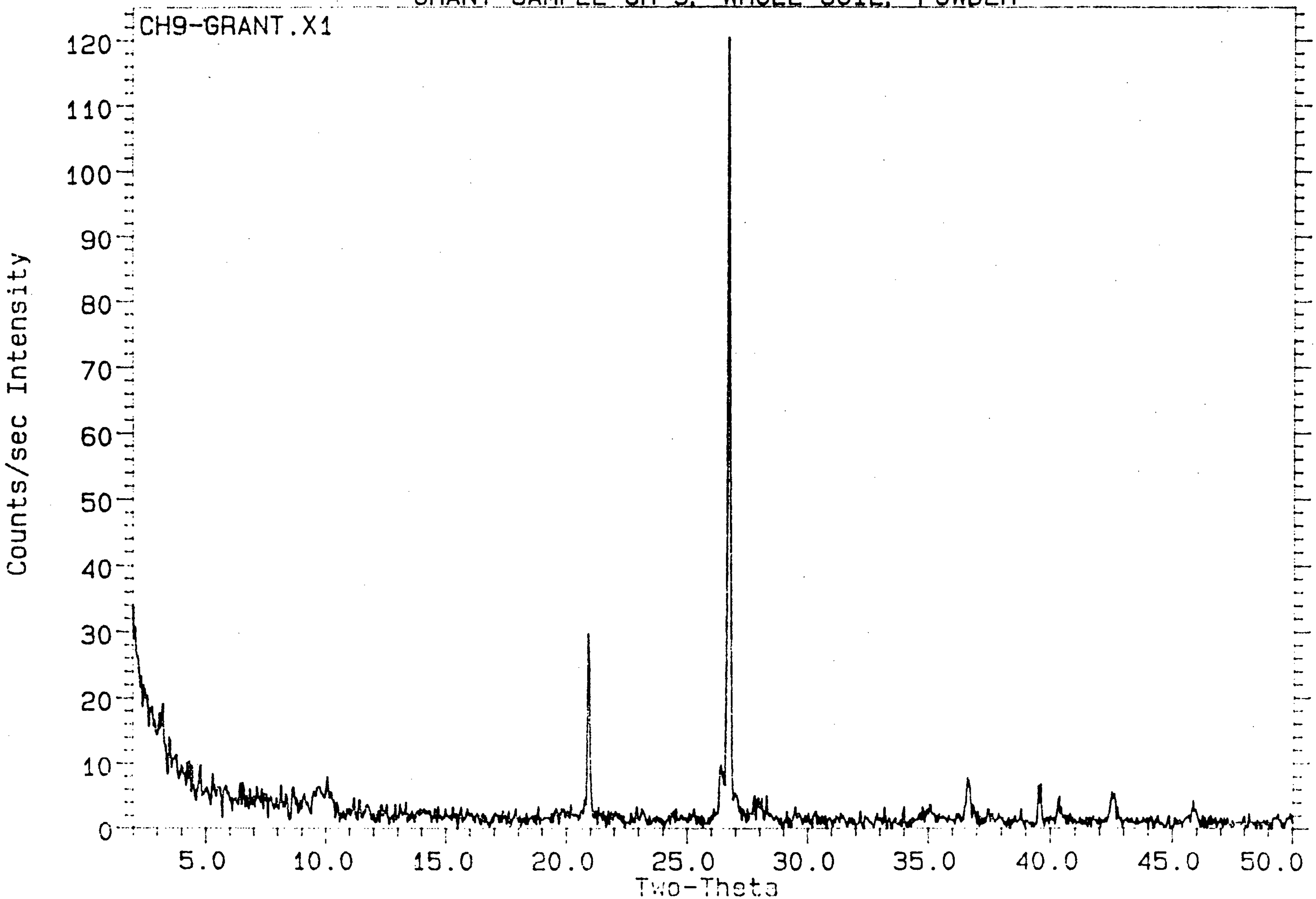
Siemens Analytical X-Ray Instruments Inc. 2-MAY-89

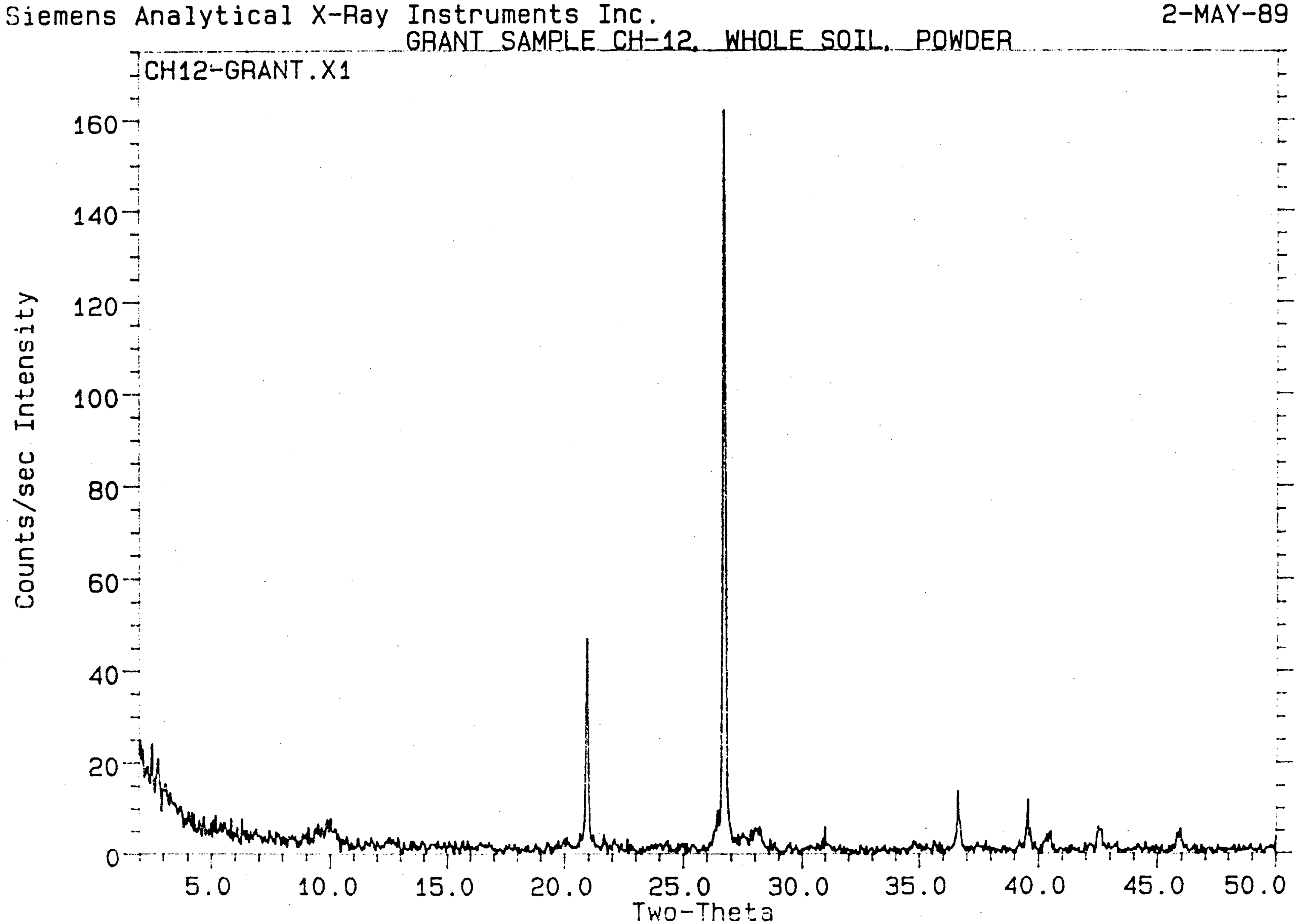
GRANT SAMPLE CH-8, WHOLE SOIL POWDER



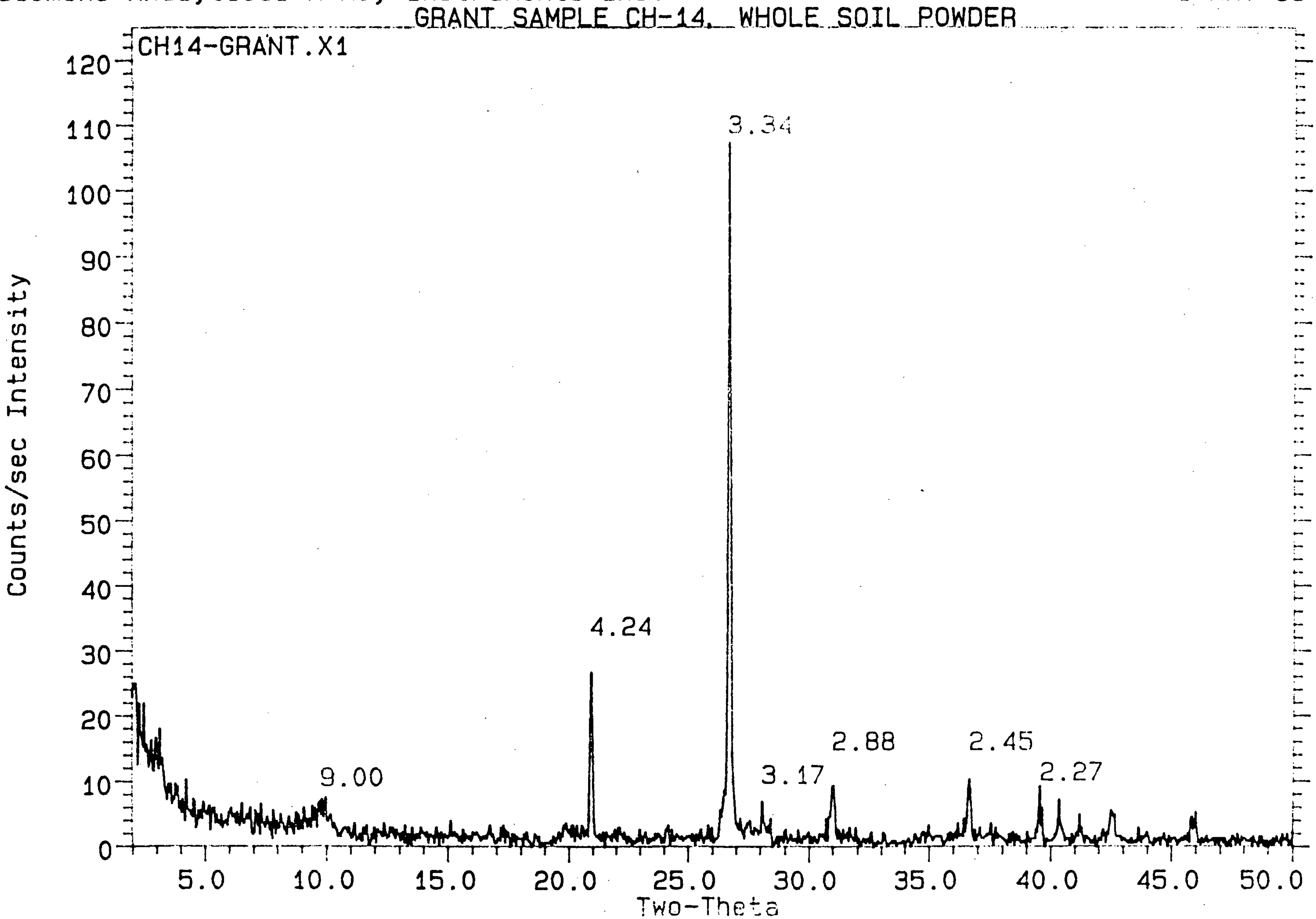
Siemens Analytical X-Ray Instruments Inc. 2-MAY-89

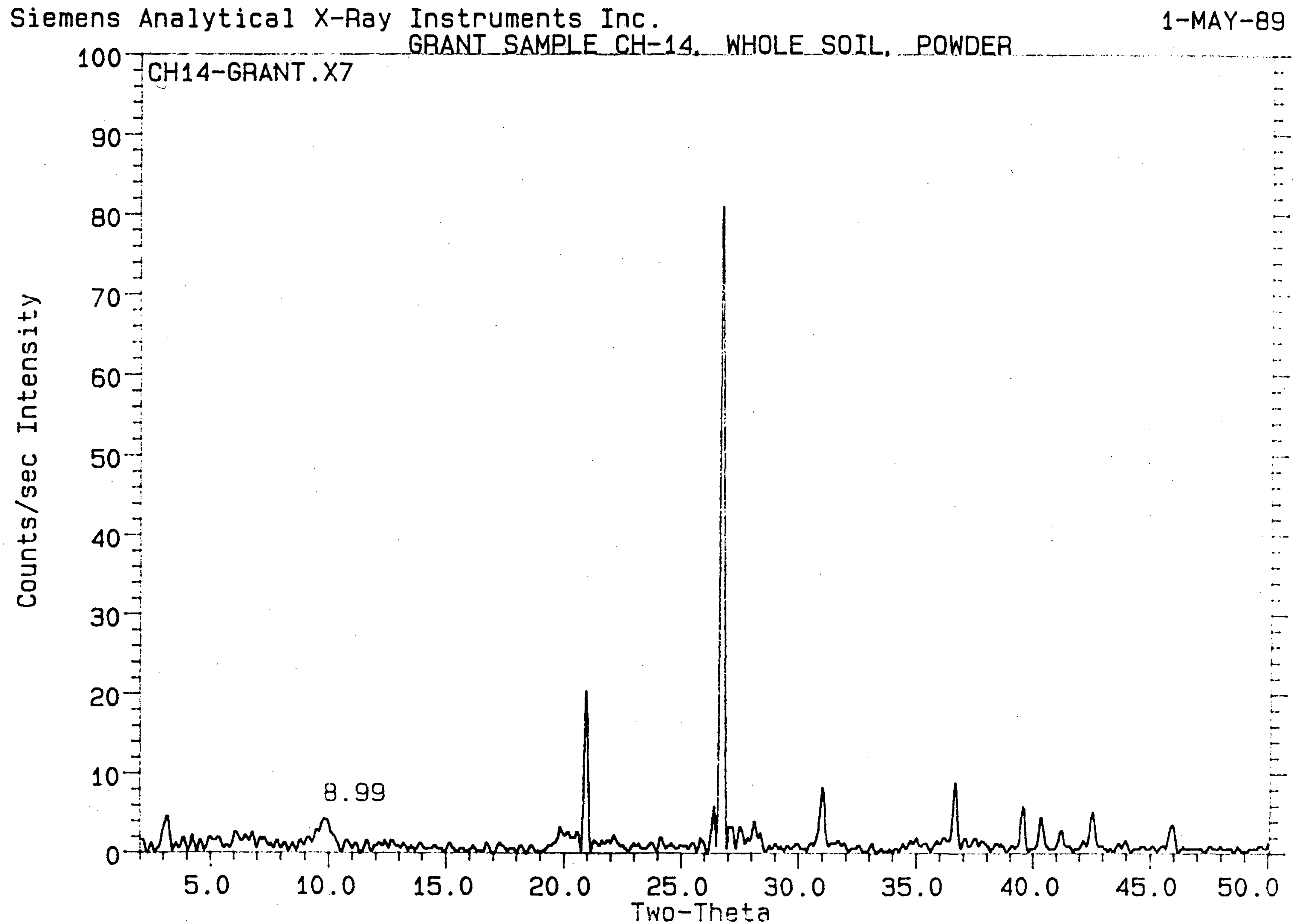
GRANT SAMPLE CH-9, WHOLE SOIL, POWDER



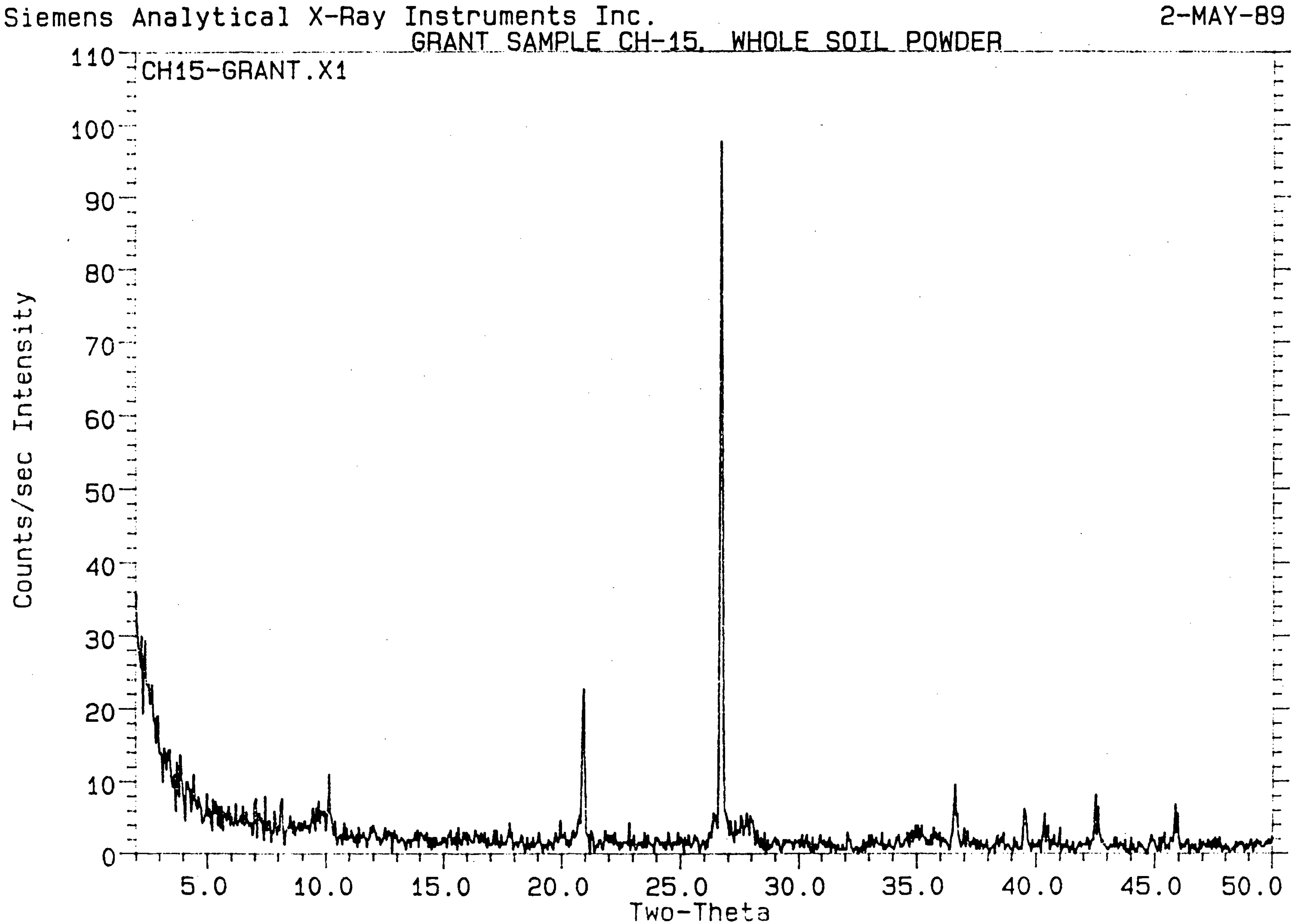

Siemens Analytical X-Ray Instruments Inc.
2-MAY-89
GRANT SAMPLE CH-12, WHOLE SOIL, POWDER
CH12-GRANT.X1
Counts/sec Intensity
160
140
120
100
80
60
40
20
0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
Two-Theta

Siemens Analytical X-Ray Instruments Inc. 1-MAY-89

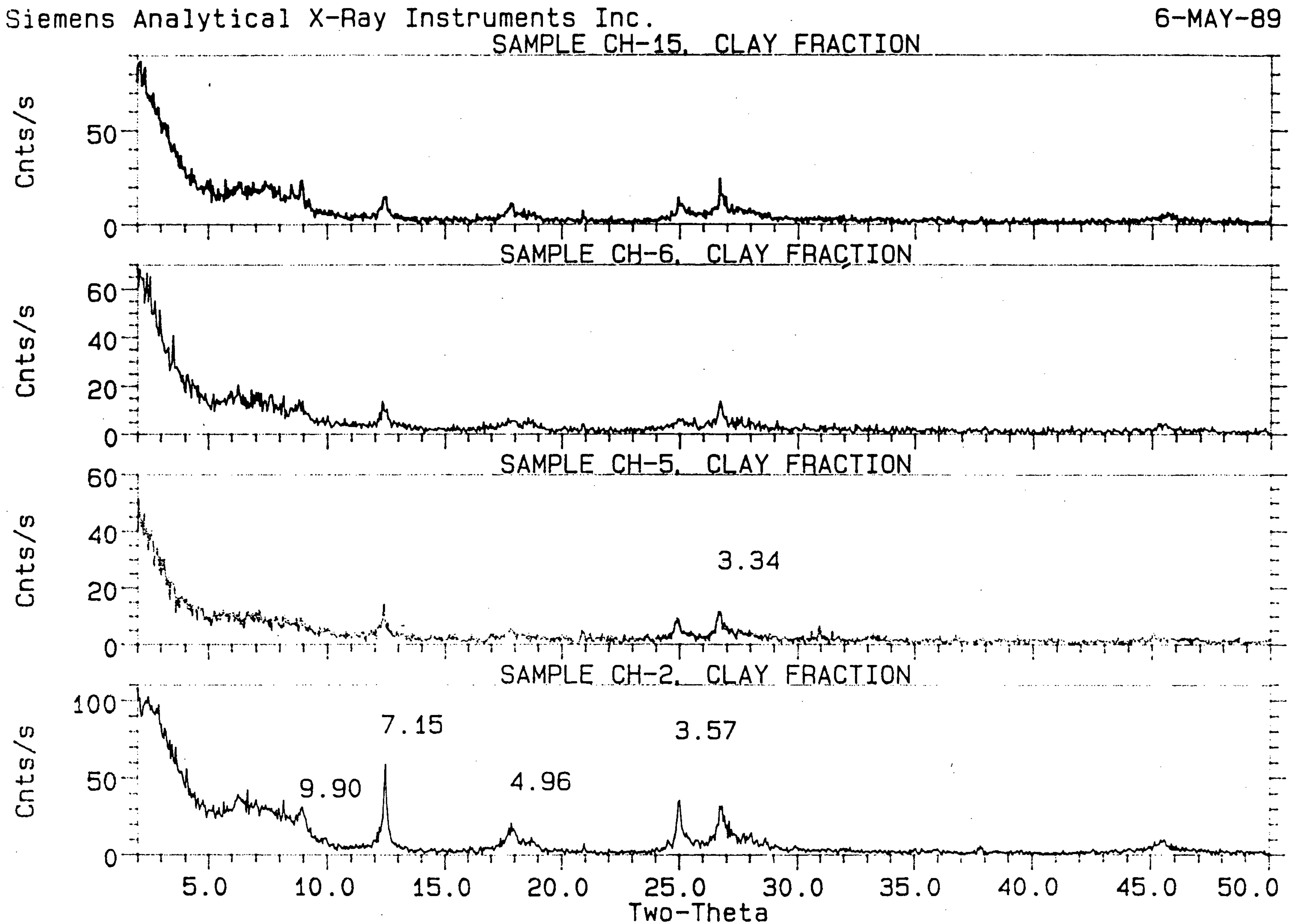




Siemens Analytical X-Ray Instruments Inc.
1-MAY-89
GRANT SAMPLE CH-14, WHOLE SOIL, POWDER
CH14-GRANT.X7
Counts/sec Intensity
100
90
80
70
60
50
40
30
20
10
0
8.99
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
Two-Theta



Siemens Analytical X-Ray Instruments Inc.
2-MAY-89
GRANT SAMPLE CH-15, WHOLE SOIL POWDER
CH15-GRANT.X1
Counts/sec Intensity
Two-Theta
0
10
20
30
40
50
60
70
80
90
100
110
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0

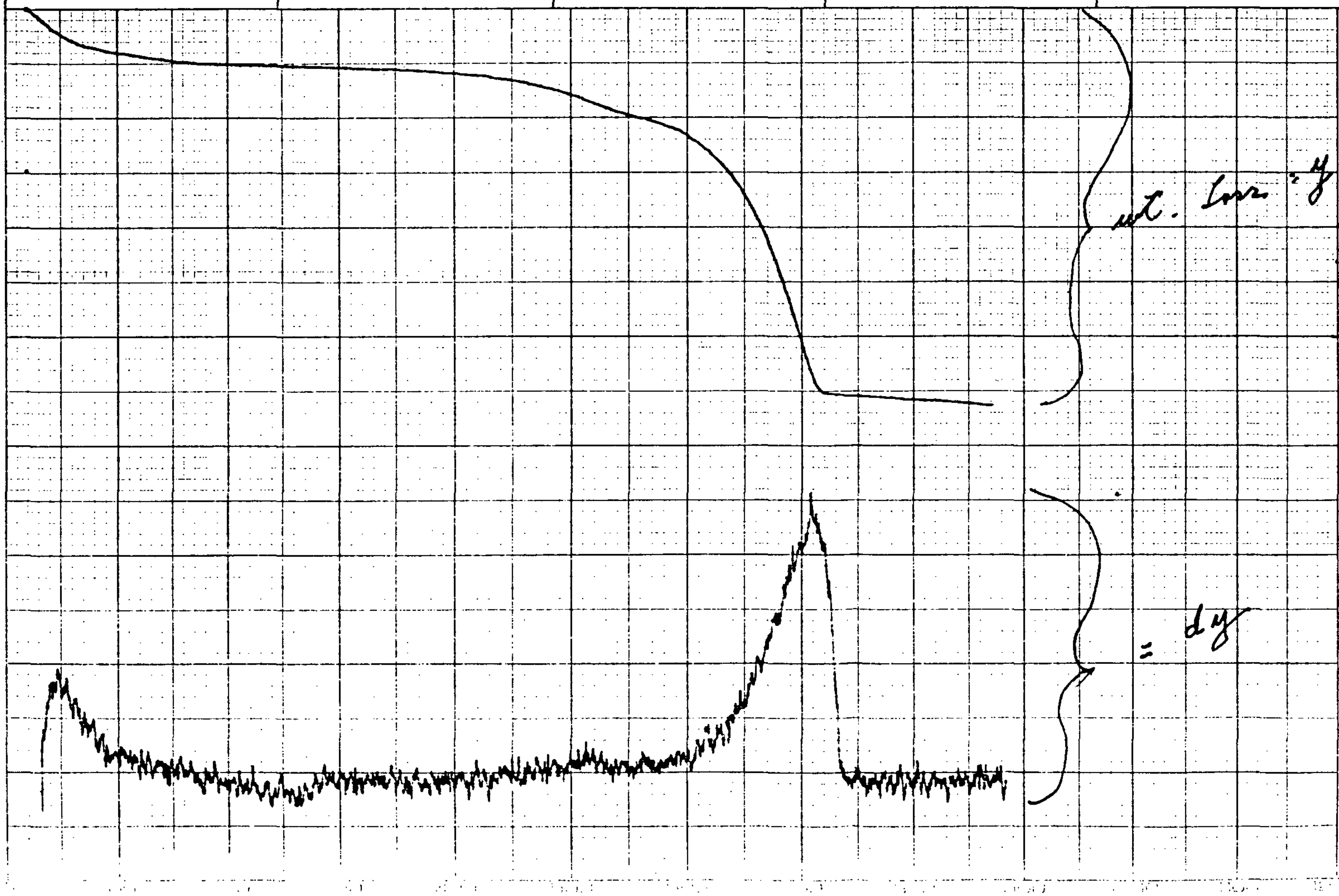

Siemens Analytical X-Ray Instruments Inc.
6-MAY-89
SAMPLE CH-15, CLAY FRACTION
Cnts/s
50
0
SAMPLE CH-6, CLAY FRACTION
Cnts/s
60
40
20
0
SAMPLE CH-5, CLAY FRACTION
Cnts/s
60
40
20
0
3.34
SAMPLE CH-2, CLAY FRACTION
Cnts/s
100
50
0
7.15
3.57
9.90
4.96
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
Two-Theta

PART NO. 990090

RUN NO.___ DATE 4/18/89 OPERATOR___ SAMPLE: CH -14 ATM___ @___ FLOW RATE___	T-AXIS SCALE, °C/in 100 PROG. RATE, °C/min___ HEAT___COOL___ISO___ SHIFT, in 0	DTA-DSC SCALE, °C/in___ (mcal/sec)/in___ WEIGHT, mg___ REFERENCE___	TGA SCALE, %/in 2.5 SUPPRESSION, mg 10.33 WEIGHT, mg___ TIME CONST., sec___ dY, (mg/min)/in___	TMA SCALE, mils/in___ MODE___ SAMPLE SIZE___ LOAD, g___ dY, (10X), (mils/min)/in___	

DUPONT Instruments

MEASURED VARIABLE %



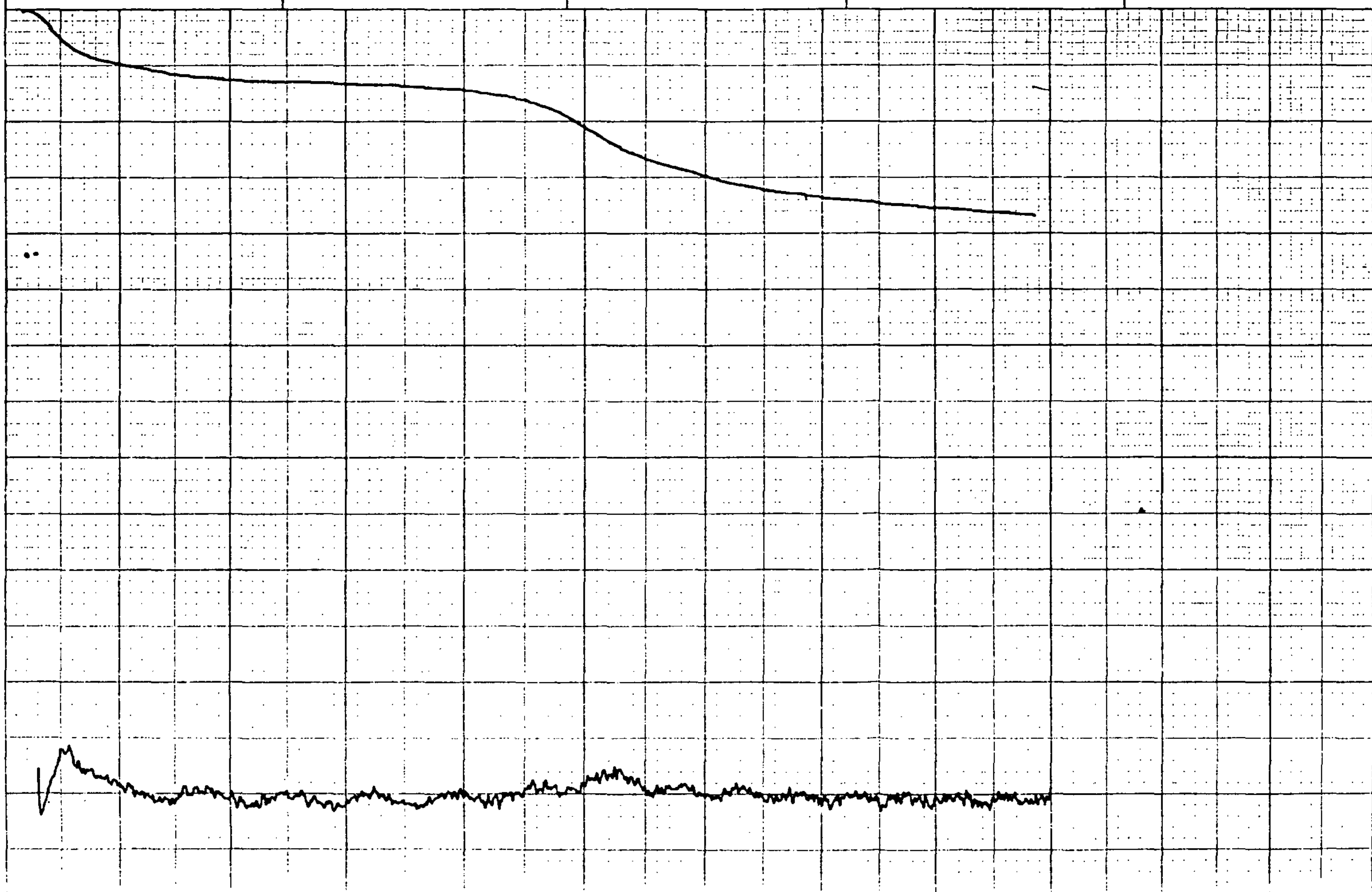
~~6~~ % 2:1
~~27~~ % kln
~~31~~ % $CaCO_3$

2.5%

same for all patterns

PART NO. 990090

RUN NO.___ DATE 4/15/89	T-AXIS	DTA-DSC	TGA	TMA	
OPERATOR	SCALE, °C/in 100	SCALE, °C/in	SCALE, ~~mg~~ %/in 2.5	SCALE, mils/in	
SAMPLE: CH - 1	PROG. RATE, °C/min	(mcal/sec)/in	SUPPRESSION, mg ~~2206~~ 80	MODE	
	HEAT___ COOL___ ISO___	WEIGHT, mg	WEIGHT, mg	SAMPLE SIZE	
ATM___ @___	SHIFT, in 0	REFERENCE	TIME CONST., sec	LOAD, g	
FLOW RATE			dY, (mg/min)/in	dY, (10X), (mils/min)/in	



7 % 2:1 expanding
14 % kaolinite

DU PONT Instruments

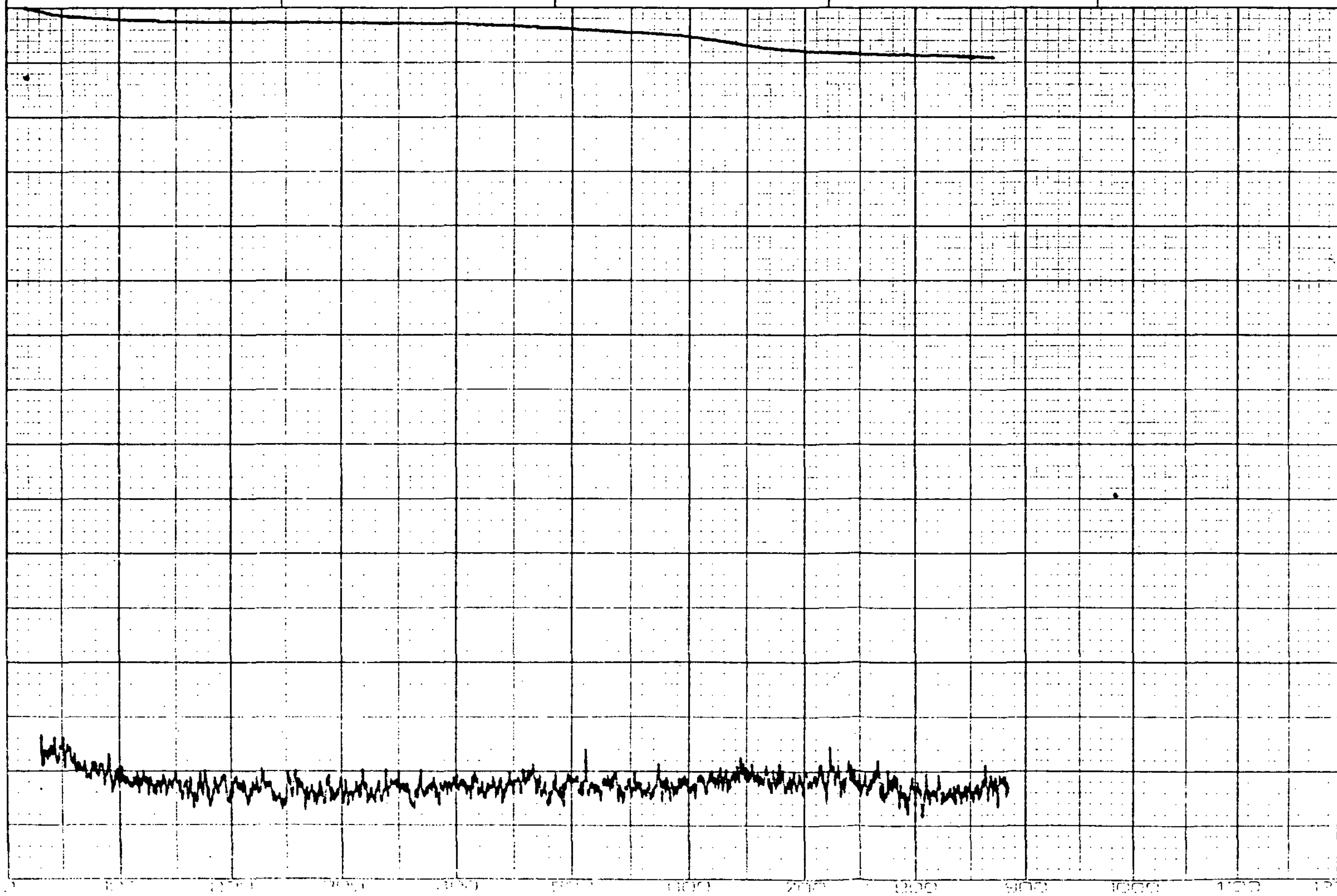
MEASURED VARIABLE

PART NO. 990090

RUN NO.__ DATE 4/12/89	T-AXIS	DTA-DSC	TGA	TMA	
OPERATOR	SCALE, °C/in 100	SCALE, °C/in	SCALE, %/in 2.5	SCALE, mils/in	
SAMPLE: CH-8	PROG. RATE, °C/min 10	(mcal/sec)/in	SUPPRESSION, mg 11.69	MODE	
	HEAT ✓ COOL __ ISO __	WEIGHT, mg	WEIGHT, mg 11.69 / .8	SAMPLE SIZE	
ATM __ @	SHIFT, in 0	REFERENCE	TIME CONST., sec 2	LOAD, g	
FLOW RATE			dY, (mg/min)/in .05	dY, (10X), (mils/min)/in	

DUPONT Instruments

MEASURED VARIABLE

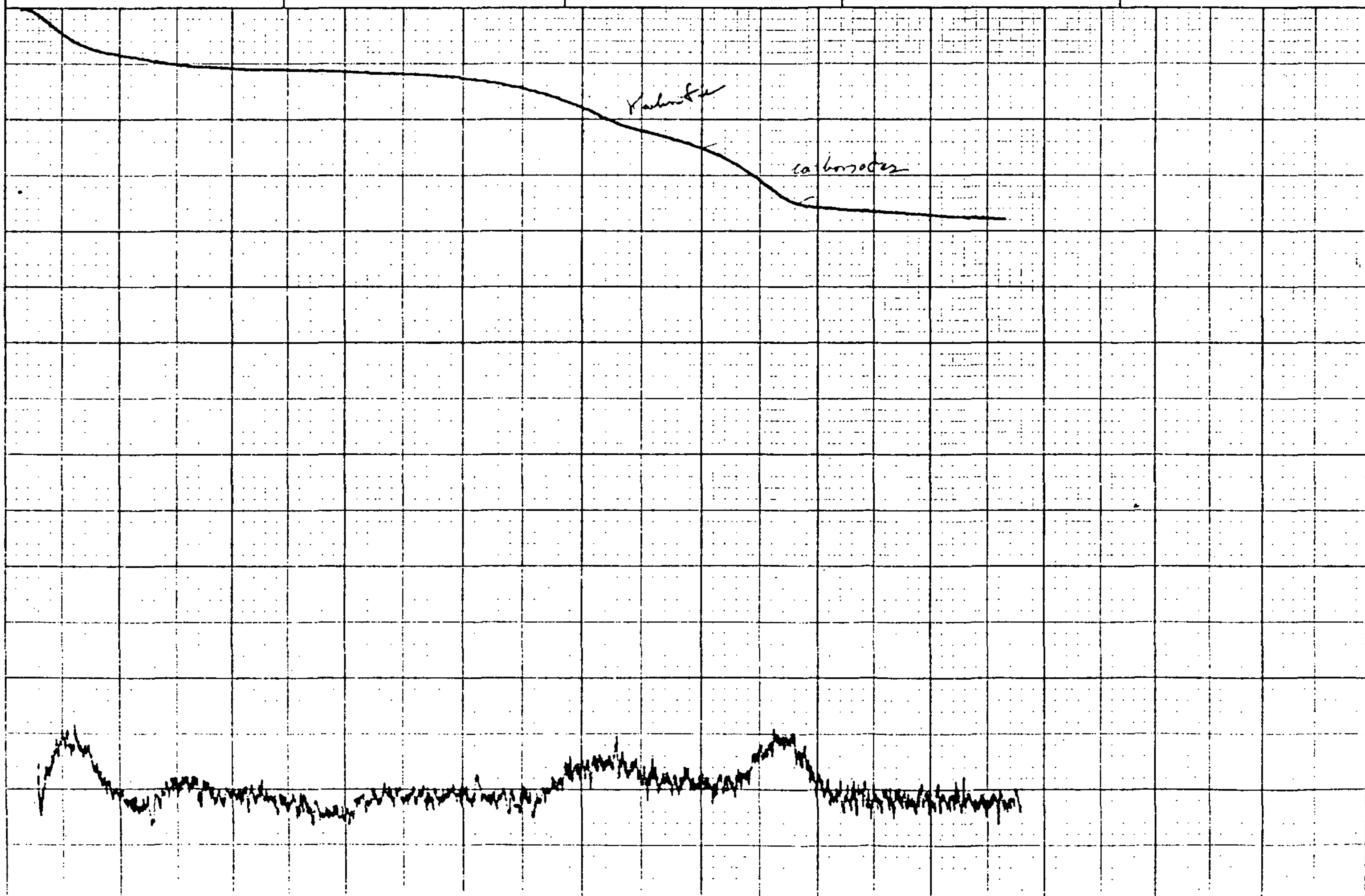


Trace Carbonate

Trace kaolinite

PART NO. 990090

RUN NO.___ DATE___	T-AXIS	DTA-DSC	TGA	TMA	
OPERATOR___	SCALE, °C/in 100	SCALE, °C/in ___	SCALE, %/in 2.5	SCALE, mils/in ___	
SAMPLE: CH - 9	PROG. RATE, °C/min___	(mcal/sec)/in ___	SUPPRESSION, mg 10.09	MODE ___	
	HEAT___ COOL___ ISO___	WEIGHT, mg ___	WEIGHT, mg ___	SAMPLE SIZE ___	
ATM___ @ ___	SHIFT, in 0	REFERENCE ___	TIME CONST., sec ___	LOAD, g ___	
FLOW RATE___			dY, (mg/min)/in ___	dY, (10X), (mils/min)/in ___	



6% 2:1

?% kln

3% $CaCO_3$

DUPONT Instruments

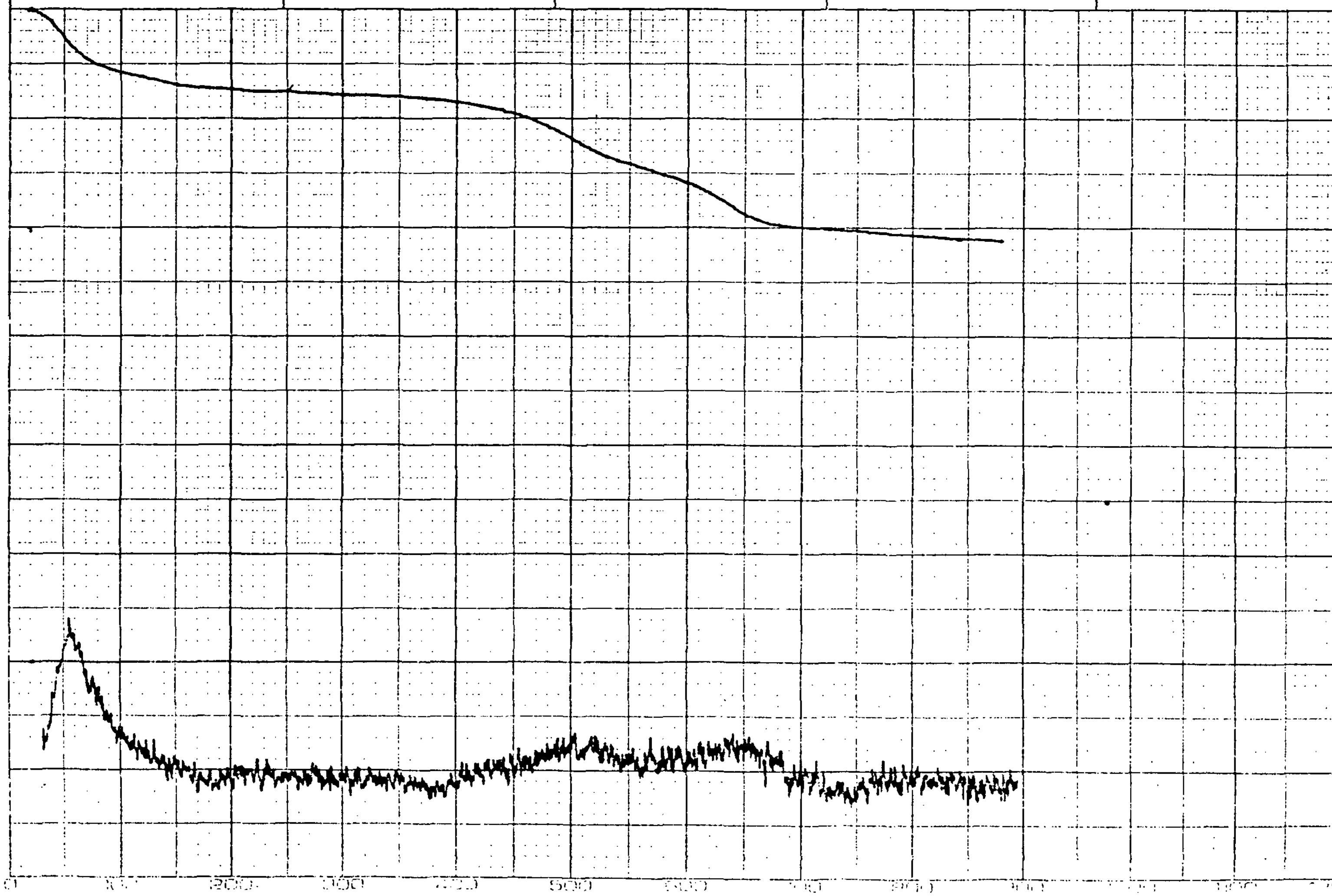
MEASURED VARIABLE

PART NO. 990090

	T-AXIS	DTA-DSC	TGA	TMA	
RUN NO.___ DATE______	SCALE, °C/in 100	SCALE, °C/in ______	SCALE, ~~mg~~/in 2.5	SCALE, mils/in ______	
OPERATOR______	PROG. RATE, °C/min______	(mcal/sec)/in______	SUPPRESSION, mg 9.43	MODE______	
SAMPLE: CH-15	HEAT___ COOL___ ISO___	WEIGHT, mg______	WEIGHT, mg______	SAMPLE SIZE______	
ATM______ @______	SHIFT, in 0	REFERENCE______	TIME CONST., sec______	LOAD, g______	
FLOW RATE______			dY, (mg/min)/in______	dY, (10X), (mils/min)/in ______	

Du Pont Instruments

MEASURED VARIABLE ______



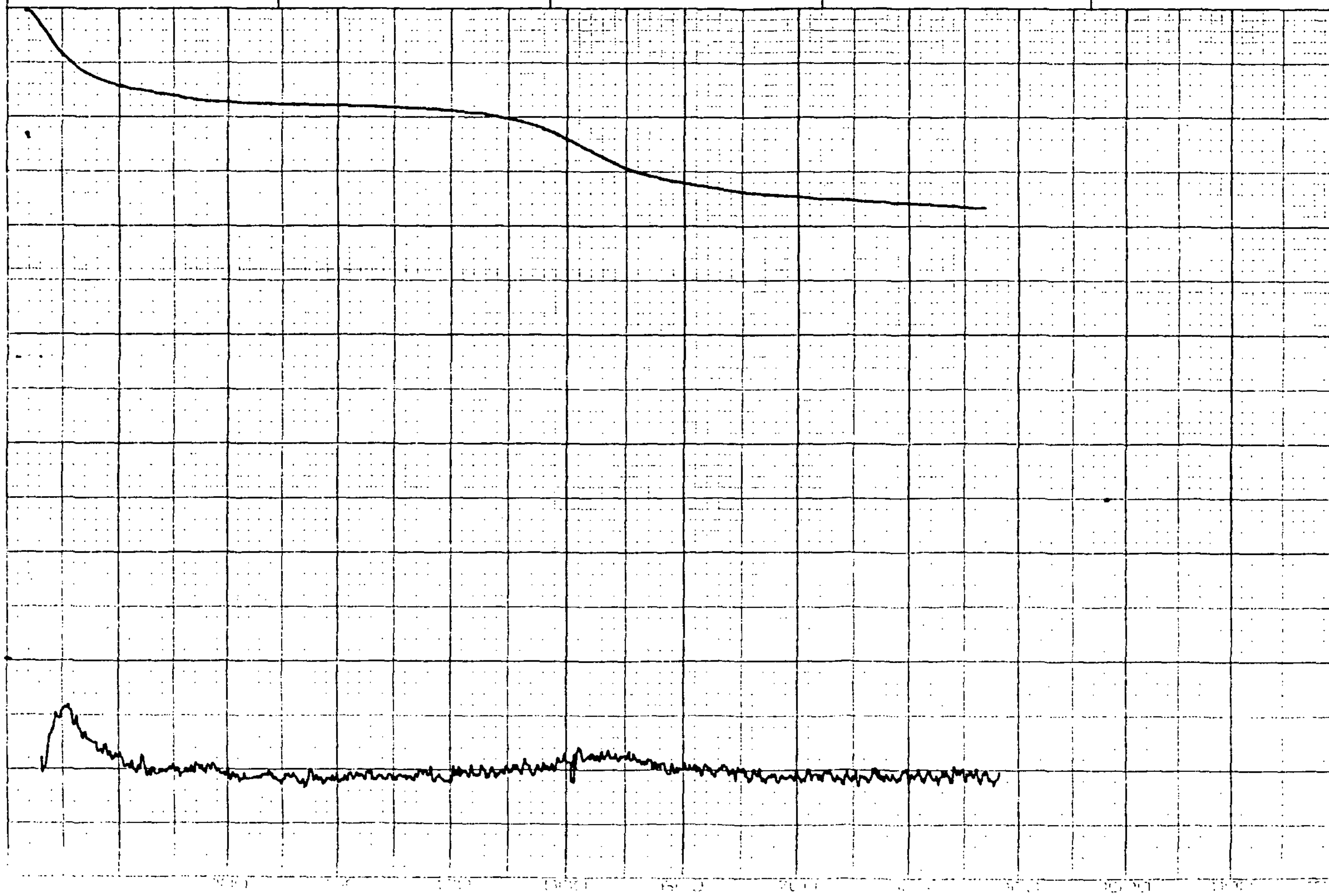
8.5% 2:1
10% KI4
2.8 $CaCO_3$

PART NO. 990090

RUN NO.___ DATE___	T-AXIS	DTA-DSC	TGA	TMA	CH-2
OPERATOR___	SCALE, °C/in 100	SCALE, °C/in ___	SCALE, ~~mg~~ %/in 2.5	SCALE, mils/in ___	
SAMPLE:	PROG. RATE, °C/min ___	(mcal/sec)/in ___	SUPPRESSION, ~~mg~~ 80% 10.0%	MODE ___	
	HEAT___ COOL___ ISO___	WEIGHT, mg ___	WEIGHT, mg ___	SAMPLE SIZE ___	
ATM___	SHIFT, in 0	REFERENCE ___	TIME CONST., sec ___	LOAD, g ___	
FLOW RATE___			dY, (mg/min)/in ___	dY, (10X), (mils/min)/in ___	

DUPONT Instruments

MEASURED VARIABLE

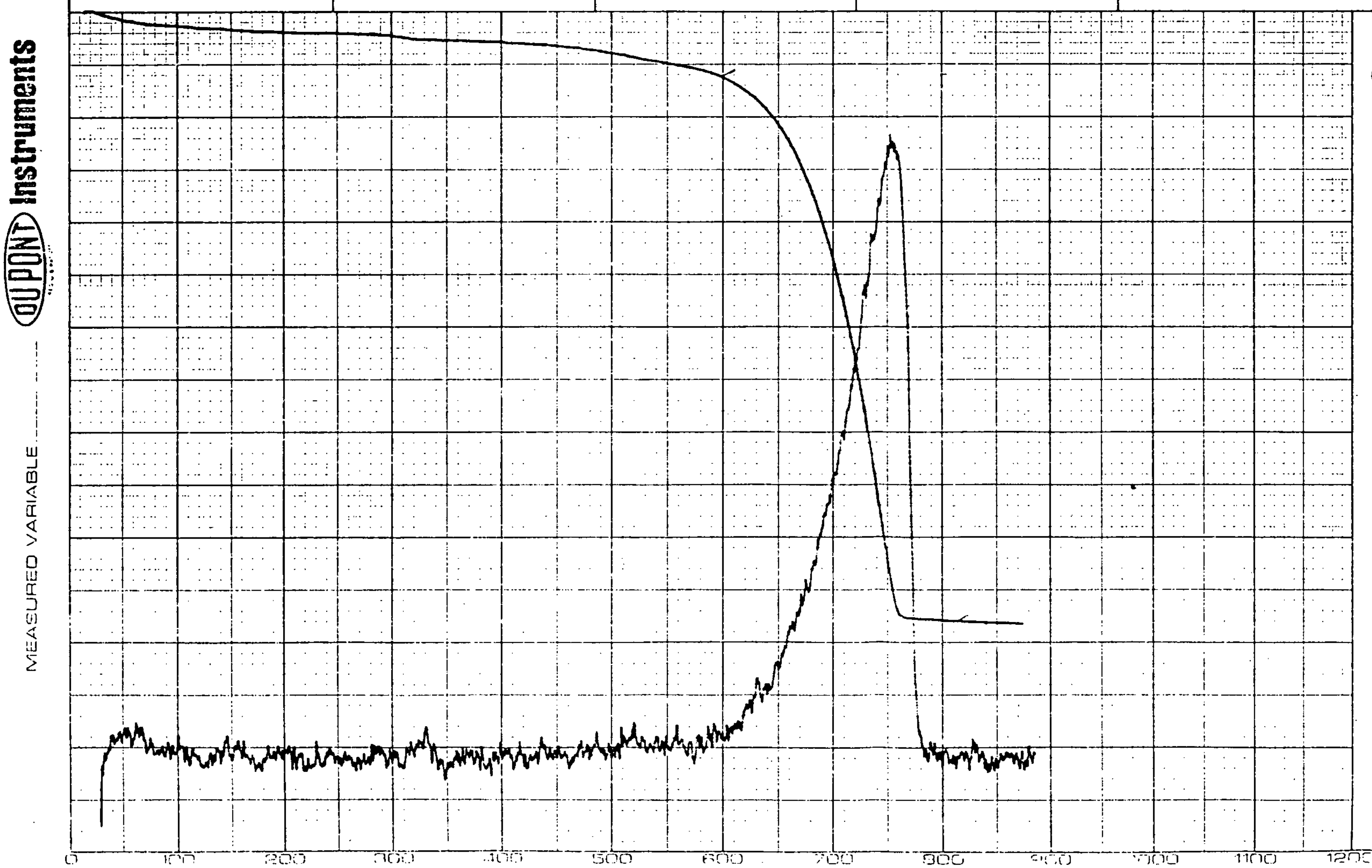


12.5% Kln
10.% 2:1 expanding

PART NO. 990090

RUN NO.__ DATE__	T-AXIS	DTA-DSC	TGA	TMA	CH-5
OPERATOR__	SCALE, °C/in 100	SCALE, °C/in __	SCALE, ~~mg~~ %/in 2.5	SCALE, mils/in __	
SAMPLE:	PROG. RATE, °C/min __	(mcal/sec)/in __	SUPPRESSION, mg 12.88	MODE __	
	HEAT__ COOL__ ISO__	WEIGHT, mg __	WEIGHT, mg 12.88/.8	SAMPLE SIZE __	
ATM__ @__	SHIFT, in 0	REFERENCE __	TIME CONST., sec 2	LOAD, g __	
FLOW RATE__			dY, (mg/min)/in 0.05	dY, (10X), (mils/min)/in __	

DUPONT Instruments



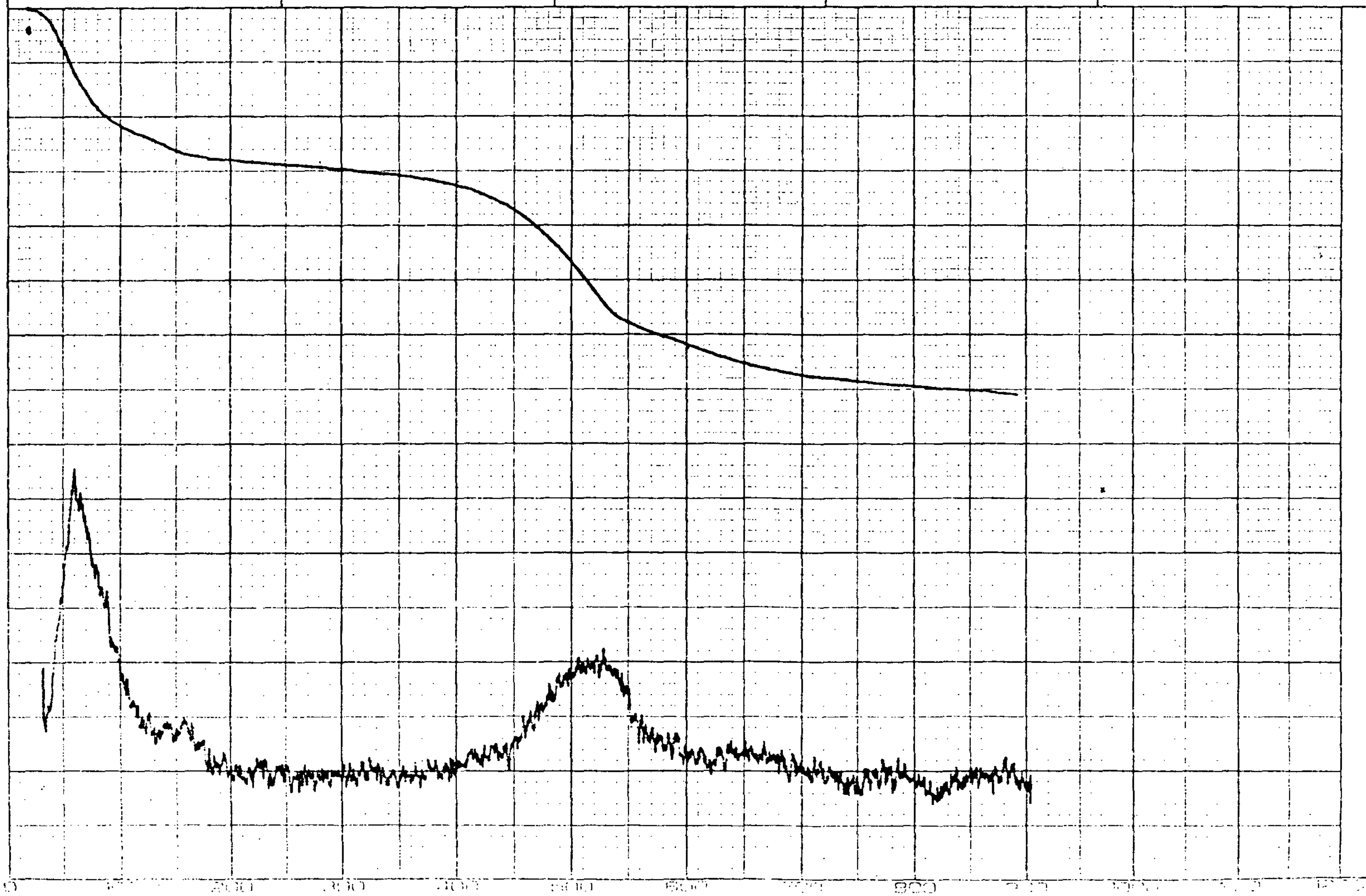
Trace Carbonate
(5.2 * 2.5)/.44
29 % $CaCO_3$ equivalent

PART NO. 990090

	T-AXIS	DTA-DSC	TGA	TMA	
RUN NO.___ DATE_____	SCALE, °C/in 100	SCALE, °C/in _____	SCALE, % /in 2.5	SCALE, mils/in _____	
OPERATOR_____	PROG. RATE, °C/min_____	(mcal/sec)/in _____	SUPPRESSION, mg 12.33	MODE_____	
SAMPLE: CH-6	HEAT___COOL___ISO___	WEIGHT, mg_____	WEIGHT, mg 12.33/1.80	SAMPLE SIZE_____	
ATM_____	SHIFT, in 0	REFERENCE_____	TIME CONST., sec_____	LOAD, g_____	
FLOW RATE_____			dY, (mg/min)/in _____	dY, (10X), (mils/min)/in ___	

DUPONT Instruments

MEASURED VARIABLE



16 % 2:1 expanding
27 % kaolinite

KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD— ENVIRONMENTAL SAMPLES KM-4778

FACILITY	SAMPLING FIRM	SAMPLE
NAME: CIMARRON FACILITY	NAME: JAMES L. GRANT & ASSOC.	☐ Effluent ☐ Groundwater
ADDRESS: HIGHWAY 74 N	ADDRESS: 8301 E. PRENTICE #402, ENGLEWOOD CO. 80111	☒ Solid ☐ Surface Water
CRESCENT, OK. 73028	SIGNATURE: [signature]	☐

NO.	LOCATION	DATE	TIME	WEATHER TEMP	WEATHER PREC	SAMPLE TYPE AND METHOD COMP.	GRAB	MECH	MAN	TIMES CASING CLEARED	NO OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
CH-1	WELL 1323						X				1	EXCHANGEABLE CATION (EXC) MINERALOGY (MIN) CATION EXCHANGE CAPACITY (CEC) GRAIN SIZE (GS)	
CH-2	WELL 1323					X					1	CEC, EXC, MIN, GS	
CH-3	WELL 1326					X					1	CEC, EXC, GS	
CH-4	WELL 1328						X				1	CEC, EXC, GS	
CH-5	WELL 1328						X				1	CEC, EXC, GS, MIN	
CH-6	WELL 1336						X				1	CEC, EXC, GS, MIN	
CH-7	WELL 1321						X				1	CEC, EXC, GS	
CH-8	WELL 1321						X				1	MIN.	
CH-9	BORROW MAT'L					X					1	CEC, EXC, GS, MIN	
CH-10	WELL 1324					X					1	CEC, EXC, GS	
CH-11	WELL 1325					X					1	CEC, EXC, GS	

RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME	ADDITIONAL REMARKS
[signature]				
				PLEASE CALL PAT BREEN
				(303) 779-0576 WITH
DISPATCHED BY (SIGNATURE) / DATE / TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME	QUESTIONS.

CARRIER: FED EXP AIRBILL # 3041510404

ADDRESS:

METHOD OF SHIPMENT:

LABORATORY: DEPT. AGRONOMY & SOIL, AUBURN UNIV.

ADDRESS: 202 FUNCHESS HALL, AUBURN, ALA. 36849-5412

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES OR ASTM

☒ Yes ☐ No, explain:

KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD— ENVIRONMENTAL SAMPLES KM-4775

FACILITY	SAMPLING FIRM	SAMPLE
NAME: Cimarron Facility	NAME: James L. Grant & Assoc.	☐ Effluent ☐ Groundwater
ADDRESS: Highway 74, Crescent, OK 73028	ADDRESS: 8301 E. Prentice #402, Englewood, Co. 80111	☒ Solid ☐ Surface Water
	SIGNATURE: [signature]	☐

NO.	LOCATION	DATE	TIME	WEATHER TEMP	WEATHER PREC	SAMPLE TYPE AND METHOD COMP.	GRAB	MECH	MAN	TIMES CASING CLEARED	NO OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
CH-12	Borrow mat'l					X					1	Exchangeable Cation (EXC) Grain size (GS) Cation Exchange Capacity (CEC) Mineralogy (MIN)	
CH-13	Well 1332					X					1	CEC, EXC, GS	
CH-14	Well 1334						X				1	CEC, EXC, GS, MIN	
CH-15	Well 1334						X				1	CEC, EXC, GS, MIN	
CH-16	Borrow mat'l					X					1	Matric Potential	
CH-17	Well 1332					X					1	Matric Potential	
CH-18	Well 1326					X					1	Matric Potential	
CH19	Well 1336						X				1	Matric Potential	

RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME
[signature]			

DISPATCHED BY (SIGNATURE)	DATE	TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME

CARRIER: Fed Exp. Airbill # 3041510404

ADDRESS:

METHOD OF SHIPMENT:

LABORATORY: Dept of Agronomy & Soil, Auburn Univ.

ADDRESS: 202 Funchess Hall, Auburn ALA 36849-5412

ADDITIONAL REMARKS: Please call Pat Breen (303) 779-0576 with questions

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES or ASTM

☒ Yes ☐ No (explain above)

APPENDIX H

DISTRIBUTION COEFFICIENT ANALYSES

Equilibrium Distribution Coefficients - Batch Determination Techniques

submitted to

Kerr McGee Tech Center
Oklahoma City, Oklahoma

June 6, 1989

by

B. F. Hajek

Equilibrium Distribution Coefficients - Batch Determination Techniques

B. F. Hajek

Introduction

The equilibrium distribution coefficient (K_d) is an easily determined equilibrium constant for trace ion adsorption on soils. In using this coefficient the assumption is made that ion exchange extends over a short, nearly linear, section of an adsorption isotherm. This assumption is usually valid since trace ions are present in small concentrations and do not occupy a significant portion of all ion exchange sites (1, 2, 3).

The K_d is calculated from data obtained in batch equilibrium tests by use of the equation,

$$K_d = \frac{Co - C}{C} \quad \frac{\text{ml soln}}{\text{g soil}},$$

in which C_o is the initial concentration of radionuclide in solution and C is the equilibrium concentration after solution - soil contact.

Batch Equilibrium Method

Five grams of soil obtained from samples collected by test borings are equilibrated with 20 ml of solution by shaking continuously for 16 hours (overnight). The solution used should simulate, as closely as possible, the solution that will actually flow through the soil. This can be groundwater or seepage water obtained on-site, simulated acid process solution, or ground water-acid process solution mixtures. The solution used is traced with ions of interest such as U, Ra, Th, and As. A higher soil-solution ratio may be required for U adsorption tests since adsorption will probably be low (<2). A 1:1 ratio may be needed in this case. A lower ratio may be needed for Ra and Th since K_d's may exceed 500 ml/g.

Radionuclide concentration in the equilibrium solution should be such that $>10{,}000$ counts can be accumulated in a reasonable period of time to give a counting error of less than one percent. All K_d tests should be made in duplicate.

The soil sample is usually that fraction that passes a 2 mm sieve. If porous rock or porous gravel are tested for adsorption the solid-solution ratio should be increased and a value for in-place density (bulk density) will be needed to express adsorption on a volume basis.

Solution characteristics required:
1. initial pH
2. final pH
3. concentration of major competing cations and anions

Soil characteristics:
1. grain size distribution
2. qualitative mineralogy
3. approximate bulk density
4. pH of a 1:1, soil:water suspension

References

1. D. W. Bensen. 1960. Review of soil chemistry research at Hanford. HW-67201. General Electric Co., Richland, Washington.

2. W. J. Kaufman. 1963. An appraisal of the distribution coefficient for estimating underground movement of radioisotopes. HNS-1229-21. Hazelton - Nuclear Sci. Corp., Pal Alto, California.

3. W. E. Prout. 1958. Adsorption of radioactive waste by Savannah River Plant Soil. Soil Sci. Vol. 86, pp. 13-17.

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 14-JUN-89

SAMPLE ID: 967479
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\14-JUN-89\CH-1R
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results by 6-21-89;1705-JAE-18P71
20 ml Spiked Water;Spiked U232 850pCi/l

Th-228	0.60+-0.52 pCi/l	pH initial	7.45
U232	1.2+-0.60 pCi/l	pH final	7.90

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: [signature] 6/21/89 D. Keck 6/27/89

KERR-MCGEE CORPORATION Technology Division

This/these samples are being returned to you.

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967484
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-1RR
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results by 6-21-89;1705-JAE-18P72
100 ml Spiked Water;Spiked U232 850pCi/l

Th-228	1.50+-0.74 pCi/l	pH initial	7.11
U232	7.5+-1.5 pCi/l	pH final	7.38

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: DASh 6/21/89 D. Kerr

KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

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27-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967474
07:53 a.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-1X
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967474
XRD of crystalline phases
1688-JAH-22P82;1724-SMA-6P4,5,11,12

Major	Quartz = SiO_2	+20	45.72 %
Accessory	I, M, F	+60	73.05 %
Bulk Density	77 lbs/ft3	+100	77.60 %
pH of 1:1 soil	7.6	+200	82.41 %
+8	0.17 %	+325	87.04 %

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

****

* APPROVED: CDE 6-27-89 [signature] 6-27-89 [signature] *

****

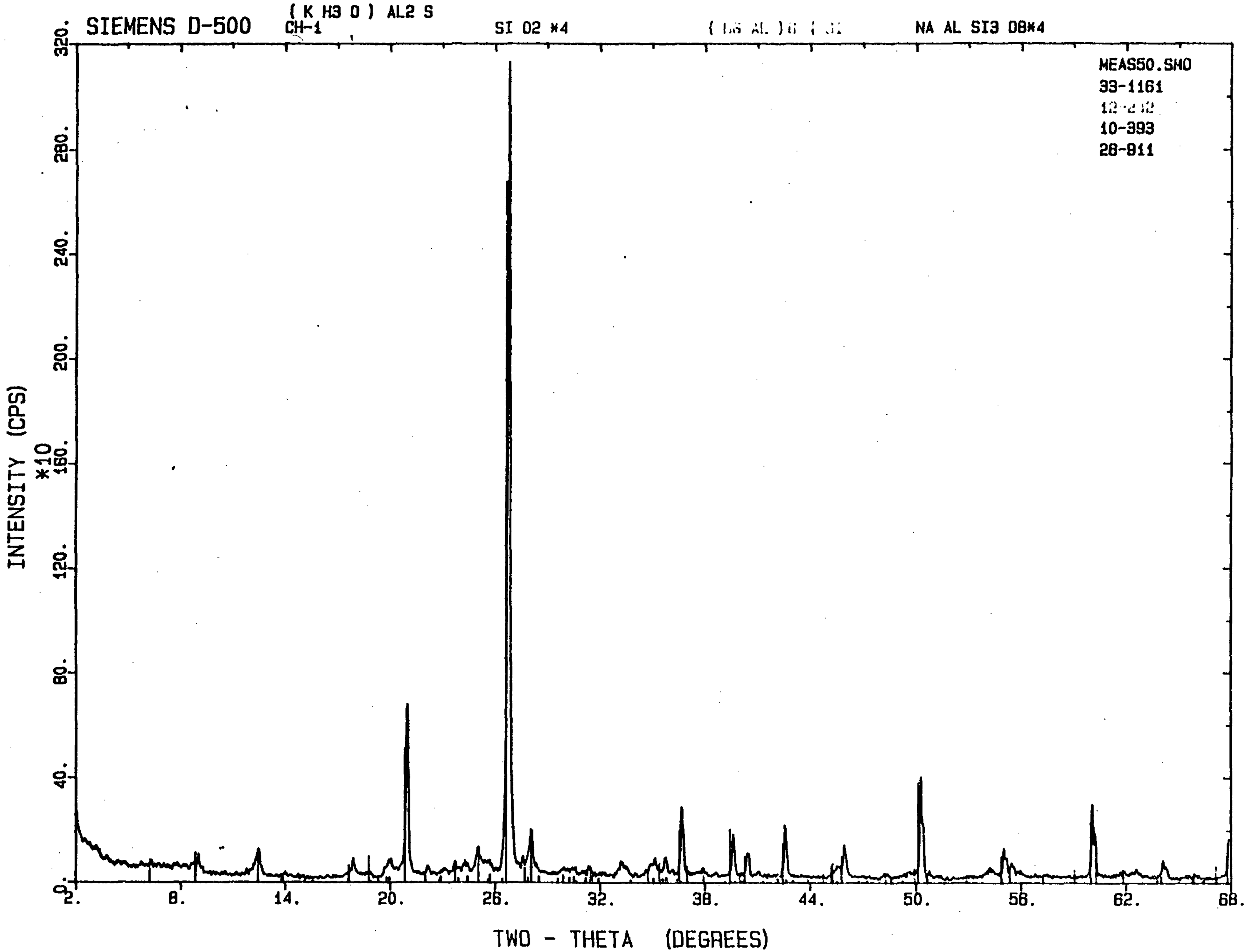
KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.

I - Illite clay - $(K, H_3O)Al_2Si_3AlO_{10}(OH)_2$

M - Montmorillonite - Chlorite clay

F - Feldspar - $NaAlSi_3O_8$



SIEMENS D-500
(K H3 O) AL2 S
CH-1
SI O2 *4
NA AL SI3 O8*4
MEAS50.SMO
33-1161
10-393
28-811
INTENSITY (CPS)
*10
0.
40.
80.
120.
160.
200.
240.
280.
320.
2.
8.
14.
20.
26.
32.
38.
44.
50.
56.
62.
68.
TWO - THETA (DEGREES)

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967480
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-5R
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
20 ml Spiked Water;Spiked U232 850pCi/1

Th-228	0.90+-0.60 pCi/1	pH initial	7.45
U232	2.7+-0.90 pCi/1	pH final	7.76

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

****
APPROVED: 6/21/89 D. Keck
****

KERR-MCGEE CORPORATION Technology Division
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This/these samples are being returned to you.

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967485
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-5RR
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
100 ml Spiked Water;Spiked U232 850pCi/l

Th-228	0.90+-0.60 pCi/l	pH initial	7.22
U232	3.6+-1.0 pCi/l	pH final	7.46

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

****
* APPROVED: ______________________________ *
****

KERR-MCGEE CORPORATION Technology Division
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This/these samples are being returned to you.

27-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967475
07:53 a.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-5X
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967474
XRD of crystalline phases

Major	Quartz = SiO_2 & Calcite = $CaCO_3$	+20	32.44 %
Accessory	Dolomite = $CaMg(CO_3)_2$ & Kaolinte = $Al_2Si_2O_5(OH)_4$	+60	56.56 %
Bulk Density	87 lbs/ft3	+100	78.36 %
pH of 1:1 soil	8.8	+200	92.97 %
+8	0.03 %	+325	96.94 %

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

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*******************************************************
*                                                     *
* APPROVED: CDE 6-27-89  JB 6/27/89                   *
*                                                     *
*******************************************************
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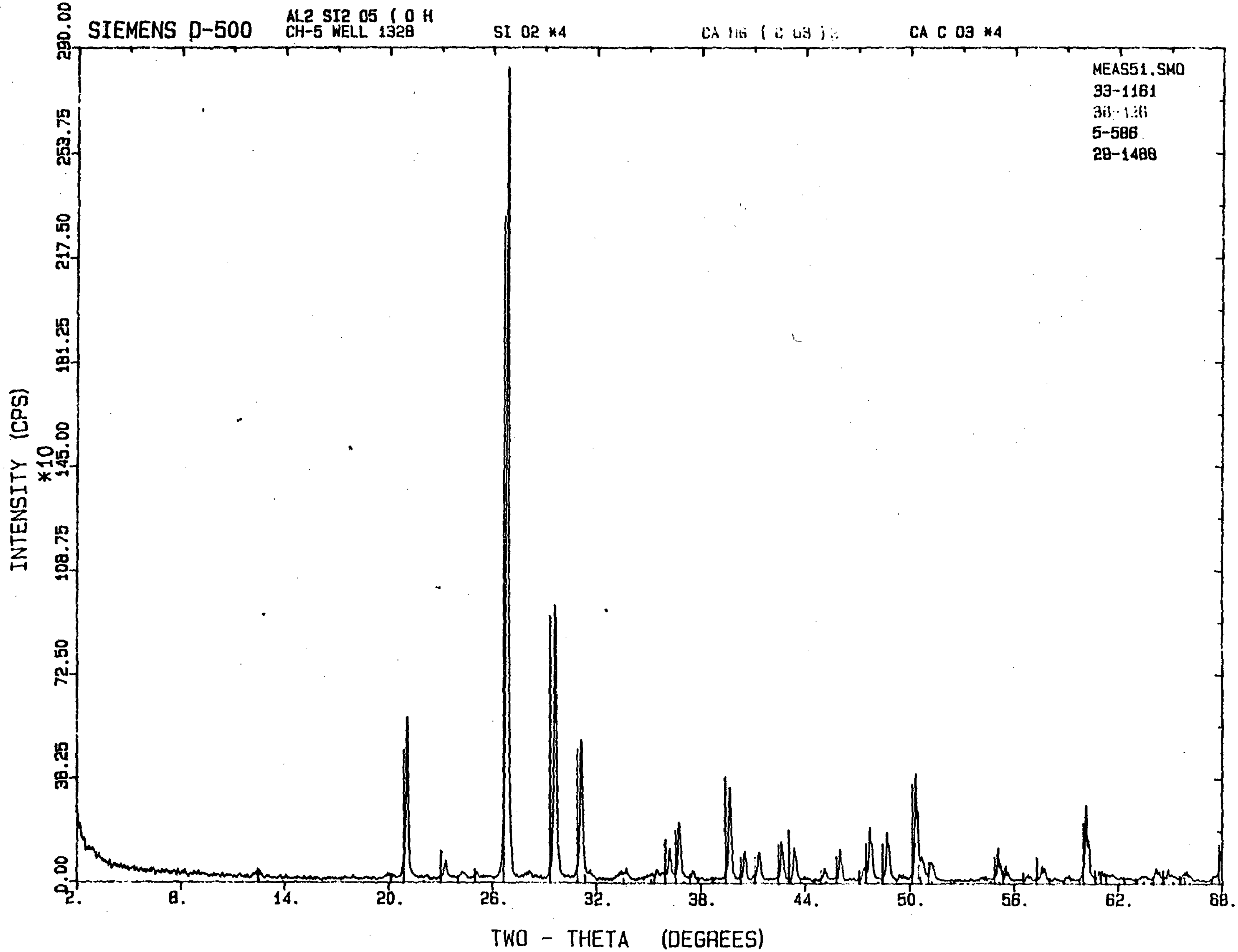
KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.


SIEMENS D-500
AL2 SI2 05 (O H
CH-5 WELL 1328
SI O2 *4
CA C O3 *4
MEAS51.SMO
33-1161
5-586
28-1488
INTENSITY (CPS)
*10
290.00
253.75
217.50
181.25
145.00
108.75
72.50
36.25
0.00
2.
8.
14.
20.
26.
32.
38.
44.
50.
56.
62.
68.
TWO - THETA (DEGREES)

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967481
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-6R
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
20 ml Spiked Water;Spiked U232 850pCi/l

Th-228	0.60+-0.52 pCi/l	pH initial	7.50
U232	9.3+-1.7 pCi/l	pH final	7.82

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: [signature] 6/21/89

KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967486
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-6RR
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
100 ml Spiked Water;Spiked U232 850pCi/l

Th-228	0.90+-0.60 pCi/l	pH initial	7.19
U232	9.9+-1.7 pCi/l	pH final	7.40

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: [signature] 6/21/89 D. Kirk

KERR-MCGEE CORPORATION Technology Division

This/these samples are being returned to you.

27-Jun-1989

AFE/PROJECT NUMBER: 84007 SAMPLE ID: 967476

DATE RECEIVED: 12-JUN-89 08:17 a.m.

LOCATION: Cimarron

SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-6X

SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967474

XRD on crystalline phases

Major	Quartz = SiO_2	+20	41.63 %
Accessory	I, M, F	+60	80.97 %
Bulk Density	77 lbs/ft3	+100	88.43 %
pH of 1:1 soil	8.1	+200	94.85 %
+8	0.14 %	+325	97.83 %

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

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*************************************************************
*                                                           *
* APPROVED: CDE 6-27-89  RB 6-27-89                         *
*                                                           *
*************************************************************
```

KERR-MCGEE CORPORATION Technology Division

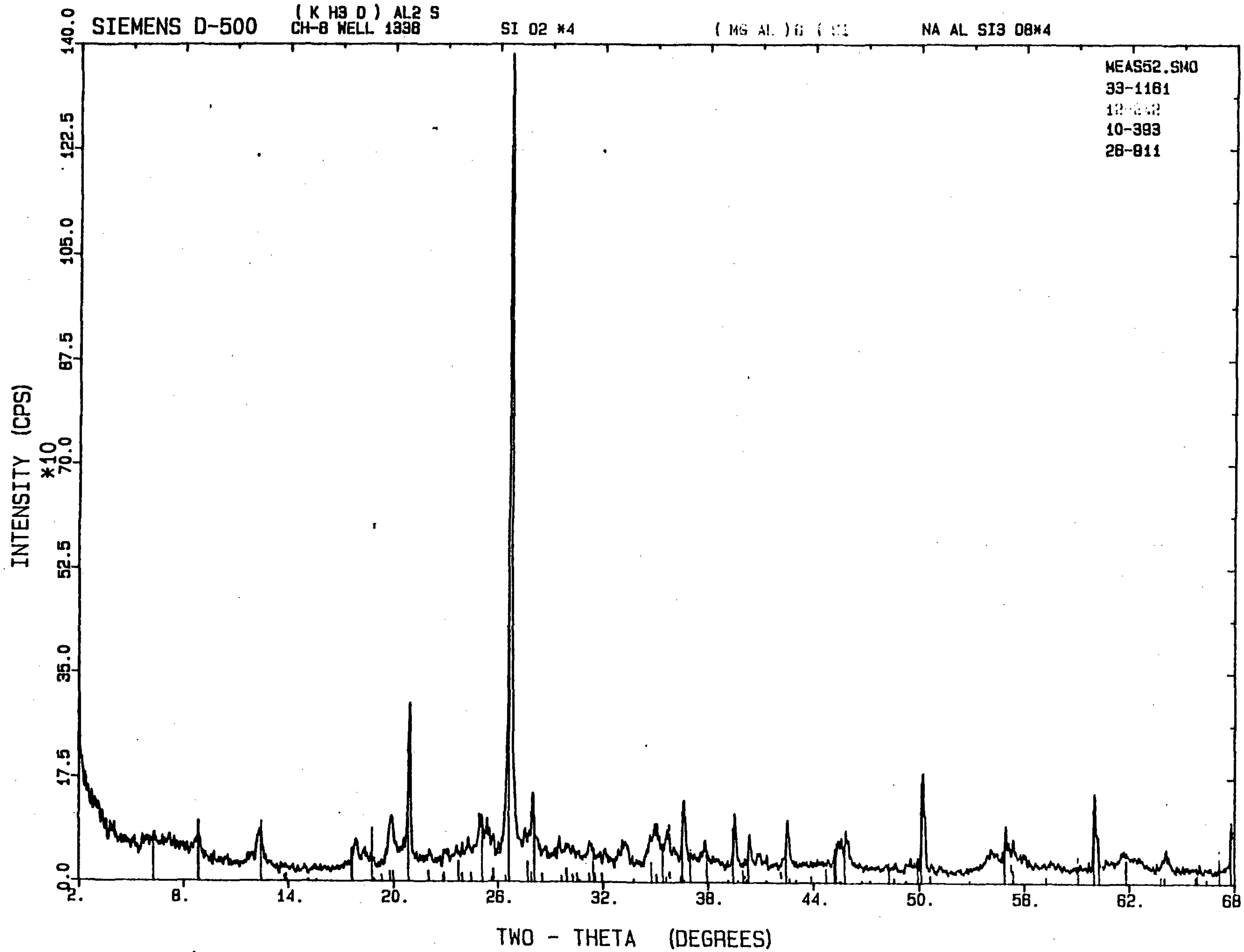
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.

I - Illite clay - $(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$

M - Montmorillonite - Chlorite clay

F - Feldspar - $NaAlSi_3O_8$


SIEMENS D-500
(K H3 O) AL2 S
CH-8 WELL 1338
SI O2 *4
NA AL SI3 O8*4
MEAS52.SMO
33-1161
10-393
26-811
INTENSITY (CPS)
*10
0.0
17.5
35.0
52.5
70.0
87.5
105.0
122.5
140.0
2.
8.
14.
20.
26.
32.
38.
44.
50.
56.
62.
68.
TWO - THETA (DEGREES)

21-Jun-1989

AFE/PROJECT NUMBER: 84007 SAMPLE ID: 967482
DATE RECEIVED: 12-JUN-89 02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-8R
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
20 ml Spiked Water;Spiked U232 850pCi/l

Th-228	1.20+-0.42 pCi/l	pH initial	7.49
U232	1.2+-0.60 pCi/l	pH final	7.75

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

****
* APPROVED: DASh 6/21/89 D. Keele *
****

KERR-MCGEE CORPORATION Technology Division
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This/these samples are being returned to you.

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967487
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-8RR
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
100 ml Spiked Water;Spiked U232 850pCi/l

Th-228	0.90+-0.60 pCi/l	pH initial	7.20
U232	1.5+-0.67 pCi/l	pH final	7.42

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: [signature] 6/21/89 D. Keck

KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.

27-Jun-1989

AFE/PROJECT NUMBER: 84007 SAMPLE ID: 967477
DATE RECEIVED: 12-JUN-89 07:53 a.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-8X
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967474
XRD of crystalline phases

Major	Quartz = SiO_2	+20	11.72 %
Accessory	C, D, I, M	+60	29.35 %
Bulk Density	84 lbs/ft3	+100	57.80 %
pH of 1:1 soil	8.2	+200	91.93 %
+8	0.01 %	+325	97.14 %

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

```
*******************************************************
*                                                     *
* APPROVED: CWE 6-27-89  [signature] 6-27-89          *
*                                                     *
*******************************************************
```

KERR-MCGEE CORPORATION Technology Division
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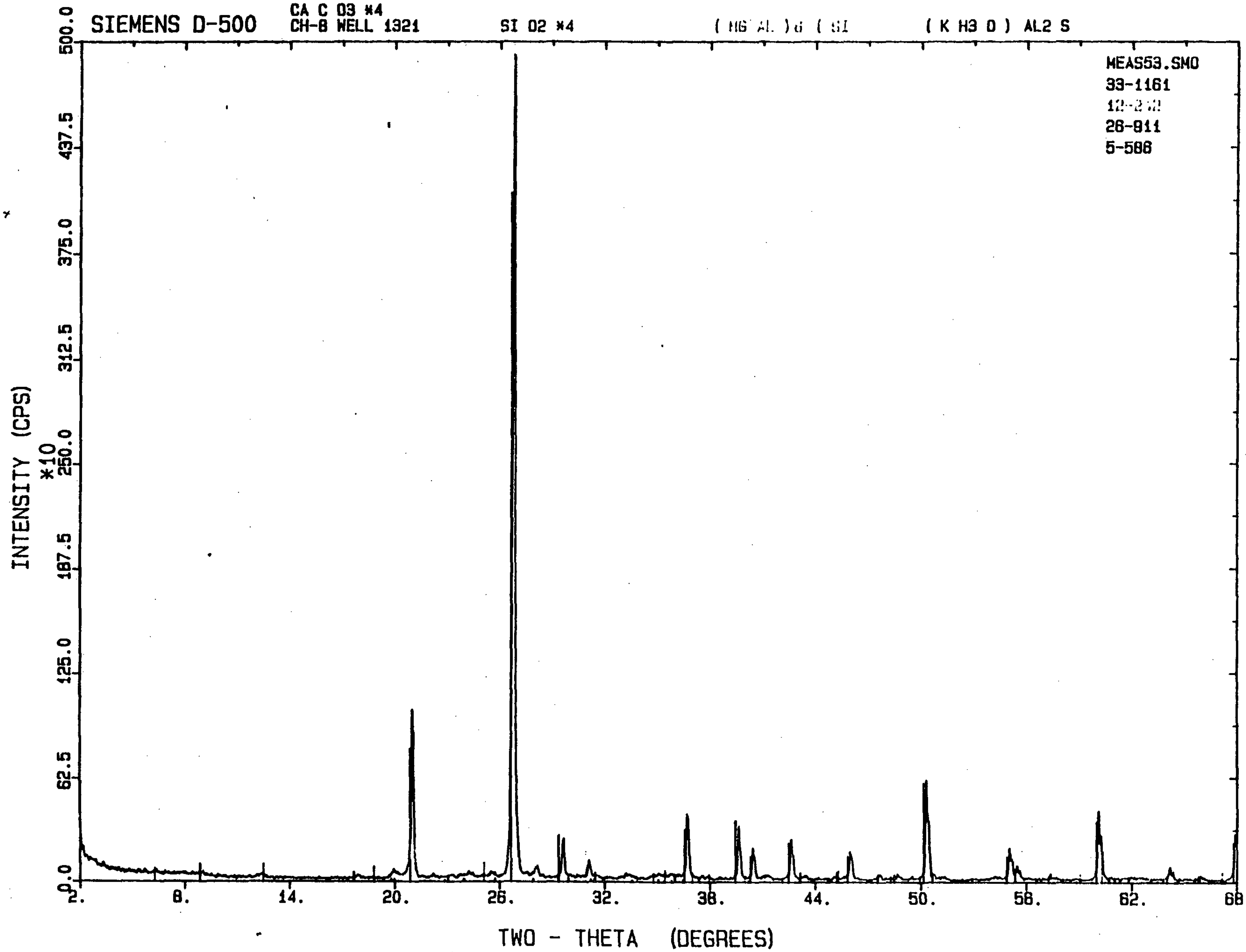
This/these samples are being returned to you.

C - Calcite - $CaCO_3$
D - Dolomite - $CaMg(CO_3)_2$
I - Illite clay - $(K, H_3O) Al_2 Si_3 AlO_{10} (OH)_2$
M - Montmorillonite - Chlorite clay


SIEMENS D-500
CA C O3 *4
CH-B WELL 1321
SI O2 *4
(K H3 O) AL2 S
MEAS53.SMO
33-1161
26-911
5-586
INTENSITY (CPS) *10
0.0
62.5
125.0
187.5
250.0
312.5
375.0
437.5
500.0
2.
8.
14.
20.
26.
32.
38.
44.
50.
56.
62.
68.
TWO - THETA (DEGREES)

21-Jun-1989

AFE/PROJECT NUMBER: 84007
SAMPLE ID: 967483
DATE RECEIVED: 12-JUN-89
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-14R
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
20 ml Spiked Water;Spiked U232 850pCi/l

Th-228	1.20+-0.42 pCi/l	pH initial	7.50
U232	3.0+-0.95 pCi/l	pH final	7.82

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: [signature] 6/21/89 D. Kerr

KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.

21-Jun-1989

AFE/PROJECT NUMBER: 84007
DATE RECEIVED: 12-JUN-89

SAMPLE ID: 967488
02:27 p.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-14RR
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967479
Results needed by 6-21-89
100 ml Spiked Water:Spiked U232 850pCi/l

Th-228	0.60+-0.52 pCi/l	pH initial	7.23
U232	2.1+-0.99 pCi/l	pH final	7.46

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

APPROVED: 6/21/89

KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL

This/these samples are being returned to you.

27-Jun-1989

AFE/PROJECT NUMBER: 84007 SAMPLE ID: 967478
DATE RECEIVED: 12-JUN-89 07:53 a.m.

LOCATION: Cimarron
SUBMITTED BY: R. Fine

SAMPLE NAME: RF \CIM\12-JUN-89\ CH-14X
SAMPLE DESCRIPTION: Soil

NOTES: NBR same as 967474
XRD of crystalline phases

Major	Quartz = SiO_2 & Dolomite = $CaMg(CO_3)_2$	+20	26.23 %
Accessory	C, I, M	+60	58.53 %
Bulk Density	84 lbs/ft3	+100	68.44 %
pH of 1:1 soil	8.7	+200	84.63 %
+8	0.05 %	+325	92.63 %

Where noted by a "*", the analysis follows an indirect methodology and the concentration noted is inferred from the test protocol.

****
APPROVED: CQE 6-27-89 [signature] 6-27-89
****

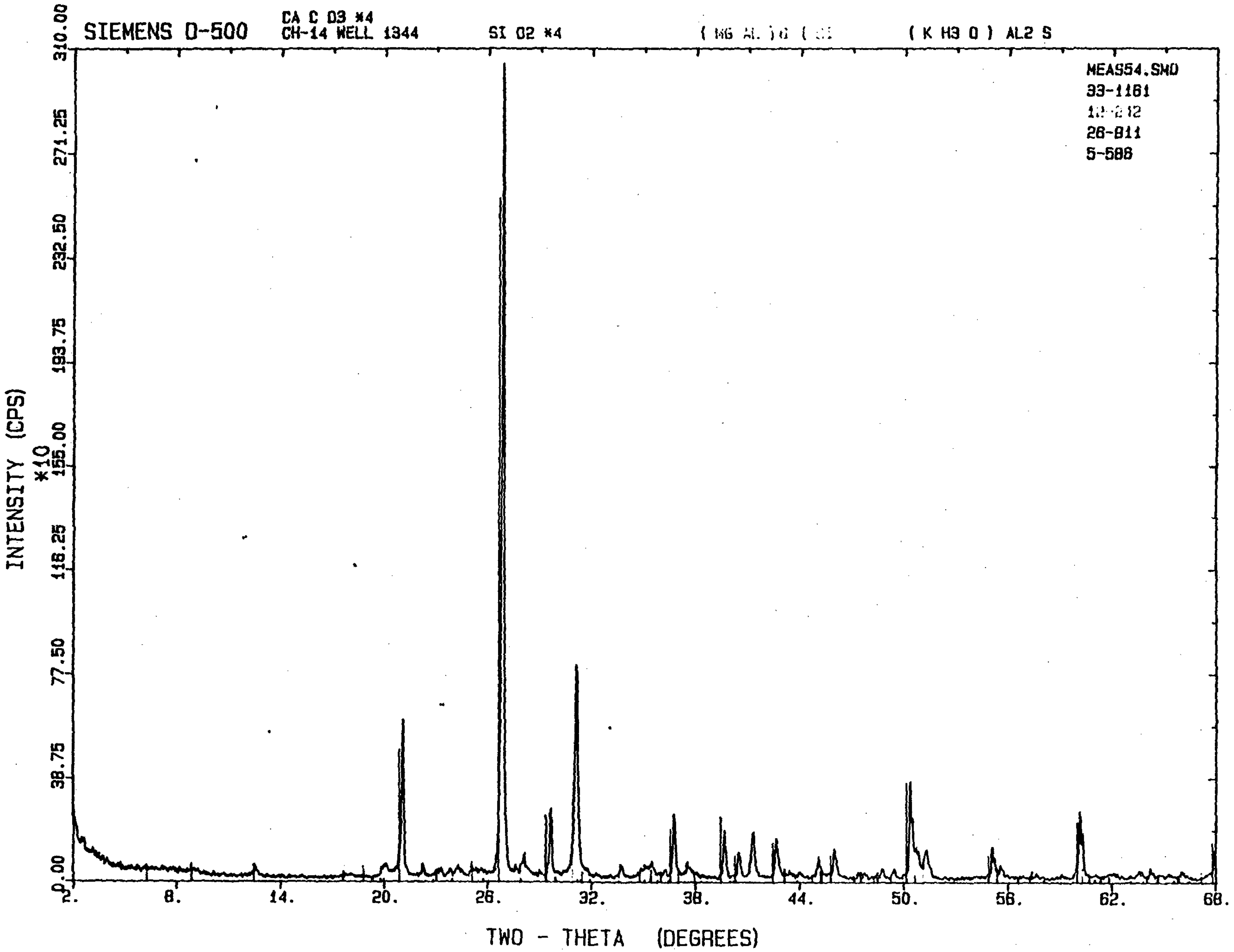
KERR-MCGEE CORPORATION Technology Division
Proprietary Information of the Company TO BE KEPT CONFIDENTIAL .

This/these samples are being returned to you.

C - Calcite - $CaCO_3$

I - Illite clay - $(K,H_3O)Al_2Si_3AlO_{10}(OH)_2$

M - Montmorillonite - Chlorite clay


SIEMENS D-500
CA C O3 *4
CH-14 WELL 1344
SI O2 *4
(K H3 O) AL2 S
MEAS54.SMD
33-1161
26-811
5-588
INTENSITY (CPS) *10
TWO - THETA (DEGREES)

KERR-McGEE CORPORATION

CHAIN OF CUSTODY RECORD — ENVIRONMENTAL SAMPLES KM-4775 6-12-89

FACILITY	SAMPLING FIRM	SAMPLE
NAME: Cimarron Facility	NAME: Cimarron Corp	☐ Effluent ☐ Groundwater
ADDRESS: Crescent, OK	ADDRESS: Crescent, OK	☐ Solid ☐ Surface Water
	SIGNATURE: [signature]	☐

NO.	LOCATION	DATE	TIME	WEATHER TEMP.	WEATHER PREC.	COMP.	GRAB	MECH	MAN.	TIMES CASING CLEARED	NO OF CONTAINERS	ANALYSIS REQUIRED	REMARKS
1	1324 A	6-12-89					X			5	2	Distribution Coefficient Analysis	Two one gallon Cubi-tainers

RELINQUISHED BY (SIGNATURE)	RECEIVED BY (SIGNATURE)	DATE	TIME
[signature]			

DISPATCHED BY (SIGNATURE)	DATE	TIME	RECEIVED FOR LABORATORY (SIGNATURE)	DATE	TIME
			[signature]	6/13/89	8:00

CARRIER

LABORATORY

ADDRESS

ADDRESS

METHOD OF SHIPMENT

ADDITIONAL REMARKS: This sample submitted at request of Pat Breene, J.L. Grant Assoc., for analysis as discussed with Dr. Van de Steeg.

ALL ANALYSIS PERFORMED BY EPA APPROVED PROCEDURES

☐ Yes ☐ No, explain above

APPENDIX I

HELP MODEL SIMULATIONS

DEFAULT, UNVEGETATED, UNCOMPACTED SOIL CHARACTERISTICS

SOIL TEXTURE			DIMENSIONLESS			SAT. HYD.
HELP	USDA	USCS	POROSITY	FIELD CAPACITY	WILTING POINT	CONDUCTIVITY (CM/SEC)
1	CoS	GS	0.417	0.045	0.018	1.0E-02
2	S	SW	0.437	0.062	0.024	5.8E-03
3	FS	SM	0.457	0.083	0.033	3.1E-03
4	LS	SM	0.437	0.105	0.047	1.7E-03
5	LFS	SM	0.457	0.131	0.058	1.0E-03
6	SL	SM	0.453	0.190	0.085	7.2E-04
7	FSL	SM	0.473	0.222	0.104	5.2E-04
8	L	ML	0.463	0.232	0.116	3.7E-04
9	SiL	ML	0.501	0.284	0.135	1.9E-04
10	SCL	SC	0.398	0.244	0.136	1.2E-04
11	CL	CL	0.464	0.310	0.187	6.4E-05
12	SiCL	CL	0.471	0.342	0.210	4.2E-05
13	SC	CH	0.430	0.321	0.221	3.3E-05

ENTER RETURN TO VIEW THE REST OF THE SOIL TYPES.

11	CL	CL	0.464	0.310	0.187	6.4E-05
12	SiCL	CL	0.471	0.342	0.210	4.2E-05
13	SC	CH	0.430	0.321	0.221	3.3E-05

ENTER RETURN TO VIEW THE REST OF THE SOIL TYPES.

SOIL TEXTURE			DIMENSIONLESS			SAT. HYD.
HELP	USDA	USCS	POROSITY	FIELD CAPACITY	WILTING POINT	CONDUCTIVITY (CM/SEC)
14	SiC	CH	0.479	0.371	0.251	2.5E-05
15	C	CH	0.475	0.378	0.265	1.7E-05
16	Liner Soil		0.430	0.366	0.280	1.0E-07
17	Liner Soil		0.400	0.356	0.290	1.0E-08
18	Mun. Waste		0.520	0.294	0.140	2.0E-04
19	USER SPECIFIED SOIL CHARACTERISTICS					
20	USER SPECIFIED SOIL CHARACTERISTICS					

5.9 ENTER SOIL TEXTURE OF SOIL LAYER 1.

2.67
.67

****
****

CIMARRON DECOMISSIONING PROGRAM, CASE LF1
CIMARRON FUEL FABRICATION FACILITY
05-22-89

****
****

LAYER 1

****

AVERAGE MONTHLY VALUES IN INCHES FOR 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
STD. DEVIATIONS	0.55	0.75	1.10	1.90	2.74	1.27
	1.97	1.59	2.55	2.00	1.67	0.77
RUNOFF						
TOTALS	0.011	0.012	0.045	0.357	0.883	0.039
	0.010	0.000	0.013	0.120	0.159	0.039
STD. DEVIATIONS	0.050	0.052	0.119	0.707	1.398	0.120
	0.044	0.000	0.037	0.347	0.597	0.122
EVAPOTRANSPIRATION						
TOTALS	0.790	0.882	1.456	1.789	3.284	6.254
	4.491	2.456	2.689	1.727	1.044	0.857
STD. DEVIATIONS	0.384	0.479	0.617	0.611	0.705	0.672
	2.071	1.330	1.202	0.563	0.384	0.421
PERCOLATION FROM LAYER 2						
TOTALS	0.1267	0.1199	0.1494	0.1771	0.2237	0.1723
	0.0440	0.0000	0.0049	0.0652	0.1075	0.1332
STD. DEVIATIONS	[illegible]	0.1095	[illegible]	0.0990	0.0785	0.0702

0.0438 0.0000 0.0114 0.0747 0.1178 0.1227

****

****

AVERAGE ANNUAL TOTALS (AND STD. DEVIATIONS) FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)	PERCENT
PRECIPITATION	30.85 (5.709)	257075.	100.00
RUNOFF	1.687 (2.218)	14056.	5.47
EVAPOTRANSPIRATION	27.719 (3.734)	230989.	89.85
PERCOLATION FROM LAYER 2	1.3239 (0.5450)	11033.	4.29

****

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PEAK DAILY VALUES FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	4.63	38583.3
RUNOFF	3.217	26805.3
PERCOLATION FROM LAYER 2	0.0103	85.5
HEAD ON LAYER 2	24.3	
SNOW WATER	1.28	10681.1
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.4200	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1028	

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CIMARRON DECOMISSIONING PROGRAM, CASE LF2
CIMARRON FUEL FABRICATION FACILITY
5-22-89

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LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4200 VOL/VOL
FIELD CAPACITY	=	0.2400 VOL/VOL
WILTING POINT	=	0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1886 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000099999975 CM/SEC

LAYER 2

BARRIER SOIL LINER

THICKNESS	=	12.00 INCHES
POROSITY	=	0.3300 VOL/VOL
FIELD CAPACITY	=	0.2400 VOL/VOL
WILTING POINT	=	0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3300 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000001000000 CM/SEC

GENERAL SIMULATION DATA

SCS RUNOFF CURVE NUMBER	=	65.00
TOTAL AREA OF COVER	=	100000. SQ FT
EVAPORATIVE ZONE DEPTH	=	24.00 INCHES
UPPER LIMIT VEG. STORAGE	=	10.0800 INCHES
INITIAL VEG. STORAGE	=	4.5275 INCHES

SOIL WATER CONTENT INITIALIZED BY PROGRAM.

CLIMATOLOGICAL DATA

SYNTHETIC RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
SOLAR RADIATION FOR OKLAHOMA CITY OKLAHOMA

MAXIMUM LEAF AREA INDEX = 2.00
START OF GROWING SEASON (JULIAN DATE) = 98
END OF GROWING SEASON (JULIAN DATE) = 307

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AVERAGE MONTHLY VALUES IN INCHES FOR 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
STD. DEVIATIONS	0.55	0.75	1.10	1.90	2.74	1.27
	1.97	1.59	2.55	2.00	1.67	0.77
RUNOFF						
TOTALS	0.000	0.000	0.000	0.051	0.234	0.000
	0.010	0.000	0.012	0.121	0.057	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.201	0.505	0.000
	0.045	0.000	0.037	0.349	0.257	0.000
EVAPOTRANSPIRATION						
TOTALS	0.781	0.885	1.459	1.803	3.306	5.454
	3.007	2.449	2.691	1.745	1.037	0.858
STD. DEVIATIONS	0.372	0.482	0.618	0.613	0.751	1.133
	1.768	1.325	1.217	0.566	0.396	0.410
PERCOLATION FROM LAYER 2						
TOTALS	0.2337	0.2089	0.3218	0.6076	1.0633	0.5912
	0.0348	0.0000	0.0447	0.5105	0.6927	0.5559
STD. DEVIATIONS	0.4050	0.2692	0.3677	0.5195	0.8079	0.6397
	0.0962	0.0000	0.1061	0.7241	0.7733	0.6571

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AVERAGE ANNUAL TOTALS (AND STD. DEVIATIONS) FOR 1 THROUGH 20

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	30.85	(5.709)	257075.	100.00

RUNOFF	0.485 (0.923)	4043.	1.57
EVAPOTRANSPIRATION	25.477 (3.570)	212310.	82.59
PERCOLATION FROM LAYER 2	4.8651 (2.6231)	40542.	15.77

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PEAK DAILY VALUES FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	4.63	38583.3
RUNOFF	1.566	13053.3
PERCOLATION FROM LAYER 2	0.1018	848.2
HEAD ON LAYER 2	24.1	
SNOW WATER	1.28	10681.1

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4200

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1028

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CIMARRON DECOMISSIONING PROGRAM, CASE LF3
CIMARRON FUEL FABRICATION FACILITY
05-22-89

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LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4200 VOL/VOL
FIELD CAPACITY	=	0.2900 VOL/VOL
WILTING POINT	=	0.1870 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2544 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000049999987 CM/SEC

LAYER 2

BARRIER SOIL LINER

THICKNESS	=	12.00 INCHES
POROSITY	=	0.3300 VOL/VOL
FIELD CAPACITY	=	0.2900 VOL/VOL
WILTING POINT	=	0.1870 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3300 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.0000001000000 CM/SEC

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AVERAGE MONTHLY VALUES IN INCHES FOR 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13

STD. DEVIATIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1.97	1.59	2.55	2.00	1.67	0.77

RUNOFF

TOTALS	0.009	0.000	0.063	0.467	1.109	0.085
	0.124	0.034	0.305	0.407	0.188	0.030
STD. DEVIATIONS	0.039	0.000	0.178	0.828	1.452	0.181
	0.326	0.124	0.476	0.736	0.688	0.093

EVAPOTRANSPIRATION

TOTALS	0.836	0.947	1.532	1.900	3.498	5.878
	3.092	2.388	2.741	1.844	1.094	0.925
STD. DEVIATIONS	0.388	0.493	0.728	0.655	0.824	1.025
	1.878	1.342	1.215	0.624	0.446	0.450

PERCOLATION FROM LAYER 2

TOTALS	0.1247	0.1184	0.1476	0.1765	0.2169	0.1328
	0.0093	0.0000	0.0050	0.0621	0.1110	0.1387
STD. DEVIATIONS	0.1149	0.1046	0.1153	0.0964	0.0729	0.0639
	0.0174	0.0000	0.0115	0.0980	0.1149	0.1163

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AVERAGE ANNUAL TOTALS (AND STD. DEVIATIONS) FOR 1 THROUGH 20

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	30.85	(5.709)	257075.	100.00
RUNOFF	2.822	(2.657)	23513.	9.15
EVAPOTRANSPIRATION	26.676	(3.673)	222303.	86.47
PERCOLATION FROM LAYER 2	1.2427	(0.5148)	10356.	4.03

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PEAK DAILY VALUES FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	4.63	38583.3
RUNOFF	3.177	26478.0
PERCOLATION FROM LAYER 2	0.0102	85.4
HEAD ON LAYER 2	24.2	

SNOW WATER 1.28 10683.1

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4200

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1857

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CIMARRON DECOMISSIONING PROGRAM, CASE LF4
CIMARRON FUEL FABRICATION FACILITY
05-22-89

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LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	24.00 INCHES
POROSITY	=	0.4200 VOL/VOL
FIELD CAPACITY	=	0.2400 VOL/VOL
WILTING POINT	=	0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1876 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000099999975 CM/SEC

LAYER 2

BARRIER SOIL LINER

THICKNESS	=	12.00 INCHES
POROSITY	=	0.3300 VOL/VOL
FIELD CAPACITY	=	0.2900 VOL/VOL
WILTING POINT	=	0.1870 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3300 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.0000000100000 CM/SEC

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AVERAGE MONTHLY VALUES IN INCHES FOR 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.87	1.25	2.09	3.04	4.85	3.03
	2.83	2.27	4.40	3.27	1.77	1.13

STD. DEVIATIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	1.97	1.59	2.55	2.00	1.67	0.77

RUNOFF

TOTALS	0.032	0.076	0.224	0.543	1.168	0.075
	0.010	0.000	0.013	0.127	0.176	0.063
STD. DEVIATIONS	0.102	0.229	0.469	0.946	1.525	0.251
	0.044	0.000	0.037	0.356	0.654	0.197

EVAPOTRANSPIRATION

TOTALS	0.789	0.887	1.461	1.788	3.221	6.315
	4.833	2.458	2.690	1.722	1.043	0.859
STD. DEVIATIONS	0.383	0.478	0.617	0.611	0.689	0.574
	1.990	1.338	1.199	0.560	0.384	0.422

PERCOLATION FROM LAYER 2

TOTALS	0.0137	0.0132	0.0164	0.0189	0.0235	0.0185
	0.0057	0.0000	0.0005	0.0066	0.0111	0.0140
STD. DEVIATIONS	0.0132	0.0119	0.0127	0.0106	0.0080	0.0069
	0.0047	0.0000	0.0011	0.0097	0.0124	0.0129

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AVERAGE ANNUAL TOTALS (AND STD. DEVIATIONS) FOR 1 THROUGH 20

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	30.85	(5.709)	257075.	100.00
RUNOFF	2.508	(2.687)	20899.	8.13
EVAPOTRANSPIRATION	28.066	(3.508)	233886.	90.98
PERCOLATION FROM LAYER 2	0.1422	(0.0574)	1185.	0.46

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PEAK DAILY VALUES FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	4.63	38583.3
RUNOFF	3.312	27598.7
PERCOLATION FROM LAYER 2	0.0010	8.6
HEAD ON LAYER 2	24.3	

SNOW WATER 1.29 10681.1

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4200

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1028

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CIMARRON DECOMISSIONING PROGRAM, CASE NA1
CIMARRON FUEL FABRICATION FACILITY
05-22-89

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LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	36.00 INCHES
POROSITY	=	0.4200 VOL/VOL
FIELD CAPACITY	=	0.2400 VOL/VOL
WILTING POINT	=	0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2056 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000099999975 CM/SEC

LAYER 2

[illegible]

THICKNESS	=	12.00 INCHES
POROSITY	=	0.3300 VOL/VOL
FIELD CAPACITY	=	0.2400 VOL/VOL
WILTING POINT	=	0.1040 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3300 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.000001000000 CM/SEC

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AVERAGE MONTHLY VALUES IN INCHES FOR 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	3.27	1.77	1.13
STD. DEVIATIONS	0.55	0.75	1.10	1.90	2.74	1.27
	1.97	1.59	2.55	2.00	1.67	0.77
RUNOFF						
TOTALS	0.000	0.000	0.000	0.051	0.152	0.000
	0.010	0.000	0.012	0.121	0.012	0.000
STD. DEVIATIONS	0.000	0.000	0.000	0.202	0.350	0.000
	0.045	0.000	0.037	0.349	0.054	0.000
EVAPOTRANSPIRATION						
TOTALS	0.780	0.885	1.459	1.803	3.306	5.253
	2.914	2.449	2.698	1.741	1.039	0.866
STD. DEVIATIONS	0.370	0.482	0.618	0.613	0.752	1.204
	1.768	1.325	1.212	0.572	0.395	0.421
PERCOLATION FROM LAYER 2						
TOTALS	0.2733	0.2087	0.3131	0.5762	1.0641	0.7856
	0.2592	0.0077	0.0369	0.4647	0.6638	0.6193
STD. DEVIATIONS	0.4515	0.2976	0.3449	0.4838	0.7934	0.7764
	0.4416	0.0346	0.0879	0.6657	0.7562	0.7237

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AVERAGE ANNUAL TOTALS (AND STD. DEVIATIONS) FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)	PERCENT
PRECIPITATION	30.85 (5.709)	257075.	100.00
RUNOFF	0.358 (0.692)	2984.	1.16

EVAPOTRANSPIRATION	25.192 (3.646)	209936.	81.66
PERCOLATION FROM LAYER 2	5.2727 (2.9241)	43939.	17.09

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PEAK DAILY VALUES FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	4.63	38583.3
RUNOFF	1.519	12658.6
PERCOLATION FROM LAYER 2	0.1086	904.7
HEAD ON LAYER 2	26.4	
SNOW WATER	1.28	10681.1
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.3921	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.1028	

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CIMARRON DECOMISSIONING PROGRAM, CASE NA2
CIMARRON FUEL FABRICATION FACILITY
05-22-89

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LAYER 1

VERTICAL PERCOLATION LAYER

THICKNESS	=	36.00 INCHES
POROSITY	=	0.4200 VOL/VOL
FIELD CAPACITY	=	0.2900 VOL/VOL
WILTING POINT	=	0.1870 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2497 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.0000499999987 CM/SEC

LAYER 2

BARRIER SOIL LINER

THICKNESS	=	12.00 INCHES
POROSITY	=	0.3300 VOL/VOL
FIELD CAPACITY	=	0.2900 VOL/VOL
WILTING POINT	=	0.1870 VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.3300 VOL/VOL
SATURATED HYDRAULIC CONDUCTIVITY	=	0.0000010000000 CM/SEC

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AVERAGE MONTHLY VALUES IN INCHES FOR 1 THROUGH 20

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	0.87	1.25	2.09	3.04	4.85	3.03
	2.88	2.27	4.40	[illegible]	1.77	[illegible]

	1.97	1.59	2.55	2.00	1.67	0.77

RUNOFF

TOTALS	0.000	0.000	0.014	0.189	0.577	0.035
	0.125	0.034	0.306	0.397	0.082	0.000
STD. DEVIATIONS	0.000	0.000	0.061	0.472	0.893	0.108
	0.326	0.124	0.476	0.750	0.355	0.000

EVAPOTRANSPIRATION

TOTALS	0.834	0.948	1.540	1.906	3.542	4.823
	2.697	2.387	2.735	1.834	1.102	0.923
STD. DEVIATIONS	0.395	0.496	0.721	0.657	0.867	1.291
	1.779	1.344	1.208	0.640	0.437	0.460

PERCOLATION FROM LAYER 2

TOTALS	0.1773	0.1476	0.2632	0.4975	0.8370	0.4777
	0.0295	0.0000	0.0339	0.3759	0.5397	0.3885
STD. DEVIATIONS	0.3343	0.1813	0.3549	0.4833	0.7287	0.5712
	0.1132	0.0000	0.0826	0.5893	0.5925	0.5714

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AVERAGE ANNUAL TOTALS (AND STD. DEVIATIONS) FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)	PERCENT
PRECIPITATION	30.85 (5.709)	257075.	100.00
RUNOFF	1.759 (1.950)	14658.	5.70
EVAPOTRANSPIRATION	25.271 (3.707)	210591.	81.92
PERCOLATION FROM LAYER 2	3.7678 (2.1737)	31398.	12.21

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PEAK DAILY VALUES FOR 1 THROUGH 20

	(INCHES)	(CU. FT.)
PRECIPITATION	4.63	38583.3
RUNOFF	2.789	23242.1
PERCOLATION FROM LAYER 2	0.1119	932.6
HEAD ON LAYER 2	27.6	

SNOW WATER 1.28 10681.1

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.4141

MINIMUM VEG. SOIL WATER (VOL/VOL) 0.1856

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APPENDIX J

TRANSS MODEL SIMULATIONS

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**********************************************************************
*
*          ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
*          *11/26/85* VERSION
*          SEMI-INFINITE PROFILE
*
*          NUCLIDE DECAY (THALF)
*          LINEAR ADSORPTION (R)
*          GENERAL NUCLIDE RELEASE CURVE
*          TRANSPORT SUM OVER PATHLINES
*
*          CIMARRON LANDFILL: Kd=2000 controlled release - U-238
*                   VADOSE ZONE
**********************************************************************

NUCLIDE:  U-238


INPUT PARAMETERS
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V =         1.38                D =         1.00
R =      10600.0                T0 = 4.4377E+05
TOTAL =1.81E+12                 TDECAY=0.000E-01
THALF=  4.5000E+09              C0 =  1.931E+06
XL =2.0000E+01
NUCLIDE DECAY CONSTANT = 1.54033E-10


CONTROL FLAGS:
IOPTBC= 0  IFLUX= 0  ITYPE= 1  IOPT= 3


RELEASE MODEL PARAMETERS:
PLAN VIEW AREA=8.0000E+04
DEPTH=1.0000E+01
WATER FLUX Q=3.3000E-01
THETA   =0.3000
MAX CONCENTRATION=1.0000E+12
RELEASE CURVE ERROR=1.0000E-02


FRACTION REMAINING CURVE
      TIME        FRACTION

  0.00E-01         1.00000
  1.73E+03         0.98199
  3.46E+03         0.96437
  5.18E+03         0.94713
  6.89E+03         0.93027
  8.60E+03         0.91376
  1.03E+04         0.89760
  1.20E+04         0.88179
  1.37E+04         0.86632
  1.54E+04         0.85117
  1.70E+04         0.83634
  1.87E+04         0.82183
  2.04E+04         0.80762
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2.20E+04	0.79370
2.37E+04	0.78008
2.53E+04	0.76673
2.69E+04	0.75367
2.86E+04	0.74087
3.02E+04	0.72834
3.18E+04	0.71606
3.34E+04	0.70403
3.50E+04	0.69225
3.66E+04	0.68071
3.82E+04	0.66940
3.98E+04	0.65832
4.14E+04	0.64746
4.29E+04	0.63683
4.45E+04	0.62640
4.61E+04	0.61618
4.76E+04	0.60616
4.92E+04	0.59635
5.07E+04	0.58672
5.22E+04	0.57729
5.38E+04	0.56804
5.53E+04	0.55897
5.68E+04	0.55008
5.83E+04	0.54136
5.98E+04	0.53281
6.13E+04	0.52443
6.28E+04	0.51621
6.43E+04	0.50814
6.58E+04	0.50023
6.73E+04	0.49247
6.87E+04	0.48486
7.02E+04	0.47739
7.17E+04	0.47006
7.31E+04	0.46288
7.46E+04	0.45582
7.60E+04	0.44890
7.74E+04	0.44211
7.89E+04	0.43544
8.03E+04	0.42890
8.17E+04	0.42248
8.31E+04	0.41618
8.45E+04	0.40999
8.59E+04	0.40392
8.73E+04	0.39796
8.87E+04	0.39210
9.01E+04	0.38636
9.15E+04	0.38071
9.29E+04	0.37517
9.43E+04	0.36973
9.56E+04	0.36439
9.70E+04	0.35914
9.83E+04	0.35399
9.97E+04	0.34892
1.01E+05	0.34395
1.02E+05	0.33906
1.04E+05	0.33427
1.05E+05	0.32955
1.06E+05	0.32492
1.08E+05	0.32037
1.09E+05	0.31590

1.10E+05	0.31150
1.12E+05	0.30718
1.13E+05	0.30294
1.14E+05	0.29877
1.15E+05	0.29467
1.17E+05	0.29064
1.18E+05	0.28668
1.19E+05	0.28279
1.21E+05	0.27896
1.22E+05	0.27520
1.23E+05	0.27150
1.24E+05	0.26786
1.26E+05	0.26428
1.27E+05	0.26077
1.28E+05	0.25731
1.29E+05	0.25391
1.31E+05	0.25057
1.32E+05	0.24728
1.33E+05	0.24404
1.34E+05	0.24086
1.35E+05	0.23773
1.37E+05	0.23465
1.38E+05	0.23162
1.39E+05	0.22864
1.40E+05	0.22571
1.41E+05	0.22283
1.43E+05	0.21999
1.44E+05	0.21720
1.45E+05	0.00000

RELEASE INTERVAL NUMBER= 102

PATHLINE PARAMETERS:

TRAVELTIME	PATH LENGTH	VELOCITY	PDF
1.4500E+01	2.0000E+01	1.3793E+00	1.0000E+00

ADDITIONAL ZONE PARAMETERS:
XV=2.0000E+01 TV=1.4500E+01
AVERAGES:
LENGTH=2.0000E+01 TIME=1.4500E+01 VELOCITY=1.3793E+00

*** QUANTITY IS CONCENTRATION ***
CONVERSION FACTOR = 1.4713E-06

DISTANCE (X)	TIME (T)	PORE VOLUME (VVO)	QUANTITY (Q)
2.0000E+01	1.0000E+04	6.8966E+02	6.32404E-41
2.0000E+01	1.9900E+04	1.3724E+03	4.59880E-18
2.0000E+01	2.9800E+04	2.0552E+03	1.77129E-10
2.0000E+01	3.9700E+04	2.7379E+03	9.49663E-07
2.0000E+01	4.9600E+04	3.4207E+03	1.43651E-04
2.0000E+01	5.9500E+04	4.1034E+03	3.63469E-03
2.0000E+01	6.9400E+04	4.7862E+03	3.30567E-02

2.0000E+01	7.9300E+04	5.4690E+03	1.58705E-01
2.0000E+01	8.9200E+04	6.1517E+03	4.98107E-01
2.0000E+01	9.9100E+04	6.8345E+03	1.16238E+00
2.0000E+01	1.0900E+05	7.5172E+03	2.18954E+00
2.0000E+01	1.1890E+05	8.2000E+03	3.51740E+00
2.0000E+01	1.2880E+05	8.8828E+03	5.00680E+00
2.0000E+01	1.3870E+05	9.5655E+03	6.49063E+00
2.0000E+01	1.4860E+05	1.0248E+04	7.81966E+00
2.0000E+01	1.5850E+05	1.0931E+04	8.88887E+00
2.0000E+01	1.6840E+05	1.1614E+04	9.64826E+00
2.0000E+01	1.7830E+05	1.2297E+04	1.00907E+01
2.0000E+01	1.8820E+05	1.2979E+04	1.02429E+01
2.0000E+01	1.9810E+05	1.3662E+04	1.01543E+01
2.0000E+01	2.0800E+05	1.4345E+04	9.91208E+00
2.0000E+01	2.1790E+05	1.5028E+04	9.66537E+00
2.0000E+01	2.2780E+05	1.5710E+04	9.56757E+00
2.0000E+01	2.3770E+05	1.6393E+04	9.65571E+00
2.0000E+01	2.4760E+05	1.7076E+04	9.81249E+00
2.0000E+01	2.5750E+05	1.7759E+04	9.84787E+00
2.0000E+01	2.6740E+05	1.8441E+04	9.61004E+00
2.0000E+01	2.7730E+05	1.9124E+04	9.04534E+00
2.0000E+01	2.8720E+05	1.9807E+04	8.19481E+00
2.0000E+01	2.9710E+05	2.0490E+04	7.15628E+00
2.0000E+01	3.0700E+05	2.1172E+04	6.04219E+00
2.0000E+01	3.1690E+05	2.1855E+04	4.94985E+00
2.0000E+01	3.2680E+05	2.2538E+04	3.94842E+00
2.0000E+01	3.3670E+05	2.3221E+04	3.07687E+00
2.0000E+01	3.4660E+05	2.3903E+04	2.34915E+00
2.0000E+01	3.5650E+05	2.4586E+04	1.76169E+00
2.0000E+01	3.6640E+05	2.5269E+04	1.30054E+00
2.0000E+01	3.7630E+05	2.5952E+04	9.46915E-01
2.0000E+01	3.8620E+05	2.6634E+04	6.81088E-01
2.0000E+01	3.9610E+05	2.7317E+04	4.84630E-01
2.0000E+01	4.0600E+05	2.8000E+04	3.41554E-01
2.0000E+01	4.1590E+05	2.8683E+04	2.38675E-01
2.0000E+01	4.2580E+05	2.9366E+04	1.65519E-01
2.0000E+01	4.3570E+05	3.0048E+04	1.14007E-01
2.0000E+01	4.4560E+05	3.0731E+04	7.80465E-02
2.0000E+01	4.5550E+05	3.1414E+04	5.31352E-02
2.0000E+01	4.6540E+05	3.2097E+04	3.59958E-02
2.0000E+01	4.7530E+05	3.2779E+04	2.42752E-02
2.0000E+01	4.8520E+05	3.3462E+04	1.63042E-02
2.0000E+01	4.9510E+05	3.4145E+04	1.09099E-02
2.0000E+01	5.0500E+05	3.4828E+04	7.27570E-03
2.0000E+01	5.1490E+05	3.5510E+04	4.83709E-03
2.0000E+01	5.2480E+05	3.6193E+04	3.20676E-03
2.0000E+01	5.3470E+05	3.6876E+04	2.12042E-03
2.0000E+01	5.4460E+05	3.7559E+04	1.39877E-03
2.0000E+01	5.5450E+05	3.8241E+04	9.20697E-04
2.0000E+01	5.6440E+05	3.8924E+04	6.04801E-04
2.0000E+01	5.7430E+05	3.9607E+04	3.96552E-04
2.0000E+01	5.8420E+05	4.0290E+04	2.59562E-04
2.0000E+01	5.9410E+05	4.0972E+04	1.69625E-04
2.0000E+01	6.0400E+05	4.1655E+04	1.10575E-04
2.0000E+01	6.1390E+05	4.2338E+04	7.20459E-05
2.0000E+01	6.2380E+05	4.3021E+04	4.68819E-05
2.0000E+01	6.3370E+05	4.3703E+04	3.04708E-05
2.0000E+01	6.4360E+05	4.4386E+04	1.97825E-05
2.0000E+01	6.5350E+05	4.5069E+04	1.28301E-05
2.0000E+01	6.6340E+05	4.5752E+04	8.31299E-06

2.0000E+01	6.7330E+05	4.6434E+04	5.38139E-06
2.0000E+01	6.8320E+05	4.7117E+04	3.48068E-06
2.0000E+01	6.9310E+05	4.7800E+04	2.24953E-06
2.0000E+01	7.0300E+05	4.8483E+04	1.45278E-06
2.0000E+01	7.1290E+05	4.9166E+04	9.37573E-07
2.0000E+01	7.2280E+05	4.9848E+04	6.04684E-07
2.0000E+01	7.3270E+05	5.0531E+04	3.89751E-07
2.0000E+01	7.4260E+05	5.1214E+04	2.51071E-07
2.0000E+01	7.5250E+05	5.1897E+04	1.61648E-07
2.0000E+01	7.6240E+05	5.2579E+04	1.04022E-07
2.0000E+01	7.7230E+05	5.3262E+04	6.69072E-08
2.0000E+01	7.8220E+05	5.3945E+04	4.30154E-08
2.0000E+01	7.9210E+05	5.4628E+04	2.76434E-08
2.0000E+01	8.0200E+05	5.5310E+04	1.77577E-08
2.0000E+01	8.1190E+05	5.5993E+04	1.14029E-08
2.0000E+01	8.2180E+05	5.6676E+04	7.31964E-09
2.0000E+01	8.3170E+05	5.7359E+04	4.69700E-09
2.0000E+01	8.4160E+05	5.8041E+04	3.01309E-09
2.0000E+01	8.5150E+05	5.8724E+04	1.93232E-09
2.0000E+01	8.6140E+05	5.9407E+04	1.23884E-09
2.0000E+01	8.7130E+05	6.0090E+04	7.94042E-10
2.0000E+01	8.8120E+05	6.0772E+04	5.08776E-10
2.0000E+01	8.9110E+05	6.1455E+04	3.25951E-10
2.0000E+01	9.0100E+05	6.2138E+04	2.08756E-10
2.0000E+01	9.1090E+05	6.2821E+04	1.33656E-10
2.0000E+01	9.2080E+05	6.3503E+04	8.55342E-11
2.0000E+01	9.3070E+05	6.4186E+04	5.47820E-11
2.0000E+01	9.4060E+05	6.4869E+04	3.50263E-11
2.0000E+01	9.5050E+05	6.5552E+04	2.24032E-11
2.0000E+01	9.6040E+05	6.6234E+04	1.43323E-11
2.0000E+01	9.7030E+05	6.6917E+04	9.19831E-12
2.0000E+01	9.8020E+05	6.7600E+04	5.84928E-12
2.0000E+01	9.9010E+05	6.8283E+04	3.76945E-12
2.0000E+01	1.0000E+06	6.8966E+04	2.38406E-12

```
*****************************************************************
*
*         ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
*         *11/26/85* VERSION
*         SEMI-INFINITE PROFILE
*
*         NUCLIDE DECAY (THALF)
*         LINEAR ADSORPTION (R)
*         GENERAL NUCLIDE RELEASE CURVE
*         TRANSPORT SUM OVER PATHLINES
*
*         CIMARRON LANDFILL: Kd=300 controlled release - U-238
*                 VADOSE ZONE
*****************************************************************

NUCLIDE:  U-238


INPUT PARAMETERS
================

V =         1.38              D =          1.00
R =       1600.0              T0 = 6.6984E+04
TOTAL =1.81E+12               TDECAY=0.000E-01
THALF=  4.5000E+09            C0 =  1.931E+06
XL =2.0000E+01
NUCLIDE DECAY CONSTANT = 1.54033E-10


CONTROL FLAGS:
IOPTBC= 0  IFLUX= 0  ITYPE= 1  IOPT= 3


RELEASE MODEL PARAMETERS:
PLAN VIEW AREA=8.0000E+04
DEPTH=1.0000E+01
WATER FLUX Q=3.3000E-01
THETA   =0.3000
MAX CONCENTRATION=1.0000E+12
RELEASE CURVE ERROR=1.0000E-02


FRACTION REMAINING CURVE
      TIME         FRACTION

  0.00E-01          1.00000
  2.62E+02          0.98199
  5.22E+02          0.96437
  7.82E+02          0.94713
  1.04E+03          0.93027
  1.30E+03          0.91376
  1.55E+03          0.89760
  1.81E+03          0.88179
  2.06E+03          0.86632
  2.32E+03          0.85117
  2.57E+03          0.83634
  2.82E+03          0.82183
  3.07E+03          0.80762
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3.32E+03	0.79370
3.57E+03	0.78008
3.82E+03	0.76673
4.07E+03	0.75367
4.31E+03	0.74087
4.56E+03	0.72834
4.80E+03	0.71606
5.04E+03	0.70403
5.29E+03	0.69225
5.53E+03	0.68071
5.77E+03	0.66940
6.01E+03	0.65832
6.24E+03	0.64746
6.48E+03	0.63683
6.72E+03	0.62640
6.95E+03	0.61618
7.19E+03	0.60616
7.42E+03	0.59635
7.65E+03	0.58672
7.89E+03	0.57729
8.12E+03	0.56804
8.35E+03	0.55897
8.58E+03	0.55008
8.80E+03	0.54136
9.03E+03	0.53281
9.26E+03	0.52443
9.48E+03	0.51621
9.71E+03	0.50814
9.93E+03	0.50023
1.02E+04	0.49247
1.04E+04	0.48486
1.06E+04	0.47739
1.08E+04	0.47006
1.10E+04	0.46288
1.13E+04	0.45582
1.15E+04	0.44890
1.17E+04	0.44211
1.19E+04	0.43544
1.21E+04	0.42890
1.23E+04	0.42248
1.25E+04	0.41618
1.28E+04	0.40999
1.30E+04	0.40392
1.32E+04	0.39796
1.34E+04	0.39210
1.36E+04	0.38636
1.38E+04	0.38071
1.40E+04	0.37517
1.42E+04	0.36973
1.44E+04	0.36439
1.46E+04	0.35914
1.48E+04	0.35399
1.50E+04	0.34892
1.52E+04	0.34395
1.55E+04	0.33906
1.57E+04	0.33427
1.59E+04	0.32955
1.61E+04	0.32492
1.63E+04	0.32037
1.64E+04	0.31590

1.66E+04	0.31150
1.68E+04	0.30718
1.70E+04	0.30294
1.72E+04	0.29877
1.74E+04	0.29467
1.76E+04	0.29064
1.78E+04	0.28668
1.80E+04	0.28279
1.82E+04	0.27896
1.84E+04	0.27520
1.86E+04	0.27150
1.88E+04	0.26786
1.90E+04	0.26428
1.91E+04	0.26077
1.93E+04	0.25731
1.95E+04	0.25391
1.97E+04	0.25057
1.99E+04	0.24728
2.01E+04	0.24404
2.03E+04	0.24086
2.04E+04	0.23773
2.06E+04	0.23465
2.08E+04	0.23162
2.10E+04	0.22864
2.12E+04	0.22571
2.13E+04	0.22283
2.15E+04	0.21999
2.17E+04	0.21720
2.19E+04	0.00000

RELEASE INTERVAL NUMBER= 102

PATHLINE PARAMETERS:

TRAVELTIME	PATH LENGTH	VELOCITY	PDF
1.4500E+01	2.0000E+01	1.3793E+00	1.0000E+00

ADDITIONAL ZONE PARAMETERS:
XV=2.0000E+01 TV=1.4500E+01
AVERAGES:
LENGTH=2.0000E+01 TIME=1.4500E+01 VELOCITY=1.3793E+00

*** QUANTITY IS CONCENTRATION ***
CONVERSION FACTOR = 1.4713E-06

DISTANCE (X)	TIME (T)	PORE VOLUME (VVO)	QUANTITY (Q)
2.0000E+01	5.0000E+03	3.4483E+02	3.80731E-08
2.0000E+01	5.9896E+03	4.1307E+02	6.21516E-06
2.0000E+01	6.9792E+03	4.8132E+02	2.23932E-04
2.0000E+01	7.9687E+03	5.4957E+02	3.12617E-03
2.0000E+01	8.9583E+03	6.1782E+02	2.31289E-02
2.0000E+01	9.9479E+03	6.8606E+02	1.09677E-01
2.0000E+01	1.0937E+04	7.5431E+02	3.76197E-01

2.0000E+01	1.1927E+04	8.2256E+02	1.01204E+00
2.0000E+01	1.2917E+04	8.9080E+02	2.25872E+00
2.0000E+01	1.3906E+04	9.5905E+02	4.35414E+00
2.0000E+01	1.4896E+04	1.0273E+03	7.46753E+00
2.0000E+01	1.5885E+04	1.0955E+03	1.16510E+01
2.0000E+01	1.6875E+04	1.1638E+03	1.68223E+01
2.0000E+01	1.7865E+04	1.2320E+03	2.27791E+01
2.0000E+01	1.8854E+04	1.3003E+03	2.92352E+01
2.0000E+01	1.9844E+04	1.3685E+03	3.58657E+01
2.0000E+01	2.0833E+04	1.4368E+03	4.23497E+01
2.0000E+01	2.1823E+04	1.5050E+03	4.84038E+01
2.0000E+01	2.2812E+04	1.5733E+03	5.38029E+01
2.0000E+01	2.3802E+04	1.6415E+03	5.83841E+01
2.0000E+01	2.4792E+04	1.7098E+03	6.20688E+01
2.0000E+01	2.5781E+04	1.7780E+03	6.48211E+01
2.0000E+01	2.6771E+04	1.8463E+03	6.66601E+01
2.0000E+01	2.7760E+04	1.9145E+03	6.76427E+01
2.0000E+01	2.8750E+04	1.9828E+03	6.78521E+01
2.0000E+01	2.9740E+04	2.0510E+03	6.74008E+01
2.0000E+01	3.0729E+04	2.1193E+03	6.64572E+01
2.0000E+01	3.1719E+04	2.1875E+03	6.52792E+01
2.0000E+01	3.2708E+04	2.2557E+03	6.41974E+01
2.0000E+01	3.3698E+04	2.3240E+03	6.35212E+01
2.0000E+01	3.4687E+04	2.3922E+03	6.34178E+01
2.0000E+01	3.5677E+04	2.4605E+03	6.38398E+01
2.0000E+01	3.6667E+04	2.5287E+03	6.45399E+01
2.0000E+01	3.7656E+04	2.5970E+03	6.51537E+01
2.0000E+01	3.8646E+04	2.6652E+03	6.53060E+01
2.0000E+01	3.9635E+04	2.7335E+03	6.47002E+01
2.0000E+01	4.0625E+04	2.8017E+03	6.31672E+01
2.0000E+01	4.1615E+04	2.8700E+03	6.06752E+01
2.0000E+01	4.2604E+04	2.9382E+03	5.73101E+01
2.0000E+01	4.3594E+04	3.0065E+03	5.32397E+01
2.0000E+01	4.4583E+04	3.0747E+03	4.86751E+01
2.0000E+01	4.5573E+04	3.1430E+03	4.38376E+01
2.0000E+01	4.6562E+04	3.2112E+03	3.89291E+01
2.0000E+01	4.7552E+04	3.2795E+03	3.41242E+01
2.0000E+01	4.8542E+04	3.3477E+03	2.95567E+01
2.0000E+01	4.9531E+04	3.4159E+03	2.53212E+01
2.0000E+01	5.0521E+04	3.4842E+03	2.14756E+01
2.0000E+01	5.1510E+04	3.5524E+03	1.80470E+01
2.0000E+01	5.2500E+04	3.6207E+03	1.50386E+01
2.0000E+01	5.3490E+04	3.6889E+03	1.24352E+01
2.0000E+01	5.4479E+04	3.7572E+03	1.02099E+01
2.0000E+01	5.5469E+04	3.8254E+03	8.32850E+00
2.0000E+01	5.6458E+04	3.8937E+03	6.75333E+00
2.0000E+01	5.7448E+04	3.9619E+03	5.44606E+00
2.0000E+01	5.8437E+04	4.0302E+03	4.36965E+00
2.0000E+01	5.9427E+04	4.0984E+03	3.48965E+00
2.0000E+01	6.0417E+04	4.1667E+03	2.77486E+00
2.0000E+01	6.1406E+04	4.2349E+03	2.19769E+00
2.0000E+01	6.2396E+04	4.3032E+03	1.73415E+00
2.0000E+01	6.3385E+04	4.3714E+03	1.36368E+00
2.0000E+01	6.4375E+04	4.4397E+03	1.06895E+00
2.0000E+01	6.5365E+04	4.5079E+03	8.35436E-01
2.0000E+01	6.6354E+04	4.5761E+03	6.51134E-01
2.0000E+01	6.7344E+04	4.6444E+03	5.06186E-01
2.0000E+01	6.8333E+04	4.7126E+03	3.92560E-01
2.0000E+01	6.9323E+04	4.7809E+03	3.03759E-01
2.0000E+01	7.0312E+04	4.8491E+03	2.34552E-01

2.0000E+01	7.1302E+04	4.9174E+03	1.80757E-01
2.0000E+01	7.2292E+04	4.9856E+03	1.39043E-01
2.0000E+01	7.3281E+04	5.0539E+03	1.06771E-01
2.0000E+01	7.4271E+04	5.1221E+03	8.18565E-02
2.0000E+01	7.5260E+04	5.1904E+03	6.26598E-02
2.0000E+01	7.6250E+04	5.2586E+03	4.78962E-02
2.0000E+01	7.7240E+04	5.3269E+03	3.65616E-02
2.0000E+01	7.8229E+04	5.3951E+03	2.78738E-02
2.0000E+01	7.9219E+04	5.4634E+03	2.12248E-02
2.0000E+01	8.0208E+04	5.5316E+03	1.61435E-02
2.0000E+01	8.1198E+04	5.5999E+03	1.22655E-02
2.0000E+01	8.2187E+04	5.6681E+03	9.30967E-03
2.0000E+01	8.3177E+04	5.7364E+03	7.05936E-03
2.0000E+01	8.4167E+04	5.8046E+03	5.34811E-03
2.0000E+01	8.5156E+04	5.8728E+03	4.04820E-03
2.0000E+01	8.6146E+04	5.9411E+03	3.06174E-03
2.0000E+01	8.7135E+04	6.0093E+03	2.31386E-03
2.0000E+01	8.8125E+04	6.0776E+03	1.74738E-03
2.0000E+01	8.9115E+04	6.1458E+03	1.31866E-03
2.0000E+01	9.0104E+04	6.2141E+03	9.94459E-04
2.0000E+01	9.1094E+04	6.2823E+03	7.48741E-04
2.0000E+01	9.2083E+04	6.3506E+03	5.63911E-04
2.0000E+01	9.3073E+04	6.4188E+03	4.24463E-04
2.0000E+01	9.4062E+04	6.4871E+03	3.19322E-04
2.0000E+01	9.5052E+04	6.5553E+03	2.40099E-04
2.0000E+01	9.6042E+04	6.6236E+03	1.80441E-04
2.0000E+01	9.7031E+04	6.6918E+03	1.35542E-04
2.0000E+01	9.8021E+04	6.7601E+03	1.01768E-04
2.0000E+01	9.9010E+04	6.8283E+03	7.63769E-05
2.0000E+01	1.0000E+05	6.8966E+03	5.72969E-05

```
**********************************************************************
*
*         ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
*         *11/26/85* VERSION
*         SEMI-INFINITE PROFILE
*
*         NUCLIDE DECAY (THALF)
*         LINEAR ADSORPTION (R)
*         GENERAL NUCLIDE RELEASE CURVE
*         TRANSPORT SUM OVER PATHLINES
*
*         CIMARRON LANDFILL: Kd=2000 controlled release - U-238
*                  SATURATED ZONE
**********************************************************************
```

NUCLIDE: U-238

INPUT PARAMETERS
================

```
V =      130.38                D =        1.00
R =     10600.0                T0 = 4.8815E+05
TOTAL =1.81E+12                TDECAY=0.000E-01
THALF=  4.5000E+09             C0 =  4.539E+05
XL =1.0000E+03
NUCLIDE DECAY CONSTANT = 1.54033E-10
```

CONTROL FLAGS:
IOPTBC= 0 IFLUX= 0 ITYPE= 1 IOPT= 3

RELEASE MODEL PARAMETERS:
PLAN VIEW AREA=8.0000E+04
DEPTH=1.0000E+01
WATER FLUX Q=3.0000E-01
THETA   =0.3000
MAX CONCENTRATION=1.0000E+12
RELEASE CURVE ERROR=1.0000E-02

FRACTION REMAINING CURVE

TIME	FRACTION
0.00E-01	1.00000
1.91E+03	0.98199
3.81E+03	0.96437
5.70E+03	0.94713
7.58E+03	0.93027
9.46E+03	0.91376
1.13E+04	0.89760
1.32E+04	0.88179
1.50E+04	0.86632
1.69E+04	0.85117
1.87E+04	0.83634
2.06E+04	0.82183
2.24E+04	0.80762

2.42E+04	0.79370
2.60E+04	0.78008
2.78E+04	0.76673
2.96E+04	0.75367
3.14E+04	0.74087
3.32E+04	0.72834
3.50E+04	0.71606
3.68E+04	0.70403
3.85E+04	0.69225
4.03E+04	0.68071
4.20E+04	0.66940
4.38E+04	0.65832
4.55E+04	0.64746
4.72E+04	0.63683
4.90E+04	0.62640
5.07E+04	0.61618
5.24E+04	0.60616
5.41E+04	0.59635
5.58E+04	0.58672
5.75E+04	0.57729
5.91E+04	0.56804
6.08E+04	0.55897
6.25E+04	0.55008
6.42E+04	0.54136
6.58E+04	0.53281
6.75E+04	0.52443
6.91E+04	0.51621
7.07E+04	0.50814
7.24E+04	0.50023
7.40E+04	0.49247
7.56E+04	0.48486
7.72E+04	0.47739
7.88E+04	0.47006
8.04E+04	0.46288
8.20E+04	0.45582
8.36E+04	0.44890
8.52E+04	0.44211
8.68E+04	0.43544
8.83E+04	0.42890
8.99E+04	0.42248
9.14E+04	0.41618
9.30E+04	0.40999
9.45E+04	0.40392
9.61E+04	0.39796
9.76E+04	0.39210
9.91E+04	0.38636
1.01E+05	0.38071
1.02E+05	0.37517
1.04E+05	0.36973
1.05E+05	0.36439
1.07E+05	0.35914
1.08E+05	0.35399
1.10E+05	0.34892
1.11E+05	0.34395
1.13E+05	0.33906
1.14E+05	0.33427
1.16E+05	0.32955
1.17E+05	0.32492
1.18E+05	0.32037
1.20E+05	0.31590

1.21E+05	0.31150
1.23E+05	0.30718
1.24E+05	0.30294
1.26E+05	0.29877
1.27E+05	0.29467
1.28E+05	0.29064
1.30E+05	0.28668
1.31E+05	0.28279
1.33E+05	0.27896
1.34E+05	0.27520
1.35E+05	0.27150
1.37E+05	0.26786
1.38E+05	0.26428
1.40E+05	0.26077
1.41E+05	0.25731
1.42E+05	0.25391
1.44E+05	0.25057
1.45E+05	0.24728
1.46E+05	0.24404
1.48E+05	0.24086
1.49E+05	0.23773
1.50E+05	0.23465
1.52E+05	0.23162
1.53E+05	0.22864
1.54E+05	0.22571
1.56E+05	0.22283
1.57E+05	0.21999
1.58E+05	0.21720
1.59E+05	0.00000

RELEASE INTERVAL NUMBER= 102

PATHLINE PARAMETERS:

TRAVELTIME	PATH LENGTH	VELOCITY	PDF
2.2010E+01	1.0190E+03	4.6297E+01	5.5556E+01
2.2019E+01	1.0200E+03	4.6324E+01	5.0000E+02
2.2020E+01	1.0210E+03	4.6367E+01	0.0000E-01

ADDITIONAL ZONE PARAMETERS:
XV=2.0000E+01 TV=1.4500E+01
AVERAGES:
LENGTH=1.0000E+03 TIME=2.2016E+01 VELOCITY=4.6329E+01

*** QUANTITY IS CONCENTRATION ***
CONVERSION FACTOR = 3.2695E-05

DISTANCE (X)	TIME (T)	PORE VOLUME (VVO)	QUANTITY (Q)
1.0000E+03	2.0699E+05	9.5897E+03	8.66687E-76
1.0000E+03	2.0799E+05	9.6360E+03	8.62836E-70
1.0000E+03	2.0899E+05	9.6823E+03	3.17715E-64
1.0000E+03	2.0999E+05	9.7286E+03	6.42212E-59
1.0000E+03	2.1099E+05	9.7748E+03	7.18788E-54

1.0000E+03	2.1199E+05	9.8211E+03	4.49258E-49
1.0000E+03	2.1298E+05	9.8674E+03	1.58123E-44
1.0000E+03	2.1398E+05	9.9136E+03	3.15993E-40
1.0000E+03	2.1498E+05	9.9599E+03	3.61465E-36
1.0000E+03	2.1598E+05	1.0006E+04	2.38584E-32
1.0000E+03	2.1698E+05	1.0052E+04	9.15884E-29
1.0000E+03	2.1798E+05	1.0099E+04	2.06094E-25
1.0000E+03	2.1898E+05	1.0145E+04	2.73963E-22
1.0000E+03	2.1998E+05	1.0191E+04	2.16808E-19
1.0000E+03	2.2097E+05	1.0238E+04	1.02935E-16
1.0000E+03	2.2197E+05	1.0284E+04	2.95472E-14
1.0000E+03	2.2297E+05	1.0330E+04	5.16805E-12
1.0000E+03	2.2397E+05	1.0376E+04	5.55195E-10
1.0000E+03	2.2497E+05	1.0423E+04	3.69344E-08
1.0000E+03	2.2597E+05	1.0469E+04	1.53464E-06
1.0000E+03	2.2697E+05	1.0515E+04	4.01964E-05
1.0000E+03	2.2797E+05	1.0561E+04	6.70478E-04
1.0000E+03	2.2896E+05	1.0608E+04	7.20154E-03
1.0000E+03	2.2996E+05	1.0654E+04	5.05334E-02
1.0000E+03	2.3096E+05	1.0700E+04	2.35763E-01
1.0000E+03	2.3196E+05	1.0747E+04	7.48886E-01
1.0000E+03	2.3296E+05	1.0793E+04	1.67476E+00
1.0000E+03	2.3396E+05	1.0839E+04	2.76649E+00
1.0000E+03	2.3496E+05	1.0885E+04	3.60737E+00
1.0000E+03	2.3596E+05	1.0932E+04	4.02280E+00
1.0000E+03	2.3695E+05	1.0978E+04	4.13995E+00
1.0000E+03	2.3795E+05	1.1024E+04	4.13679E+00
1.0000E+03	2.3895E+05	1.1070E+04	4.10350E+00
1.0000E+03	2.3995E+05	1.1117E+04	4.06559E+00
1.0000E+03	2.4095E+05	1.1163E+04	4.02750E+00
1.0000E+03	2.4195E+05	1.1209E+04	3.98973E+00
1.0000E+03	2.4295E+05	1.1256E+04	3.95232E+00
1.0000E+03	2.4395E+05	1.1302E+04	3.91525E+00
1.0000E+03	2.4494E+05	1.1348E+04	3.87853E+00
1.0000E+03	2.4594E+05	1.1394E+04	3.84216E+00
1.0000E+03	2.4694E+05	1.1441E+04	3.80613E+00
1.0000E+03	2.4794E+05	1.1487E+04	3.77043E+00
1.0000E+03	2.4894E+05	1.1533E+04	3.73507E+00
1.0000E+03	2.4994E+05	1.1579E+04	3.70004E+00
1.0000E+03	2.5094E+05	1.1626E+04	3.66534E+00
1.0000E+03	2.5194E+05	1.1672E+04	3.63097E+00
1.0000E+03	2.5293E+05	1.1718E+04	3.59692E+00
1.0000E+03	2.5393E+05	1.1765E+04	3.56318E+00
1.0000E+03	2.5493E+05	1.1811E+04	3.52977E+00
1.0000E+03	2.5593E+05	1.1857E+04	3.49667E+00
1.0000E+03	2.5693E+05	1.1903E+04	3.46387E+00
1.0000E+03	2.5793E+05	1.1950E+04	3.43139E+00
1.0000E+03	2.5893E+05	1.1996E+04	3.39921E+00
1.0000E+03	2.5993E+05	1.2042E+04	3.36733E+00
1.0000E+03	2.6092E+05	1.2088E+04	3.33575E+00
1.0000E+03	2.6192E+05	1.2135E+04	3.30447E+00
1.0000E+03	2.6292E+05	1.2181E+04	3.27347E+00
1.0000E+03	2.6392E+05	1.2227E+04	3.24278E+00
1.0000E+03	2.6492E+05	1.2273E+04	3.21237E+00
1.0000E+03	2.6592E+05	1.2320E+04	3.18224E+00
1.0000E+03	2.6692E+05	1.2366E+04	3.15240E+00
1.0000E+03	2.6792E+05	1.2412E+04	3.12283E+00
1.0000E+03	2.6891E+05	1.2459E+04	3.09354E+00
1.0000E+03	2.6991E+05	1.2505E+04	3.06453E+00
1.0000E+03	2.7091E+05	1.2551E+04	3.03579E+00

1.0000E+03	2.7191E+05	1.2597E+04	3.00732E+00
1.0000E+03	2.7291E+05	1.2644E+04	2.97912E+00
1.0000E+03	2.7391E+05	1.2690E+04	2.95118E+00
1.0000E+03	2.7491E+05	1.2736E+04	2.92350E+00
1.0000E+03	2.7591E+05	1.2782E+04	2.89609E+00
1.0000E+03	2.7690E+05	1.2829E+04	2.86893E+00
1.0000E+03	2.7790E+05	1.2875E+04	2.84202E+00
1.0000E+03	2.7890E+05	1.2921E+04	2.81537E+00
1.0000E+03	2.7990E+05	1.2968E+04	2.78896E+00
1.0000E+03	2.8090E+05	1.3014E+04	2.76281E+00
1.0000E+03	2.8190E+05	1.3060E+04	2.73690E+00
1.0000E+03	2.8290E+05	1.3106E+04	2.71123E+00
1.0000E+03	2.8390E+05	1.3153E+04	2.68580E+00
1.0000E+03	2.8489E+05	1.3199E+04	2.66062E+00
1.0000E+03	2.8589E+05	1.3245E+04	2.63567E+00
1.0000E+03	2.8689E+05	1.3291E+04	2.61095E+00
1.0000E+03	2.8789E+05	1.3338E+04	2.58646E+00
1.0000E+03	2.8889E+05	1.3384E+04	2.56220E+00
1.0000E+03	2.8989E+05	1.3430E+04	2.53818E+00
1.0000E+03	2.9089E+05	1.3477E+04	2.51437E+00
1.0000E+03	2.9189E+05	1.3523E+04	2.49079E+00
1.0000E+03	2.9288E+05	1.3569E+04	2.46743E+00
1.0000E+03	2.9388E+05	1.3615E+04	2.44429E+00
1.0000E+03	2.9488E+05	1.3662E+04	2.42137E+00
1.0000E+03	2.9588E+05	1.3708E+04	2.39866E+00
1.0000E+03	2.9688E+05	1.3754E+04	2.37617E+00
1.0000E+03	2.9788E+05	1.3800E+04	2.35388E+00
1.0000E+03	2.9888E+05	1.3847E+04	2.33181E+00
1.0000E+03	2.9988E+05	1.3893E+04	2.30994E+00
1.0000E+03	3.0087E+05	1.3939E+04	2.28828E+00
1.0000E+03	3.0187E+05	1.3986E+04	2.26682E+00
1.0000E+03	3.0287E+05	1.4032E+04	2.24556E+00
1.0000E+03	3.0387E+05	1.4078E+04	2.22450E+00
1.0000E+03	3.0487E+05	1.4124E+04	2.20364E+00
1.0000E+03	3.0587E+05	1.4171E+04	2.18297E+00
1.0000E+03	3.0687E+05	1.4217E+04	2.16250E+00
1.0000E+03	3.0787E+05	1.4263E+04	2.14222E+00
1.0000E+03	3.0886E+05	1.4309E+04	2.12213E+00
1.0000E+03	3.0986E+05	1.4356E+04	2.10223E+00
1.0000E+03	3.1086E+05	1.4402E+04	2.08251E+00
1.0000E+03	3.1186E+05	1.4448E+04	2.06298E+00
1.0000E+03	3.1286E+05	1.4495E+04	2.04363E+00
1.0000E+03	3.1386E+05	1.4541E+04	2.02447E+00
1.0000E+03	3.1486E+05	1.4587E+04	2.00548E+00
1.0000E+03	3.1586E+05	1.4633E+04	1.98667E+00
1.0000E+03	3.1685E+05	1.4680E+04	1.96804E+00
1.0000E+03	3.1785E+05	1.4726E+04	1.94959E+00
1.0000E+03	3.1885E+05	1.4772E+04	1.93130E+00
1.0000E+03	3.1985E+05	1.4818E+04	1.91319E+00
1.0000E+03	3.2085E+05	1.4865E+04	1.89525E+00
1.0000E+03	3.2185E+05	1.4911E+04	1.87747E+00
1.0000E+03	3.2285E+05	1.4957E+04	1.85987E+00
1.0000E+03	3.2385E+05	1.5004E+04	1.84242E+00
1.0000E+03	3.2484E+05	1.5050E+04	1.82515E+00
1.0000E+03	3.2584E+05	1.5096E+04	1.80803E+00
1.0000E+03	3.2684E+05	1.5142E+04	1.79107E+00
1.0000E+03	3.2784E+05	1.5189E+04	1.77428E+00
1.0000E+03	3.2884E+05	1.5235E+04	1.75764E+00
1.0000E+03	3.2984E+05	1.5281E+04	1.74115E+00
1.0000E+03	3.3084E+05	1.5327E+04	1.72482E+00

1.0000E+03	3.3184E+05	1.5374E+04	1.70865E+00
1.0000E+03	3.3283E+05	1.5420E+04	1.69262E+00
1.0000E+03	3.3383E+05	1.5466E+04	1.67675E+00
1.0000E+03	3.3483E+05	1.5512E+04	1.66103E+00
1.0000E+03	3.3583E+05	1.5559E+04	1.64545E+00
1.0000E+03	3.3683E+05	1.5605E+04	1.63002E+00
1.0000E+03	3.3783E+05	1.5651E+04	1.61473E+00
1.0000E+03	3.3883E+05	1.5698E+04	1.59959E+00
1.0000E+03	3.3983E+05	1.5744E+04	1.58459E+00
1.0000E+03	3.4082E+05	1.5790E+04	1.56973E+00
1.0000E+03	3.4182E+05	1.5836E+04	1.55500E+00
1.0000E+03	3.4282E+05	1.5883E+04	1.54042E+00
1.0000E+03	3.4382E+05	1.5929E+04	1.52597E+00
1.0000E+03	3.4482E+05	1.5975E+04	1.51166E+00
1.0000E+03	3.4582E+05	1.6021E+04	1.49749E+00
1.0000E+03	3.4682E+05	1.6068E+04	1.48344E+00
1.0000E+03	3.4782E+05	1.6114E+04	1.46953E+00
1.0000E+03	3.4881E+05	1.6160E+04	1.45575E+00
1.0000E+03	3.4981E+05	1.6207E+04	1.44210E+00
1.0000E+03	3.5081E+05	1.6253E+04	1.42857E+00
1.0000E+03	3.5181E+05	1.6299E+04	1.41518E+00
1.0000E+03	3.5281E+05	1.6345E+04	1.40190E+00
1.0000E+03	3.5381E+05	1.6392E+04	1.38876E+00
1.0000E+03	3.5481E+05	1.6438E+04	1.37573E+00
1.0000E+03	3.5581E+05	1.6484E+04	1.36283E+00
1.0000E+03	3.5680E+05	1.6530E+04	1.35005E+00
1.0000E+03	3.5780E+05	1.6577E+04	1.33739E+00
1.0000E+03	3.5880E+05	1.6623E+04	1.32485E+00
1.0000E+03	3.5980E+05	1.6669E+04	1.31242E+00
1.0000E+03	3.6080E+05	1.6716E+04	1.30011E+00
1.0000E+03	3.6180E+05	1.6762E+04	1.28792E+00
1.0000E+03	3.6280E+05	1.6808E+04	1.27584E+00
1.0000E+03	3.6380E+05	1.6854E+04	1.26388E+00
1.0000E+03	3.6479E+05	1.6901E+04	1.25202E+00
1.0000E+03	3.6579E+05	1.6947E+04	1.24028E+00
1.0000E+03	3.6679E+05	1.6993E+04	1.22865E+00
1.0000E+03	3.6779E+05	1.7039E+04	1.21713E+00
1.0000E+03	3.6879E+05	1.7086E+04	1.20571E+00
1.0000E+03	3.6979E+05	1.7132E+04	1.19441E+00
1.0000E+03	3.7079E+05	1.7178E+04	1.18321E+00
1.0000E+03	3.7179E+05	1.7225E+04	1.17211E+00
1.0000E+03	3.7278E+05	1.7271E+04	1.16112E+00
1.0000E+03	3.7378E+05	1.7317E+04	1.15023E+00
1.0000E+03	3.7478E+05	1.7363E+04	1.13944E+00
1.0000E+03	3.7578E+05	1.7410E+04	1.12875E+00
1.0000E+03	3.7678E+05	1.7456E+04	1.11817E+00
1.0000E+03	3.7778E+05	1.7502E+04	1.10768E+00
1.0000E+03	3.7878E+05	1.7548E+04	1.09729E+00
1.0000E+03	3.7978E+05	1.7595E+04	1.08700E+00
1.0000E+03	3.8077E+05	1.7641E+04	1.07681E+00
1.0000E+03	3.8177E+05	1.7687E+04	1.06671E+00
1.0000E+03	3.8277E+05	1.7734E+04	1.05671E+00
1.0000E+03	3.8377E+05	1.7780E+04	1.04681E+00
1.0000E+03	3.8477E+05	1.7826E+04	1.03726E+00
1.0000E+03	3.8577E+05	1.7872E+04	1.03246E+00
1.0000E+03	3.8677E+05	1.7919E+04	1.08024E+00
1.0000E+03	3.8777E+05	1.7965E+04	1.49252E+00
1.0000E+03	3.8876E+05	1.8011E+04	3.42473E+00
1.0000E+03	3.8976E+05	1.8057E+04	8.91009E+00
1.0000E+03	3.9076E+05	1.8104E+04	1.79456E+01

1.0000E+03	3.9176E+05	1.8150E+04	2.49223E+01
1.0000E+03	3.9276E+05	1.8196E+04	2.32933E+01
1.0000E+03	3.9376E+05	1.8242E+04	1.45954E+01
1.0000E+03	3.9476E+05	1.8289E+04	6.13730E+00
1.0000E+03	3.9576E+05	1.8335E+04	1.73579E+00
1.0000E+03	3.9675E+05	1.8381E+04	3.31003E-01
1.0000E+03	3.9775E+05	1.8428E+04	4.26679E-02
1.0000E+03	3.9875E+05	1.8474E+04	3.72808E-03
1.0000E+03	3.9975E+05	1.8520E+04	2.21190E-04
1.0000E+03	4.0075E+05	1.8566E+04	8.94757E-06
1.0000E+03	4.0175E+05	1.8613E+04	2.47445E-07
1.0000E+03	4.0275E+05	1.8659E+04	4.69373E-09
1.0000E+03	4.0375E+05	1.8705E+04	6.12791E-11
1.0000E+03	4.0474E+05	1.8751E+04	5.50359E-13

```
**********************************************************************
*
*         ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
*         *11/26/85* VERSION
*         SEMI-INFINITE PROFILE
*
*         NUCLIDE DECAY (THALF)
*         LINEAR ADSORPTION (R)
*         GENERAL NUCLIDE RELEASE CURVE
*         TRANSPORT SUM OVER PATHLINES
*
*         CIMARRON LANDFILL: Kd=300 controlled release - U-238
*              SATURATED ZONE
**********************************************************************
```

NUCLIDE: U-238

INPUT PARAMETERS
================

```
V =       130.38              D =        1.00
R =       1600.0              T0 = 7.3683E+04
TOTAL =1.81E+12               TDECAY=0.000E-01
THALF=  4.5000E+09            C0 =  4.539E+05
XL =1.0000E+03
NUCLIDE DECAY CONSTANT = 1.54033E-10
```

CONTROL FLAGS:
IOPTBC= 0 IFLUX= 0 ITYPE= 1 IOPT= 3

RELEASE MODEL PARAMETERS:
PLAN VIEW AREA=8.0000E+04
DEPTH=1.0000E+01
WATER FLUX Q=3.0000E-01
THETA   =0.3000
MAX CONCENTRATION=1.0000E+12
RELEASE CURVE ERROR=1.0000E-02

FRACTION REMAINING CURVE

TIME	FRACTION
0.00E-01	1.00000
2.88E+02	0.98199
5.75E+02	0.96437
8.60E+02	0.94713
1.14E+03	0.93027
1.43E+03	0.91376
1.71E+03	0.89760
1.99E+03	0.88179
2.27E+03	0.86632
2.55E+03	0.85117
2.83E+03	0.83634
3.10E+03	0.82183
3.38E+03	0.80762

3.66E+03	0.79370
3.93E+03	0.78008
4.20E+03	0.76673
4.47E+03	0.75367
4.74E+03	0.74087
5.01E+03	0.72834
5.28E+03	0.71606
5.55E+03	0.70403
5.81E+03	0.69225
6.08E+03	0.68071
6.34E+03	0.66940
6.61E+03	0.65832
6.87E+03	0.64746
7.13E+03	0.63683
7.39E+03	0.62640
7.65E+03	0.61618
7.91E+03	0.60616
8.16E+03	0.59635
8.42E+03	0.58672
8.67E+03	0.57729
8.93E+03	0.56804
9.18E+03	0.55897
9.43E+03	0.55008
9.68E+03	0.54136
9.93E+03	0.53281
1.02E+04	0.52443
1.04E+04	0.51621
1.07E+04	0.50814
1.09E+04	0.50023
1.12E+04	0.49247
1.14E+04	0.48486
1.17E+04	0.47739
1.19E+04	0.47006
1.21E+04	0.46288
1.24E+04	0.45582
1.26E+04	0.44890
1.29E+04	0.44211
1.31E+04	0.43544
1.33E+04	0.42890
1.36E+04	0.42248
1.38E+04	0.41618
1.40E+04	0.40999
1.43E+04	0.40392
1.45E+04	0.39796
1.47E+04	0.39210
1.50E+04	0.38636
1.52E+04	0.38071
1.54E+04	0.37517
1.56E+04	0.36973
1.59E+04	0.36439
1.61E+04	0.35914
1.63E+04	0.35399
1.66E+04	0.34892
1.68E+04	0.34395
1.70E+04	0.33906
1.72E+04	0.33427
1.74E+04	0.32955
1.77E+04	0.32492
1.79E+04	0.32037
1.81E+04	0.31590

1.83E+04	0.31150
1.85E+04	0.30718
1.87E+04	0.30294
1.90E+04	0.29877
1.92E+04	0.29467
1.94E+04	0.29064
1.96E+04	0.28668
1.98E+04	0.28279
2.00E+04	0.27896
2.02E+04	0.27520
2.04E+04	0.27150
2.06E+04	0.26786
2.09E+04	0.26428
2.11E+04	0.26077
2.13E+04	0.25731
2.15E+04	0.25391
2.17E+04	0.25057
2.19E+04	0.24728
2.21E+04	0.24404
2.23E+04	0.24086
2.25E+04	0.23773
2.27E+04	0.23465
2.29E+04	0.23162
2.31E+04	0.22864
2.33E+04	0.22571
2.35E+04	0.22283
2.37E+04	0.21999
2.39E+04	0.21720
2.41E+04	0.00000

RELEASE INTERVAL NUMBER= 102

PATHLINE PARAMETERS:

TRAVELTIME	PATH LENGTH	VELOCITY	PDF
2.2010E+01	1.0190E+03	4.6297E+01	5.5556E+01
2.2019E+01	1.0200E+03	4.6324E+01	5.0000E+02
2.2020E+01	1.0210E+03	4.6367E+01	0.0000E-01

ADDITIONAL ZONE PARAMETERS:
XV=2.0000E+01 TV=1.4500E+01
AVERAGES:
LENGTH=1.0000E+03 TIME=2.2016E+01 VELOCITY=4.6329E+01

*** QUANTITY IS CONCENTRATION ***
CONVERSION FACTOR = 3.2695E-05

DISTANCE (X)	TIME (T)	PORE VOLUME (VVO)	QUANTITY (Q)
1.0000E+03	3.1955E+04	1.4805E+03	1.39843E-49
1.0000E+03	3.2953E+04	1.5267E+03	1.64081E-23
1.0000E+03	3.3951E+04	1.5729E+03	2.06558E-07
1.0000E+03	3.4949E+04	1.6192E+03	3.18349E+00
1.0000E+03	3.5947E+04	1.6654E+03	2.73703E+01

1.0000E+03	3.6945E+04	1.7116E+03	2.57405E+01
1.0000E+03	3.7943E+04	1.7579E+03	2.41840E+01
1.0000E+03	3.8941E+04	1.8041E+03	2.27217E+01
1.0000E+03	3.9939E+04	1.8503E+03	2.13477E+01
1.0000E+03	4.0937E+04	1.8966E+03	2.00569E+01
1.0000E+03	4.1935E+04	1.9428E+03	1.88441E+01
1.0000E+03	4.2933E+04	1.9890E+03	1.77046E+01
1.0000E+03	4.3931E+04	2.0353E+03	1.66340E+01
1.0000E+03	4.4929E+04	2.0815E+03	1.56282E+01
1.0000E+03	4.5927E+04	2.1277E+03	1.46832E+01
1.0000E+03	4.6925E+04	2.1740E+03	1.37953E+01
1.0000E+03	4.7923E+04	2.2202E+03	1.29611E+01
1.0000E+03	4.8921E+04	2.2665E+03	1.21774E+01
1.0000E+03	4.9919E+04	2.3127E+03	1.14411E+01
1.0000E+03	5.0916E+04	2.3589E+03	1.07492E+01
1.0000E+03	5.1914E+04	2.4052E+03	1.00993E+01
1.0000E+03	5.2912E+04	2.4514E+03	9.48857E+00
1.0000E+03	5.3910E+04	2.4976E+03	8.91481E+00
1.0000E+03	5.4908E+04	2.5439E+03	8.37575E+00
1.0000E+03	5.5906E+04	2.5901E+03	7.86929E+00
1.0000E+03	5.6904E+04	2.6363E+03	7.39345E+00
1.0000E+03	5.7902E+04	2.6826E+03	6.94641E+00
1.0000E+03	5.9898E+04	2.7750E+03	1.91932E+00
1.0000E+03	6.0896E+04	2.8213E+03	1.61312E-09