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1992 ANNUAL REPORT

HYDROLOGIC STUDIES IN WELLS OPEN THROUGH LARGE INTERVALS

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SUMMARY OF 1992 ACTIVITIES

BACKGROUND

This report describes and summarizes activities, data, and preliminary data interpretation from the INEL Oversight Program R&D-1 project titled "Hydrologic Studies In Wells Open Through Large Intervals." The project is designed to use a straddle-packer system to isolate, hydraulically test, and sample specific intervals of monitoring wells that are open (uncased, unscreened) over large intervals of the Snake River Plain aquifer. The objectives of the project are to determine and compare vertical variations in water quality and aquifer properties that have previously only been determined in an integrated fashion over the entire thickness of the open interval of the observation wells. A complete description of project objectives is available in the "Funding Proposal for Research and Development on INEL by the State of Idaho In Support of Environmental Assessments" submitted to the U.S. Department of Energy.

The straddle-packer was in the first season of checkout and field implementation in 1992. This report describes data collection and activities at the INEL during the summer and fall of 1992 with the straddle-packer, and with borehole geophysical logging by Boise State University in support of the straddle-packer testing and sampling activities. It should be noted that field activities were supported logistically by the U.S. Geological Survey which also collected verification samples and participated in sampling and analysis of ^{36}Cl (results not yet received) and ^{129}I. Also, microbiological sampling and analyses were performed by EG&G in cooperation with the Oversight Program and researchers on this project.

CONTRACT REQUIREMENTS

This report was cooperatively prepared by staff of the Idaho Geologic Survey, Idaho State University, Boise State University, the University of Idaho and the INEL Oversight Program. The report satisfies contractual obligations for an end-of-year report as specified in Appendix D of the contract between the INEL Oversight Program and the Idaho Water Resources Research Institute at the University of Idaho, and reporting requirements to DOE.

PURPOSE AND SCOPE

The purpose of this report is to document and summarize field activities, computer data files and water quality samples, and to provide a preliminary interpretation of the data. This report is not intended to represent final results and data interpretation.

TESTING OF USGS WELL 44

The straddle-packer was used to hydraulically test and sample 10 intervals (some overlapping) in well USGS 44, just west of the Idaho Chemical Processing Plant. Time-consuming equipment and procedure testing in this well prevented use of the straddle-packer in other wells during the 1992 season.

Equipment set-up and data collection on USGS 44 began in early July and continued at an intense pace until mid-August. In mid-August the packer was positioned on an interval 500 to 515 feet below land surface, where it remained for the duration of 1992. The packer system was used during the fall of 1992 to acquire long-term hydraulic response data from the 500 to 515 foot interval.

Activities during the data collection period from July 1 through August 19, 1992 are summarized in Appendix A. Initial testing during this period was conducted using a 20 foot straddle interval. After completing all possible 20 foot intervals the packer system was removed from the well and reconfigured to straddle a 15 foot interval. All intervals in the well were tested with either the 15 or the 20 foot straddle interval.

Objectives and procedures were similar for all tested intervals. Modifications to procedures were made as more was learned about the packer system and the characteristics of the aquifer. The intent was to hydraulically test and sample as many of the intervals as possible, recognizing that extremely low and extremely high permeability intervals created problems for hydraulic testing or sampling. Tracer (lithium bromide) was also routinely emplaced to identify mixing and purging characteristics of the intervals. A list of the successfully tested intervals in well USGS 44, and the tests and samples conducted in each interval, is given in table 1.

Table 1. Testing and Sampling in Specific Intervals in Well USGS 44.

Interval	Hydraulic Tests		Sampling	
(ft. bls)	Slug	Pumping	Chem./Rad.	Microbial
467-482	Yes	Yes	Yes	Yes
480-495	Yes	Yes	No	No
495-515	Yes	No	Yes	Yes
500-515	No	No	No	No
519-534	Yes	Yes	Yes	Yes
535-555	No	Yes	Yes	Yes
557-577	No	Yes	Yes	Yes
580-600	Yes	Yes	Yes	Yes
600-620	Yes	Yes	No	No
600-650	Yes	Yes	No	No

SIGNIFICANT RESULTS OF 1992

The field experiences and analysis and interpretation of the data collected during 1992 provide valuable insights into guiding the directions and procedures to be implemented in subsequent years. A list of the significant findings from the 1992 research effort is as follows:

IN RELATION TO AQUIFER CHARACTERISTICS:

1) In the vicinity of USGS well 44, the aquifer is vertically well mixed between the water table and about 580 feet in depth below land surface (upper portion of the I basalt flow group). The high degree of mixing is indicated by:
   a) lack of any statistically significant vertical variations in chemical or radionuclide concentrations,
   b) little vertical variation in static head,
   c) significant vertical borehole flow, even with low vertical head gradients, and
   d) little variation in microbial populations in the upper basalt flows.

2) Significant isotopic and chemical (^3H, ^{129}I, Na, Cl), and microbial contrasts exist between ground water at depths less than 580 feet below land surface and ground-water sampled from 580 feet to the base of the well at 651 feet below land surface. The intervals below 580 feet below land surface correspond to the interior portion of the I basalt flow group.

IN RELATION TO TESTING METHODS:

3) Single well tracer methods have been demonstrated to be useful for determination of borehole purge efficiency as well as estimation of hydrologic properties.

4) The high precision pressure sensing instrumentation has been found essential to determination of the small variations in static head and drawdowns induced during pumping.

5) Traditional methods of estimating aquifer properties of hydraulic conductivity and storativity are often not applicable in the high permeability zones of the Snake River Plain aquifer.

6) Recirculation is necessary to insure mixing while discharging from some intervals in order to achieve a valid tracer test and to sample low hydraulic conductivity intervals.

The preliminary results of the program are described in greater detail in a series of 3 papers presented at the Idaho Ground-Water Quality Workshop in February, 1993, sponsored by the Idaho Department of Water Resources and the Idaho Water Resources Research Institute. The three papers are included as appendices to this report. A description of the packer system, and the preliminary results of the hydrologic investigations is presented in Appendix B, "Application of a Straddle-Packer System for Water Quality Monitoring and Hydrologic Testing in Wells Open Over Large Intervals at the INEL." The paper included as Appendix C describes vertical variations in ground-water quality in Well 44 and is titled "Vertical Variations in Groundwater Chemistry Near the CPP: Implications for Groundwater Monitoring at the INEL." A detailed summary of the collected ground-water quality data is presented in Appendix D. Data and preliminary results from tracer testing are described in Appendix E. The report included as Appendix E has been expanded from the form presented at the Water Quality Workshop to include data summaries. Interpretation of the data is continuing and will be included in subsequent publications.

BOREHOLE GEOPHYSICAL LOGGING

During 1992, Boise State University borehole geophysical logging activities complemented the packer testing and can be summarized as follows:

1) Completed progress report compiling all previous flowmeter studies and results from flowmeter logging of wells 44 and 46 at the INEL (see Appendix F: "Impeller Flow-Meter Logging of Vertical Cross Flow between Basalt Aquifers through Wells at the INEL").

2) Improved and calibrated bi-directional impeller flowmeter logging system which can now reliably measure in-hole vertical flow to 3 ft/min precision when being trolled in a well.

3) Logging in 1992 in wells 44 and 46 showed cross flows of up to 20 ft/min and strong, rapid responses to the production well pumping cycles at the ICPP (responses within 2 minutes causing reversal of cross flow direction). Logging in well 45 did not detect a response to the pumping cycles at the ICPP production wells.

4) Current work is now focused on improving high-precision temperature logs to detect cross flow in wells, and on exploring the use of fluid-conductivity logs to detect variations in water chemistry in zones of interest in wells being tested with the straddle-packer system.

APPENDIX B

PRELIMINARY RESULTS FROM:
IDAHO GROUND-WATER QUALITY WORKSHOP

"APPLICATION OF A STRADDLE-PACKER SYSTEM FOR WATER QUALITY MONITORING AND HYDROLOGIC TESTING IN WELLS OPEN OVER LARGE INTERVALS AT THE INEL"

APPLICATION OF A STRADDLE-PACKER SYSTEM FOR WATER QUALITY MONITORING AND HYDROLOGIC TESTING IN WELLS OPEN OVER LARGE INTERVALS AT THE INEL

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ABSTRACT

A significant fraction of the wells into the Snake River Plain Aquifer at the INEL that are monitored regularly for water quality and water level are open to the aquifer over large intervals. In particular, more than 40 wells are open into the aquifer for more than 100 vertical feet. More than 30 of these wells are open for over 150 vertical feet, and some are open for greater than 250 vertical feet.

Monitor wells open over large intervals present several problems for water quality sampling. Water samples collected from the upper portion of wells open over large intervals through multiple water-bearing zones may be diluted with uncontaminated or less contaminated water from different water producing zones of the well. Water level measurements taken in wells open over large or multiple intervals are weighted averages of hydraulic heads in the open intervals. A single measurement of hydraulic conductivity in a well open over a large interval through multiple water-bearing zones will not reflect variations in hydraulic conductivity of individual zones. Vertical variations in head and hydraulic conductivity exert significant control over the flow of water and migration of contaminants within monitoring wells and through the Snake River Plain aquifer .

The INEL Oversight Program in cooperation with Idaho universities, the Idaho Geological Survey, and the US. Geological Survey designed and acquired a straddle packer system capable of collecting water quality samples from and measuring hydraulic head in discrete intervals. Water quality sampling and hydraulic testing of the Snake River Plain aquifer at the INEL began in well USGS-44 in July of 1992.

Hydraulic testing in well USGS-44 consisted of pump tests, injection tests, slug tests, and static head monitoring. Analysis of the results from the hydraulic testing program is complicated by several factors. Little or no drawdown occurred in high hydraulic conductivity zones during pumping tests, while low hydraulic conductivity zones were drawn down excessively. Extremely rapid aquifer response and varying valve opening times complicates slug test analysis. Static head monitoring is complicated by pumping from ICPP production wells and the presence of air bubbles in the pressure transducers.

Nine intervals were packed off in USGS-44 and hydraulically tested. Hydraulic conductivity values range from approximately 1 ft/day in the lower portion of the well to greater than 1,000 ft/day in upper intervals. Static head variations between packed off zones are less than 0.1 ft.

I. INTRODUCTION

The Idaho National Engineering Laboratory (INEL) covers 894 square miles of the Eastern Snake River Plain in southeastern Idaho (figure 1). The INEL was established in 1949 for the construction, operation, and testing of various types of nuclear reactors by the Atomic Energy Commission. Originally known as the National Reactor Testing Station, the INEL has the worlds largest and most varied collection of reactors (Robertson et. al., 1974).

Monitor Well Network at the INEL

Over one hundred monitor wells have been constructed at the INEL since its inception in 1949. A significant fraction of the monitor wells into the Snake River Plain aquifer constructed prior to 1990 are open over large intervals to multiple water-bearing zones. In particular, more than forty wells into the Sake River Plain aquifer that are sampled regularly for water quality and measured for water level are open to the aquifer for more than 100 vertical feet; more than thirty of these wells are open for more than 150 vertical feet; and some are open for more than 250 vertical feet. Currently accepted monitor well construction standards for monitor wells in complex hydrogeologic settings call for small open intervals in discrete zones (NWWA, 1986).

Wells open over large intervals through multiple water-bearing zones pose three basic problems for monitoring contamination and determining hydrologic characteristics of the upper parts of the Snake River Plain aquifer.

1. Water samples collected from one portion of wells open over large intervals through multiple water-bearing zones may be diluted with uncontaminated or less contaminated water from other portions of the well. This dilution can make contaminant detection difficult or impossible since contaminant concentrations may be reduced to levels below the detection limit for the prescribed analytical methods (NWWA, 1986).
2. Water level measurements taken in wells open over large or multiple intervals are weighted averages of hydraulic heads in the open intervals. The weighted average heads may be different than heads that would be measured in the upper, or any discrete, portion of the aquifer.
3. Measurements of transmissivity in wells open over large intervals through multiple water-bearing zones are the sum of the transmissivities of the individual zones. Transmissivity in individual zones may vary over several orders of magnitude.

The monitor well network at the ICPP and the data collected and interpreted from it over the past 40 years represent a significant investment. Data have been and continue to be collected, reported, and interpreted from many wells without quantitatively determining the effects of large open intervals. The data have also been used to demonstrate the presence or absence of organic, heavy metal, and radioactive contaminants throughout the INEL site. However, as a result of monitor well construction methods used from 1950 through the 1980's at the INEL and the above-mentioned problems associated with large open intervals, significant questions about the meaning of the data collected have been raised.

II. INEL Oversight Program Straddle Packer Project

The INEL Oversight Program was established by the legislature of the State of Idaho in 1989 to provide an unbiased and independent source of information regarding the INEL's impact on public health and the environment. The INEL Oversight Program is administered through the Idaho Department of Health and Welfare. One of the activities of the Oversight Program is to conduct independent health and environmental studies.

In order to conduct independent environmental and hydrologic studies of the Snake River Plain aquifer and to be able to validate existing data, the INEL Oversight Program in cooperation with Idaho universities, the Idaho Geological Survey, and the U.S. Geological Survey designed and acquired a straddle packer system capable of collecting water quality samples from and measuring hydraulic head in discrete intervals. Water quality sampling and hydraulic testing of the Snake River Plain aquifer began in well USGS-44 in July of 1992 and continues.

III. DESCRIPTION OF STRADDLE PACKER

The straddle packer utilized in this testing program was built by Baski, Inc. of Denver, Colorado. The minimum straddled interval length is 12.5 feet. From top to bottom the packer consists of (see figure 3):

1. riser valve
2. upper transducer
3. upper packer
4. circulation valve
5. pump
6. middle transducer
7. lower packer
8. lower transducer

The riser valve controls the flow of water through the riser pipe. It consists of an inflatable bladder contained within a stainless steel housing and the necessary fittings for inflation. When uninflated, water flows between the bladder and the outer housing. When inflated, the bladder expands and shuts off flow.

The transducers are Paroscientific DIGIQUARTZ® intelligent depth sensors with an operating range of 0 to 400 psia and a repeatability of ± 0.0005 % full scale. The upper and lower transducers are housed in 5 " diameter stainless steel housings and sense pressures above and below the packed off interval. The middle transducer is housed in the lower end of the pump shroud and senses pressure within the packed off interval.

The packers are sliding end packers, with the lower end of each packer free to slide up the mandrel as the packer inflates and increases in diameter. The total length of each packer is 4.18 feet. The lower 1.41 feet of the upper packer and upper 1.41 feet of the lower packer are chemically inert Viton, and the remaining 2.77' of each packer is made of rubber. Separate inflation lines allow independent inflation and deflation.

The circulation valve is attached to the discharge end of the pump and allows the discharge from the pump to either re-circulate within the packed off interval or to be discharged to the surface. It is controlled by gas pressure. When open, the circulation valve directs the pump discharge into the packed off interval, and when closed to the surface.

The pump is a 5 horse stainless steel Grundfos pump, housed within a stainless steel pump shroud between the packers. The pump intakes are located at the top of the lower packer, which is connected to the pump shroud by 2" pipes of varying length to control the length of the packed off interval.

The straddle packer is operated via eight 1100 foot control lines which are housed on spools in the support bus. Five of the lines are stainless steel tubing; two ¼" diameter stainless steel inflation lines to inflate the packers, a 3/16" diameter stainless steel inflation line to operate the riser valve, two 3/16" diameter stainless steel lines to operate the circulation valve, a teflon coated pump power cable, a teflon coated transducer cable, and a ½" diameter teflon injection line for emplacement of tracer.

Data are collected on a portable computer. A field computer purchased for the project and loaded with ASYST© data acquisition software experienced hardware failures repeatedly during the testing period. A laptop computer using a BASIC program was used to collect the majority of the data. Two BASIC programs were used to record data from the transducers. The program used during slug testing, pumping tests, and injection tests recorded pressure at a rate of approximately 3 reads per second. A second program with a user programmable read rate was used for static head monitoring. During static head monitoring the pressure was recorded every five minutes.

IV. HYDRAULIC TESTING PROCEDURES IN WELL USGS-44

Straddle packer testing in well USGS-44 began in July of 1992. Well USGS-44 is located west of the ICPP and south of the Big Lost River (see figure 2). The well was constructed in 1957 and is 650 feet deep. The well is cased from 2 feet above land surface to 460 feet below land surface and is open from 460 feet to 650 feet. The water table is approximately 461 feet below land surface. Nine intervals were packed off and hydraulically tested. Hydraulic testing consisted of static head monitoring, slug tests, pump tests, and injection tests.

Static Head Monitoring

Non-pumping water levels were observed in most intervals for a continuous period of 10 hours or more. The non-pumping observations showed a distinct water-level response to pumping from the ICPP production wells located more than 2500 feet away, and to changes in barometric pressure (figure 4.) ICPP pumping effects are apparent from the oscillation with a period of about 6 hours, and an amplitude of about 0.04 feet. Barometric pressure is transmitted to aquifer water pressure with a 50% efficiency in the 500 to 515 foot straddled interval as shown in figure 4. Head changes resulting from barometric pressure variations are expected to be less than 0.5 feet, and variation due to the ICPP pumping is typically less than 0.04 feet.

Project objectives included determination of hydrostatic head profiles in the borehole. The interpretation of static head data, however, is complicated by four conditions:

1. Hydraulic head is continually changing in response to changes in barometric pressure.
2. Hydraulic head is continually changing in response to pumping of the ICPP production wells.
3. Air bubbles may have been introduced into the transducer sensing system.
4. Small vertical hydraulic head gradients exist relative to variations induced by other factors listed above.

The combined effects of these four conditions result in vertical head profiles containing a relatively high degree of uncertainty.

Hydrostatic head was estimated at each packed interval when the ICPP production well was off and also when the pump was operating. Transducer observations in packed off intervals were normally averaged for periods of at least 8 hours which included both the on and off cycles of the ICPP production well. Head was determined as the sum of pressure, in feet of water, and the elevation of the point of observation (the middle transducer), in feet above mean sea level. Calculated water-level elevations were adjusted by 50% of the difference between the barometric reading at the time of observation and an average barometric reading.

Little vertical variation in hydrostatic head is apparent from the straddle-packer testing in well USGS-44. Figure 8 shows the hydrostatic head profile determined by the procedure described above. The maximum difference between intervals was less than 0.4 feet. It is likely that the cumulative error from the above list of problems may be as large as the 0.4 feet of variation observed.

Slug tests

Slug tests were carried out on four low hydraulic conductivity intervals, 480-495 feet, 580-600 feet, 580-650 feet, 600-620 feet, and 620-650 feet. Both positive head slug tests where the head is raised and negative head slug tests where the head is depressed were conducted.

Positive head slug tests are performed by deflating the packers and pumping a slug of water into the riser pipe from the open borehole. After shutting off the pump, the riser valve is closed, trapping the slug within the riser pipe. The packers are then inflated. When the pressure in the packed off interval has stabilized, the circulation valve is opened to allow water to flow into the packed off interval and the slug is released by opening the riser valve. Head changes on all three transducers are monitored and recorded.

The procedures for a negative head slug test are similar to those for a positive head slug test. The packers are deflated, circulation and riser valves opened, and nitrogen gas introduced into the riser pipe to depress the head. When the head is depressed sufficiently, the riser valve is closed and the packers re-inflated. The test is then begun by opening the riser valve and allowing the head in the packed off interval to return to static while recording heads on all three transducers.

Analysis and interpretation of slug test data is complicated by two factors. First, slow riser valve opening times result in non-instantaneous head changes and difficulty in determining when the test actually started. When the pressure on the riser valve is released at the surface, the riser valve bladder begins to deflate. The rate at which the bladder deflates and opens is a function of the amount of pressure exerted on the valve by the head in the riser pipe. As the valve opens, the head in the interval slowly begins to change until the valve opens completely. This violates the assumptions of instantaneous head change (Cooper et al., 1967). As much as 4 feet of head was lost during valve opening in a slug test with a 17 foot initial head change. Slow opening of the riser valve also complicates determination of slug test starting times. A plot of observed head changes and theoretical head changes from a slug test on the 600-650 feet interval appears in figure 5.

Secondly, extremely rapid aquifer response in high hydraulic conductivity zones complicates analysis. High hydraulic conductivity zones are able to accept a slug faster than it can escape from the straddle packer. This also violates the instantaneous head change assumption and turns the attempted slug test into a variable discharge injection test of very short duration.

Pumping Tests

Pumping tests were conducted in conjunction with sampling of packed off intervals and during LiBr tracer recovery tests. Static heads were monitored prior to beginning pumping to determine any antecedent trends. A attempt was made to conduct all sampling during the off cycle at the ICPP production wells, so the status of the ICPP production wells was determined prior to sampling.

Different pumping test procedures were used depending on whether the pumping test was conducted during LiBr recovery or during sampling. Briefly, the LiBr test consists of emplacement of LiBr, circulation of the LiBr in the packed off interval by pumping with the circulation valve open, then stopping the pump, closing the circulation valve, and then starting the pump and discharging to the surface. The pumping test begins during the final step, when discharge to the surface begins.

Sampling typically occurred after the LiBr recovery test. Once it had been determined that the interval was purged, the pump was shut off and heads allowed to return to static conditions. Once heads returned to static, the pump was turned on and drawdown monitored and recorded.

Analysis of pumping test data is complicated by two factors:

1. Extremely rapid aquifer response,
2. small drawdowns.

A log-log graph of drawdown versus time from a pump test of the 600-650 feet interval appears in figure 6.

Extremely rapid aquifer response and very small drawdowns resulted in total drawdowns measured in the hundreds or tenths of feet occurring in less than one second in nearly all of the intervals pumped. The pumping test data from high transmissivity zones cannot be analyzed using conventional curve matching analytical techniques.

Injection Tests

Injection tests were completed on three low hydraulic conductivity intervals, 600-620 feet, 600-650 feet, and 480-495 feet. Injection tests were not planned as part of the original hydraulic testing procedures. The idea of performing injection tests occurred when head increases in the packed interval were noticed during emplacement of LiBr tracer in a low hydraulic conductivity interval. The procedure for injection tests is as follows:

1. Inflate packers and monitor static head in packed interval.
2. When head in packed interval stabilizes pump 5 gallons of de-ionized water down the injection line at ~ 0.7 gallons per minute while monitoring head changes in the packed off interval.
3. Continue to monitor and record head changes after pumping stops to gather recovery data.

Injection test analysis is complicated by a time lag between the start of pumping at the surface and when the pressure begins to rise in the packed off interval.

V. PRELIMINARY RESULTS OF HYDRAULIC TESTING IN WELL USGS-44

Hydraulic testing in well USGS-44 utilizing the straddle-packer system indicate that the vertical distribution of hydraulic conductivity in the Snake River Plain aquifer in the vicinity of the ICPP is highly heterogeneous and that very small head differences may exist within the well.

Hydraulic conductivity in well USGS-44 varies over several orders of magnitude. The vertical distribution of hydraulic conductivity is shown in figure 7. Hydraulic conductivities were determined by slug tests in low hydraulic conductivity intervals. The hydraulic conductivities in the high hydraulic conductivity intervals are those reported by Morin et al. (in press). These hydraulic conductivity values are average values over the length of the interval tested. Low hydraulic conductivity zones too small to pack off and test are interpreted to exist within high hydraulic conductivity zones based on caliper logs. Large breakouts in the borehole are generally high hydraulic conductivity zones, and small diameter competent rock intervals are generally low hydraulic conductivity zones. These generalizations are supported by straddle-packer testing results.

The distribution of hydraulic head measured in well USGS-44 using the straddle-packer is depicted in figure 8. A high degree of uncertainty in the head values exists due to the previously mentioned factors . The amount of variation in hydraulic head appears to be less than or equal to the uncertainty in the values.

VII. IMPLICATIONS FOR WATER QUALITY SAMPLING AND FUTURE RESEARCH

Implications for Water Quality Sampling

The heterogeneous distribution of hydraulic conductivity and variations in hydraulic head in well USGS-44 have implications for water quality sampling. Natural vertical flow patterns under ambient conditions in well USGS-44 described by Morin et al. (in press) are similar to vertical flow patterns that would exist under the head and hydraulic conductivity distribution as measured using the straddle-packer. Natural vertical flow conditions existing within the well could result in contaminated water flowing from one zone to another contaminated, less contaminated, or uncontaminated zone.

Water quality sampling in well USGS-44 is currently conducted with a pump located 500 feet below land surface opposite the 495-515 feet high hydraulic conductivity interval. The percentage of water collected from this pump location that comes from the 495-515 feet interval or from the high hydraulic conductivity intervals above and below has not been quantified. Water quality samples collected from well USGS-44 using the present pump location may represent the 495-515 feet interval entirely or may represent that interval diluted to an unknown extent with water from other high hydraulic conductivity intervals.

Future Research

Potential future research projects associated with the straddle-packer fall into two categories:

1. Develop methods to overcome hydraulic testing problems identified during the initial test period,
2. Develop methods for extrapolation of packer results.

The accuracy of hydraulic head measurements can be improved by designing a pressure sensing system that will not allow air to be introduced into the transducers while the straddle-packer is being lowered into wells or transported. Determination of the exact timing of the ICPP production well cycles may enable drawdown and recovery data from ICPP pumping to be analysed as pumping tests.

Slug test analysis complications can be solved by determining the sensitivity of test results to varying the time the test starts and initial head changes. The problem of slow valve rsponse could also be corrected by replacing the riser valve with or adding a faster acting valve.

Pumping tests are hindered by the small discharge from the straddle-packer sampling pump and the resulting small head changes in the packed off interval. The situation can be remedied by pumping water down the straddle-packer from the surface at a higher rate, resulting in greater head changes in the packed off interval. Multiple well pump tests could also be conducted utilizing existing packers and larger capacity pumps in storage at the INEL site in the pumped well and the straddle-packer in an observation well.

Research projects to extrapolate packer results to other wells include developing a borehole computer model that will reflect laminar flow conditions in basalt and laminar or turbulent flow in the borehole and allows placement of a pump and analysis of results. The model would then be tested using hydraulic and water quality data from well USGS-44.

The affect of pump placement on water quality sampling in wells open over large intervals through multiple water bearing zones needs to be evaluated. A testing program in well USGS-44 using varying pumping rates and pump locations can be correlated with results from straddle-packer testing.

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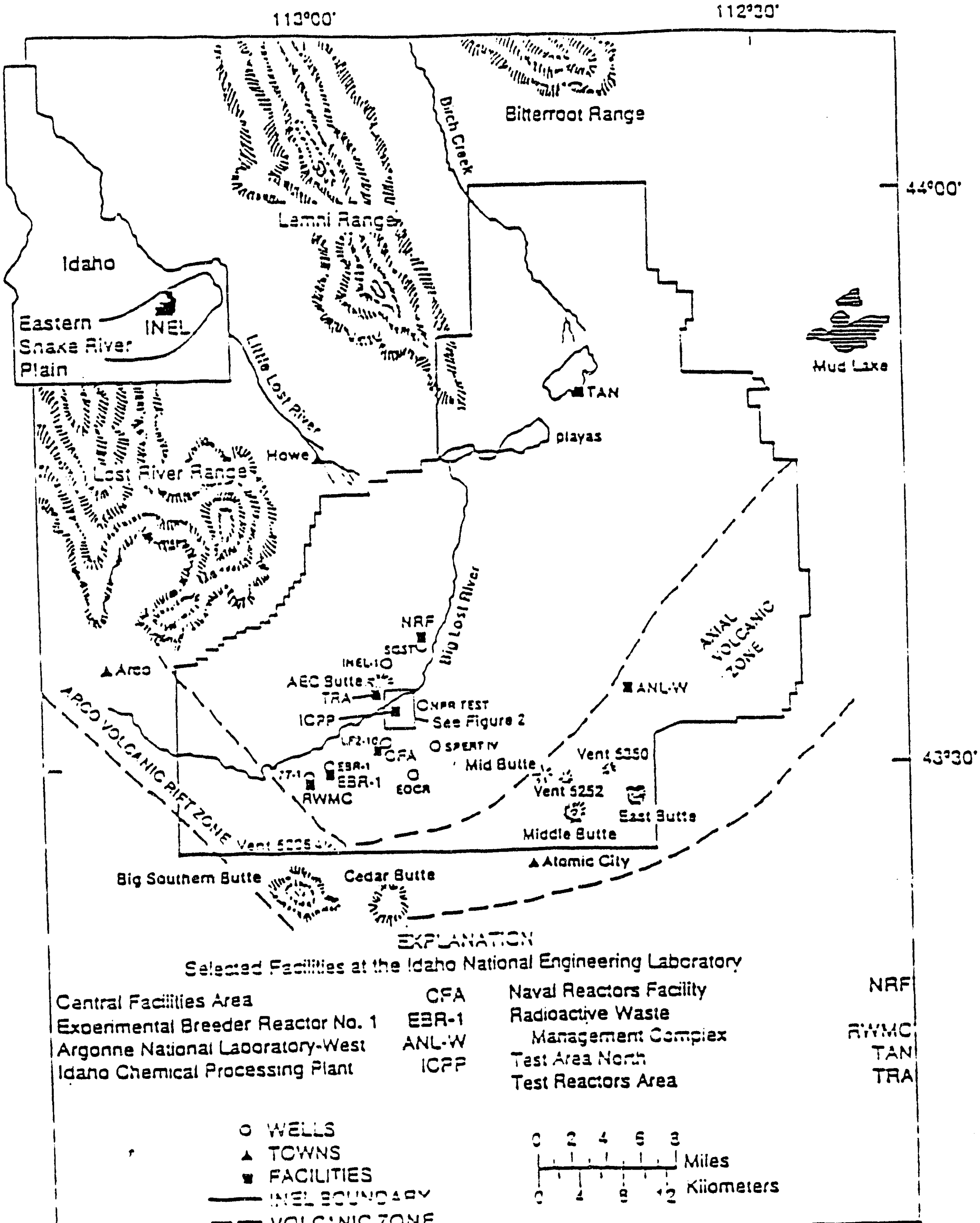

Figure 1. Location of the Idaho Chemical Processing Plant and selected features at and near the Idaho National Engineering Laboratory (after Anderson, 1991).

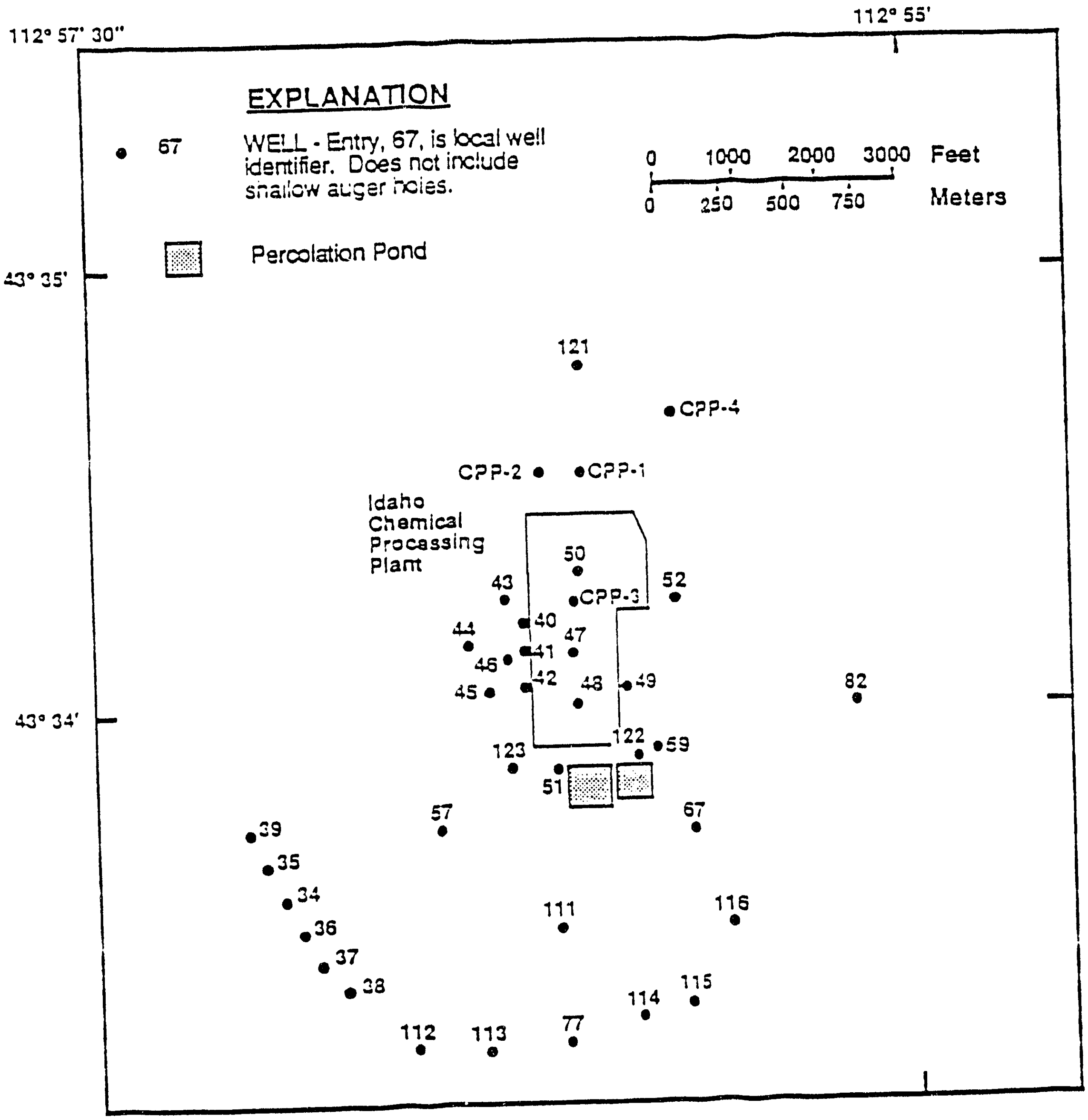

Figure 2. Location map of ground water monitoring wells and production wells penetrating the upper portion of the Snake River Plain aquifer in the vicinity of the ICPP (after Anderson, 1991).

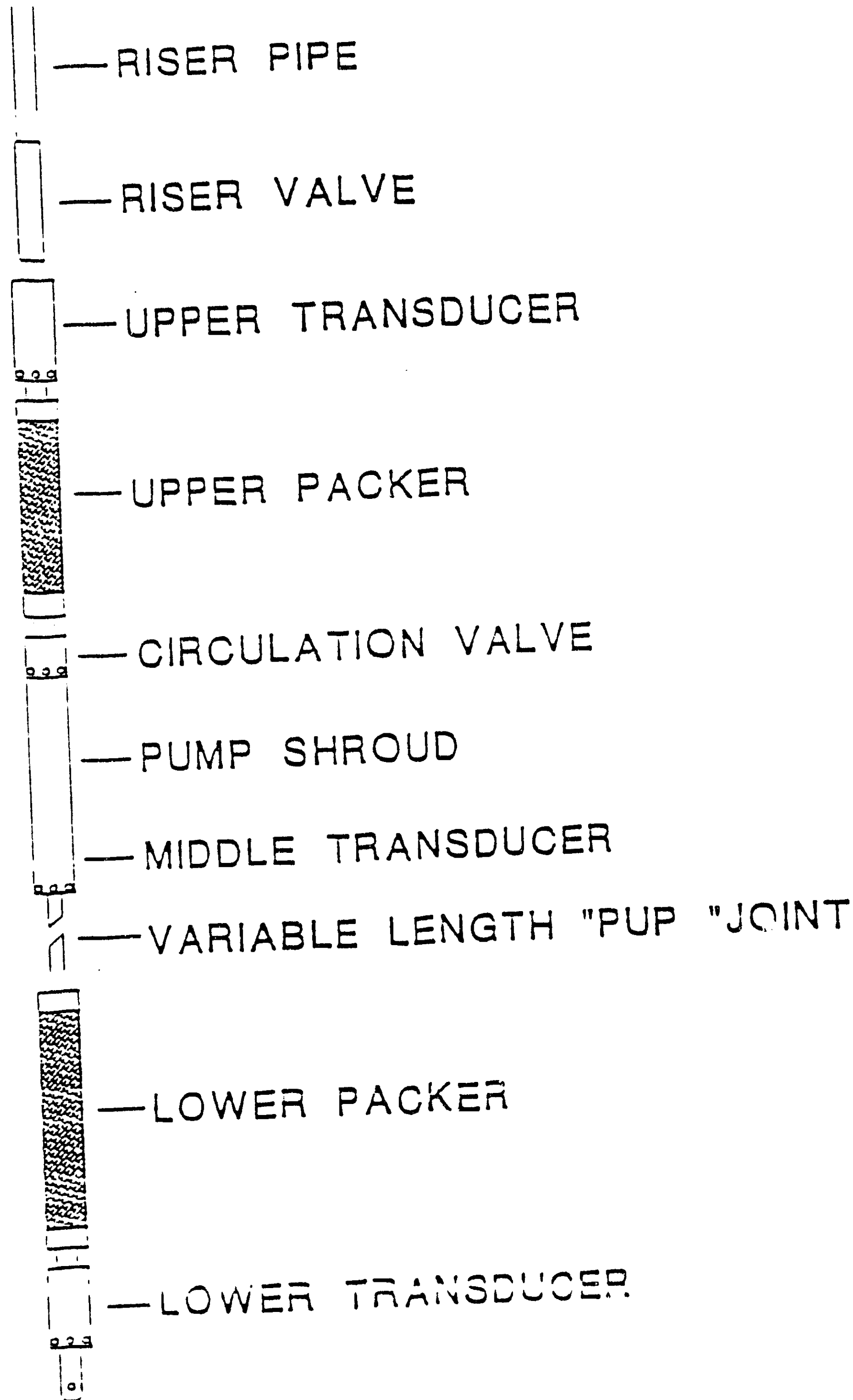

Figure 3. Schematic diagram of straddle packer components (not to scale).

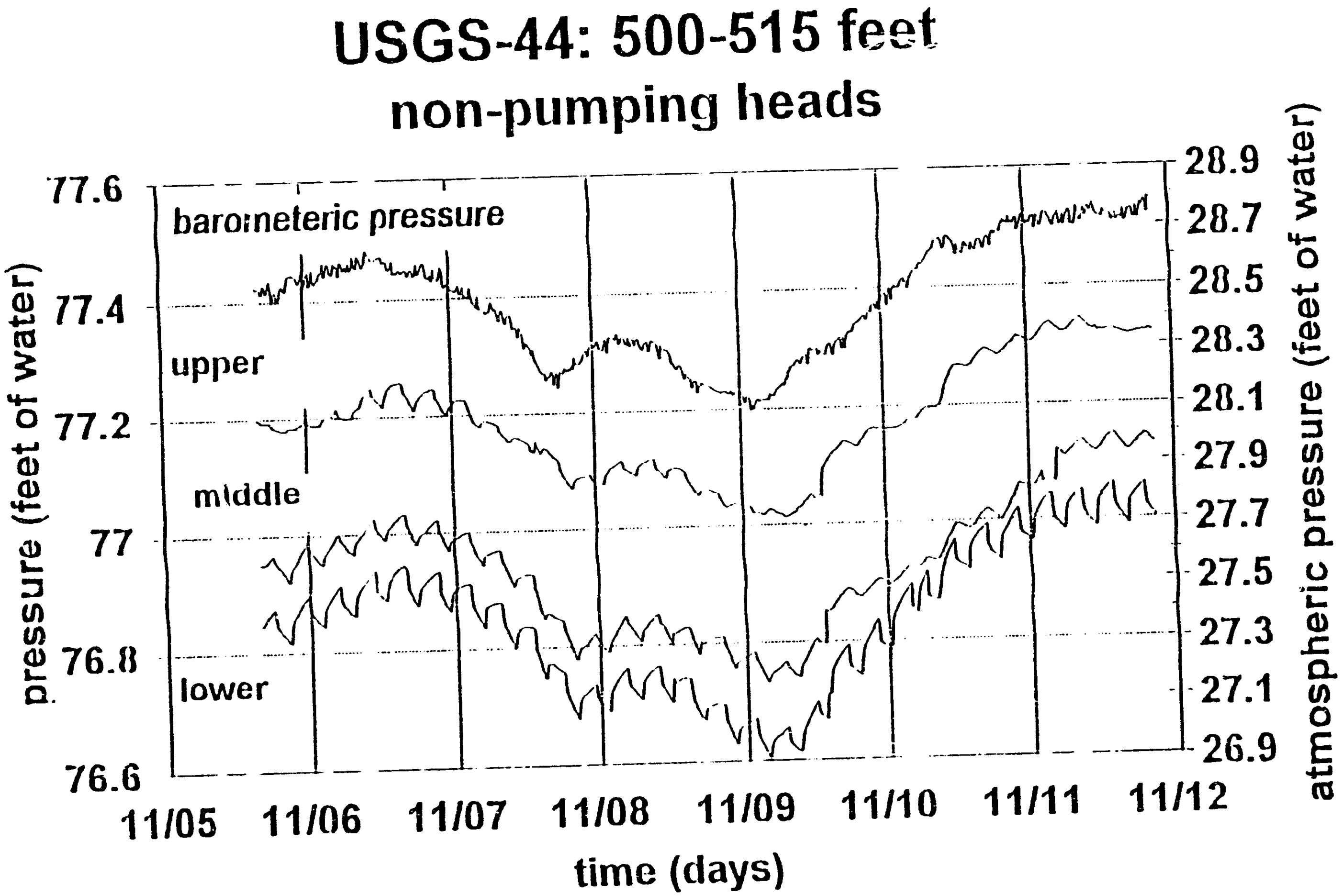

Figure 4. Non-pumping heads in well USGS-44, 500-515 feet during a 6 day monitoring period showing water level fluctuations in response to pumping from the ICPP production wells and changes in barometric pressure. Barometric pressure scale (right) is twice the hydrostatic pressure scale (left).

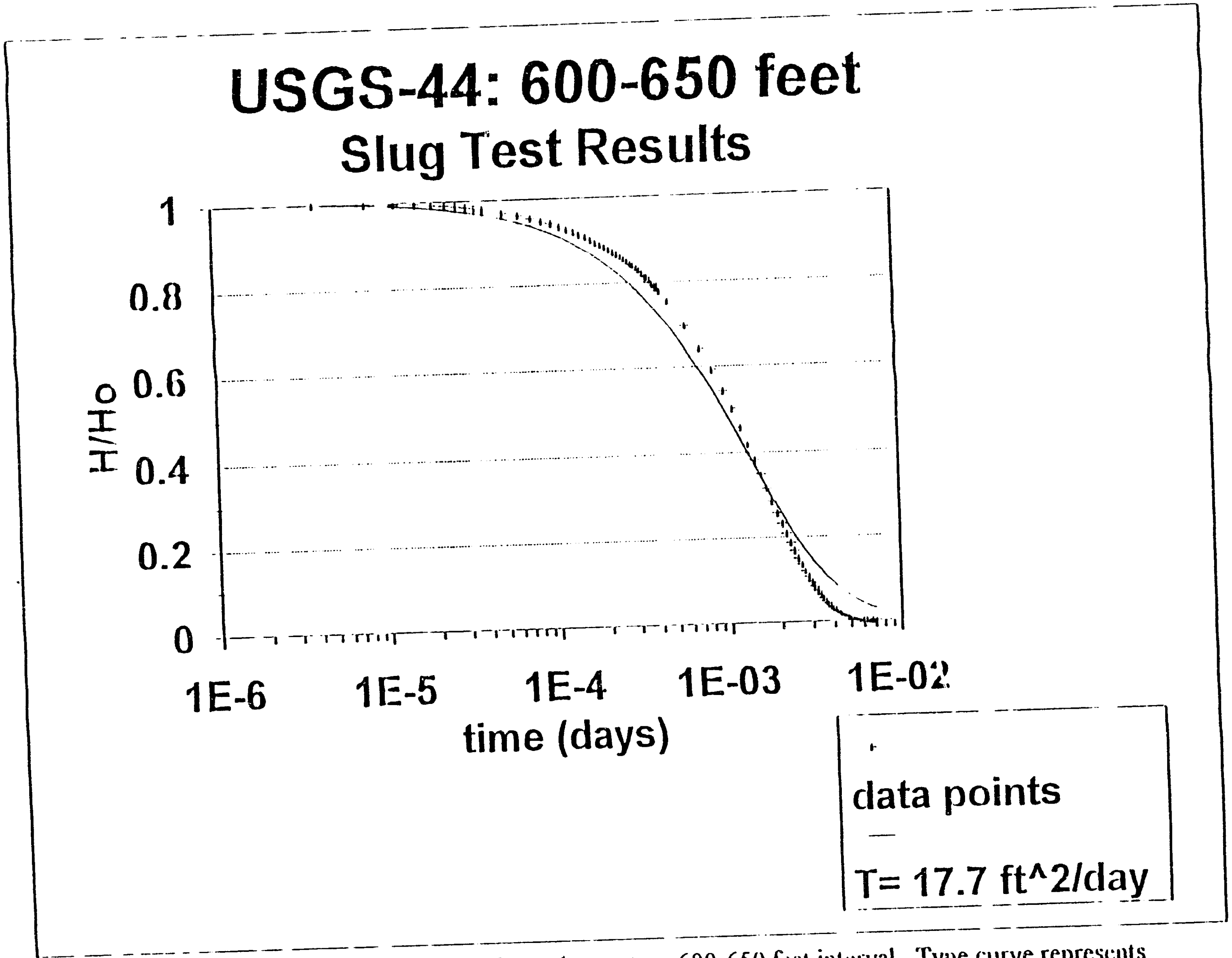

Figure 5. Graph of H/Ho vs. time from slug test on 600-650 feet interval. Type curve represents theoretical head changes for a transmissivity of 17.7 ft^2/day. Note the deviations of the data points from the type curve due to slow valve opening times and violations of slug test assumptions.

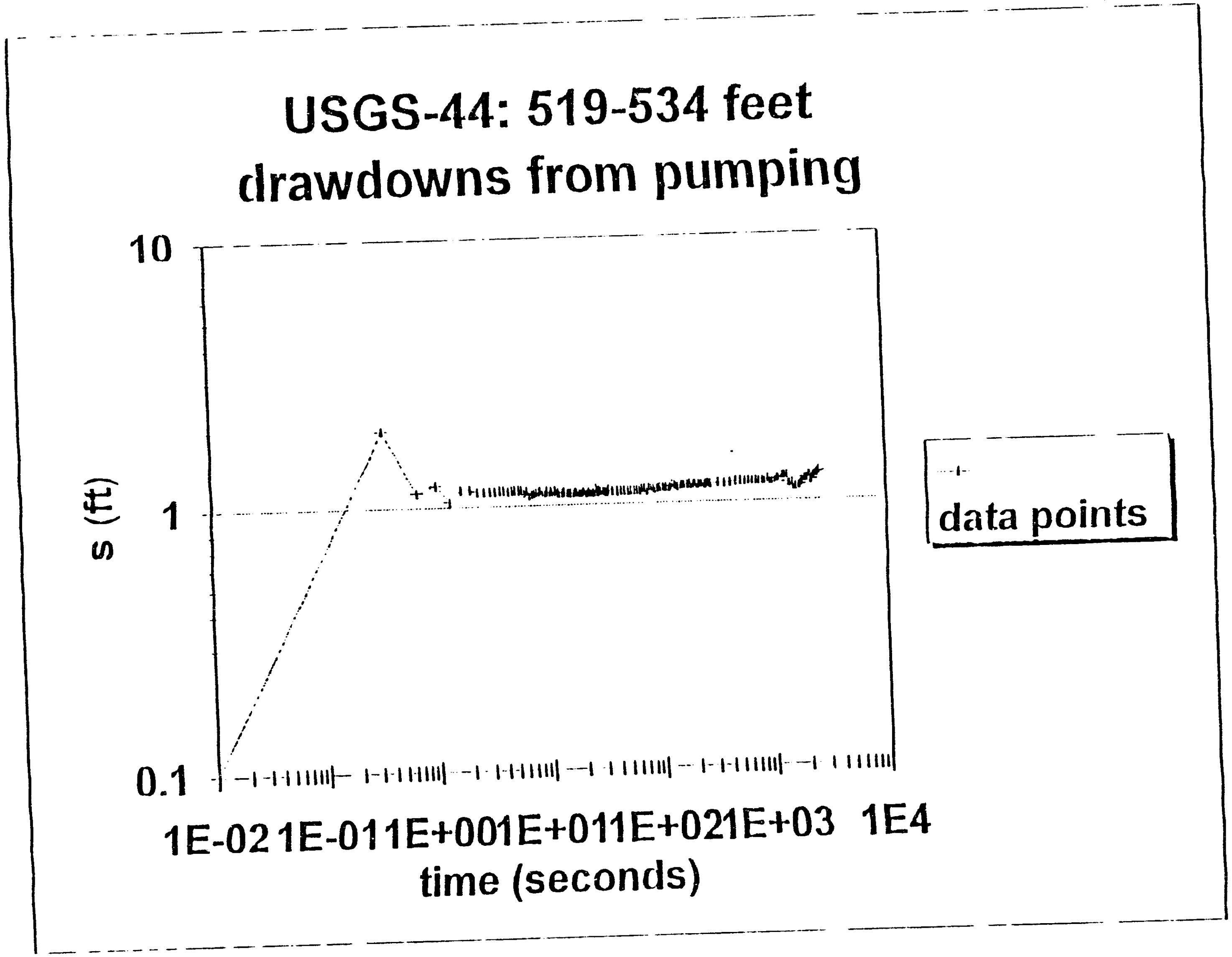

Figure 6. Log-log plot of drawdown vs. time for interval 519-534 feet. Q = ~20 gpm. Note that all drawdown occurred within 0.34 seconds.

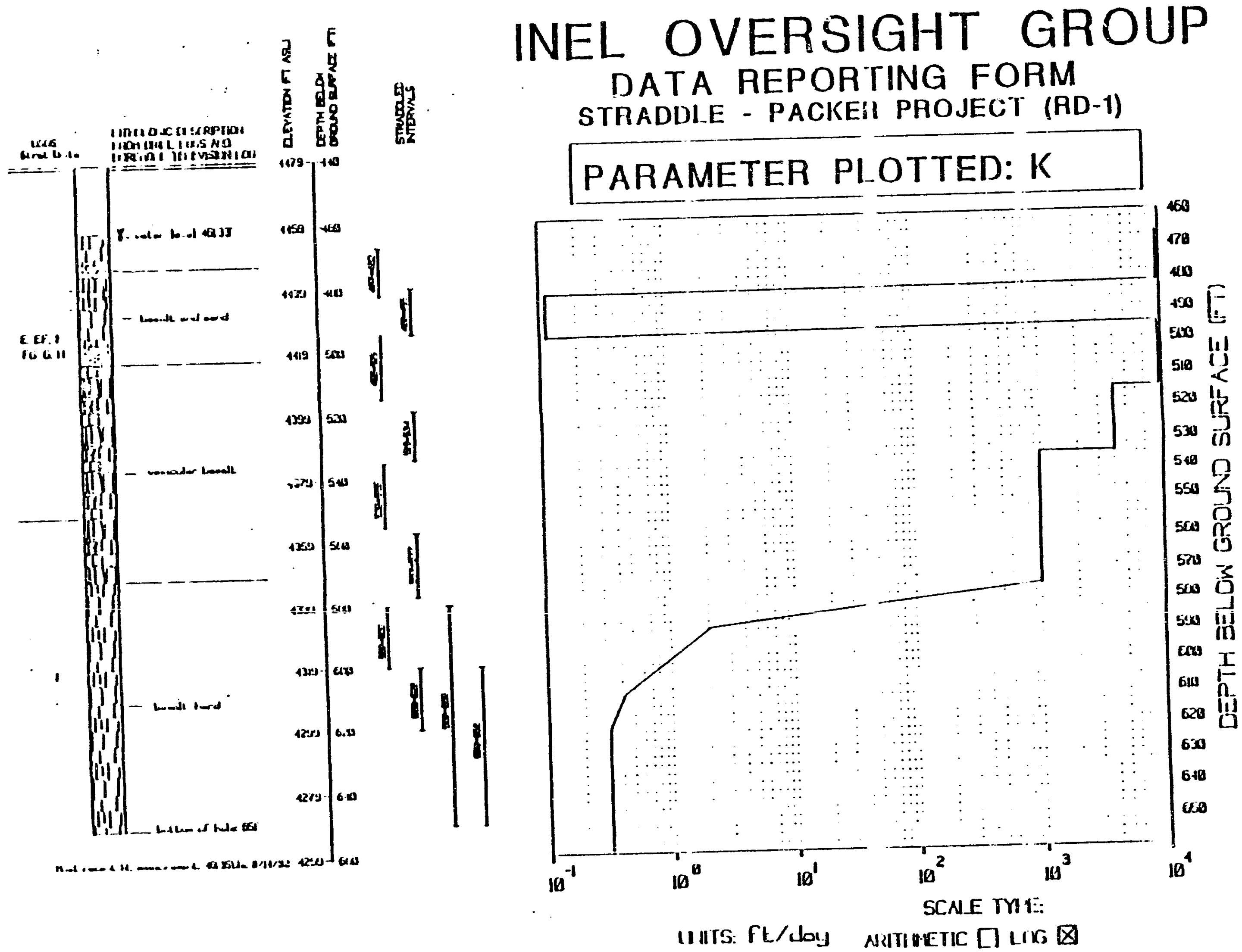

Figure 7. Distribution of average hydraulic conductivity in well USGS-44. Low hydraulic conductivity intervals determined from slug tests, high hydraulic conductivity intervals from Morin et al. (in press).

INEL OVERSIGHT GROUP

DATA REPORTING FORM

STRADDLE - PACKER PROJECT (RD-1)

PARAMETER PLOTTED: head

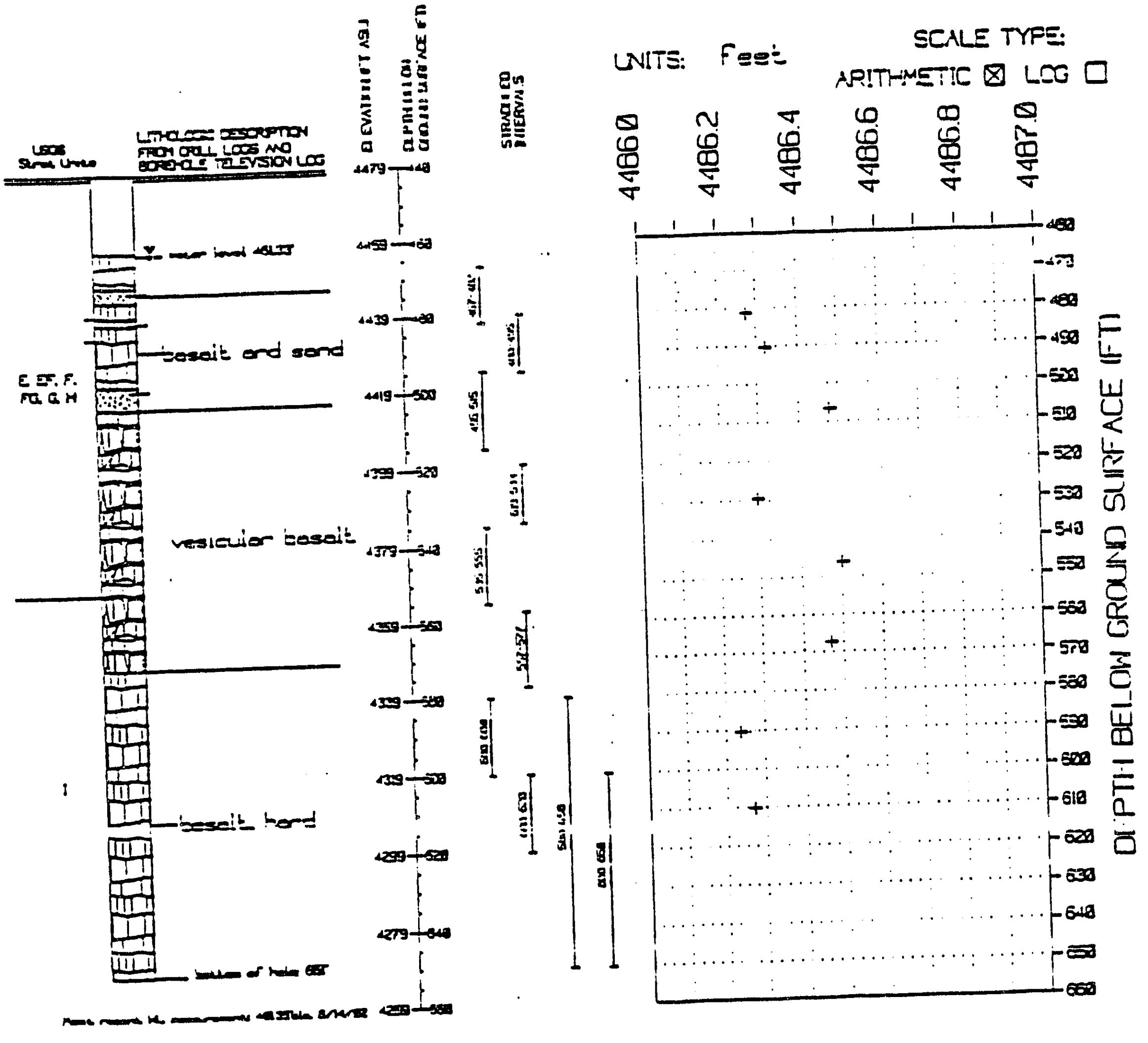

Figure 8. Distribution of hydraulic head in well USGS-44.

APPENDIX C

PRELIMINARY RESULTS FROM: IDAHO GROUND-WATER QUALITY WORKSHOP

"VERTICAL VARIATIONS IN GROUNDWATER CHEMISTRY NEAR THE CPP: IMPLICATIONS FOR GROUNDWATER MONITORING AT THE INEL"

VERTICAL VARIATIONS IN GROUNDWATER CHEMISTRY NEAR THE CPP: IMPLICATIONS FOR GROUNDWATER MONITORING AT THE INEL

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Detailed chemical analyses have been obtained from samples collected at USGS monitoring well #44 with the INEL Oversight Program straddle packer system. The analytical data include field measurements of transient fluid parameters using a flow cell system, and laboratory instrumental analyses of a wide spectrum of inorganic and organic parameters. Additional duplicate samples were also collected for analyses of a variety of stable and radioactive isotopes; analyses of these samples were not available at the time of preparation of this abstract.

Seven well intervals, varying from 15 to 20 feet in length, were sampled. The upper six were packed off on both sides with the straddle packer tool. A lithium bromide tracer test was performed for each, prior to sampling, to insure that the intervals had been isolated from upper and lower portions of the well by the packer. The lower interval, from 580 to 640 feet (base of the well) was packed only at the top.

The upper five packed intervals, over a depth range of 467 to 577 feet, appear relatively uniform in chemical composition. Constituents occur at concentration levels comparable to previous measurements based on bailer and USGS well pump tests.

Most constituents exhibit little or no systematic variability in concentration over the sampled intervals. However, a stepwise change in the concentrations of several chemical compounds occurs at a depth of between 557 and 580 feet. Below this a variety of compounds, including silica, sodium, potassium, magnesium, chloride, fluoride, and nitrate+nitrite, increase in concentration by from 10 to 50%. Chloride increase correlates on a charge balance basis with increases in sodium and potassium. Calcium, on the other hand, mirrors these increases, decreasing downward by 13% (from 60 to 52 ppm).

The break in trends of water chemistry correlates with a reduction in permeability of the sampled intervals of more than an order of magnitude (K values drop from about $10^{3.5}$ to less than 10^{2}). The pattern of changes in water composition near the base of Well #44 and correlation with permeability change suggests that solutes injected into the aquifer at the CPP may remain in lower portions of the aquifer system.

VERTICAL VARIATIONS IN GROUNDWATER CHEMISTRY NEAR THE CPP: IMPLICATIONS FOR GROUNDWATER MONITORING AT THE INEL

ISU/IGS GEOCHEMISTRY TEAM:

Mike McCurry, Jeanne Fromm (ISU)
John Welhan (IGS)
* Mason Estes (ISU)

FUNDING AND LOGISTICAL SUPPORT:
Idaho State Department of Health & Welfare

PROBLEM

- Is there a three-dimensional chemical structure to the aquifer system underlying the INEL?

OBJECTIVES

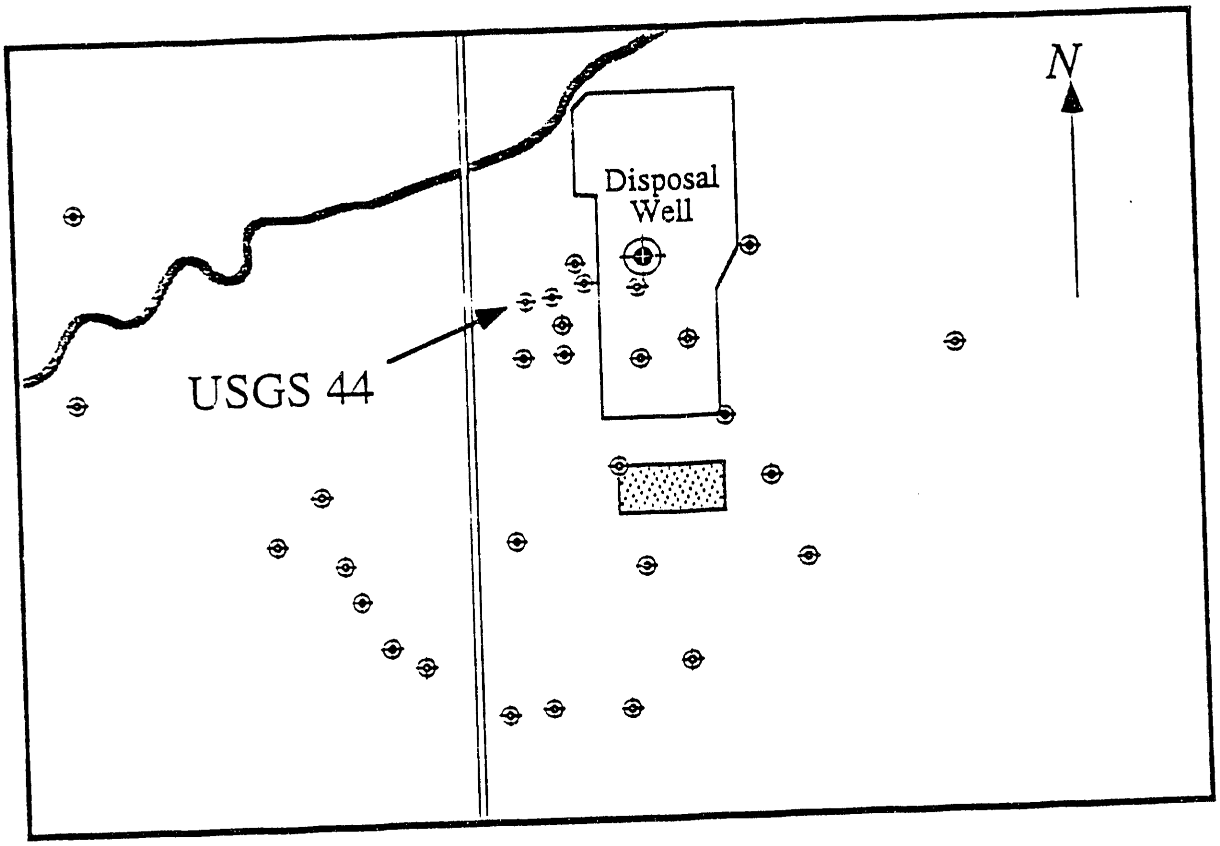
Near-term:

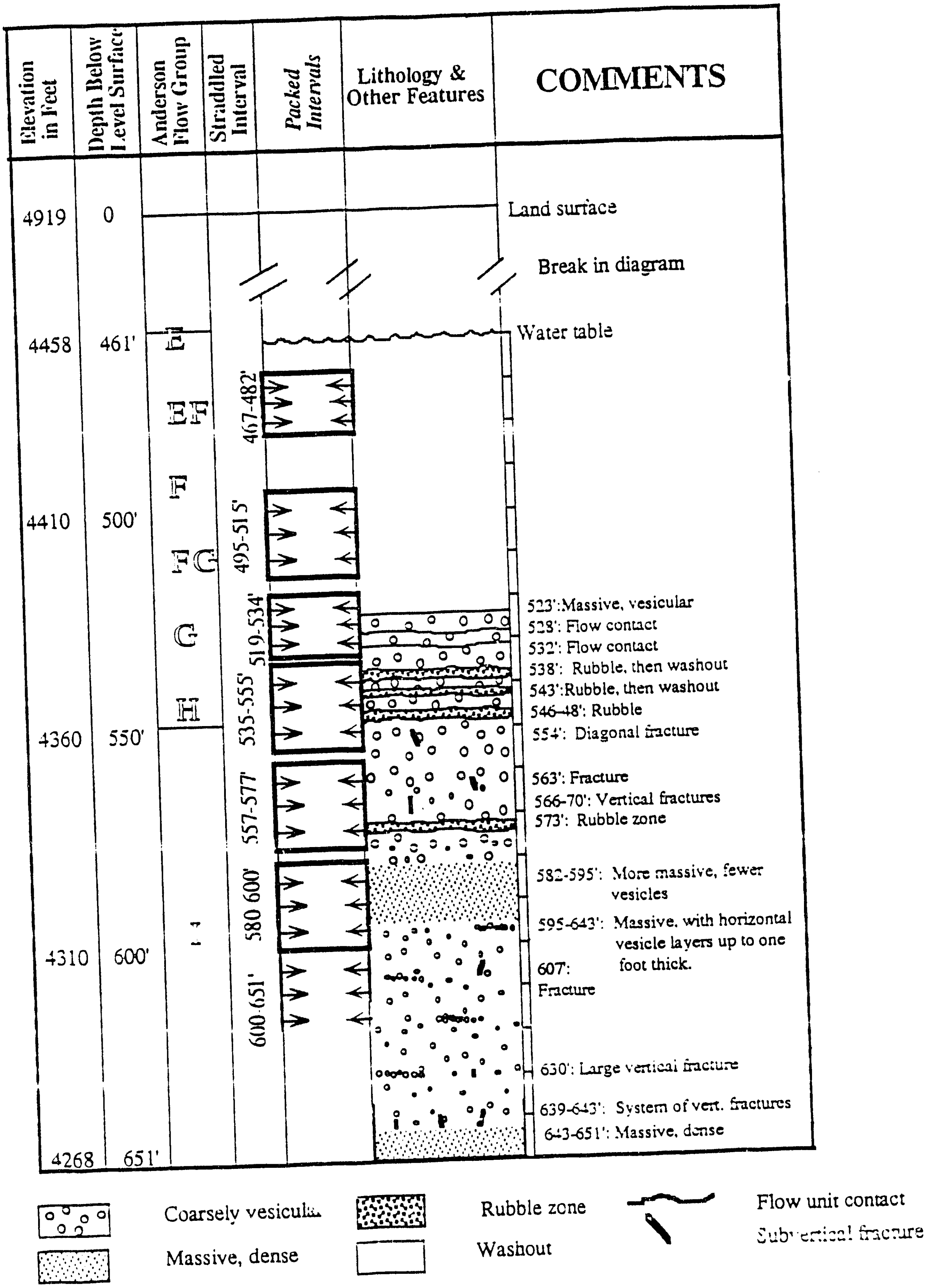
- Obtain a representation of the vertical chemical and isotopic structure of the aquifer system at USGS 44
- Compare and contrast the chemical profile with in-situ monitoring system data
- Correlate water quality data with country-rock lithology and structure, well flow patterns and permeability characteristics

Long-term goals:

- Estimate volumes/scales of geochemically distinct reservoirs
- Determine the origin of vertical variations in water quality
- Recommend improvements for future monitoring activities

Idaho Chemical Processing Plant and Aquifer Monitoring Wells

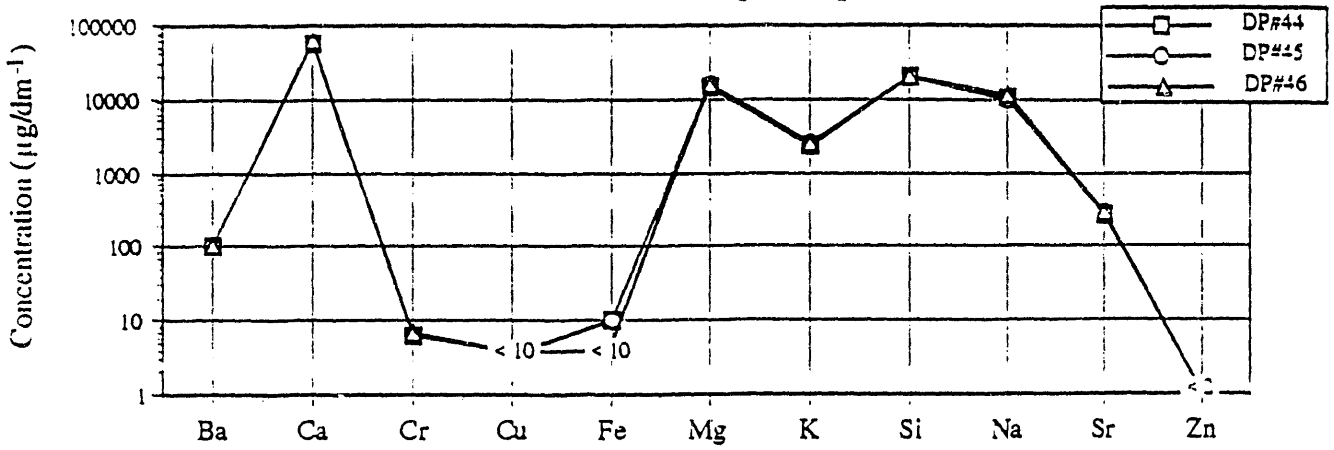




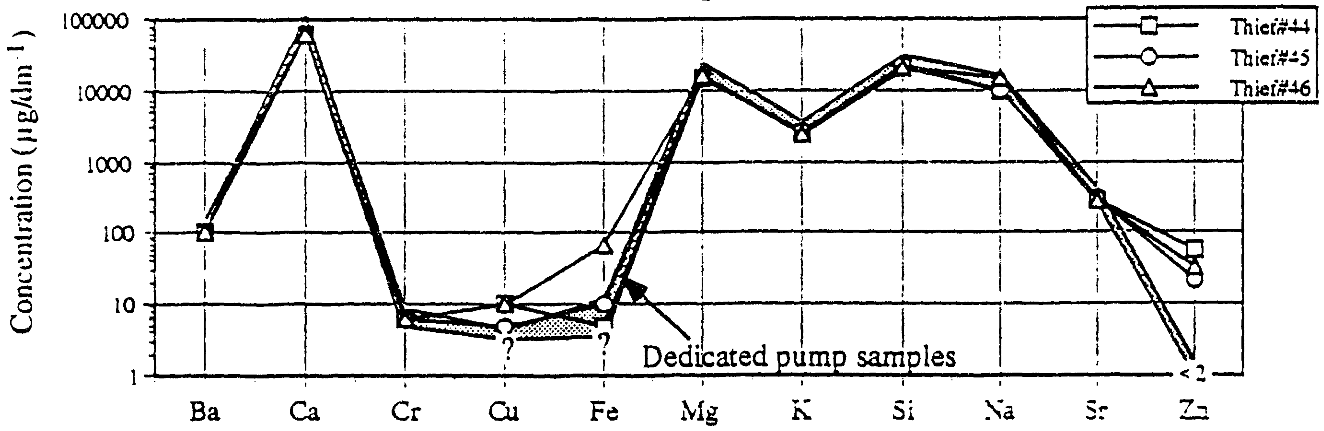
Elevation in Feet
Depth Below Level Surface
Anderson Flow Group
Straddled Interval
Packed Intervals
Lithology & Other Features
COMMENTS
4919
0
Land surface
Break in diagram
4458
461'
Water table
467-482'
4410
500'
495-515'
519-534'
535-555'
4360
550'
557-577'
580-600'
4310
600'
600-651'
4268
651'
E
F
G
H
523':Massive, vesicular
528': Flow contact
532': Flow contact
538': Rubble, then washout
543':Rubble, then washout
546-48': Rubble
554': Diagonal fracture
563': Fracture
566-70': Vertical fractures
573': Rubble zone
582-595': More massive, fewer vesicles
595-643': Massive, with horizontal vesicle layers up to one foot thick.
607: Fracture
630': Large vertical fracture
639-643': System of vert. fractures
643-651': Massive, dense
Coarsely vesicular
Massive, dense
Rubble zone
Washout
Flow unit contact
Subvertical fracture

Comparison of dissolved metals for thief, dedicated pump and packer samples for USGS wells #44, 45, and 46

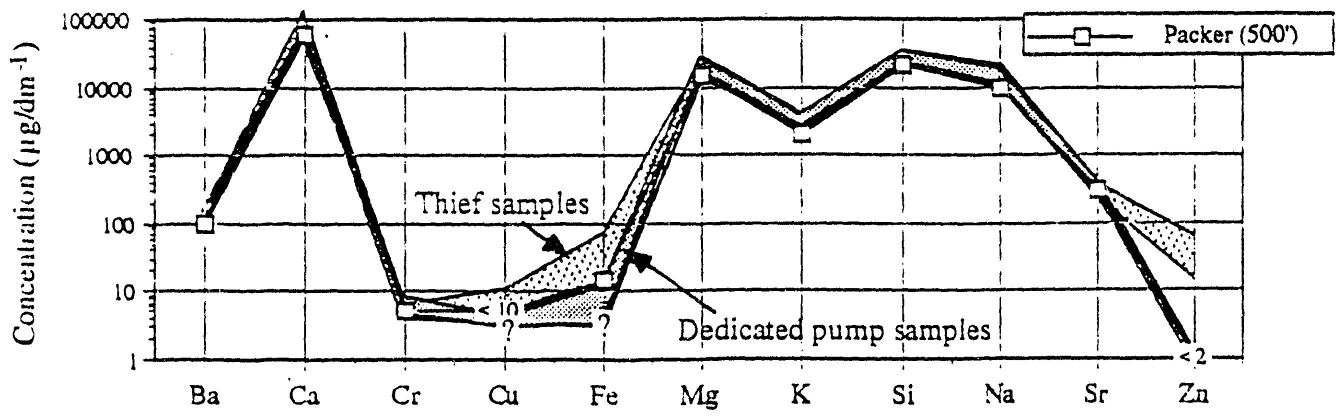
USGS Dedicated Pump Samples (500')



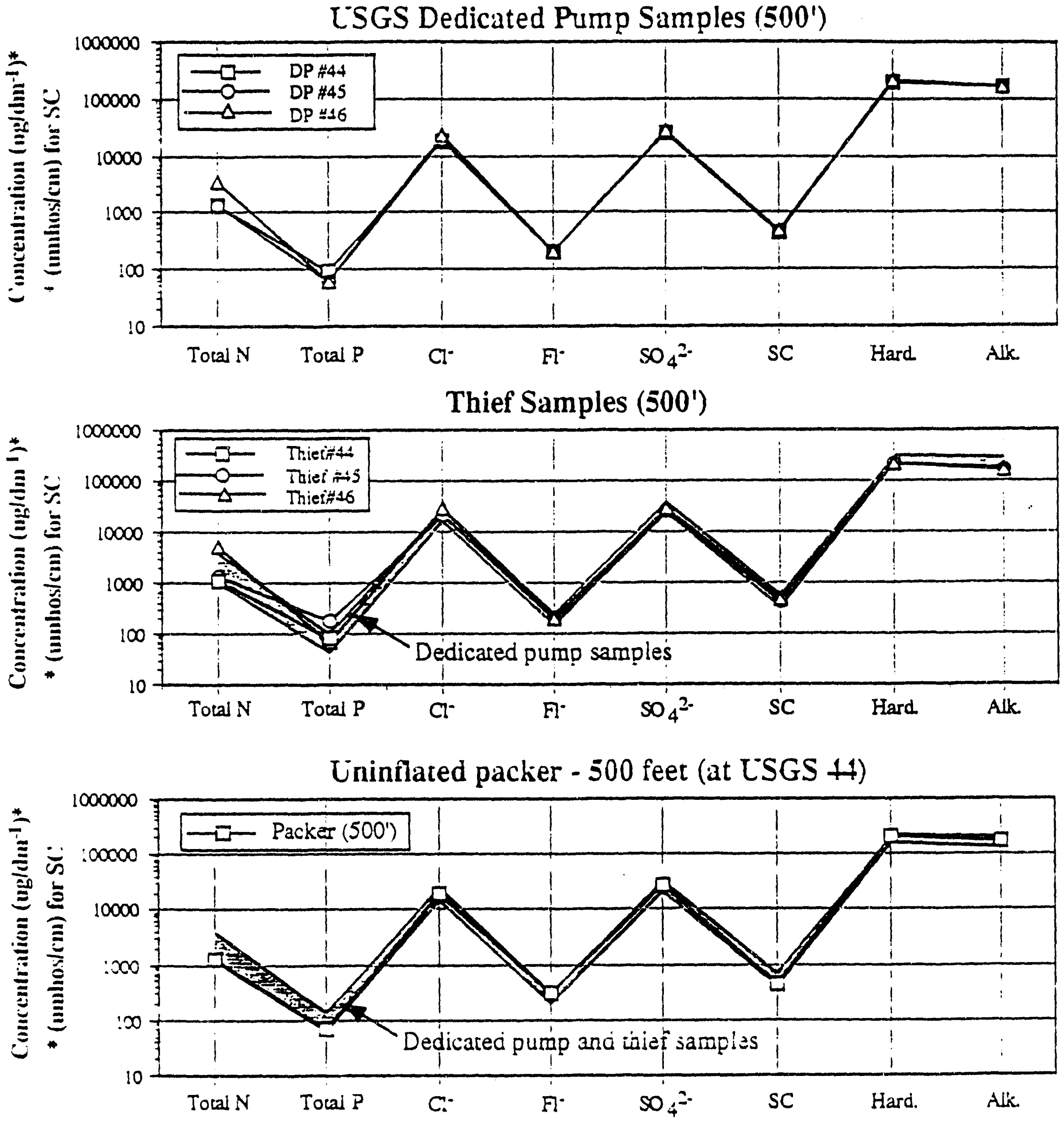
Thief Samples (500')

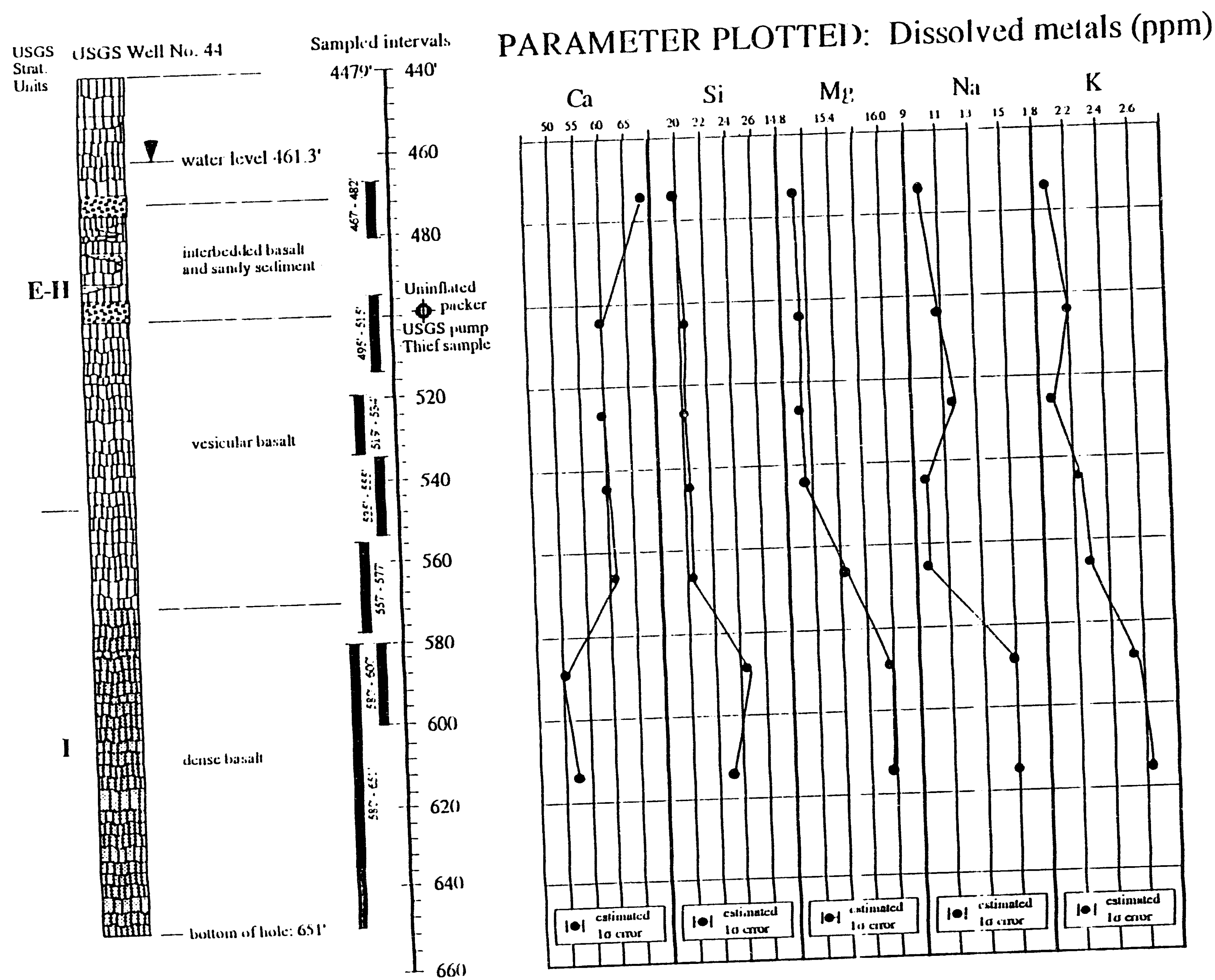


Uninflated packer - 500 feet (at USGS 44)

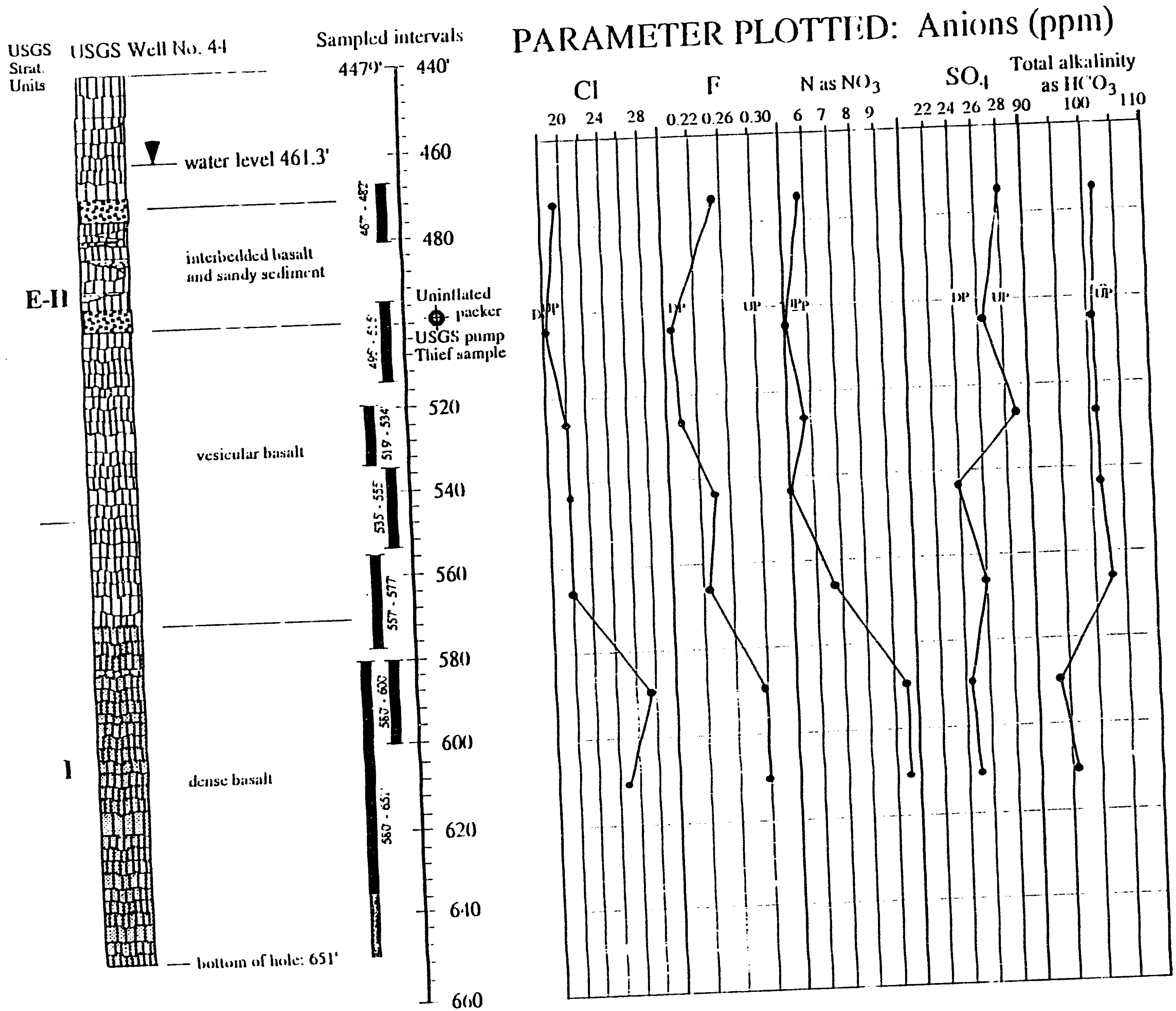


Comparison of nonmetals for thief, dedicated pump and packer samples for USGS wells #44, 45, and 46

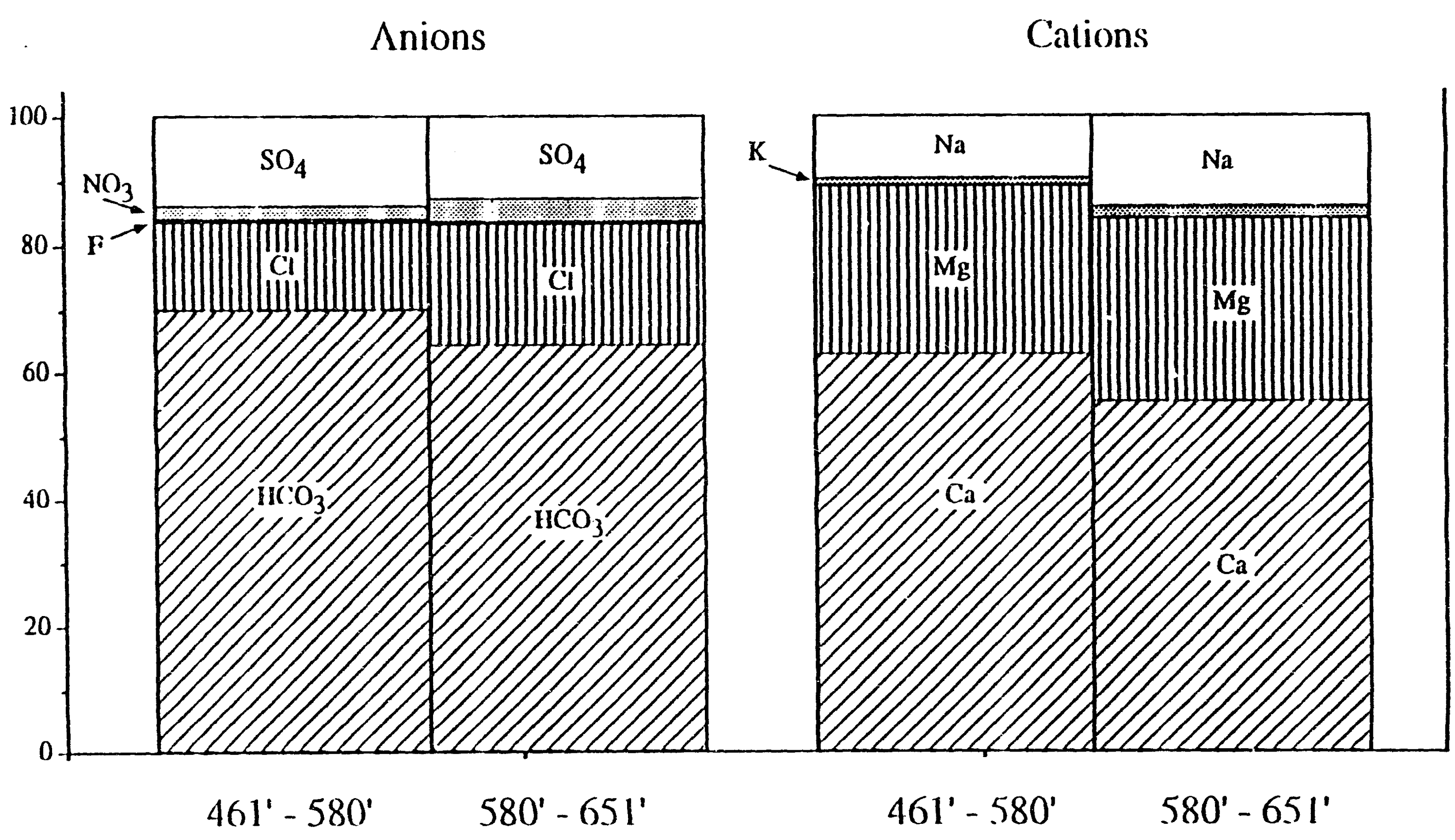




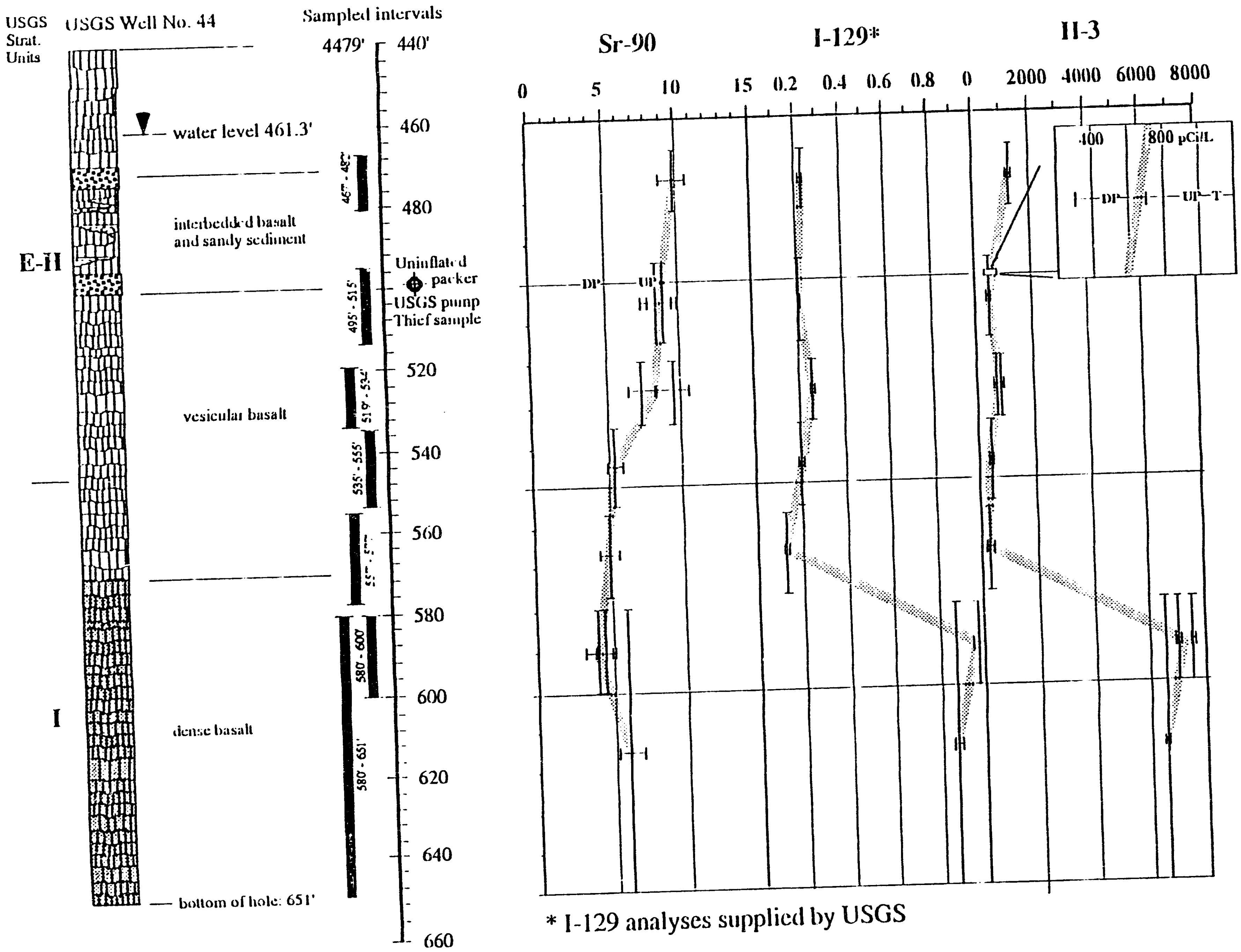
USGS Strat. Units
USGS Well No. 44
Sampled intervals
PARAMETER PLOTTED: Dissolved metals (ppm)
4479'
440'
460
480
520
540
560
580
600
620
640
660
water level 461.3'
interbedded basalt and sandy sediment
vesicular basalt
dense basalt
bottom of hole: 651'
E-II
I
Uninflated packer
USGS pump
Thief sample
467 - 482'
495' - 515'
517 - 534'
535' - 555'
557 - 577'
582' - 600'
582' - 651'
Ca
Si
Mg
Na
K
50 55 60 65
20 22 24 26
14.8 15.4 16.0
9 11 13 15 18
22 24 26
estimated 1σ error


PARAMETER PLOTTED: Anions (ppm)
USGS Strat. Units
USGS Well No. 44
Sampled intervals
4470'
440'
water level 461.3'
interbedded basalt and sandy sediment
vesicular basalt
dense basalt
bottom of hole: 651'
E-II
I
Uninflated packer
USGS pump
Thief sample
Cl
F
N as NO3
SO4
Total alkalinity as HCO3
460
480
520
540
560
580
600
620
640
660

Percent of total charged species (as meq/L)



PARAMETER PLOTTED: Radionuclides (pCi/L)



* I-129 analyses supplied by USGS

CONCLUSIONS

- Significant vertical heterogeneity in water quality occurs within USGS monitoring well #44

  Water quality is characterized by two principal water chemistries :

  - Shallow water (461 - 570 feet): relatively free of obvious anthropogenic components and remarkably homogeneous in chemistry despite significant vertical fluctuations in lithology and hydrology

  - Deep water (> 570 feet): distinguished by subtle, charge-balanced shifts in major anions and cations, and by large increases in conservative radionuclide abundances

- Shallow water chemistry is adequately sampled by the in-situ monitoring system

- Chemically distinctive deeper water probably retains anthropogenic constituents introduced during past expanded plume event(s).

- Significant amounts of contaminated water may reside in intergranular (cf. vesicular) pore spaces of basaltic lava flows (e.g. Knutson, *et al.*, 1990), largely isolated from the regional aquifer flow.

APPENDIX D:

TABULATION OF PRELIMINARY GROUND-WATER QUALITY DATA

Each column of the following table represents a specific sample, and each row represents one of the 221 individual analytes.

[illegible] WATER QUALITY DATA

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Abbreviations: SL = State Lab; UI = University of Idaho Lab; DP = Dedicated pump (USGS); UP = [illegible]; PCn - ICPP production pump on;													
2	[illegible] production pump off; DR - [illegible]; RB - [illegible] Blanks (from steam cleaner only); FB - Field Blanks (from DI water tank)													
3	2 σ analytical uncertainty for radiological parameters at 95% confidence level													
4	Well #	USGS 44	USGS44	USGS44	USGS44	USGS45	USGS45	USGS45	USGS45	USGS46	USGS46	USGS46	USGS46	USGS[illegible]
5	Sample [illegible]	DP	DP	DP	DP	DP	DP	DP	DP	DP	DP	DP	DP	[illegible]
6		SL	UI	UI/SL	USGS dup	SL	USGS dup	UI	UI/SL	SL	USGS dup	UI	UI/SL	SL
7														
8	ANALYTE													
9	Metals													
10	Al (ug/l)		<100					<100				<100		
11	Sb (ug/l)		<1					<1				<1		
12	[illegible]	<10	<1		<1.0		<10	1.3			<10	1.2		<10
13	Ba (ug/l)	100	90	3.00	100		100	30	0.50		100	90	0.90	100
14	Be (ug/l)	<5	<10		<5		<5	<10			<5	<10		<5
15	Cd (ug/l)	<1	<20		<1		<1	<20			<1	<20		<1
16	Ca (ug/l)	59,000	57000	0.97	59,000		61,000	58,000	0.95		60,000	60000	1.00	61,000
17	Cr (ug/l)	6.5	<20		6.5		6.7	<20			6.3	<20		6.3
18	Co (ug/l)		<30					<30				<30		
19	Cu (ug/l)	<10	<20		<10		<10	<20			10	<20		<10
20	Fe (ug/l)	10	<10	1.00	10		<10	<10			<10	<10		10
21	Pb (ug/l)	<5	<1		<5		<5	<1			<5	<1		<5
22	Li (ug/l)		<4					22				6		
23	Mg (ug/l)	15,000	15000	1.00	15,500		16,500	16,000	0.97		15,000	16,000	1.07	15,000
24	Mn (ug/l)	<10	<20		<10		<10	<20			<10	<20		<10
25	Hg (ug/l)	<0.5			<0.5		<0.5				<0.5			<0.5
26	Mo (ug/l)		<50					<50				<50		
27	Ni (ug/l)	<10	<50		<10		<10	<50			<10	<50		<10
28	[illegible]		20					30				40		
29	K (ug/l)	2,300	2500	1.09	2,600		2,500	3000	1.20		2,400	3000	1.25	2,600
30	[illegible]		NA					NA				NA		
31	Se (ug/l)	<5	1.7		<5		<5	1.2			<5	1.1		<5
32	SiO2 (ug/l)							11000			none	<10000		22,000
33	Si (ug/l)		10000											
34	Ag (ug/l)	<1	5		<1		<1	20			<1	<5		<1
35	Na (ug/l)	11,000	9700	0.88	10,000		10,000	10000	0.83		10,000	12000	1.22	10,000
36	Sr (ug/l)	270	310	1.16	300		290	330	1.13		290	300	1.03	310
37	Tl (ug/l)		NA					NA				NA		
38	Tl (ug/l)													
39	U (ug/l)							<50				<50		
40	V (ug/l)		<50					<20			60	<20		21
41	Zn (ug/l)	<2	<20		<2		<2	<20						
42											none			
43	Anions										none			<30
44	[illegible] (ug/l)	<30			<30		<30				none			21,000
45	Cl (ug/l)	18,000			20,000		23,000				none			2[illegible]
46	F (ug/l)	200			200		200				none			
47	Br (ug/l)										none			
48	NO3 (ug/l)										none			26,300
49	SO4 (ug/l)	24500			25,000		27,300							
50														
51	Other, non-org[illegible]		NA							10				
52	Total N as Nitrate		<50			10				10				
53	Total N as Ammonia		<20			20				2,500	1,060			1,200
54	Total N (NO3-N & NO2-[illegible]	1320			1,390	1,200	3,350				<50			<50
55	Total Kjeldahl N as N ([illegible]	<50			<50		<50			30	30			170
56	Total Phosphorus as P ([illegible]	90			60	30	50				none			439
57	[illegible]	434			420		465				none			203,000
58	Hardness as CaCO3 in [illegible]	189,000			202,000		218,000				none			160,000
59	Total Alkalinity in ug/l ([illegible]	170000			163,000		170,000							
60														
61	Radiological parameters													
62	Sr-90 (pCi/L)													
63	± Sr-90													
64	I-129 (pCi/L) (USGS)													
65	± I-129													
66	H-3 (pCi/L)													
67	± H-3													
68	[illegible] (per mil)													
69	[illegible] (per mil)													
70														

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
71	Organic analyses (ug/l)													
72	Bromodichloromethane (	ndl			ndl		ndl				ndl			
73	Bromoform (ug/l)	ndl			ndl		ndl				ndl			
74	Chloroform (ug/l)	ndl			ndl		ndl				ndl			
75	Dibromochloromethane (	ndl			ndl		ndl				ndl			
76	Vinyl chloride (ug/l)	ndl			ndl		ndl				ndl			
77	1,1-Dichloroethene (ug/l)	ndl			ndl		ndl				ndl			
78	1,1,1-Trichloroethane (ug	ndl			ndl		ndl				ndl			
79	Carbon tetrachloride (ug/l	ndl			ndl		ndl				ndl			
80	Benzene (ug/l)	ndl			ndl		ndl				ndl			
81	1,2-Dichloroethane (ug/l)	ndl			ndl		ndl				ndl			
82	Trichloroethylene (ug/l)	ndl			ndl		ndl				ndl			
83	1,4-Dichlorobenzene (ug	ndl			ndl		ndl				ndl			
84	Bromobenzene (ug/l)	ndl			ndl		ndl				ndl			
85	Bromochloromethane (ug	ndl			ndl		ndl				ndl			
86	Bromomethane (ug/l)	ndl			ndl		ndl				ndl			
87	n-Butylbenzene (ug/l)	ndl			ndl		ndl				ndl			
88	sec-Butylbenzene (ug/l)	ndl			ndl		ndl				ndl			
89	tert-Butylbenzene (ug/l)	ndl			ndl		ndl				ndl			
90	Chlorobenzene (ug/l)	ndl			ndl		ndl				ndl			
91	Chloroethane (ug/l)	ndl			ndl		ndl				ndl			
92	Chloromethane (ug/l)	ndl			ndl		ndl				ndl			
93	2-Chlorotoluene (ug/l)	ndl			ndl		ndl				ndl			
94	[illegible]	ndl			ndl		ndl				ndl			
95	1,2-Dibromo-3-chloroprop	ndl			ndl		ndl				ndl			
96	1,2-Dibromoethane (EDB	ndl			ndl		ndl				ndl			
97	Dibromomethane (ug/l)	ndl			ndl		ndl				ndl			
98	1,3-Dichlorobenzene (ug/	ndl			ndl		ndl				ndl			
99	1,2-Dichlorobenzene (ug/	ndl			ndl		ndl				ndl			
100	Dichlorodifluoromethane	ndl			ndl		ndl				ndl			
101	1,1-Dichloroethane (ug/l)	ndl			ndl		ndl				ndl			
102	cis-1,2-Dichloroethene (u	ndl			ndl		ndl				ndl			
103	trans-1,2-Dichloroethene	ndl			ndl		ndl				ndl			
104	1,2-Dichloropropane (ug/	ndl			ndl		ndl				ndl			
105	1,3-Dichloropropane (ug/	ndl			ndl		ndl				ndl			
106	2,2-Dichloropropane (ug/	ndl			ndl		ndl				ndl			
107	1,1-Dichloropropene (ug/	ndl			ndl		ndl				ndl			
108	cis-1,3-Dichloropropene (	ndl			ndl		ndl				ndl			
109	trans-1,3-Dichloropropen	ndl			ndl		ndl				ndl			
110	Ethylbenzene (ug/l)	ndl			ndl		ndl				ndl			
111	Hexachlorobutadiene (ug/	ndl			ndl		ndl				ndl			
112	Isopropylbenzene (ug/l)	ndl			ndl		ndl				ndl			
113	p-Isopropyltoluene (ug/l)	ndl			ndl		ndl				ndl			
114	Methylene chloride (ug/l	ndl			ndl		ndl				ndl			
115	Naphthalene (ug/l)	ndl			ndl		ndl				ndl			
116	n-Propylbenzene (ug/l)	ndl			ndl		ndl				ndl			
117	Styrene (ug/l)	ndl			ndl		ndl				ndl			
118	1,1,1,2-Tetrachloroethane	ndl			ndl		ndl				ndl			
119	1,1,2,2-Tetrachloroethane	ndl			ndl		ndl				ndl			
120	Tetrachloroethene (ug/l)	ndl			ndl		ndl				ndl			
121	Toluene (ug/l)	ndl			ndl		ndl				ndl			
122	1,2,3-Trichlorobenzene (u	ndl			ndl		ndl				ndl			
123	1,2,4-Trichlorobenzene (u	ndl			ndl		ndl				ndl			
124	1,1,2-Trichloroethane (ug	ndl			ndl		ndl				ndl			
125	Trichlorofluoromethane (	ndl			ndl		ndl				ndl			
126	1,2,3-Trichloropropane (u	ndl			ndl		ndl				ndl			
127	1,2,4-Trimethylbenzene (	ndl			ndl		ndl				ndl			
128	1,3,5-Trimethylbenzene (	ndl			ndl		ndl				ndl			
129	m-Xylene + p-Xylene (ug	ndl			ndl		ndl				ndl			
130	o-Xylene (ug/l)	ndl			ndl		ndl							
131	Acenaphthene	ndl			ndl		ndl							
132	Acenaphthylene, µg/L	ndl			ndl		ndl							
133	Aldrin	ndl			ndl		ndl							
134	Aniline, µg/L	ndl			ndl		ndl							
135	Anthracene	ndl			ndl		ndl							
136	Aroclor 1016	ndl			ndl		ndl							
137	Aroclor 1221	ndl			ndl		ndl							
138	Aroclor 1232	ndl			ndl		ndl							
139	Aroclor 1242	ndl			ndl		ndl							
140	Aroclor 1248	ndl			ndl		ndl							

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
141	Aroclor-1254	nd			nd		nd							
142	Aroclor-1260	nd			nd		nd							
143	Benzoic acid	nd			nd		nd							
144	Benzo(a)anthracene	nd			nd		nd							
145	Benzo(b)fluoranthene	nd			nd		nd							
146	Benzo(k)fluoranthene	nd			nd		nd							
147	Benzo(g,h,i)perylene	nd			nd		nd							
148	Benzo(a)pyrene	nd			nd		nd							
149	Benzyl alcohol	nd			nd		nd							
150	a-BHC	nd			nd		nd							
151	b-BHC	nd			nd		nd							
152	d-BHC	nd			nd		nd							
153	g-BHC (Lindane)	nd			nd		nd							
154	Bis(2-chloroethoxy) meth	nd			nd		nd							
155	Bis (2-chloroethyl) ether	nd			nd		nd							
156	Bis(2-chloroisopropyl) et	nd			nd		nd							
157	Bis(2-ethylhexyl) phthala	nd			nd		nd							
158	4-Bromophenyl phenyl et	nd			nd		nd							
159	Butyl benzyl phthalate	nd			nd		nd							
160	Chlordane	nd			nd		nd							
161	4-Chloro-3-methylphenol	nd			nd		nd							
162	1-Chloronaphthalene	nd			nd		nd							
163	2-Chloronaphthalene	nd			nd		nd							
164	2-Chlorophenol	nd			nd		nd							
165	4-Chlorophenyl phenyl et	nd			nd		nd							
166	Chrysene	nd			nd		nd							
167	4,4'-DDD	nd			nd		nd							
168	4,4'-DDE	nd			nd		nd							
169	4,4'-DDT	nd			nd		nd							
170	Dibenzo(a,h)anthracene	nd			nd		nd							
171	Dibenzofuran	nd			nd		nd							
172	Di-n-butyl phthalate	nd			nd		nd							
173	3,3'-Dichlorobenzidine	nd			nd		nd							
174	2,4-Dichlorophenol, [illegible]	nd			nd		nd							
175	Dieldrin	nd			nd		nd							
176	Diethyl phthalate, [illegible]	nd			nd		nd							
177	2,4-Dimethylphenol	nd			nd		nd							
178	Dimethyl phthalate	nd			nd		nd							
179	4,6-Dinitro-2-methylphen	nd			nd		nd							
180	2,4-Dinitrophenol	nd			nd		nd							
181	2,4-Dinitrotoluene	nd			nd		nd							
182	2,6-Dinitrotoluene	nd			nd		nd							
183	Diphenylamine	nd			nd		nd							
184	1,2-Diphenylhydrazine	nd			nd		nd							
185	Di-n-octyl phthalate, [illegible]	nd			nd		nd							
186	Endosulfan I	nd			nd		nd							
187	Endosulfan II	nd			nd		nd							
188	Endosulfan sulfate	nd			nd		nd							
189	Endrin	nd			nd		nd							
190	Endrin aldehyde	nd			nd		nd							
191	Endrin ketone	nd			nd		nd							
192	Fluoranthene	nd			nd		nd							
193	Fluorene	nd			nd		nd							
194	Heptachlor	nd			nd		nd							
195	Heptachlor epoxide	nd			nd		nd							
196	Hexachlorobenzene	nd			nd		nd							
197	Hexachlorobutadiene	nd			nd		nd							
198	Hexachlorocyclopentadie	nd			nd		nd							
199	Hexachloroethane	nd			nd		nd							
200	Indeno(1,2,3-cd)pyrene	nd			nd		nd							
201	Isophorone	nd			nd		nd							
202	2-Methylnaphthalene	nd			nd		nd							
203	Naphthalene	nd			nd		nd							
204	2-Nitroaniline	nd			nd		nd							
205	3-Nitroaniline	nd			nd		nd							
206	4-Nitroaniline	nd			nd		nd							
207	Nitrobenzene	nd			nd		nd							
208	2-Nitrophenol	nd			nd		nd							
209	4-Nitrophenol	nd			nd		nd							
210	[illegible]	nd			nd		nd							

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
211	N-Nitrosodiphenylamine	nd			nd		nd							
212	N-Nitrosodi-n-propylamine	nd			nd		nd							
213	Pentachlorophenol	nd			nd		nd							
214	Phenanthrene	nd			nd		nd							
215	Phenol	nd			nd		nd							
216	Pyrene	nd			nd		nd							
217	Toxaphene	nd			nd		nd							
218	1,2,4-Trichlorobenzene	nd			nd		nd							
219	2,4,5-Trichlorophenol	nd			nd		nd							
220	2,4,6-Trichlorophenol	nd			nd		nd							
221	Trifluralin	nd			nd		nd							

[illegible] Sum92 WaterQual Data

Row	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
1															
2															
3										USGS44	USGS44	USGS44	USGS44	USGS44	USGS44
4	[illegible]	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	495-515	495-515	495-515	495-515	519-534	519-534
5	Dup	Thick	UP-150	UP-150	467-482	467-493	467-484	467-484	467-482	SL	USGS	SL	ISL/CL	SL	USGS
6	SL	SL	SL	SL-dup	SL	USGS	UI	ISL/CL	UI/USGS	POn	POn	POH			
7															
8															
9							<100								
10							7.5								
11						<10	1.4				<10	<10		<10	<10
12	<10	20	<10	<10		100	100		1.00		<100	<100		100	100
13	[illegible]	<100	100	<100		<5	<10				<5	<5		<5	<5
14	<5	<3	<2	<2		<1	<20				<1	<1		<1	<1
15	<1	[illegible]	<1	<1					[illegible]		20,000	20,000		21,000	[illegible]
16	21,700	100	50,000	58,000		50,000	56,000				5.3	5.9		6	5.5
17	5	<5	5.5	5.5		5.5	<20								
18							<30				<10	<10		<10	<10
19		<10	<10	<10		<20	<20				10	<10		<10	<10
20	[illegible]	20	20	<10		10	<10				<5	<5		<5	<5
21	<5	20	<5	<5		<5	25								
22									1.00		15,000	15,000		15,000	[illegible]
23	10,000	9,700	15,000	15,000		15,000	15,000				<10	<10		<10	<10
24	<10	<10	<10	<10		<10	<25				<0.5	<0.5		<0.5	<0.5
25	<0.5	<0.5	<0.5	<0.5		<0.5									
26							<50				<10	<10		<10	<10
27	<50	21	<10	<10		<10	<50								
28							<5				2,000	2,000		2,000	2,000
29	2,000	9,000	2,100	2000		2,200	2000		1.01						
30							NA				<5	<5		<5	<5
31	<5	20	<5	<5		<5	1.5		1.01		21,200	20,400		20,000	21,000
32	20,000		21,200	19,900		21,200									
33							10000				<1	<1		<1	<1
34	<1	<1	<1	<1		<1	2		0.30		10,000	12,000		11,000	10,000
35	15,000	9,400	10,000	10,000		11,000	9400		1.00		310	310		310	310
36	280	<1	310	300		300	300								
37							NA								
38									2					2	
39															
40							<50				<2	<2		<2	<2
41	32	23	<2	<2		<2	<20								
42															
43											<80	<80		<90	<90
44	120	<30	<30	<80		<30					18,000	20,000		20,000	20,000
45	[illegible]	[illegible]	[illegible]	20,000		19,000					200	200		200	[illegible]
46	[illegible]	970	130	200		180									
47															
48											27,000	28,000		30,000	[illegible]
49	23,200	19,700	25,000	28,000		26,000									
50															
51										10					
52					10					10					
53					20					1,100	1,070	none		[illegible]	[illegible]
54	[illegible]	27	[illegible]	[illegible]	1,020	[illegible]					<50	none		<50	[illegible]
55	<50	3,000	<50	<50		<50				30	<50	none		<50	[illegible]
56	[illegible]	5,410	60	<50	30	<50					435	421		430	435
57	[illegible]	[illegible]	441	410		427					212,000	202,000		200,000	208,000
58	[illegible]	<1000	203,000	200,000		212,000					165,000	170,000		162,000	170,000
59	[illegible]	<1000	170,000	171,000		165,000									
60															
61									9.8					3.8	
62									1.0					1.0	0.257
63											0.212				0.206
64						0.220					0.205				
65						0.205								[illegible]	
66									1000					[illegible]	
67									100					[illegible]	
68									-135.3					-125.3	
69									17.9					17.9	
70															

INEL\OR Sum92\WaterQual Data

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
71															
72		nd	nd	nd		nd					nd	nd		nd	nd
73		nd	nd	nd		nd					nd	nd		nd	nd
74		nd	nd	nd		nd					nd	nd		nd	nd
75		nd	nd	nd		nd					nd	nd		nd	nd
76		4.03	nd	nd		nd					nd	nd		nd	nd
77		4.61	nd	nd		nd					nd	nd		nd	nd
78		[illegible]	nd	nd		nd					nd	nd		nd	nd
79		[illegible]	nd	nd		nd					nd	nd		nd	nd
80		[illegible]	nd	nd		nd					nd	nd		nd	nd
81		[illegible]	nd	nd		nd					nd	nd		nd	nd
82		5.31	nd	nd		nd					nd	nd		nd	nd
83		4.82	nd	nd		nd					nd	nd		nd	nd
84		nd	nd	nd		nd					nd	nd		nd	nd
85		nd	nd	nd		nd					nd	nd		nd	nd
86		nd	nd	nd		nd					nd	nd		nd	nd
87		nd	nd	nd		nd					nd	nd		nd	nd
88		nd	nd	nd		nd					nd	nd		nd	nd
89		nd	nd	nd		nd					nd	nd		nd	nd
90		nd	nd	nd		nd					nd	nd		nd	nd
91		nd	nd	nd		nd					nd	nd		nd	nd
92		nd	nd	nd		nd					nd	nd		nd	nd
93		nd	nd	nd		nd					nd	nd		nd	nd
94		nd	nd	nd		nd					nd	nd		nd	nd
95		nd	nd	nd		nd					nd	nd		nd	nd
96		nd	nd	nd		nd					nd	nd		nd	nd
97		nd	nd	nd		nd					nd	nd		nd	nd
98		nd	nd	nd		nd					nd	nd		nd	nd
99		nd	nd	nd		nd					nd	nd		nd	nd
100		nd	nd	nd		nd					nd	nd		nd	nd
101		nd	nd	nd		nd					nd	nd		nd	nd
102		nd	nd	nd		nd					nd	nd		nd	nd
103		nd	nd	nd		nd					nd	nd		nd	nd
104		nd	nd	nd		nd					nd	nd		nd	nd
105		nd	nd	nd		nd					nd	nd		nd	nd
106		nd	nd	nd		nd					nd	nd		nd	nd
107		nd	nd	nd		nd					nd	nd		nd	nd
108		nd	nd	nd		nd					nd	nd		nd	nd
109		nd	nd	nd		nd					nd	nd		nd	nd
110		nd	nd	nd		nd					nd	nd		nd	nd
111		nd	nd	nd		nd					nd	nd		nd	nd
112		nd	nd	nd		nd					nd	nd		nd	nd
113		nd	nd	nd		nd					nd	nd		nd	nd
114		nd	nd	nd		nd					nd	nd		nd	nd
115		nd	nd	nd		nd					nd	nd		nd	nd
116		nd	nd	nd		nd					nd	nd		nd	nd
117		nd	nd	nd		nd					nd	nd		nd	nd
118		nd	nd	nd		nd					nd	nd		nd	nd
119		nd	nd	nd		nd					nd	nd		nd	nd
120		5.15	nd	nd		nd					nd	nd		nd	nd
121		nd	nd	nd		nd					nd	1.55		1.65	2.03
122		nd	nd	nd		nd					nd	nd		nd	nd
123		nd	nd	nd		nd					nd	nd		nd	nd
124		nd	nd	nd		nd					nd	nd		nd	nd
125		nd	nd	nd		nd					nd	nd		nd	nd
126		nd	nd	nd		nd					nd	nd		nd	nd
127		nd	nd	nd		nd					nd	nd		nd	nd
128		nd	nd	nd		nd					nd	nd		nd	nd
129		nd	nd	nd		nd					nd	nd		nd	nd
130		nd	nd	nd		nd					nd	nd		nd	nd
131			nd	nd		nd					nd	nd		nd	nd
132			nd	nd		nd					nd	nd		nd	nd
133			nd	nd		nd					nd	nd		nd	nd
134			nd	nd		nd					nd	nd		nd	nd
135			nd	nd		nd					nd	nd		nd	nd
136			nd	nd		nd					nd	nd		nd	nd
137			nd	nd		nd					nd	nd		nd	nd
138			nd	nd		nd					nd	nd		nd	nd
139			nd	nd		nd					nd	nd		nd	nd
140			nd	nd		nd					nd	nd		nd	nd

INTLO[illegible] WaterQual Data

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
141			nd	nd		nd					nd	nd		nd	nd
142			nd	nd		nd					nd	nd		nd	nd
143			nd	nd		nd					nd	nd		nd	nd
144			nd	nd		nd					nd	nd		nd	nd
145			nd	nd		nd					nd	nd		nd	nd
146			nd	nd		nd					nd	nd		nd	nd
147			nd	nd		nd					nd	nd		nd	nd
148			nd	nd		nd					nd	nd		nd	nd
149			nd	nd		nd					nd	nd		nd	nd
150			nd	nd		nd					nd	nd		nd	nd
151			nd	nd		nd					nd	nd		nd	nd
152			nd	nd		nd					nd	nd		nd	nd
153			nd	nd		nd					nd	nd		nd	nd
154			nd	nd		nd					nd	nd		nd	nd
155			nd	nd		nd					nd	nd		nd	nd
156			nd	nd		nd					nd	nd		nd	nd
157			nd	nd		nd					nd	nd		nd	nd
158			nd	nd		nd					nd	nd		nd	nd
159			nd	nd		nd					nd	nd		nd	nd
160			nd	nd		nd					nd	nd		nd	nd
161			nd	nd		nd					nd	nd		nd	nd
162			nd	nd		nd					nd	nd		nd	nd
163			nd	nd		nd					nd	nd		nd	nd
164			nd	nd		nd					nd	nd		nd	nd
165			nd	nd		nd					nd	nd		nd	nd
166			nd	nd		nd					nd	nd		nd	nd
167			nd	nd		nd					nd	nd		nd	nd
168			nd	nd		nd					nd	nd		nd	nd
169			nd	nd		nd					nd	nd		nd	nd
170			nd	nd		nd					nd	nd		nd	nd
171			nd	nd		nd					nd	nd		nd	nd
172			nd	nd		nd					nd	nd		nd	nd
173			nd	nd		nd					nd	nd		nd	nd
174			nd	nd		nd					nd	nd		nd	nd
175			nd	nd		nd					nd	nd		nd	nd
176			nd	nd		nd					nd	nd		nd	nd
177			nd	nd		nd					nd	nd		nd	nd
178			nd	nd		nd					nd	nd		nd	nd
179			nd	nd		nd					nd	nd		nd	nd
180			nd	nd		nd					nd	nd		nd	nd
181			nd	nd		nd					nd	nd		nd	nd
182			nd	nd		nd					nd	nd		nd	nd
183			nd	nd		nd					nd	nd		nd	nd
184			nd	nd		nd					nd	nd		nd	nd
185			nd	nd		nd					nd	nd		nd	nd
186			nd	nd		nd					nd	nd		nd	nd
187			nd	nd		nd					nd	nd		nd	nd
188			nd	nd		nd					nd	nd		nd	nd
189			nd	nd		nd					nd	nd		nd	nd
190			nd	nd		nd					nd	nd		nd	nd
191			nd	nd		nd					nd	nd		nd	nd
192			nd	nd		nd					nd	nd		nd	nd
193			nd	nd		nd					nd	nd		nd	nd
194			nd	nd		nd					nd	nd		nd	nd
195			nd	nd		nd					nd	nd		nd	nd
196			nd	nd		nd					nd	nd		nd	nd
197			nd	nd		nd					nd	nd		nd	nd
198			nd	nd		nd					nd	nd		nd	nd
199			nd	nd		nd					nd	nd		nd	nd
200			nd	nd		nd					nd	nd		nd	nd
201			nd	nd		nd					nd	nd		nd	nd
202			nd	nd		nd					nd	nd		nd	nd
203			nd	nd		nd					nd	nd		nd	nd
204			nd	nd		nd					nd	nd		nd	nd
205			nd	nd		nd					nd	nd		nd	nd
206			nd	nd		nd					nd	nd		nd	nd
207			nd	nd		nd					nd	nd		nd	nd
208			nd	nd		nd					nd	nd		nd	nd
209			nd	nd		nd					nd	nd		nd	nd

	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd
[illegible]			nd	nd		nd					nd	nd		nd	nd

D:\ELOP\Sum92\WaterQual Data

	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
3	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44
4	519-534	519-534	519-534	535-555	535-555	535-555	535-555	535-555	535-555	535-555	535-555	535-555	557-577	557-577	557-577
5	[illegible]	[illegible]	[illegible]	SL	SL-dup	SL-dup	SL-dup	SL-dup	USGS	UI	ISU/CL	USSL	SL	USGS	UI
8													<100		<100
9										100			<1		<1
10	<100									<1			1.5	<10	1.5
11	<1				<10	<10	<10	<10	<10	1.1		1.10	110	100	110
12	<1				100	100	100	100	100	110			<10	<5	<10
13	[illegible]		1.00		<5	<5	<5	<5	<5	<10			<20	<5	<2
14	[illegible]				<1	<1	<1	<1	<1	<20		[illegible]	[illegible]	[illegible]	[illegible]
15	<20				51,000	51,000	51,000	51,000	60,000	59000			<20	5.2	<20
16			1.00		5.3	5	5.7	5.1	5.4	<20			<30		[illegible]
17	<20									<10			<20	<10	<20
18	[illegible]				<10	<10	<10	<10	<10	<20			<10	<10	<10
19	<2				<10	<10	<10	<10	<10	<10			<1	<5	<1
20	[illegible]				<5	<5	<5	<5	<5	<1			50		[illegible]
21	[illegible]									[illegible]		1.00	10,000	[illegible]	[illegible]
22	210				15,000	15,000	15,000	15,000	15,000	15,000			<20	<10	<20
23	[illegible]		[illegible]		<10	<10	<10	<10	<10	<20				<0.5	
24	<5				<0.5	<0.5	<0.5	<0.5	<0.5				<50		<50
25										<50			<5	[illegible]	[illegible]
26	<10				<10	<10	<10	<10	<10	<50			20		30
27	[illegible]									6		1.20	1700	3,100	[illegible]
28	[illegible]				2,200	2,200	2,200	2,400	2,200	2800			NA		NA
29	[illegible]		1.4							NA			4	<5	[illegible]
30	[illegible]				<5	<5	<5	<5	<5	<1.5				23,200	
31								21,500					10,000		
32			1.02							10,000		>3	4	<1	4
33	10,000				<1	<1	<1	<1	<1	3		0.93	9500	15,000	9500
34			0.71		10,000	10,000	10,000	10,000	10,000	9800		1.00	320	230	[illegible]
35	10,000				310	310	310	310	310	310			NA		NA
36	[illegible]		0.97							NA					
37	[illegible]											17			
38										<50			<50		<50
39		2								<20			<20	<2	<2
40	<50				<2	<2	<2	<2	<2						
41	<20														
42														<50	
43								<50						25,000	
44								20,000						200	
45								230							
47														25,000	
48								26,000							
50													10		
51													10		
52				10									1,100	2,150	
53				10				1,500						140	
54				1,100				<50					20	<50	
55								[illegible]						[illegible]	
56				20				44						210,000	
57								210,000						150,000	
58								170,000							
60												5.5			
61												0.6			
62		3.5													0.132
63		[illegible]								0.00					0.124
64										0.005					
65												4.0			
66												[illegible]			
67		[illegible]										[illegible]			
68		[illegible]										[illegible]			
69		[illegible]													

	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
71								nd						nd	
72								nd						nd	
73								nd						nd	
74								nd						nd	
75								nd						nd	
76								nd						nd	
77								nd						nd	
78								nd						nd	
79								nd						nd	
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81								nd						nd	
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83								nd						nd	
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105								nd						nd	
106								nd						nd	
107								nd						nd	
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112								nd						nd	
113								nd						nd	
114								nd						nd	
115								nd						nd	
116								nd						nd	
117								nd						nd	
118								nd						nd	
119								nd						nd	
120								[illegible]						nd	
121								nd						3.7	
122								nd						nd	
123								nd						nd	
124								nd						nd	
125								nd						nd	
126								nd						nd	
127								nd						nd	
128								nd						nd	
129								nd						nd	
130								nd						nd	
131								nd						nd	
132								nd						nd	
133								nd						nd	
134								nd						nd	
135								[illegible]						nd	
136								nd						nd	
137								nd						nd	
138								nd						[illegible]	
139								nd						nd	
140															

	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
141								nd						nd	
142								nd						nd	
143								nd						nd	
144								nd						nd	
145								nd						nd	
146								nd						nd	
147								nd						nd	
148								nd						nd	
149								nd						nd	
150								nd						nd	
151								nd						nd	
152								nd						nd	
153								nd						nd	
154								nd						nd	
155								nd						nd	
156								nd						nd	
157								nd						nd	
158								nd						nd	
159								nd						nd	
160								nd						nd	
161								nd						nd	
162								nd						nd	
163								nd						nd	
164								nd						nd	
165								nd						nd	
166								nd						nd	
167								nd						nd	
168								nd						nd	
169								nd						nd	
170								nd						nd	
171								nd						nd	
172								nd						nd	
173								nd						nd	
174								nd						nd	
175								nd						nd	
176								nd						nd	
177								nd						nd	
178								nd						nd	
179								nd						nd	
180								nd						nd	
181								nd						nd	
182								nd						nd	
183								nd						nd	
184								nd						nd	
185								nd						nd	
186								nd						nd	
187								nd						nd	
188								nd						nd	
189								nd						nd	
190								nd						nd	
191								nd						nd	
192								nd						nd	
193								nd						nd	
194								nd						nd	
195								nd						nd	
196								nd						nd	
197								nd						nd	
198								nd						nd	
199								nd						nd	
200								nd						nd	
201								nd						nd	
202								nd						nd	
203								nd						nd	
204								nd						nd	
205								nd						nd	
206								nd						nd	
207								nd						nd	
208								nd						nd	
209								nd						nd	

INELOP/Sum92'WaterQual Data

	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR
211								ndl						ndl	
212								ndl						ndl	
213								ndl						ndl	
214								ndl						ndl	
215								ndl						ndl	
216								ndl						ndl	
217								ndl						ndl	
218								ndl						ndl	
219								ndl						ndl	
220								ndl						ndl	
221								ndl						ndl	

	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG
1															
2															
3															
4	[illegible]	[illegible]	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44	USGS44			
5	557-577	557-577	580-651	580-651	580-651	580-651	580-651	580-600	580-600	580-600	580-600	580-600	Spike	Spike	Spike
6	ISU CL	UUSL	SL	USGS	UI	ISU CL	UUSL	SL	USGS	UI	ISU CL	UUSL	SL	SL	SL
7								PCn	PCn	PCn			(7-10-92)	(7-22-92)	(7-22-92)
8															
9															
10					<100					<100					
11					<1					<1					
12				<10				[illegible]		[illegible]			[illegible]		[illegible]
13		1.00		100	70		0.70	100		70		0.70	<100		<100
14				<5	<10			<5		<10			<5		<5
15				<1	<20			<1		<20			20		23
16		[illegible]		[illegible]	51,000		[illegible]	52,000		48,000		[illegible]	[illegible]		[illegible]
17				[illegible]	<20			4		<20			<2		<2
18					<30					<30					
19				[illegible]	<20			[illegible]		<2			[illegible]		[illegible]
20				<10	<10			<10		<10			20		20
21				<5	<1			<5		<1			[illegible]		[illegible]
22					[illegible]					70					
23		1.00		16,000	16,000		[illegible]	16,000		16,000		1.00	9,700		9,700
24				[illegible]	[illegible]			[illegible]		<2			[illegible]		[illegible]
25				<0.5				<0.5					<0.5		<0.5
26					<50					<50					
27				<10	<50			<10		<50			27		25
28					<5					<5					
29		1.00		3000	3500		1.17	3000		3500		1.17	10,000		9,500
30					NA					NA					[illegible]
31				<5	1.4			<5		1.4			21		[illegible]
32				24,000			[illegible]	24,000				[illegible]			[illegible]
33		[illegible]			12,000					12,000					
34				<1	4			<1		4		[illegible]	<1		<1
35		1.00		15,000	15,000		1.00	15,000		15,000		1.07	2,800		9,600
36		1.00		300	300		1.00	300		280		0.93	<1		<1
37					NA					NA					
38															
39	17					2					2				
40					<50					<50					
41				<2	<20			<2		<20			20		[illegible]
42															
43													<80		80
44				<80				<80					<1,000		20,000
45				27,000				25,000					<100		1000
46				300				300							
47															
48															
49				24,000				25,000					<1,000		19,000
50															
51															
52			10						10						
53			10						10						
54			1,000	2,150				2,150	2,000				4,780		5,000
55				<50				<50					50		<20
56			22	<50				<50	[illegible]				[illegible]		[illegible]
57				<1				<1					5		<1
58				[illegible]				[illegible]					<2,000		<2,000
59				152,000				152,000					<1,000		<1000
60															
61															
62	4.2					5.1					4.3				
63	3.7					0.3					0.3				
64				0.370					0.970						
65				0.020					0.020						
66	[illegible]					650					735				
67	[illegible]					100					100				
68	[illegible]					[illegible]					126				
69	[illegible]					13.0					[illegible]				
70															

	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG
71															
72													nd	nd	
73													nd	nd	
74													nd	nd	
75													nd	nd	
76													6.63	3.2	
77													4.3	4.1	
78													5.53	3.6	
79													4.72	3.8	
80													6.14	4.9	
81													5.43	1.7	
82													6.01	7.6	
83													3.3	2.1	
84													nd	nd	
85													nd	nd	
86													nd	nd	
87													nd	nd	
88													nd	nd	
89													nd	nd	
90													nd	nd	
91													nd	nd	
92													nd	nd	
93													nd	nd	
94													nd	nd	
95													nd	nd	
96													nd	nd	
97													nd	nd	
98													nd	nd	
99													nd	nd	
100													nd	nd	
101													nd	nd	
102													nd	nd	
103													nd	nd	
104													nd	nd	
105													nd	nd	
106													nd	nd	
107													nd	nd	
108													nd	nd	
109													nd	nd	
110													nd	nd	
111													nd	nd	
112													nd	nd	
113													nd	nd	
114													1.15	0.6	
115													nd	nd	
116													nd	nd	
117													nd	nd	
118													nd	nd	
119													nd	nd	
120													4.45	5.5	
121													nd	nd	
122													nd	nd	
123													nd	nd	
124													nd	nd	
125													nd	nd	
126													nd	nd	
127													nd	nd	
128													nd	nd	
129													nd	nd	
130													nd	nd	
131			nd	nd				nd					nd		
132			nd	nd				nd					9.68		
133			nd	nd				nd					nd		
134			nd	nd				nd					nd		
135			nd	nd				nd					nd		
136			nd	nd				nd							
137			nd	nd				nd					nd		
138			nd	nd				nd					nd		
139			nd	nd				nd					nd		
140			nd	nd				nd							

[illegible]

	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG
141			nd	nd				nd					nd		
142			nd	nd				nd					nd		
143			nd	nd				nd					nd		
144			nd	nd				nd					nd		
145			nd	nd				nd					nd		
146			nd	nd				nd					nd		
147			nd	nd				nd					nd		
148			nd	nd				nd					nd		
149			nd	nd				nd					nd		
150			nd	nd				nd					nd		
151			nd	nd				nd					nd		
152			nd	nd				nd					nd		
153			nd	nd				nd					nd		
154			nd	nd				nd					nd		
155			nd	nd				nd					nd		
156			nd	nd				nd					nd		
157			nd	nd				nd					nd		
158			nd	nd				nd					5.7[illegible]		
159			nd	nd				nd					nd		
160			nd	nd				nd					nd		
161			nd	nd				nd					nd		
162			nd	nd				nd					nd		
163			nd	nd				nd					nd		
164			nd	nd				nd					nd		
165			nd	nd				nd					nd		
166			nd	nd				nd					nd		
167			nd	nd				nd					nd		
168			nd	nd				nd					nd		
169			nd	nd				nd					nd		
170			nd	nd				nd					nd		
171			nd	nd				nd					nd		
172			nd	nd				nd					nd		
173			nd	nd				nd					nd		
174			nd	nd				nd					92.9		
175			nd	nd				nd					nd		
176			nd	nd				nd					nd		
177			nd	nd				nd					nd		
178			nd	nd				nd					nd		
179			nd	nd				nd					nd		
180			nd	nd				nd					nd		
181			nd	nd				nd					nd		
182			nd	nd				nd					nd		
183			nd	nd				nd					nd		
184			nd	nd				nd					nd		
185			nd	nd				nd					5.72		
186			nd	nd				nd					nd		
187			nd	nd				nd					nd		
188			nd	nd				nd					nd		
189			nd	nd				nd					nd		
190			nd	nd				nd					nd		
191			nd	nd				nd					nd		
192			nd	nd				nd					nd		
193			nd	nd				nd					nd		
194			nd	nd				nd					nd		
195			nd	nd				nd					nd		
196			nd	nd				nd					nd		
197			nd	nd				nd					nd		
198			nd	nd				nd					nd		
199			nd	nd				nd					nd		
200			nd	nd				nd					nd		
201			nd	nd				nd					nd		
202			nd	nd				nd					nd		
203			nd	nd				nd					nd		
204			nd	nd				nd					nd		
205			nd	nd				nd					nd		
206			nd	nd				nd					nd		
207			nd	nd				nd					nd		
208			nd	nd				nd					nd		
209			nd	nd				nd					nd		
210			nd	nd				nd					nd		

RTEL OP/Sum92/WaterQual Data

	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG
211			nd.	nd!				nd!					nd.		
212			nd!	nd!				nd!					nd.		
213			nd!	nd!				nd!					nd!		
214			nd!	nd!				nd!					nd!		
215			nd!	nd!				nd!					nd!		
216			nd!	nd!				nd!					nd!		
217			nd!	nd!				nd!					nd!		
218			nd.	nd!				nd!					nd!		
219			nd!	nd!				nd!					nd!		
220			nd!	nd!				nd!					5.74		
221			nd!	nd!				nd!					nd!		

[illegible]/Sum92/WaterQual Data

	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU
1														
2														
3														
4														
5	Spike	Spike	Spike	Spike	Lab Blank	Lab Blank	Lab Blank	Lab Blank	Lab Blank	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL	SL
7	(8-3-92)	(8-3-92)	(8-10-92)	(8-13-92)	(7-10-92)	(7-28-92)	(8-3-92)	(8-10-92)	(8-13-92)	(7/10/92)	(8-10-92)	(7-10-92)	(8-10-92)	
8														
9														
10														
11														
12			21		<10	<10		<10	<10	<10	<10	<10	<10	<10
13			<100		<100	<100		<100	<100	<100	<100	<100	<100	<100
14			<5		<5	<5		<5	<5	<5	<5	<5	<5	<5
15			[illegible]		<1	<1		<1	<1	3.5	<1	<1	<1	<1
16			<100		500	[illegible]		<100	1,[illegible]	300	100	200	[illegible]	[illegible]
17			<2		<2	<2		<2	<2	<2	<2	<2	<2	5.3
18														
19			<10		<10	<10		<10	<10	<10	<10	<10	<10	<10
20			20		<10	<10		<10	40	[illegible]	<10	<10	30	10
21			16		<5	<5		<5	<5	<5	<5	<5	<5	<5
22														
23			9,500		<100	<100		<100	200	<100	<100	<100	100	15,000
24			<10		<10	<10		<10	<10	<10	<10	<10	<10	<10
25			<0.5		<0.5	<0.5		<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
26														
27			[illegible]		<10	<10		<10	<10	<10	<10	<10	<10	<10
28														
29			9,000		100	<100		<100	400	200	<100	<100	100	2,100
30														
31			[illegible]		<5	<5		<5	<5	<5	<5	<5	<5	<5
32			<100		<100	<100		<300		700	300	300		21,000
33														
34			<1		<1	<1		<1	<1	<1	<1	<1	<1	<1
35			9,400		<100	100		<100	1,100	1,400	399	900	700	10,000
36			<1		<1	<1		<1	5.4	1	<1	<1	2.6	300
37														
38														
39														
40														
41			21		<2	<2		<2	35	27	<2	<2	16	<2
42														
43														
44			<80		<80	<80		<80	<80	<80	<80	<80	<80	<80
45			20,000		1000	<1000		<1000	<1,000	2000	<1000	31,000	<1,000	19,000
46			300		<100	<100		<100	<100	<100	<100	350	<100	[illegible]
47														
48														
49			10,000		<1000	<1000		<1000	<1,000	<1000	<1000	13,000	<1000	27,000
50														
51														
52														
53														
54			5,700		170			92	30	33	3	22	none	1,250
55			120		<50			120	380	340	150	70	none	<50
56			330		<50			<50	<50	<50	<50	120	none	[illegible]
57			120		2	2.3		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
58			<2000		<2000	<2000		<2000	4,000	<2000	<2000	<2,000	2,000	208,000
59			<1000		1000	<1000		<1000	7,000	2000	2000	<1,000	1,000	[illegible]
60														
61														
62														
63														
64														
65														
66														
67														
68														
69														
70														

	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ	BR	BS	BT	BU
71														
72	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
73	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
74	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
75	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
76	nd	5.43		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
77	nd	10.3		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
78	nd	13.7		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
79	nd	11.3		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
80	nd	10.1		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
81	nd	10.2		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
82	nd	12.2		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
83	nd	3.67		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
84	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
85	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
86	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
87	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
88	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
89	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
90	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
91	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
92	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
93	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
94	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
95	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
96	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
97	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
98	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
99	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
100	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
101	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
102	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
103	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
104	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
105	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
106	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
107	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
108	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
109	nd	nd		nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
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D:\TL.OP\Sum92\WaterQual Data

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APPENDIX E

RESULTS OF GROUND-WATER TRACER METHODS DURING STRADDLE PACKER TESTING AT THE ICPP, INEL JULY - SEPTEMBER, 1992

RESULTS OF GROUND WATER TRACER METHODS DURING STRADDLE PACKER TESTING AT THE ICPP, INEL JULY - SEPTEMBER, 1992

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208-236-3365

April 8, 1993

INTRODUCTION

The State Oversight Program's straddle packer sampling system was tested at the Idaho National Engineering Laboratory during July-September, 1992, in USGS monitoring well #44. The straddle packer was designed for the Oversight Program's ground water research program, to provide a means of characterizing the vertical hydraulic and water quality variations believed to exist in the eastern Snake River Plain aquifer beneath the Idaho National Engineering Laboratory. During the field program, tracer introduction and recovery experiments were conducted to evaluate QA sampling objectives as well as to assess the feasibility of obtaining additional information on aquifer/borehole characteristics such as specific discharge through different aquifer zones, integrity of packer seals, etc.

The results and preliminary interpretation of these test data are described in this report. For ease of access to the data, this report is divided into two sections: Section 1 represents a synopsis of the approach, methods, results and interpretation; Section 2 presents the details of the methods used, tabulation of all results, and discusses interpretational issues in more detail.

SECTION 1 - OVERVIEW OF RESULTS AND CONCLUSIONS

Water sampling for Bromide and the field analytical set-up used for field water parameter measurements were part of the overall tracer purge testing capability used to monitor field parameters (T, pH, Eh, dissolved oxygen, ferric/ferous iron) with a flow-cell monitoring arrangement. A summary of the data collected from the field measurements program is presented in Appendix 1.

A total of twelve tracer tests were performed on six different intervals from 467 to 600 feet below land surface (ft bls) from July 21 to September 16, 1992. Lithium bromide powder dissolved in de-ionized water was used as a tracer in all tests. Br^- concentrations were monitored in the field with an ion-selective electrode on discrete samples collected from the wellhead discharge lines that were adjusted to constant ionic strength by the addition of a constant amount of a concentrated neutral salt solution. The ion-selective electrode response was calibrated daily against Br standards that covered the working range. Precision and accuracy of Br measurements were determined from replicate analyses of standards and samples over the working concentration range and are both better than ±4% (2 sigma at 5 ppm Br). All bromide concentration data collected during purge testing are summarized in Appendix 2 and included in Lotus 1-2-3 format in the attached diskette, under file BRDATA.WK1.

All tracer tests were conducted in two phases: a) Emplacement -

introduction of a slug of a known quantity of tracer, followed by continuous mixing within the test interval for periods ranging from 8 to 72 minutes (without pumping to surface), during which time the tracer was diluted by ground water advection through the test interval; and b) Recovery - pumping of the test interval to withdraw tracer from the borehole interval and the adjacent aquifer. Once tracer recovery had been completed, water quality sampling could be initiated, with the degree of interval purging having been defined by the degree of tracer recovery.

The initial concentrations of Br^- that were emplaced in the tests averaged 500 mg/l. An average of 95% of the Br^- that was emplaced in each interval was recovered during pumping, although in two tests only 22 and 59% of the emplaced tracer was recovered due to poor mixing conditions within the test interval during recovery, rapid advective loss into the aquifer during emplacement, and/or too short a pumping period.

At the end of tracer recovery, and prior to water quality sampling, Br^- concentrations in the test interval ranged from approximately 1 to 8 mg/l above the 0.45 mg/l natural aquifer background. The highest residual amounts corresponded to intervals that were inefficiently purged during pumping or that were pumped for less than 30 minutes. Residual Br^- levels prior to water quality sampling can be used to define the proportion of sampled water that was not derived from the aquifer. However, due to the low levels of inorganic impurities in the LiBr powder (<100 ppm of other metals), the effect on measured water quality of such a small residual contamination would be undetectable for the major ions and would contribute sub-ppb levels of trace metals.

Tracer recovery data (natural log of dimensionless concentration vs time) from multiple tests on the 495-515 and one test on the 535-555 ft bls intervals are shown in Figure 1. These intervals were the only two that demonstrated adequate mixing within the borehole interval during the recovery phase, due to leakage across the packer valve designed to divert flow to the surface. The tracer concentration-time responses shown in Figure 1 are characteristic of a well-mixed volume in which the diluting solution (ie. ambient ground water) has a finite concentration of Br^-. The response is characterized by a an initial, constant, semi-logarithmic rate of decrease of concentration vs time, followed by a decreasing rate of dilution and a final approach to a constant background value. A slight flattening of the curve at intermediate times indicates the return of tracer that had advected into the formation during the emplacement phase.

A first-order tracer dilution model was developed to aid in conceptualizing the processes occurring during tracer emplacement and recovery. The model assumptions and development are described in Appendix 5, and fitting parameters derived from application of the model to the tracer recovery data are summarized in Appendix 4.

The return time of advected tracer as well as the apparent background Br⁻ concentration, C_b, was found to increase as longer tracer emplacement times were used, thus rendering the removal of tracer (plus borehole water) from the test interval more time-consuming due to the extensive advection and dispersion of tracer into the aquifer. The magnitude of this effect suggests that in a relatively low-hydraulic head interval which receives water from the borehole, pre-existing contamination of that zone by borehole water cannot be removed even by several hours of continuous purging. Therefore, it is doubtful whether water quality data on such intervals is representative of the ambient ground water at a distance beyond the borehole at that depth.

The effective volumes of the 495-515 and 535-555 intervals calculated from the initial rates of tracer dilution in the recovery phase (the slope of the straight lines) are shown in Figure 1. Other effective volumes are shown in Figure 2 (see Appendix 3 for a complete list of parameter values for all tests). The calculated volumes in intervals other than 495-515 and 535-555 were usually lower than the values estimated from caliper logs, although larger values were occasionally obtained. The wide range of apparent interval volumes shown in Figure 2 reflect inadequate mixing within the straddled intervals, indicating that little useful quantitative information can be extracted from the recovery phase data in all the two well-mixed tested intervals. The apparent tracer response and calculated apparent dilution volume that is obtained in any given interval is believed to arise due to the lack of adequate mixing within the test interval during pumping and to depend on the position of fracture-controlled conduits supplying ground water inflow to an interval relative to the position of the pump intake, thereby leading to the development of "dead" volumes or incompletely flushed zones within the straddled interval.

Despite these problems the 1992 field data suggest that the analysis of tracer recovery data has promise as a technique for independently assessing aquifer characteristics such as effective porosity and linear pore velocity, if adequate mixing can be maintained within the test interval. As shown in Figure 3, the tracer recovery data can be treated as a single-well tracer injection, drift and pumpback test by modelling the dynamic effects of pure borehole dilution and subtracting these effects from the observed concentration-time data. A methodology and theoretical basis for treating such data are currently being developed for future testing of this approach.

Due to inadequate mixing within the test intervals during the recovery phase of the 1992 tracer tests, only data from certain tests in which the dilution model parameter fitting produced results that are consistent with assumed interval volume and observed Br recovery percentage are considered reliable (tests failing this criteria are labelled "Not Mixed" in Appendix 3). In contrast, all data obtained during the well-mixed emplacement phase are reliable and can be treated quantitatively with a dilution model. Design modifications on the packer system are currently underway to provide the degree of mixing required to fully utilize tracer recovery data in future.

During the emplacement phase, the dilution rate of tracer in the test interval was calculated from the observed change in Br^- concentration between the time of emplacement and start of pumping. Since the interval was thoroughly mixed throughout the emplacement phase by using the pump to recirculate the interval fluid in a closed loop, a first-order dilution model describes the rate of tracer dilution with time (see Appendix 5 for derivation and assumptions):

$$C = (C^{\circ}-C_b)[\exp(-Ot/V) + C_b] \quad ,$$

where C° is the initial Br^- tracer concentration in the borehole when the pump began purging the interval at time $t=0$, C_b is the background Br^- concentration characteristic of ground water in the aquifer, V is the volume of the test interval and O is the interval dilution rate, or rate of flow of ground water through the test interval. Thus, on a plot of ln(C) vs t, the slope of the initial linear portion of the response defines the interval dilution rate relative to the effective mixed volume, -O/V. Figure 4 shows the semi-logarithmic dilution rate of Br^- observed during multiple tests on the 495-515 ft bls interval. The deviation of the 72 minute test (8/05) from the straight line shown in Figure 4 may be a consequence of the finite background Br concentration that is present in local ground water, or a reflection of non-ideal dilution conditions which may develop over long times in a fracture flow-dominated medium.

This simple first-order dilution model was used to interpret test results from the emplacement phase in all intervals (Appendix 3). Interval volumes were calculated from the recovery data or estimated from the caliper log. Calculated interval dilution rates for all tests are shown in Figure 5. From estimates of the cross-sectional area of the borehole in each test interval, apparent specific discharge (= O/area) was also estimated and is plotted in Figure 5. Replicate determinations of dilution rate and specific discharge for the 495-515 interval are shown in Table 1 (also Appendix 4), and provide an indication of the reproducibility that can be achieved with this borehole tracer method.

Specific discharge values calculated from these borehole dilution tests represent apparent values since they have not been corrected for flow field distortion around the borehole and so are higher than the actual specific discharge in the adjacent aquifer. Comparison of specific discharge values calculated from the 495-515 interval tests and those estimated from Darcy's Law (= K_{horiz} x regional hydraulic gradient) indicates that the apparent specific discharges calculated from tracer dilution data appear to be high by approximately a factor of 3-4 (Table 1), indicating the magnitude of the borehole flow field distortion effect. This is within the range reported in the literature for the effect of borehole-induced flow distortion.

The profiles of interval dilution rate and apparent specific discharge appear to mimic the profile of hydraulic conductivity obtained by borehole flow meter logging in this hole (Figure 6; Morin et al., 1992; Appendix 4), as would be expected if hydraulic gradients in all intervals were similar. However, as shown in Figure 6, the apparent hydraulic gradients obtained from the calculated specific discharge and hydraulic conductivity profiles, show a large increase with depth. Although the calculated hydraulic gradients are similar to regional gradients in the upper, high-permeability portion of the borehole, they are far too large in the lower part of the borehole where permeabilities are low. One possible explanation may be that the calculated specific discharge values in the deeper portions of the borehole are too high due to borehole-induced flow distortion, although the magnitude of such an effect would have to be far larger than any reported in the borehole dilution logging literature. An alternative possibility is that large vertical gradients may exist in the aquifer (as suggested by the high flow rates observed in this and nearby open boreholes during flowmeter logging; W. Bennecke and S. Wood, pers. comm., 1992 and unpubl. data), such that significant vertical flow is responsible for much of the observed tracer dilution in the lower test intervals.

References:

Morin, R., Barrash, W., Paillet, F. and Taylor, T. (1992) Geophysical logging studies in the Snake River Plain Aquifer at the Idaho National Engineering Laboratory: INEL Wells 44, 45, 46; USGS Water Resources Investigations Rept. 92-4184.

Table 1 - Tracer Dilution Rate Calculations in Interval 495-515 ft bls

Test Date	Calculated Dilution Rate[1] liter/min	Calculated Specific Discharge (in interval) cm/min	Calculated Specific Discharge (in interval) ft/day	Estimated Specific Discharge (in interval) cm/min	Estimated Specific Discharge (in interval) ft/day
				0.35[2]	16.5[2]
7/21	15.86	1.19	56.2		
7/22	16.84	1.39	65.7		
7/23	14.73	1.10	52.0		
8/06	14.12	1.13	53.4		

Average
Dilution Rate = 15.39 l/min
RMS Deviation = 1.05 (6.8%)

Footnotes

1. Total ground water flux through the test interval, as calculated from observed tracer dilution during the emplacement phase

2. Estimated from Darcy's Law, assuming a regional hydraulic gradient of 0.0015 and a hydraulic conductivity in the interval of 11000 ft/day (3300 m/day), as determined by Morin et al. (1992)

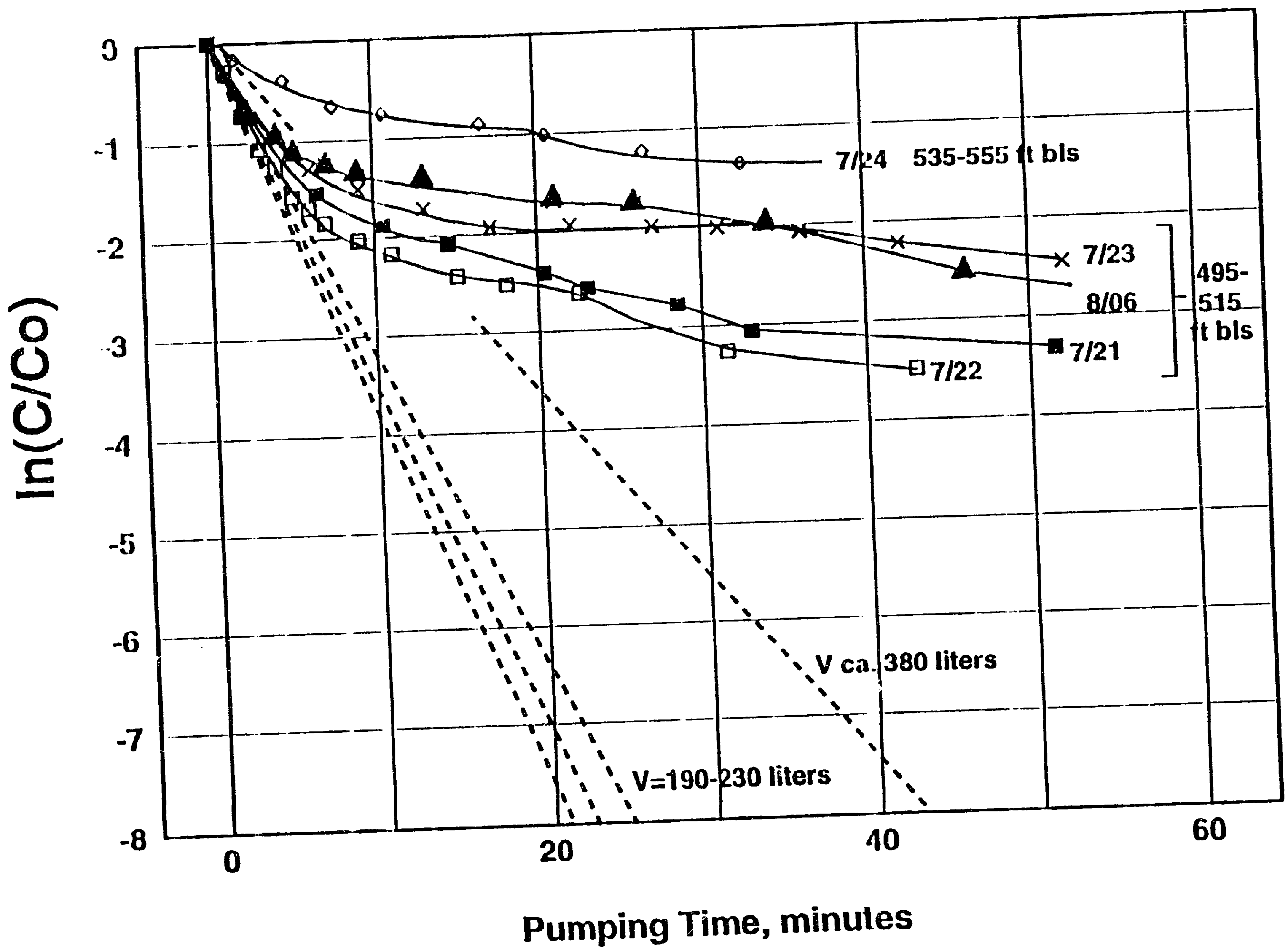


Figure 1. Examples of tracer concentration-time response during recovery phase in test intervals 495-515 and 525-555 ft bls. Dashed lines represent initial dilution rates for interval volumes shown.

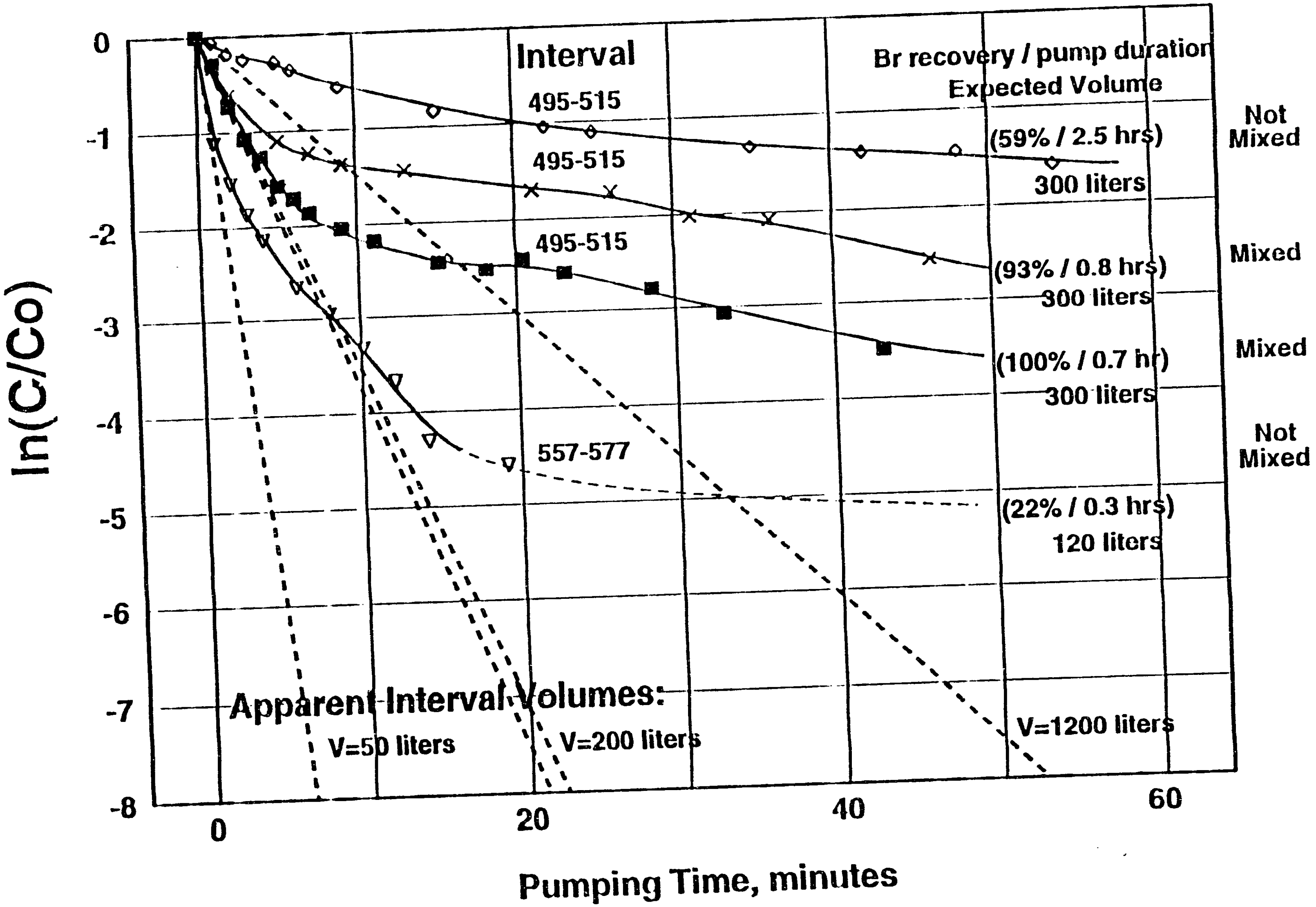


Figure 2. Characteristics of Br tracer recovery in various intervals showing the effects of different degrees of mixing on the effective dilution volumes. Note that apparent volumes calculated from initial rates of dilution (dashed line slopes) differ considerably from volumes expected from caliper logs, as shown on right of figure.

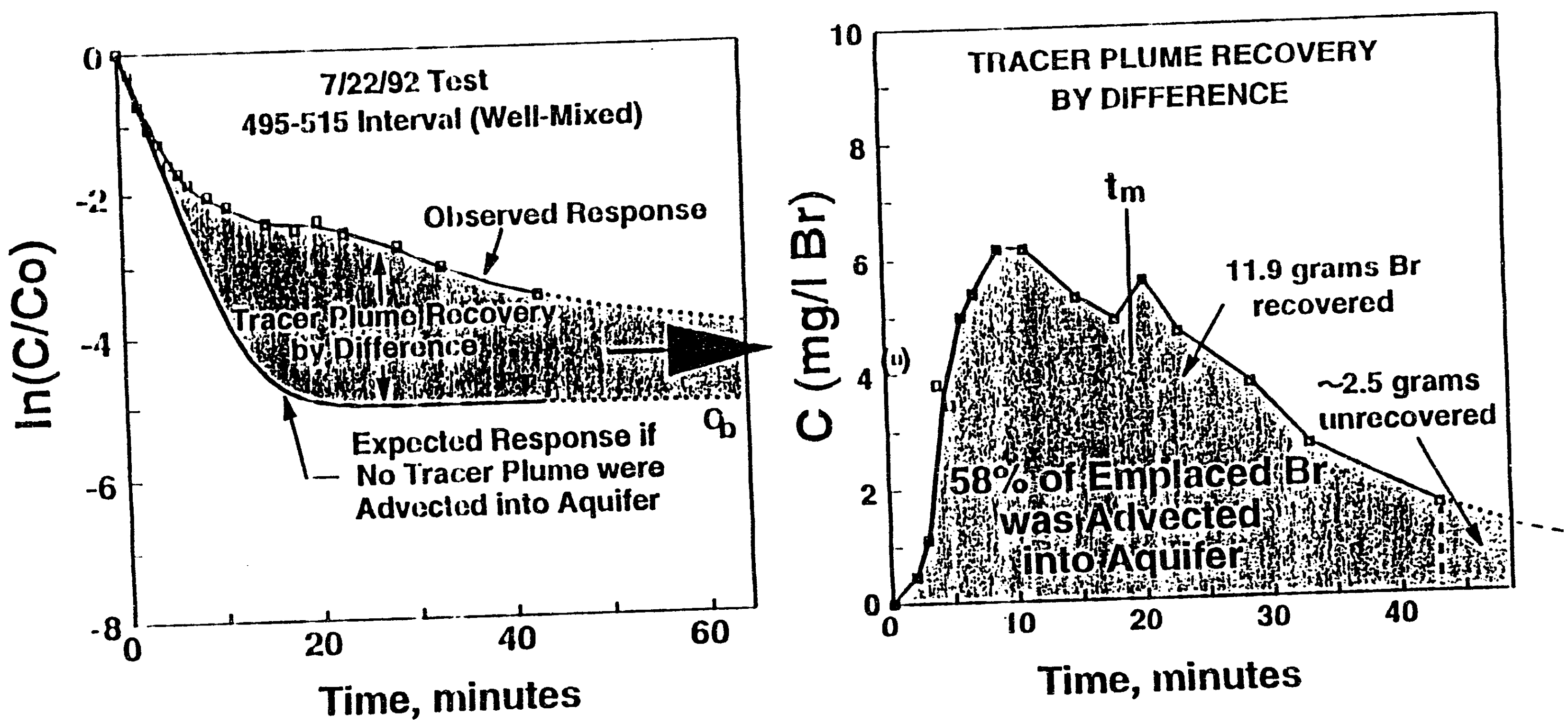


Figure 3. Proposed method for utilizing tracer recovery data in future. Tracer emplacement and recovery phases constitute a single-well injection, drift and pumpback test, wherein the mean two-way travel time of the advected tracer plume is a measure of linear pore velocity. In this test, estimated two-way travel time, tm, is approximately 20 minutes or very close to twice the circulation time during the tracer emplacement phase.

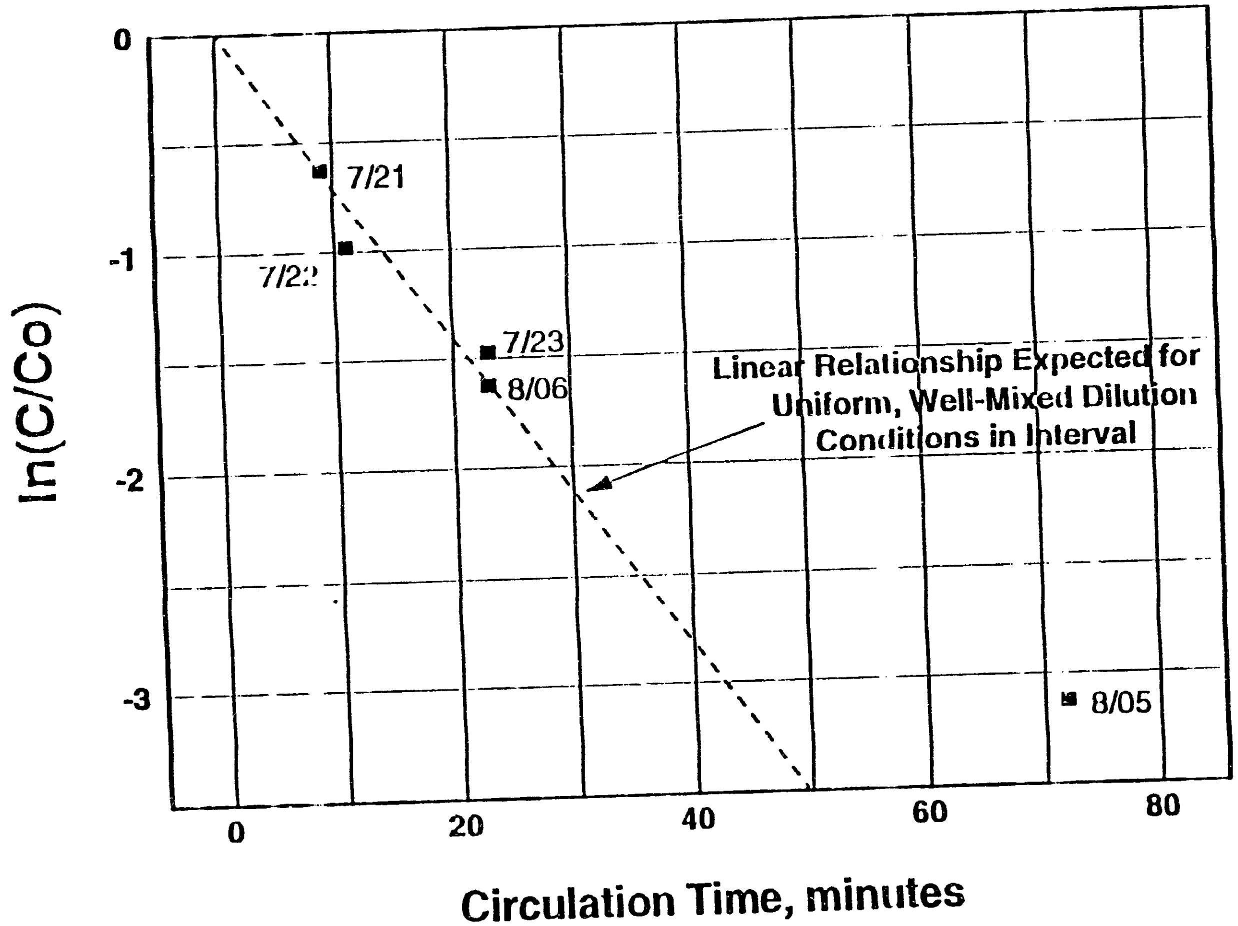


Figure 4. Dilution rates of Br tracer in replicate experiments on 495-515 interval, as calculated from emplacement phase data. Four of the five points fall along a straight line indicating that dilution within the interval can be described by a first-order dilution equation. The fifth point suggests that background Br is affecting the dilution process or that non-uniform dilution due to fracture-controlled flow is becoming progressively more important over longer dilution times.

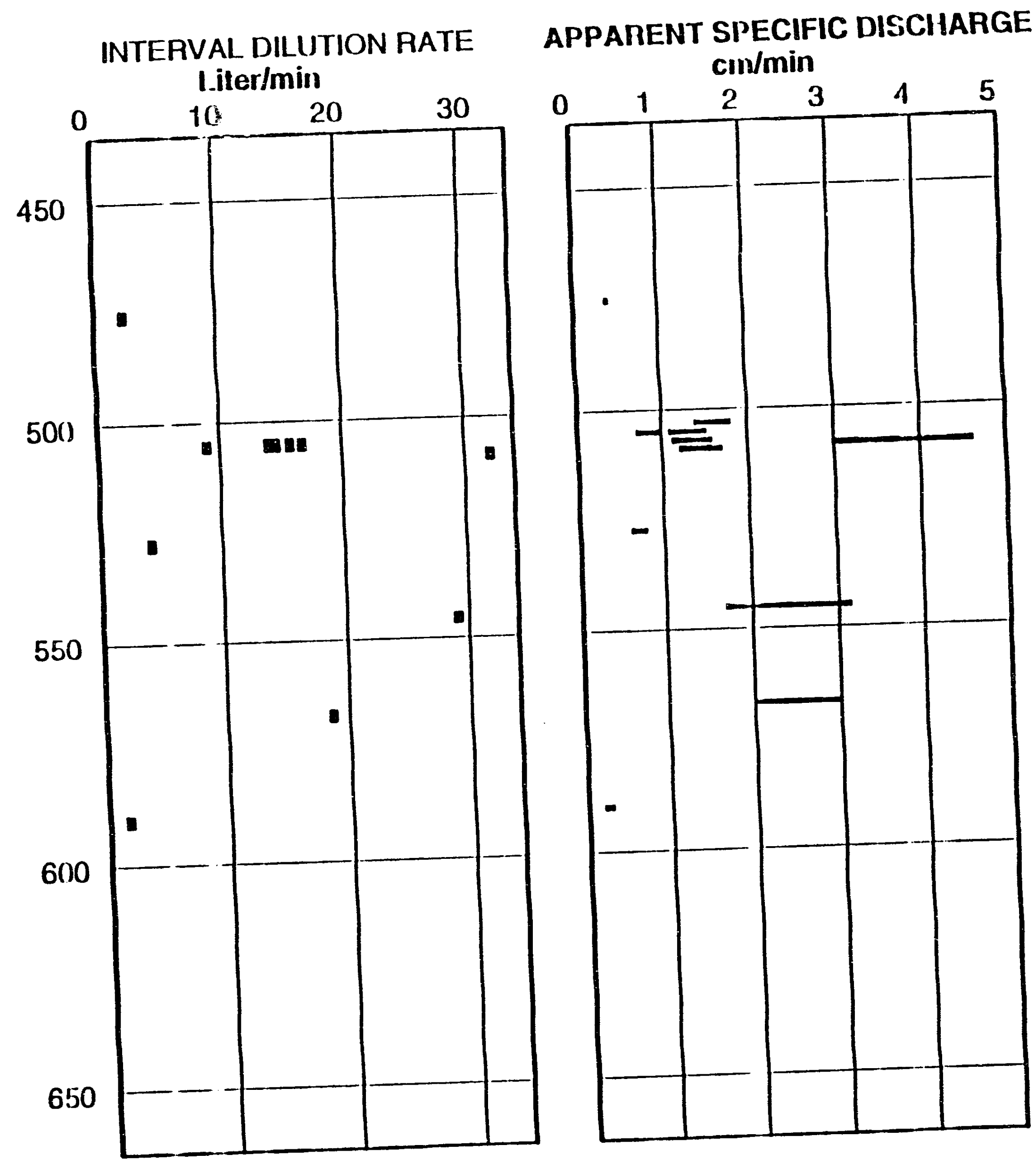


Figure 5. Calculated dilution rates and specific discharge in all intervals

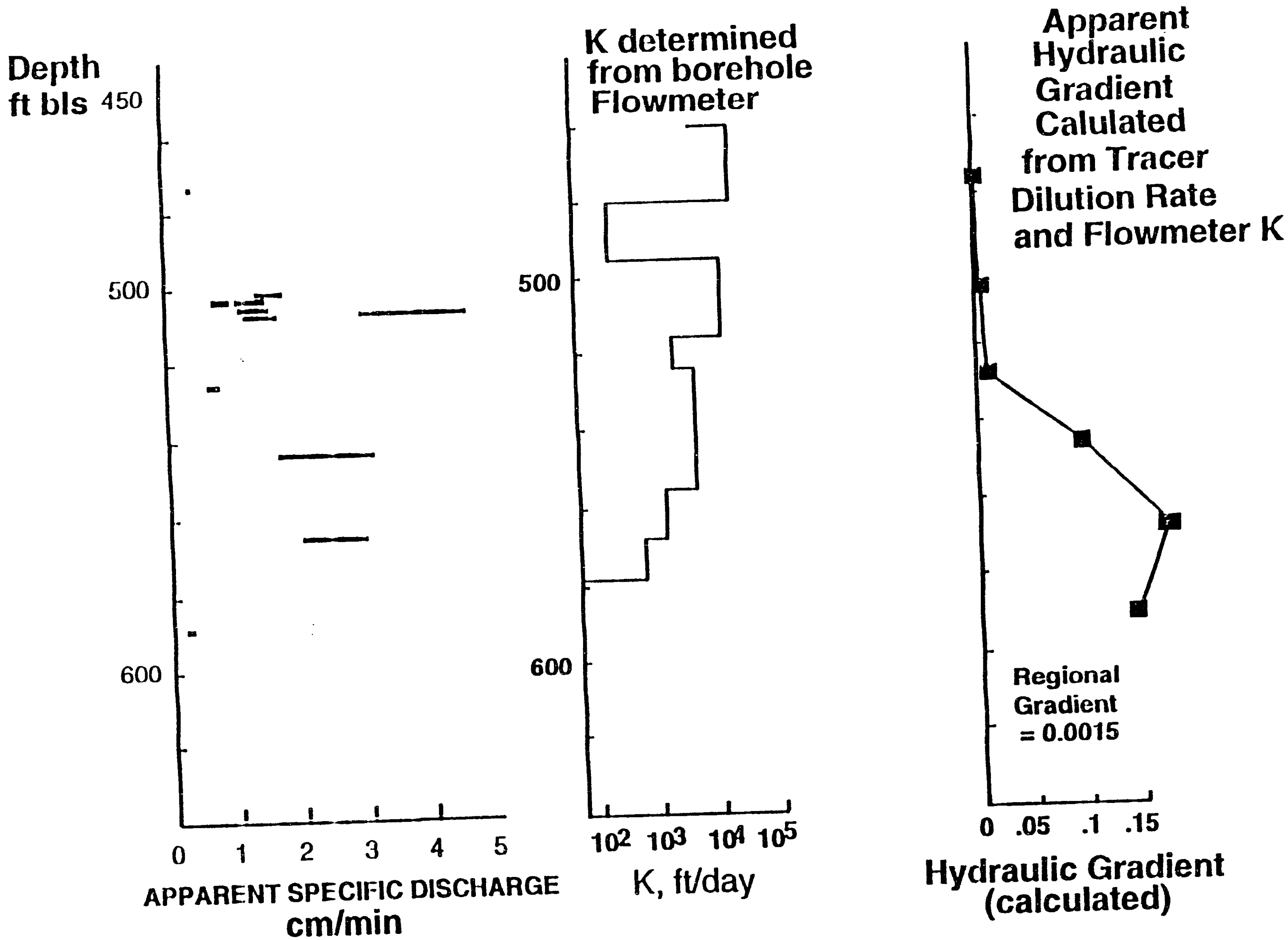


Figure 6. Apparent hydraulic gradient responsible for observed tracer dilution rate in test intervals, as calculated from hydraulic conductivity profile of Morin et al (1992) and tracer dilution rates

SECTION 2 - DATA SUMMARY AND MODEL RESULTS

Presented in Appendices 1 to 5 are the field data collected during the straddle packer testing on USGS Well 44, as well as interpretational summaries of all tracer test data sets.

Appendix 1 summarizes field measurements made on pump discharge from the test intervals, using the flow cell in the field laboratory at the well site. Since the bromide measurements were made as part of the flow cell field measurement program, these results are included here as well as in the discussion of aquifer water quality results (see attached OP Report by McMurry et al).

Appendix 2 summarizes all bromide concentration measurements made during the testing program. Data are presented as Br concentration (mg/l) vs time since start of pumping. These data are also included in spreadsheet form (Lotus 1-2-3 format) as file BRDATA.WK1 in the attached diskette.

The raw bromide recovery data of Appendix 2 were analyzed with the aid of a first-order dilution model incorporating terms for background bromide input and a step-function variation in bromide concentration recovered from the aquifer during pumpback (see Appendix 5 for model description). The model was used to generate estimates of the effective straddled interval volume (V_{eff}), initial interval concentration during emplacement (Ci), step-function duration since start of recovery (t'), and ground water advective flux through the straddled interval (Q/A). Although the concept of a step function form is too simplistic to describe the actual tracer recovery response due to dispersive transport in the aquifer, the model's principle use was in comparing and synthesing the raw tracer data derived from the tests. The best-fit values of these model parameters are summarized in Appendix 3.

A summary of pertinent tracer results is presented in Appendix 4, including model calculations of ground water advective flux, bromide recovery, and apparent hydraulic gradients derived from the tracer flux calculations and hydraulic conductivity estimates of Morin et al (1992). A comparison of interval dilution flux calculations on five sets of tracer data derived from the same test interval is also shown in Appendix 4, to demonstrate the degree of reproducibility obtained from multiple tests on the same straddled interval.

Figure A4 in Appendix 4 demonstrates the similarity of tracer responses from three tests on the same interval (7/21, 7/22, 7/23) that were performed without altering the packer's seating, and which differed only in the times employed for tracer recirculation during emplacement. The data have been normalized to the volume of solution pumped from the interval (during recovery) and to the volume of solution advected into the aquifer during emplacement (prior to pump on), based on the best-fit model parameter values shown in Appendix 3.

Note that tracer responses in the 7/21 and 7/22 tests (similar recirculation times of 9 and 11 minutes, respectively) are virtually identical during emplacement and recovery. The 7/23 test produced the same response during the first half of recovery, but the end of the tracer step function recovery, t', differs by more than 30% relative to the previous two tests; this difference reflects the greater distance over which the tracer travelled into the aquifer during the 7/23 test emplacement phase, and the subsequently longer period of time required to recover it from the aquifer during pumping.

Appendix 5 presents a brief summary of the assumptions and derivation of the tracer dilution model used in the analysis of the tracer data.

APPENDIX E1

WELLHEAD MEASUREMENTS SUMMARY - INEL TEST PHASE, 7-8/92

FLOW CELL FINAL READINGS

Date	Test Interval ft bls	Purge time,min	Alkalinity mg/l HCO3	pH	DO mg/l	T (C)	SC uS
7/20/92	495-515	33	232	>7.82	<9.83	12.3	433
7/21/92	"	40	NA	(7.46)	<9.98	12.5	436
7/22/92	"	tracer testing only					
7/24/92	535-555	60	183	>7.88	<9.72	13.1	436
7/28/92	557-577	39	262	7.77	<8.98	13	<440
7/30/92	580-btm	28	256	8.1	10.25	13.8	<455
8/03/92	580-600	72	214	>7.90	9.25	14.6	<423
8/05/92	495-515	tracer testing only					
8/06/92	"	19	NA	>7.87	<9.65	12.2	<469
8/13/92	open hole	70	220	7.78	<8.72	12.9	428
8/14/92	467-482	105	250	7.80	9.35	12.6	432
8/17/92	480-495	too tight to pump					
8/18/92	519-534	95	207,214	>7.84	9.00	12.8	<438
9/15/92	495-515	60	311	7.55	<8.7?	13.2	430
9/16/92	"	80	226	7.92	8.9?	13.3	433
Reproducibility (+/-RMS):			5	<.05	.3?	<0.1	ca. 2

Date	Interval ft bls	Eh mV (air-sat)	Eh, as % of air-sat. water	Fe-II mg/l	Fe-T mg/l	Br mg/l
7/20/92	495-515	NA		n.d.	0.015	NA
7/21/92	"	240		NA	NA	NA
7/22/92	"					0.47
7/24/92	535-555	>241(261)	>92	.006,.005	.030,.026	NA
7/28/92	557-577	294(357)	82	.001,.002	.022,.016	0.48
7/30/92	580-btm	245(305	80	.006,.003	.025,.022	NA
8/03/92	580-600	184(219)	84	n.d.	.014,.015	0.33
8/05/92	495-515					0.49
8/06/92	"	NA		NA	NA	2.4-7.0
8/13/92	open hole	211(250)	84	.003	0.040	NA
8/14/92	467-482	266(283)	94	n.d.	.025,.014	0.44
8/17/92	480-495					
8/18/92	519-534	297(306)	97	n.d.	.023,.027	.48,.58
9/15/92	495-515	264(270)	98	.004,.005	.016,.018	NA
9/16/92	"	NA		.004,.005	.008,.009	0.82
Reproducibility (+/-RMS):			?	0.0035	0.003	0.014

Note: Mean D.O. concentration corresponds to air-saturation at 5 deg-C, at 5000-10000 ft (amsl)

APPENDIX E2

WELLHEAD MEASUREMENTS SUMMARY - INEL TEST PHASE, 7-8/92

BROMIDE TRACER RECOVERY TESTS: RAW DATA

7/21/92: Total Inj'd = 24.6 grams

t, min	C, mg/l
9	33.3
13	15.1
17	10.7
21	8.7
29	5.1
38	2.7
58	2.55

7/22/92: Total Inj'd = 25 grams

t, min	C, mg/l
3	0.45
4	67.45
5	50.67
6	32.35
7	23.1
8	19
9	14
10	12.37
11	10.59
13	8.86
15	7.68
19	6
22	5.46
24.33	6.07
27	5.16
32.5	4.23
37	3.15
47	2.05

7/23/92: Total Inj'd = 21.86 grams

t, min	C, mg/l
3	3.08
5	41.55
7	20.73
9	16.01
11	11.24
14	9.07
18	7.29
22	5.95
27	5.93
32	5.7
39	5.61
47	4.46
57	3.55
67	2.8
77	2.41

7/24/92: Total Inj'd = 42.28 grams

t, min	C, mg/l
4	28.94
7	23.26
10	17.61
13	16.14
19	14.21
23	12.52
29	10.26
35	8.79

7/28/92: Total Inj'd = 118.6 grams

t, min	C, mg/l
9	117.9185
10	117.4443
11	38.47422
12	25.20305
13	18.33277
14	13.88353
16	8.289732
18	6.103297
20	4.213021
22	2.979345
24	1.582780
28	1.208347

8/03/92: Total Inj'd = 106.5 grams

t, min	C, mg/l
0	0.481237
1	0.460705
2	0.422232
3	0.435836
5	0.382398
7	0.575206
9	0.533477
11	472.2912
13	1051.814
18	320.2649
23	39.03268
27	16.12682
29	13.70787
31	14.31877
35	8.689711
40	4.518235
45	6.716023
52	2.752895
57	1.859378
62	1.787119
67	1.822891
87	1.146444
107	0.986140

8/5/92: Total Inj'd = 182.1 grams

t, min	C, mg/l
5	36.59746
6	38.67523
7	36.30989
8	32.25781
9	30.16574
11	29.11367
12	26.69383
15	21.82971
19	20.65694
21	16.49776
28	13.65214
31	12.76673
33	14.42723
41	10.31758
45	13.43844
48	9.422778
54	9.238766
60	7.828309
66	8.881452
72	8.371224
78	7.407744
86	7.037477
93	6.954693
100	7.320605
110	5.642726
117.5	5.554398
127	5.276767
144	4.857300
154	4.488849

8/6/92: Total Inj'd = 151 grams

t, min	C, mg/l
3	2.425403
4	7.101465
5	2.693940
6	149.2327
7	107.1608
8	79.47673
9	80.12130
11	49.14892
13	42.84281
15	37.64870
19	34.72721
22	50.96828
27	27.25398
32	26.06969
37	19.72922
42	18.64463
52	11.67051
63	13.99631
74	5.969335
109	4.321216

8/14/92: Total Inj'd = 74 [illegible]6 grams

t, min		C, mg/l
0		0.447145
0		0
1		0.331874
2		0.360528
3	891.8 = P	459
4		369.1707
5		53.83146
7		21.46952
9		11.06880
11		7.625305
13		5.318738
15		4.217994
17		3.740730
22		2.652777
27		2.323574
32		1.904758
42		1.362011
75		0.659910

8/18/92: Total Inj'd = 78.54 grams

t, min	C, mg/l
1	0.487016
2	0.574010
3	0.507443
4	278.2479
5	104.2225
7	48.33706
9	36.40467
11	28.80359
13	22.51039
15	17.88368
17	13.46895
19	11.95601
21	10.61302
23	8.967556
25	7.577375
29	6.562435
31	5.660136
36	4.724040
41	3.830976

9/16/92: Total Inj'd = 177 grams

t, min	C, mg/l
3	0.838680
4	177.5101
5	127.8903
6	106.7439
7	95.29194
8	89.46937
10	84.71172
12	75.62341
14	70.40825
16	66.38458
18	57.06252
20	54.94420
22	45.66694
26	34.45852
30	27.23148
34	21.61083
38	18.49821
42	15.24610
50	11.69917
56	8.939771
61	7.588112
67	6.605319
74	5.896667
81	5.111416
92	4.266254

APPENDIX E3

WELLHEAD MEASUREMENTS SUMMARY - INEL TEST PHASE, 7-8/92

BROMIDE TRACER RECOVERY TESTS: SUMMARY OF FITTING PARAMETERS

Interval	495-515	495-515	495-515	535-555	NotMixed 557-577	NotMixed* 580-600
Test Date	7/21	7/22	7/23	7/24	7/28	8/03
Co =	60	67.5	41.55	35	117.9	1050.8
Cb =	2.5	2	2.5	9	1.1	1.1
C* =	100	70	55	70	450	0
Q =	77.5	72	74	72	64	15
k =	0.06	0.055	0.06	0.06	0.01	0
V_{eff} =	230	190	230	380	50	45
t′ =	16	20	34	19	10.5	0
Ci =	111	178	180	87	2372	2367
% Br recovery	104	135	189	78	22	124
t(circ), min =	9	11	23	12	8	20
b(cm)	610	610	610	610	610	610
A(cm^2) =	13365	12148	13365	17180	6232	5912
O(cm^3/min) =	15864	16841	14727	29154	18783	1827

\+ interval dilution did not correspond to first-order removal process, indicating non-uniform tracer distribution during pumpback, possible develpment of "dead" or incompletely flushed volume within the straddled interval; note that calculated effective Volume, Br recovery, or both are anomalous.

Interval	NotMixed? 495-515	495-515	NotMixed 467-482	NotMixed 519-534	NotMixed 500-515
Test Date	8/05:	8/06:	8/14:	8/18:	9/16:
Co =	38.7	149.23	460	278.2	177.5
Cb =	4	5.5	1	2	2.5
C* =	50	350	0	0	900
Q =	74	74	74	74	72
k =	0.06	0.06	0	0	0.07
V_{eff} =	1200	200	70	50	200
t′ =	100	28	0	0	13
Ci =	152	755	1067	1571	885
% Br recovery	59	93	114	114	106
t(circ), min =	72	23	23	20	10
b(cm) =	610	610	457	457	457
A(cm^2) =	12463	12463	6382	5394	10788
Q(cm^3/min) =	22919	14119	2561	4331	32173

APPENDIX E4

WELLHEAD MEASUREMENTS SUMMARY - INEL TEST PHASE, 7-8/92

BROMIDE TRACER RECOVERY TESTS: SUMMARY

Zone	Test Date	calc'd Q, l/min	calc'd A, cm^2	calc'd q, cm/min	Flow-meter K, ft/d	calc'd i	%Br Rec'y	Interval Mixed/ not
467-482	8/14	2.56	6382	0.4	20000	0.0009	114	not
495-515	7/21	15.86	13365	1.19	10000	0.0056	104	
495-515	7/22	16.84	12148	1.39	10000	0.0066	135	
495-515	7/23	14.73	13365	1.1	10000	0.0052	189*	
495-515	8/05**	22.92	12460	0.75	10000	0.0035	59	not
495-515	8/06	14.12	12460	1.13	10000	0.0053	93	
500-515	9/15	32.17	10788	2.98	10000	0.0141	106	not ?
519-534	8/18	4.33	5394	0.8	4000	0.0094	114	not
535-555	7/24	29.15	17180	1.7	1000	0.0803	78	
557-577	7/28	18.78	6230	3.01	800	0.1780	22	not
580-600	8/03	1.83	5912	0.31	100	0.1464	124	not

Average Br recovery = 103 %

NOTE: Specific discharges plotted in Figure 6 represent values shown above, representing interval areas calculated from the fitted interval dilution volume and mean borehole diameter, as well as estimates based on values of interval area (A) estimated purely from borehole geometry.

* Unknown source of error suspected in calculation of injected mass of bromide.

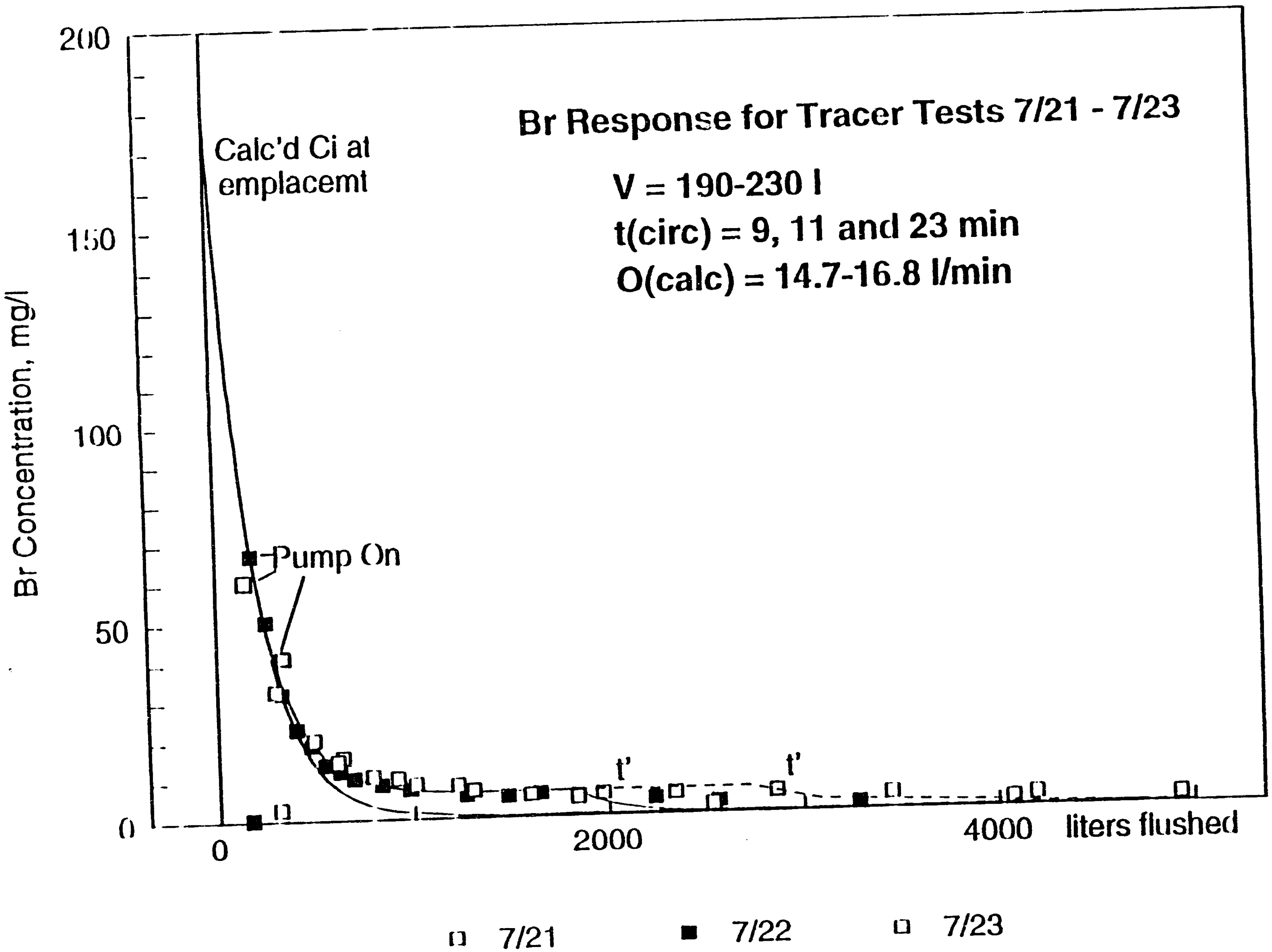
** A is assumed to be equivalent to that of 8/06, and is not calculated from apparent interval volume.

REPRODUCIBILITY OF TRACER DILUTION RATE CALCULATIONS:

Zone	Test Date	calc'd dilution rate, 1/min	calc'd q=vn, cm	calc'd gradient
495-515	7/21	15.86	1.19	0.0056
495-515	7/22	16.84	1.39	0.0065
495-515	7/23	14.73	1.1	0.0051
495-515	8/06	14.12	1.13	0.0053
495-515	8/05	22.92 (Not Mixed)	0.75	0.0035

Mean = 15.39 (Only Mixed Tests)

RMS = 1.05 6.8%



Br Response for Tracer Tests 7/21 - 7/23
V = 190-230 l
t(circ) = 9, 11 and 23 min
O(calc) = 14.7-16.8 l/min
Calc'd Ci at
emplacemt
Pump On
t'
t'
Br Concentration, mg/l
200
150
100
50
0
0
2000
4000
liters flushed
7/21
7/22
7/23

FIGURE A4

APPENDIX E5

TRACER EQUATION DEVELOPMENT

First-Order Dilution Modelling of Tracer Data, 1992 INEL Tests

Model Development:

Assume perfect mixing within test interval during emplacement and recovery phases, steady discharge (=Q), constant inflow (=I, with Br concentration Cb) and outflow (O, concentration C) of ground water to/from the test interval, and a down-gradient plume of concentration C* contributing Br back to the interval during pumping, as a step function, until $t = t'$. Tracer plume water (inflow rate I*, concentration C*) is assumed to contribute a constant fraction of total inflow to the well (kQ) during the recovery phase. The model is constructed to be generally applicable for both tracer recovery and emplacement phases; during the recirculation (emplacement) phase: $Q = 0,\ O > 0,\ t' = 0$.

Equation set-up: $I+I^*-O-Q = dV/dt = 0$ and $CbI+C^*I^*-CO-CQ = VdC/dt$

or $dC/dt+[(Q+O)/V]C = CbO/V+[Q/V][(1-k)Cb+kC^*]-(kQC^*/V)[u(t-t')]$

LaPlace transform: $pX-xo + aX = cb/p + ad/p - (af/p)\exp(-pg)$

where: $a=Q/V;\ b=O/V;\ a'=(Q+O)/V;\ c=Cb;\ d=kC^*+(1-k)Cb\ ;\ f = kC^*\ ;\ g = t'$

Solving for X: $X = xo/(p+a') + (cb+ad)/[p(p+a')] - [af/[p(p+a')]]\exp(-pg)$

Reverse transform: $x = xo\exp(-a't) + [(cb+ad)/a'][1-\exp(-a't)] - 0\ ;\ 0<t<b$

$$x = xo\exp(-a't) + [(cb+ad)/a'][1-\exp(-a't)] - (af/a')[1-\exp(-a'(t-g))]\quad ;\ t>b$$

Back-substitution and rearrangement:

$$C = (Co - C')\exp(-(Q+O)t/V) + C' \quad ;\ 0 <t< t'$$

$$C = (Co - C')\exp(-(Q+O)t/V) + C'+[kC^*Q/(Q+O)][\exp(-(Q+O)(t-t')/V)-1] \quad ;\ t > t'$$

where $C' = Cb + k(C^*-Cb)Q/(Q+O)$

The above equations are valid for the recovery phase. During the emplacement (recirculation) phase, when $Q = 0,\ O > 0,\ t' = 0$, the general solution degenerates to:

$$C = (Co - Cb)\exp(-Ot/V) + Cb$$

Fitting parameters for tracer recovery curve fitting:

Ci =	200 ppm	Br conc. at time of emplacement
Co =	60 ppm	Br conc. at start of pumping
Cb =	2.5 ppm	Local average ground water Br concentration (can be affected by Br injection)
C* =	100 ppm	Average tracer plume concentration for the step function recovery of bromide advected into the aquifer, assumed constant and <= Ci at emplacement
Q =	77.5 l/min	Pump discharge rate at well head
O =	0 l/min	Borehole outflow rate = I + I* - Q (=0 during recovery, >0 during circulation)
k =	0.06 -	Tracer plume inflow (I*) contribution to total inflow, I, as a fraction of I, equal to kQ
V =	230 l	Apparent volume of well-mixed, straddled zone (synonomous with V_{eff})
t′ =	16 min	End of tracer plume recovery step contribution
t(offset)	-4 min	Zero time offset or time lag for flow up the riser pipe

1992 ANNUAL SUMMARY

HYDROLOGIC STUDIES IN WELLS OPEN THROUGH LARGE INTERVALS

Prepared by:

IDAHO WATER RESOURCES RESEARCH INSTITUTE
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and

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and

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for

INEL OVERSIGHT PROGRAM
IDAHO DEPARTMENT OF HEALTH AND WELFARE

INTRODUCTION

BACKGROUND

This report describes and summarizes activities, data, and preliminary data interpretation from the INEL Oversight Program R&D-1 project titled "Hydrologic Studies In Wells Open Through Large Intervals." The project is designed to use a straddle-packer system to isolate, hydraulically test, and sample specific intervals of monitoring wells that are open (uncased, unscreened) over large intervals of the Snake River Plain aquifer. The objectives of the project are to determine and compare vertical variations in water quality and aquifer properties that have previously only been determined in an integrated fashion over the entire thickness of the open interval of the observation wells. A complete description of project objectives is available in the "Funding Proposal for Research and Development on INEL by the State of Idaho In Support of Environmental Assessments" submitted to the U.S. Department of Energy.

The project was in the first season of checkout and field implementation. The report describes data collection and activities at the INEL during the summer and fall of 1992.

CONTRACT REQUIREMENTS

This report was cooperatively prepared by staff of the Idaho Geologic Survey, Idaho State University, and the University of Idaho. The report satisfies contractual obligations for an end-of-year report as specified in Appendix D of the contract between the INEL Oversight Project and the Idaho Water Resources Research Institute at the University of Idaho.

PURPOSE AND SCOPE

The purpose of this report is to document and summarize field activities, computer data files, water quality samples, and provide a preliminary interpretation of the data. This report is not intended to represent final results and data interpretation.

TESTING OF USGS WELL 44

The straddle-packer was used to hydraulically test and sample 10 intervals (some overlapping) in well USGS 44, just west of the Idaho Chemical Processing Plant. Time-consuming equipment and procedure testing in this well prevented use of the straddle-packer in other wells during the 1992 season.

Equipment set-up and data collection on USGS 44 began in early July and continued at an intense pace until mid-August. In mid-August the packer was positioned on an interval 500 to 515 feet below land surface, where it remained for the duration of 1992. The packer system was used during the fall of 1992 to acquire long-term hydraulic data from the 500 to 515 foot interval.

Activities during the active data collection period from July 1 through August 19, 1992 are summarized in Appendix A. Initial testing during this period was conducted using a 20 foot straddle interval. After completing all possible 20 foot intervals the packer system was removed from the well and reconfigured to straddle a 15 foot interval. All intervals in the well were tested with either the 15 or the 20 foot straddle interval.

Objectives and procedures were similar for all tested intervals. Modifications to procedures were made as more was learned about the packer system and the characteristics of the aquifer. The intent was to hydraulically test and sample as many of the intervals as possible, recognizing that extremely low and extremely high permeability intervals created problems for hydraulic testing or sampling. Tracer (lithium bromide) was also routinely emplaced to identify mixing and purging characteristics of the intervals. A list of the successfully tested intervals in well USGS 44, and the tests and samples conducted in each interval is given in table 1.

Table 1. Testing and Sampling in Specific Intervals in Well USGS 44.

Interval	Hydraulic Tests		Sampling	
(ft. bls)	Slug	Pumping	Chem./Rad.	Microbial
467-482	Yes	Yes	Yes	Yes
480-495	Yes	Yes	No	No
495-515	Yes	No	Yes	Yes
500-515	No	No	No	No
519-534	Yes	Yes	Yes	Yes
535-555	No	Yes	Yes	Yes
557-577	No	Yes	Yes	Yes
580-600	Yes	Yes	Yes	Yes
600-620	Yes	Yes	No	No
600-650	Yes	Yes	No	No

SIGNIFICANT RESULTS OF 1992

The field experiences and analysis and interpretation of the data collected during 1992 provide valuable insights into guiding the directions and procedures to be implemented in subsequent years. A list of the significant findings from the 1992 research effort is as follows:

APPENDIX F

IMPELLER FLOW-METER LOGGING OF VERTICAL CROSS FLOW BETWEEN BASALT AQUIFERS THROUGH WELLS AT THE IDAHO NATIONAL ENGINEERING LABORATORY

IMPELLER FLOW-METER LOGGING OF VERTICAL CROSS FLOW BETWEEN BASALT AQUIFERS THROUGH WELLS AT THE IDAHO NATIONAL ENGINEERING LABORATORY EASTERN SNAKE RIVER PLAIN, IDAHO

A PROGRESS REPORT: JUNE 22, 1992

BY

WILLIAM M. BENNECKE

AND

SPENCER H. WOOD

BOREHOLE GEOPHYSICS RESEARCH PROGRAM

DEPARTMENT OF GEOSCIENCES

BOISE STATE UNIVERSITY

BOISE, IDAHO 83725

Funded by the State of Idaho - Division of Environmental Quality - INEL Oversight Program

ABSTRACT

An impeller flowmeter was used with a COLOG digital acquisition system to determine existing borehole flows, to compare with previous logging results, and to acquire flow measurements of vertical cross-flow of water in the wells between permeable zones in the open-hole intervals. A 1964 study used Tracejector Sondes to measure flow velocities and directions. The direction of flow found was predominantly downward with velocities ranging from 0-30 ft/min. Some flow reversals were noted and attributed to nearby pumping wells.

USGS wells 44 and 46 were studied in September, 1991 near the Idaho Chemical Processing Plant (ICPP). The results showed a usual overall flow direction downward with flow entering the wells at around 510 to 600 ft. below the land surface. Water exited these wells at lower levels around 550 to 580 ft. Flow velocities ranged up to 24 ft/min. A flow reversal occurred during logging of well number 46. This reversal is thought to be caused by turning on a pump at 3100 gpm.

Using published aquifer parameters the rate of propagation of a pressure change in an aquifer was calculated for the well CPP-2 turning on and off, at 3100 gpm (2 hour on and 3 hour off cycle). The finite-element program MODFLOW was run to simulate these conditions. The computations indicated that within two hours of pumping from CPP-2, only 5×10^{-5} ft of drawdown would occur at

wells 44 & 46. We do not believe that a 10^{-5} ft head difference induces flow reversals in the wells. These computations suggest that the reported transmissivity values commonly used are too small or unconfined storativity too large to simulate the situation of flow reversals. We suspect that a value for storativity considerably less than 0.08 used in computation may be more appropriate.

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LIST OF FIGURES

INTRODUCTION

At the Idaho National Engineering Laboratory (INEL) there is great concern about the potential for migration of radioactive and chemical wastes from the various facilities there to the underlying Snake River Plain Aquifer (SRPA). More than forty wells at the INEL have large open intervals, typically their wells have cemented casing to the water level, and have 100 to 300 feet of uncased borehole in the saturated zone. These open intervals have numerous fracture zones of varying aperture, overall thickness, and lateral extent. There is the high likelihood for movement of contaminants across aquitards owing to connection by wells. A better understanding of flow in these wells would help to estimate the effects of contaminant movement and their impacts on the SRPA.

Studies and projects have tried to address these issues, but the projects were done 25 years ago and overall effects of these well interconnections were never studied in detail. This study is using impeller flow-meter techniques (Hess, 1986), to measure vertical cross-flows of water in the wells between permeable zones in the open-hole intervals. This will allow a better understanding of fluid flow within wells that is needed to understand contamination routes. In this preliminary study, the 25-year old data are reviewed, and preliminary results reported of flow-meter logging in September, 1991 by Boise State University-borehole geophysics research program.

BACKGROUND

The INEL was established in 1949 by the U.S. Atomic Energy Commission as an area to build, test and operate various nuclear reactors and to have fuel processing plants and support facilities with maximum safety and isolation. Administered by the U.S. Department of Energy, the site is comprised of seven major facilities operated by government contractors. The site covers 890 square miles of semi-arid land in the north eastern part of the eastern Snake River Plain (Fig. 1). The INEL is thirty-nine miles long from north to south and thirty-six miles wide at its broadest point.

The two facilities that will be discussed in this report are the Idaho Chemical Processing Plant (ICPP) and the test Reactor Area (TRA) (Fig. 2). The ICPP complex houses reprocessing facilities for governmental defense, and research on spent nuclear fuel. Facilities at the ICPP include spent fuel storage and reprocessing areas, a waste solidification facility and related waste storage bins, remote analytical laboratories, and a coal-fired steam generating plant. The ICPP is 8 miles north of the southern boundary of the INEL and covers about 0.15 square miles. The ICPP has discharged radioactive and chemical wastes to a disposal well and unlined percolation ponds for several decades. From 1953 to 1984 the ICPP discharged low-level radioactive and chemical wastewater directly to the Snake River Plain Aquifer through well CPP DISP (Fig. 3), a 600 ft. deep disposal well. From 1974-1985, 445 million gal/year of waste water containing an average of 287 Ci/year of strontium 90 also was discharged to percolation ponds at the ICPP from 1982 to 1985 (Pittman from Anderson, 1991). The ICPP no longer discharges wastes down the disposal well, but percolation ponds are still in operation.

The TRA is a sophisticated materials testing complex housing extensive facilities for studying the effects of radiation on materials, fuel, and equipment. The Advanced Test Reactor (ATR) located at TRA produces a neutron flux that allows simulation of long duration radioactive isotopes used in medicine, research, and industry. The TRA is 2 miles northwest of the ICPP and covers about 0.10 square miles . Some knowledge of amounts of radioactive and non-radioactive wastes discharged to a deep well and to percolation ponds has been compiled by Pittman and Anderson (1991) and is summarized here: A 1,275 foot deep well located there is called the TRA DISP (Fig. 3), it was used to dispose of about 250 million gal/year of nonradioactive wastewater from 1964 to 1982. From 1959 to 1985, discharge of radioactive wastes to percolation ponds at the TRA averaged about 189 million gal/year. Nonradioactive liquid waste consisting mainly of sulfate and sodium has been discharged to a percolation pond at TRA since 1962. From 1974 to 1979, aqueous radioactive waste contained about 2,250 Ci/year of activation and fission products. This amount was reduced to about 288 Ci/year from 1980 to 1985. Tritium, which comprised about 10 percent of the radioactive waste discharged to ponds at the TRA from 1974 to 1975, comprised about 90 percent of the total radioactive discharged there from 1981 to 1985.

GENERAL HYDROGEOLOGY AT THE INEL

The regional direction of water flow in the SRPA is northeast to southwest (Fig. 4). The major area of recharge is from the Big Lost River which flows onto the eastern Snake River Plain near Arco. This river drains about 1,500 square miles of Butte and Custer Counties, including the northeastern flanks of the Pioneer Mountains and the southwestern flanks of the Lost River Range. Transmissivity of the aquifer generally ranges from 134,000 to 13,400,000 square feet/day (Bennett, 1990). In a static well, any flow produced will be due to the regional trend of the area which is quite large compared to other aquifer systems, but small compared to flow induced by a nearby pumping well.

Vertical flow velocities in a non-pumping well may be influenced by vertical head gradients, the diameters of the opening that water flows through, temperature, roughness of the borehole walls, and initial turbulence that may be present.

METHODS OF MEASURING FLOW IN STATIC WELLS

A method of finding the vertical flow velocity in a static well is by the use of impeller flowmeters (commonly called spinners). The impeller flowmeter is made up of a propeller that can range in sizes. These propellers spin when acted on by flowing water. The method of measurement is either to lower the flow-meter into the well and record flow at a stationary position or to tow the flow-meter up or down measuring flow. This later method is done because the propeller has an initial stall speed that must be overcome to spin it. When the spinner is towed, the movement of water past it generates spin which overcomes its initial stall speed. Variations on the spin velocity is taken for flow in the well. The spinner's propeller makes revolutions which act on an electrical circuit in the instrument. The circuit sends a signal in counts/seconds which can be converted into feet/minute once the flow-meter is calibrated. Spinner flowmeters are available that can measure borehole water velocities of 2 meters/minute and greater (Hess, 1985).

Flow in a static well can be also measured in other ways. One such method is the use of tracers which may be salt, radioactive materials, dyes, and others items. These tracers are used in a Tracejector Sonde. The Tracejector Sonde using radioactive material is a combination of a gamma-ray unit and an ejector unit. The position of the two units is interchangeable and can be assembled for measuring either upward or downward circulation of borehole fluids. The procedure for operating the sonde is to lower the sonde into a borehole, to a particular depth of interest, which is hypothesized to be the flow area. A minute amount of tracer then is discharged from the ejector portion of the probe. The tracer travels from the ejector to the detector point and the travel time is calculated from a stopwatch. Very slow borehole-fluid velocities of a few meters per day have been measured by using tracer techniques (Hess, 1985). However, the use of radioactive solutions in groundwater is now subject to strict regulations, brine solutions are useful only in fresh water, and both techniques are subject to considerable measurement errors caused by the differences in density between the trace solution and the borehole fluid (Hess, 1985).

Another such method to measure flow velocity in a static well, that has a similar theory and methodology as the Tracejector Sonde, is the heat-pulse flowmeter. The heat-pulse flowmeter is a combination of temperature sensors and a heating grid. The two temperature sensors are set 20 mm from either side of a heating grid (Fig. 5). The operation of the heat-pulse flowmeter is to lower it into a well, to a particular spot of interest, and then discharge a small pulse of heat which either travels up or down to the temperature sensors. The time it takes to travel to either sensor is used to calculate the velocity. The heat-pulse flowmeter has a useful flow-measuring range of 0.06 to 10 meters/minute (Hess, 1985).

PREVIOUS WORK DONE ON BOREHOLE FLOW AT INEL

Preliminary studies defining the velocity and direction of flow in static wells at INEL were reported about 25 years ago. The significance of the data were never evaluated, nor was the research continued. D.A. Morris and coworkers in 1964 noted work done with a Tracejector Sonde containg an Iodine 131 tracer. This work was done on over 20 wells at various places in the INEL area. A downward flow was determined in the wells with velocities ranging to 30 feet/minute. Illustrations from Morris and others (1964) are reproduced in this report (Fig. 6-9). The location of these wells are shown in figure 10. J.T. Barraclough and coworkers (1965) also did Tracejector Sonde work with an Iodine 131 tracer. This work was done on wells in the ICPP, area on well numbers 42, 43, 48, 49, 51, 52, 59 (Fig. 11). Direction of flow was more variable than that measured by Morris and others. The velocities ranged up to 30 feet/minute (Fig. 12). Reversals of flows were also noted and attributed to nearby pumping wells. The reversals were evident over relatively short periods of time, in some instances less than an hour.

WORK DONE IN THIS STUDY

Flowmeter, caliper, natural gamma, and temperature logs were obtained in September, 1991 on USGS wells no. 44 and 46. The wells are located adjacent to the west boundary of the ICCP (Fig. 13). Pumps were pulled from these wells in September so that the U.S. Geological Survey Borehole Geophysics group from Denver and the BSU unit could make measurements. A report is currently being prepared on the U.S. Geological Survey work by Roger Morin (review, 1992).

Logs were run to determine existing borehole conditions, to calibrate other logs needing accurate borehole diameters in order to quantify their results, and to compare with previous logging results. The logs were run from Boise State University's logging truck Mt. Sopris 3000 geophysical logging unit, 1200-meter capacity 4-conductor downhole cable, and necessary logging sondes. All data are acquired on a COLOG digital acquisition system and are output as ASCII files to PC floppy disks that can be played back at any scale. Depth precision is about 0.05 feet. This system has been in use for 2 years in aquifer studies in southwest Idaho. The various logging devices ran on USGS wells 44 and 46 were run repeatedly to check reproducibility of the sonde measurements.

An impeller flowmeter was used on the wells to acquire flow measurements of vertical cross-flow of water in the wells, between permeable zones in the wells' open-hole intervals. The impeller-flowmeter is a Mineral Logging Systems, Inc 1-7/16-inch-diameter (36.5mm) flowmeter with a voltage inhibitor (Fig. 14). The device is filled with Wesson vegetable oil to allow operation at varying pressures. For this report the propeller was a 2-3/16-inch (55.5 mm) blade. The device sends voltage pulses (4 per revolution) to a pulse-counting digital-data acquisition system and raw data is recorded as total and average number of counts per unit time.

A typical run would consist of sending the flowmeter down the hole at about 30 ft/min stopping at the bottom, and then preceding to tow up at a comparable speed. Varying towing speeds in cased portions of the well (where there was no flow present) were used to calibrate the pulse rate to vertical flow velocity. This procedure was done for each well studied (Fig. 15).

CROSS FLOW IN WELL NO. 44

In USGS well no. 44 major vertical cross flow was determined to be between fracture zones at 512 ± 2 feet and 549 ± 2 feet. These zones correspond with fracture zones detected by the caliper log from 510-516 feet and 540-546. There is also a suggestion on the flowmeter record of low flow into fracture of 574-578. This is corroborated by the isothermal zone on the temperature log (Fig. 16). Four trolls of the flow meter tool were made in well no. 44 between 11:40 and 12:15, on October 2, 1991. Flow was consistently down the well from fracture zones at 512 feet and into fracture at about 540 ft. and minor flow into fractures at about 574 to 578.

CROSS FLOW IN WELL NO. 46

In well no. 46, the flow direction actually reversed while we were making logging runs between 14:40 and 15:20, October 2, 1991 (Fig. 17). Minor flows are coming into and out of fractures at the base of the casing and down to 429 ± 2 ft. A major flow goes in and out of the fractures at 514 ± 2 ft. The flow-velocity fluctuation at 542-549 is caused by the enlarged hole diameter in a fracture zone and not on account of the fracture zone accepting a yielding flow. Major flow does go in and out of fractures between 571 and 580. The vertical-flow velocity from 514 to 574 was downward at about 23 feet per minute from 14:29 to 14:55. It apparently reversed and was flowing upward about 16 ft/min. entering and exiting from the same fracture involved in the downward flow. This upward flow was consistent for the trolls from 15:05-15:10 and 15:10-15:20 on October 2, 1991. We did not run a temperature log on USGS no. 46, but the Denver USGS unit's temperature log run on September 1991 corroborated the flow zone shown by the interval of isothermal water. Flows are determined to be coming from openings at 510 ft. and 550 ft for USGS well #44 and

510 ft and 580 ft, with a smaller flows from 600-630 ft, 480-500 ft, and 637-Bottom of well for USGS well #46 (Fig. 16).

CAUSES OF FLOW REVERSALS

The change in flow direction may be the result of well pumpage in a nearby well CPP-2 (Cpp-671 (west)), 2400 feet away (Fig. 3) which was turned on and off at various times during this study. Unfortunately the record of the exact times the pump was on during our flowmeter runs were not recorded due to a malfunctioning recorder at the pumping well. The well has a pumpage of about 3100 gallons/minute. This well appears to be producing from what Anderson (1991) described as the I basalt flow group (Fig. 18). Figure 19 shows the extent of basalt flow group I in the ICPP and TRA area. Figure 20 shows tentative correlation of gamma logs between USGS 44 and the production well CPP-2. Flow zones are identified by fracture zones on the USGS 44 caliper log. No caliper log is available for CPP-2, but we suggest a correlation of gamma log character on Fig. 20.

FLOWMETER SENSITIVITY - CALIBRATION

The flowmeter records have considerable noise, (3 to 12 ft/min) and we are presently working on instrumentation to reduce the noise level and possibly increase the sensitivity of the meter. Sensitivity of the flowmeter appears to be about 5 ft/minute. We are also acquiring a new Gearhart Flowmeter with reported sensitivity of about 2 ft/min. and are adapting it to work with our logging system. A flowmeter test calibration facility has been constructed at Boise State University.

RATE OF PROPAGATION OF A PRESSURE PULSE CAUSED BY TURNING ON A PUMP

To explore the idea that a nearby pumping well could have an effect on the flow measurements over relatively short periods of time, a look at the hydraulic diffusivity coefficient equation was used to find the rate of propagation of a pressure change in an aquifer.

From Domenico (1972, p. 319) after Theis (1935), the equation for the change of head caused by turning a pump on at time $t = 0$, at the point, $r = 0$, at a rate of Q, in a tabular confined aquifer of thickness b, uniform aquifer properties, and radial symmetry, is given by:

$$h - h_o = Q \cdot W(u)/(4\pi T)$$

where h_o = the initial head, extending from the well to infinite distance.

Q = pump rate, in gallons/day (1 gpm = 1440 gpd).

T = aquifer transmissivity, which is the thickness, b multiplied by the hydraulic conductivity, K.

W(u) = the well function, with an argument of u, the tabulated values of which are given in most texts on hydrogeology.

u = argument of the well function.

  $= r^2/4Dt$

r = distance from well

t = time

D = hydraulic diffusivity

D = T/S

T = aquifer transmissivity

S = aquifer storativity (dimensionless)

  $= \sigma_w g b(\alpha + n\beta_w)$

σ_w = density of water

g = acceleration of gravity

b = aquifer thickness

β_w = compressibility of water

n = aquifer porosity

α = compressibility of aquifer rock (elastic and inelastic combined)

Calculation of time at which a discernable pressure change is detected at a distant observation well: We would like to know how quickly the drawdown of head induced by pumping propagates through the aquifer. It is important to know when a perceptible change in head will occur at a distant observation well, after the pump at r = 0, is turned on. These estimations help in conceptualizing aquifer dynamics and in planning well tests.

Using a well tape or a pressure transducer in an observation well, 0.01 feet is about the limit of resolution of a discernable change in head.

If the pump is turned on at $t = 0$, at a rate Q, how long (t) will it take to produce a head change of 0.01 feet, at a distance r ? To solve this, we set $h - h_o = 0.01$ feet., and find the value of W(u) and hence the value of $u = r^2/4Dt$ for which that value occurs. Since the equation also involves Q, and T outside the argument for the well function, we will have to prescribe those values first in order to find the relationship between r and t, meeting those conditions.

In practical engineering units (pressure head in feet, time in days, and pumpage in gallons/day),

$$0.01 = (Q/4\pi T) \cdot W(u)$$

$$W(u) = [4\pi T/Q] \cdot (0.01)$$

Example:

Take this situation where: $Q = 3100$ gpm $= 4.46 \times 10^5$ g/day

$T = 1{,}465{,}000$ g/day· ft

$S = 0.08$

values for T and S are from well CPP-2 (Stewart, 1951) (Fig. 20).

Calculate $T/Q = 1.47 \times 10^6 / 4.46 \times 10^6 (ft^{-1}) = 0.328 (ft^{-1})$, and then

calculate:

$$W(u) = 4\pi \cdot (0.328 \; ft^{-1}) \cdot (0.01 \; ft) = 0.0412$$

Now look up the value of u for which W(u) = 0.0412. The well function W(u) is tabulated in most textbooks on hydrogeology [see for example Domenico (1975, p. 320), Freeze and Cherry (1979), or Domenico and Schwartz (1990, p. 147].

The corresponding value of u is 2.213, therefore

$$u = 2.213 = r^2/4Dt$$

$$r^2 = 2.213 \cdot 4Dt \quad \text{and} \quad t = r^2 / 8.852 \; D$$

From this we can calculate the time at which a 0.01 ft head drop will occur at any distance r, using values from Stewart (1951) derived from well tests on April 21-22 and June 29-30, 1951 on well CPP-2, S =0 .08, T = 1,465,000 g/day ft.

T = 1,465,000 g/d· ft gives D, the diffusivity. We have a problem with units using gallons. T is in gallons/day·ft, and diffusivity should be entirely in length and time units. To do this, we must convert T to length and time units. 1 gallon = 0.134 ft^3, so that T = 1,465,000 gallons/day· ft = 196,310 ft^3/day· ft = 196,310 ft^2/day.

$D = T/S = [196,310\ ft^2/day] / .08 = 2.45 \times 10^6\ ft^2/day$

Now to calculate the time t, when a pressure pulse of 0.01 feet reaches a distance of 2400 ft from the pumped well.

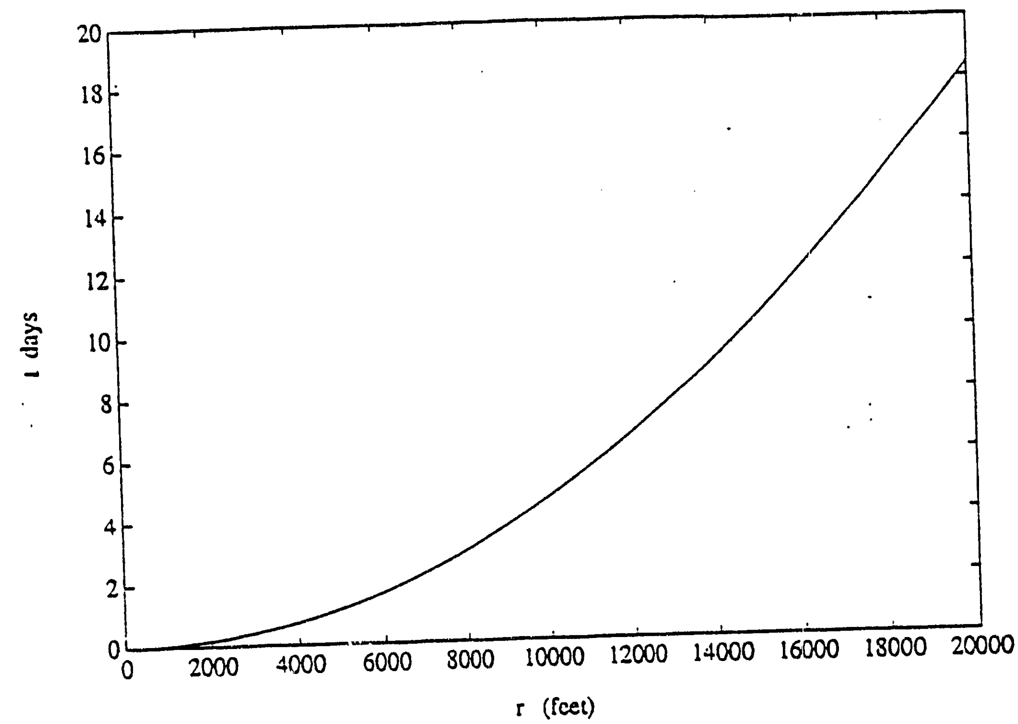
$t = r^2/8.852\ D = [2400\ ft]^2 / [8.852 \times 2.45 \times 10^6\ ft^2/day]$

$= 0.2652$ days = 382 minutes

So that according to calculations using the aquifer parameter of S=0.08, T=1,465,00 g/day/ft we should see a detectable (0.01 ft) drawdown at 2400 ft in about 6.5 hours. this seems a long, time in that we suspect effects are occurring more quickly to produce significant flow reversals of vertical flows of 20 to 30 ft/min. in wells. If S were decreased to 0.008, a factor of ten less, the effect propagates in about 0.6 hours which is more like the suspected situation. This suggests that a storativity more typical of a confined aquifer (<0.005) may be more appropriate.

One can plot a curve of the relationship for t and r, for the appearance of a discernable head change of 0.01 feet, by plotting the parabola:

$t = r^2 / 2.17 \times 10^7$ .... units of days and feet.



The slope of the straight part of this curve, and hence the rate at which the discernable signal propagates, can be calculated by differentiating the equation:

$$r^2 = 8.852\ D \cdot t$$

$$2r\ dr = 8.852\ D\ dt$$

$$dr/dt = 8.852\ D/2r = 4.426\ D/r$$

so that at a distance of 2400 feet, the signal would propagate at a rate of

$$dr/dt = 4.426\ [2.45 \times 10^6\ ft^2/day]/\ [2400\ ft] = 4.53 \times 10^3$$

ft/day

= 3.14 ft/minute, for S=0.08

If S=0.008, the rate would increase to 31.4 ft/min.

CONSIDERATION OF HYDRAULIC DIFFUSIVITY IN OTHER STUDIES

The concept of hydraulic diffusivity, as a measure of the propagation rate of a pressure disturbance in an aquifer is rarely discussed in hydrogeology textbooks. Domenico and Schwartz (1990, p. 145) show through dimensional analysis that the value of $u = r^2/4Dt$ = constant, is useful for estimating the time at which head changes occur in a basin from pumpage at a distance. However, their discussion is difficult to apply. It is hoped that the above discussion, and example shows the utility and the method of the calculation.

Hydraulic diffusivity has been considered on a larger scale in the study of earthquakes, and in particular earthquakes induced by pore pressure changes that result from the filling large reservoirs and also as a result of fluid injection into the ground (Li, 1984/85; Talwani and Acree, 1984; Rice and Cleary, 1976).

Li (1984/85) gives the expression for the half-space solution for the pressure at a point at a radial distance r away from the pressure source and at time t, due to a constant well pressure P_o exerted on the wall of a sphere of radius a, beginning at time = 0. The equation is valid for a pressure disturbance and measuring point at considerable depth below the free surface.

$$P(r,t) = P_o\, a\, [1/r \cdot \mathrm{erfc}\, \{r/\sqrt{4Dt}\}\,]$$

where erfc is the complementary error function.

Note here that the argument of the error function is the same as that for the well function W(u) considered above - and a similar kind of calculation can be made, in which Q nor T have to be assumed. One only needs a value of D, the hydraulic diffusivity, and for any detectable pressure ratio $P(r,t)/P_o$, the relationship between r, t, and D can be calculated.

Li (1984/85) has compiled values for the hydraulic diffusivity of large rock masses from a variety of sources. The values vary from 5×10^3 to 10^5 cm^2/sec. The value of 2.45×10^6 ft^2/day, used above converts to 2.6×10^4 cm^2/sec (using S=0.08) - so that the value used in the above example is reasonable. If S is more like that of a confined aquifer (0.008) then the value of D would be 2.6×10^4 cm^2/sec. and somewhat larger than those reported for large rock masses.

COMPUTER MODEL COMPUTATION OF DRAWDOWN PRESSURE

Computer modeling programs can also be used to study the time at which turning on a nearby well produces a disturbance effect in a observation well. The program MODFLOW (Mcdonald and Harbaugh, 1988) is a numerical solution for aquifer pressure variation similar to the Theis (1935) analytical solution, but which allows for irregular aquifer properties. MODFLOW was employed to calculate pressure disturbances using the same transmisivity and storativity value used in the previous equations. The model was run with well CPP-2 turned on at 3100 gpm for 2 hours and pressure variations observed at a well 2400 ft away such as USGS no. 44. The computation indicated that within two hours of pumping from CPP-2, only 5 x 10^{-5} ft. of drawdown would occur at wells 44 and 46. All of these factors would indicate the transmissivity value used is too small and or storativity is too large to simulate the situation of flow reversals caused by head fluctuation in one fracture zone. Other hydraulic parameters and geometry of the transmitting zones are being estimated to see what combination could describe the flow reversals.

CONCLUSIONS AND FUTURE RESEARCH

Various chemical and nuclear wastes reside and are moving with the groundwater beneath the INEL site. It is important to track the movement of the contaminants and to determine if any of the contaminants pose a hazard and are sufficiently concentrated to be recovered. Cross-flow across separate aquitards in the aquifer system occurs artificially and may also occur through natural connections. A better understanding of this transport is needed. Vertical cross-flows of water in open-hole intervals were studied by previous workers with varying results. An Impeller flowmeter was used in this report to quantify and compare results of flow measurements. The cross flow velocities were comparable to previous workers ranging up to 24 ft/min. A flow reversal was also noted which would indicate that a nearby pumping well could have an important control on fluid flow direction, tracking of contaminant plumes, and recovery of contaminants if necessary.

Our future research plan is to develop more precise flowmeter measurements, and to monitor corssflow over a several day period to detect exact timing of variation and reversals. We will also closely monitor timing of pumpage at nearby wells rather than rely totally on monitoring data provided by INEL personnel. Information on fluid flows and propagation of pressure variation should provided useful and detailed understanding of fluid movement near the ICPP and elsewhere on site.

In a parallel effort we intend to refine our understanding of the geometry and geologic nature of fracture zone interconnections through study of logs and cores.

Finally we will review whether S and T values used are appropriate to these aquifers, by computer calculation using varying combinations of T and S, and a pumpage of 3100 gpm. Present values used in this report do not produce a measurable head change 2400 ft away, within 2 hours. Since we believe cross-hole flows are reversed by pumping, the assumed values of T may be too small and S may be too large. Also the rate of propagation in fractured media needs to be examined.

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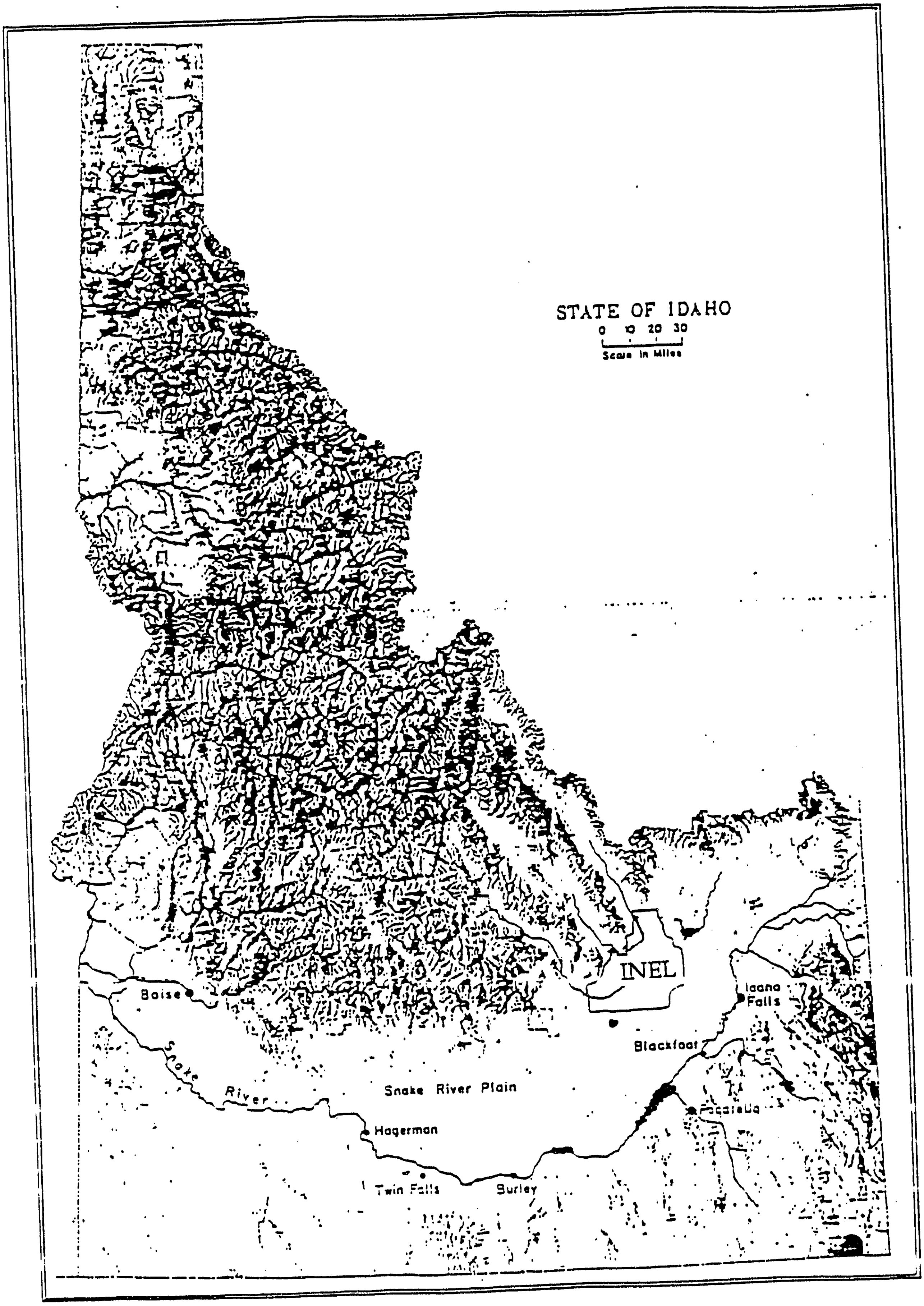


Figure 1. Map showing the location of the Idaho National Engineering Laboratory (INEL) (Barraclough, 1965).

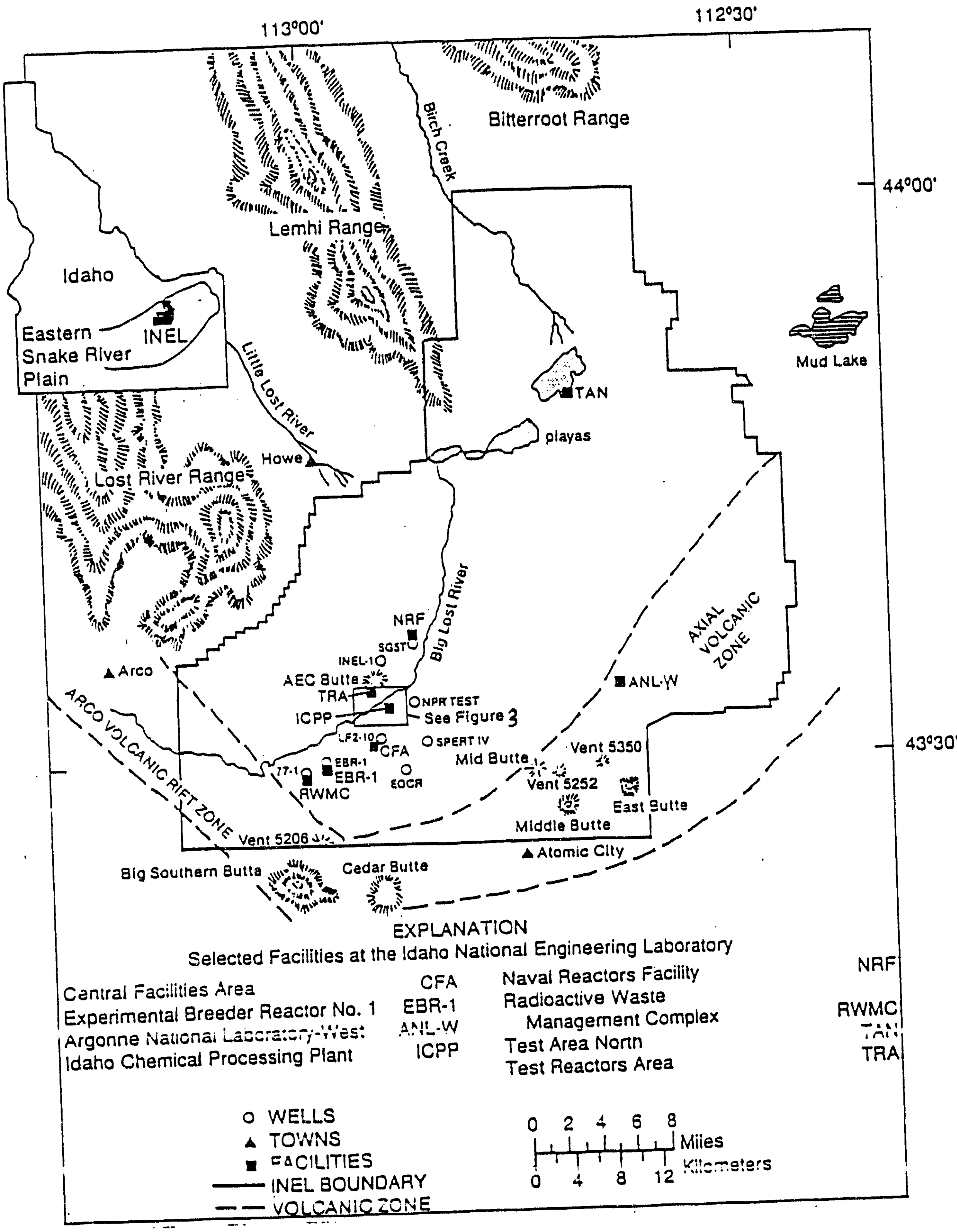


Figure 2. Map showing the location of the Idaho Chemical Processing Plant (ICPP) and the Test Reactors Area (TRA) (Anderson, 1991).

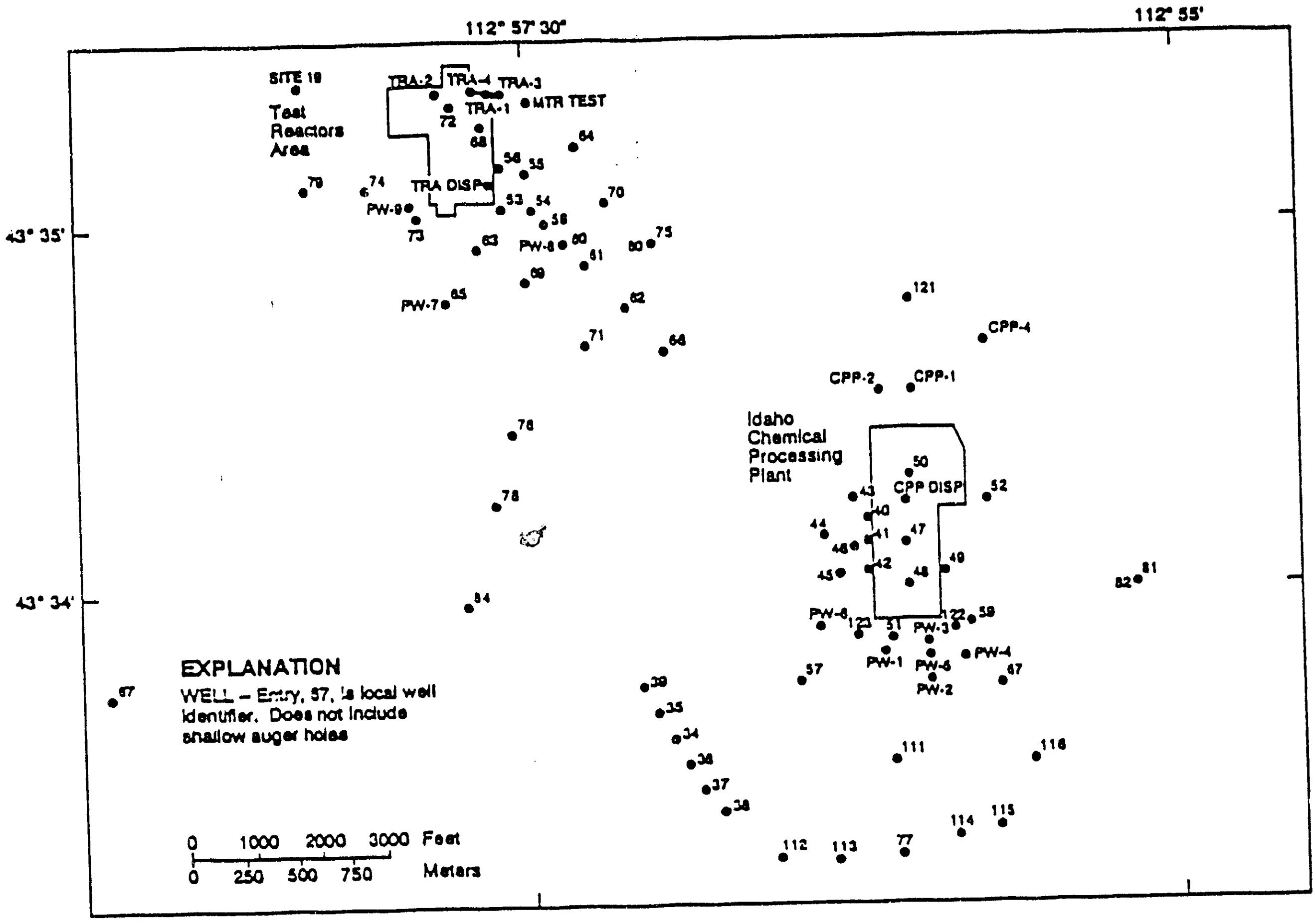


Figure 3. Map showing the location of the CPP DISP well and the TRA DISP well (Anderson, 1991).

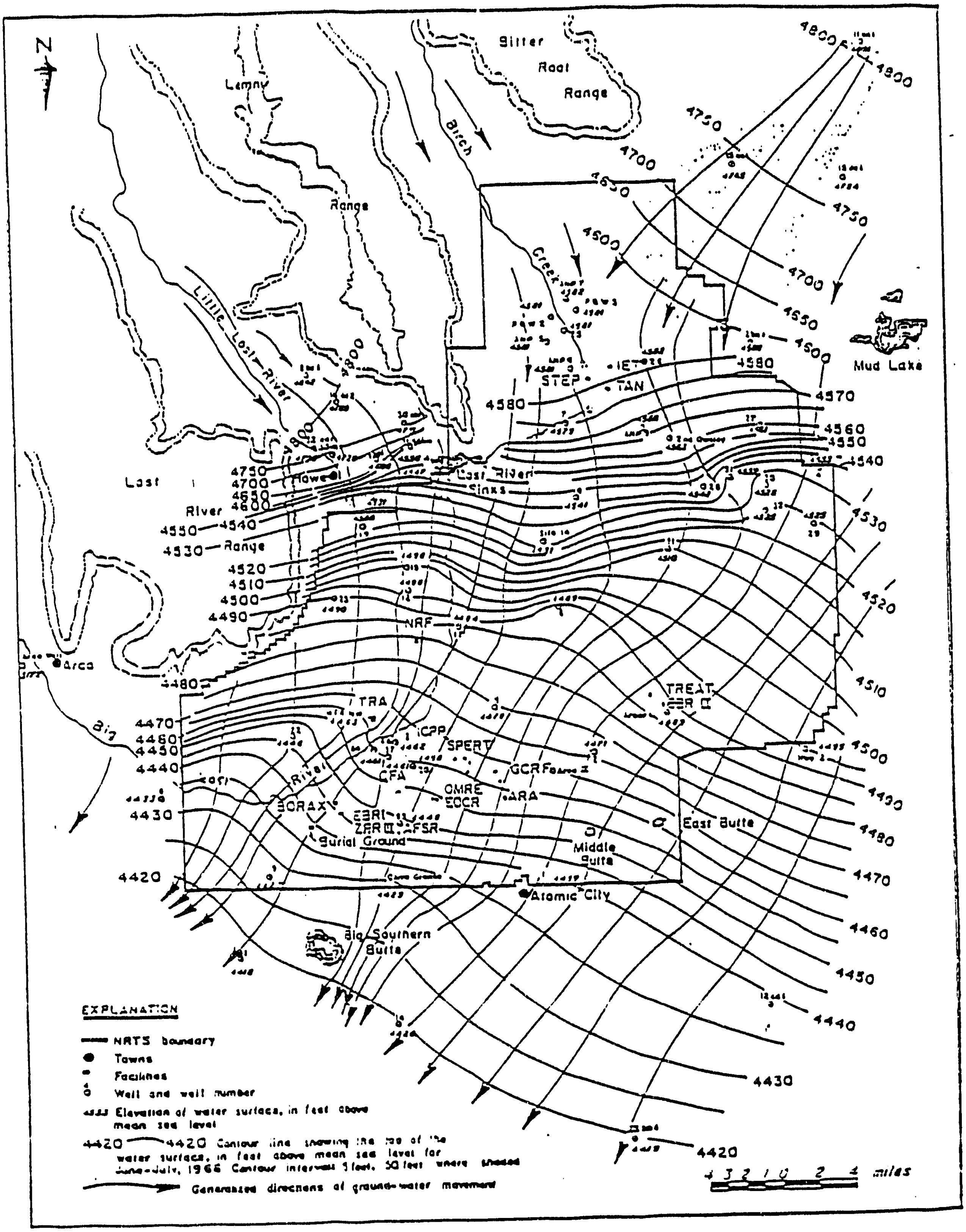


Figure 4. Map showing contours on the regional water table and the inferred directions of ground-water movement (Barraclough, 1966).

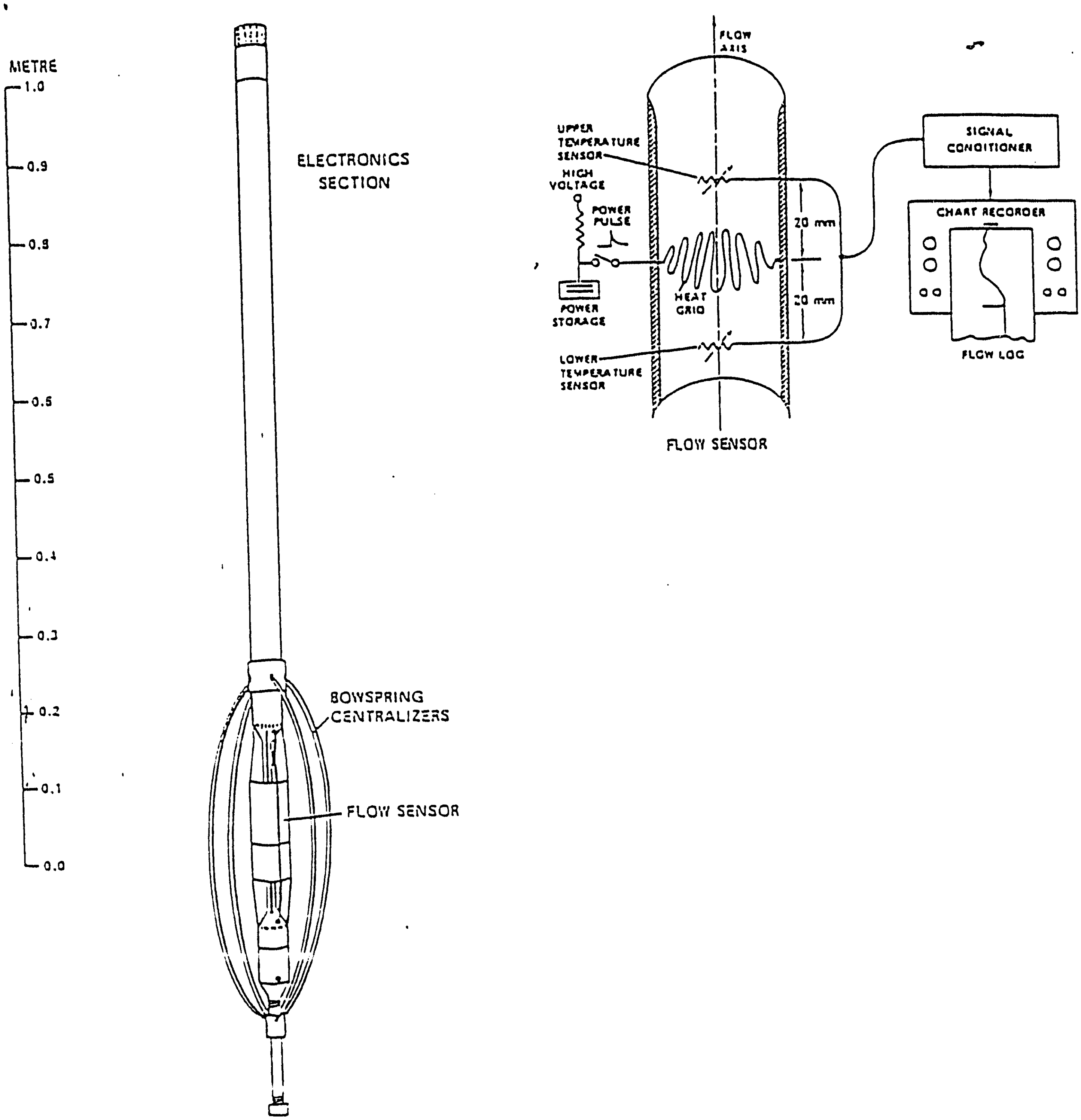


Figure 5. Showing a Heat-Pulse Flowmeter Probe (Hess, 1985).

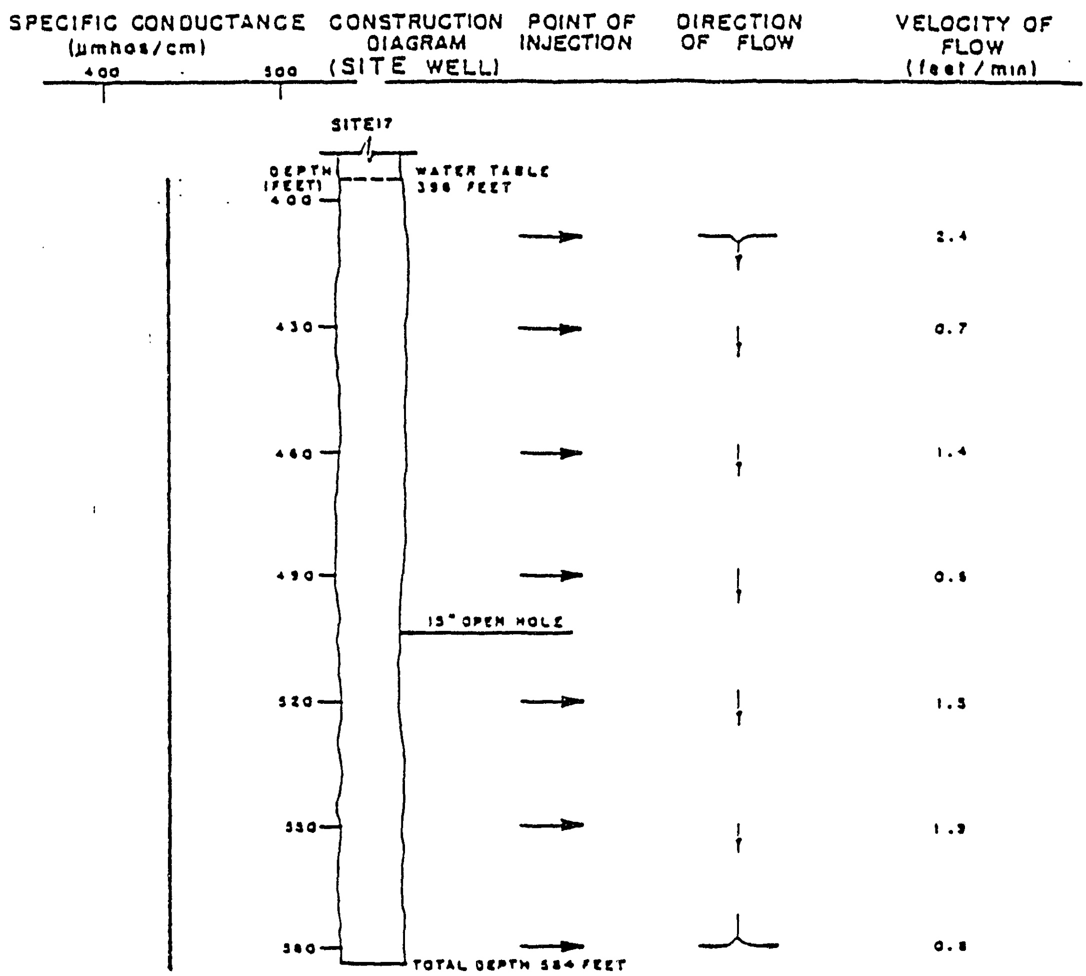


Figure 6, Showing direction and velocity of flow in Site 17 well (Morris, 1964).

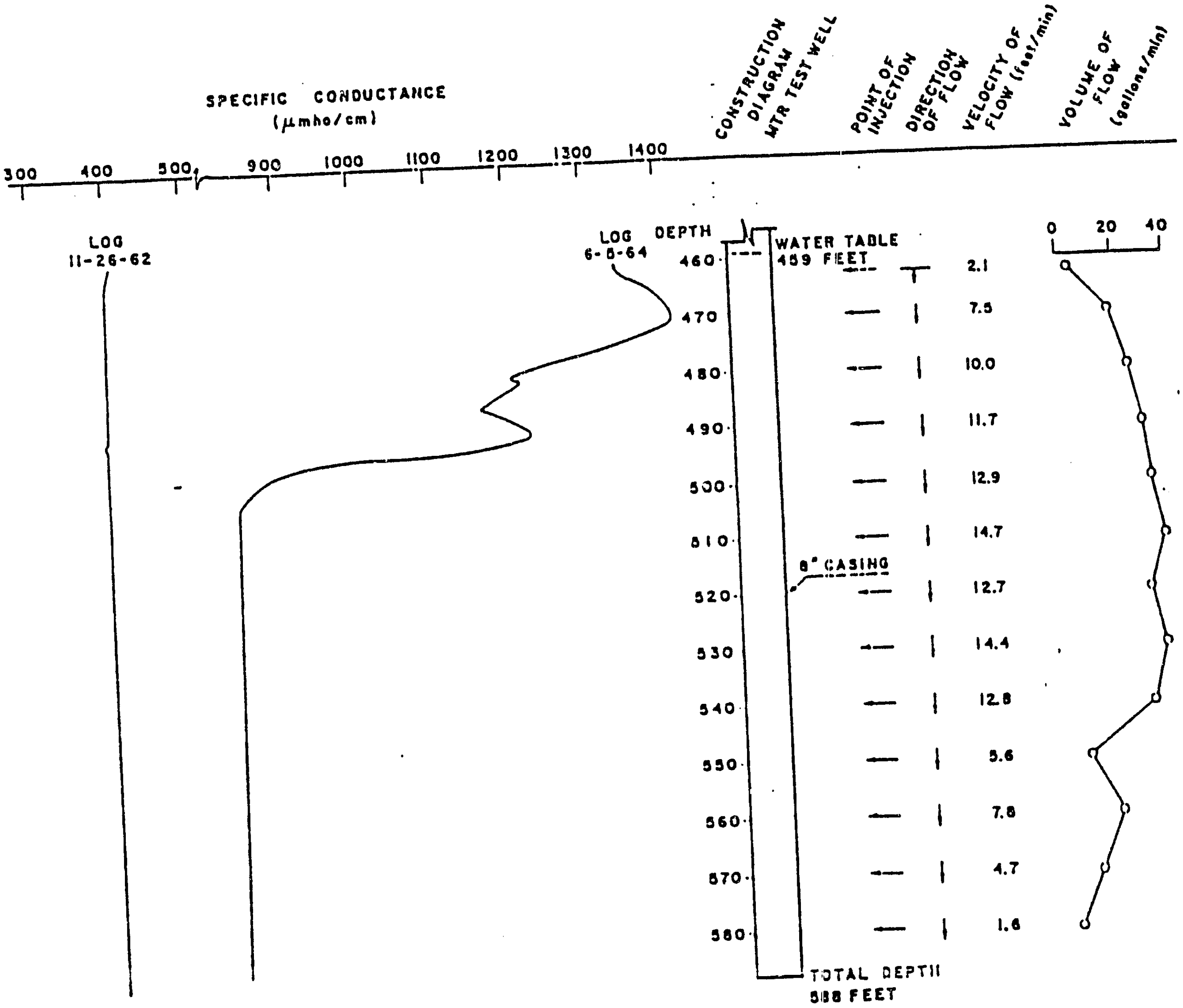


Figure 7, Showing direction and velocity of flow in MTR Test well (Morris, 1964).

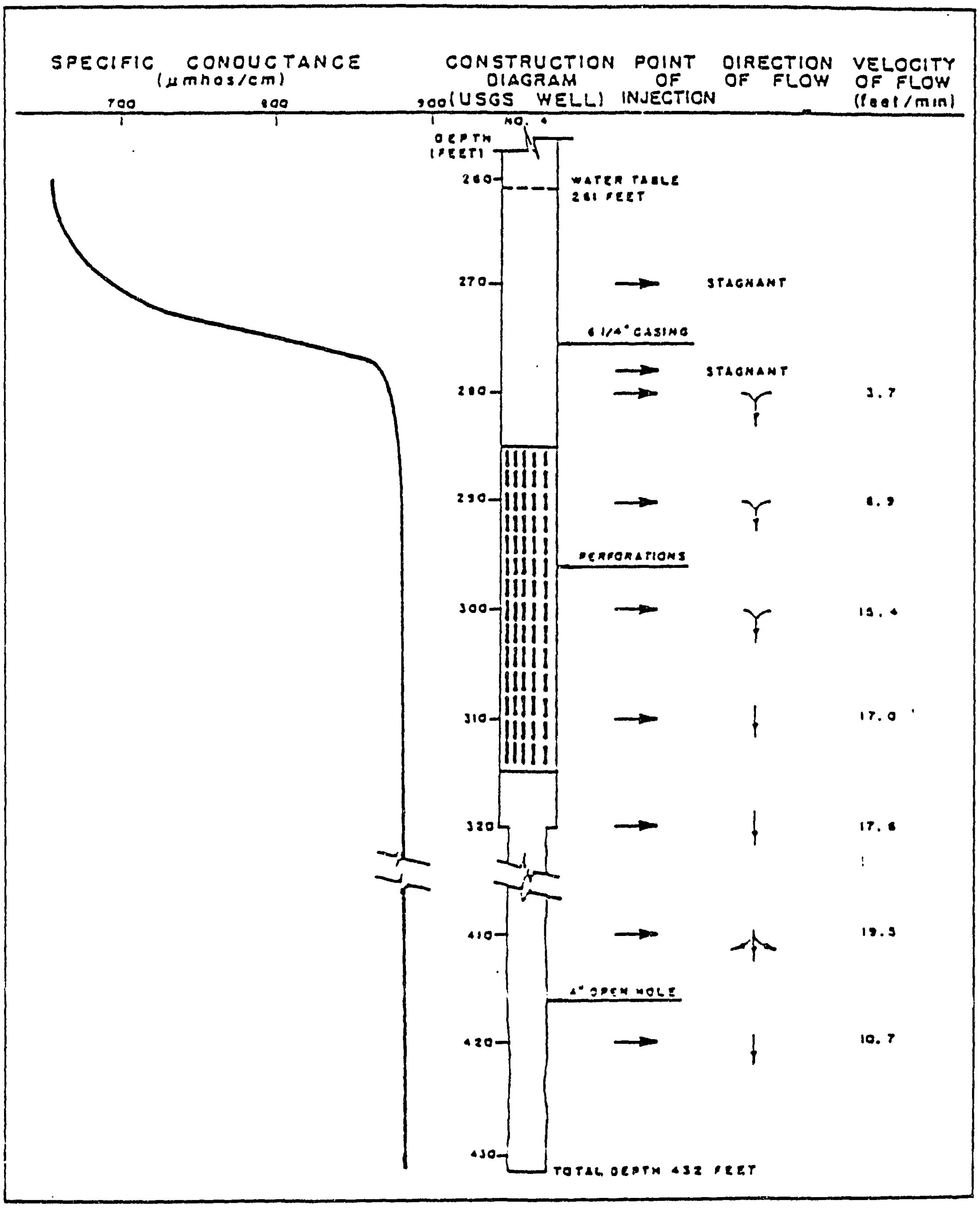


Figure 8, Showing direction and velocity of flow in USGS 4 well (Morris, 1964).

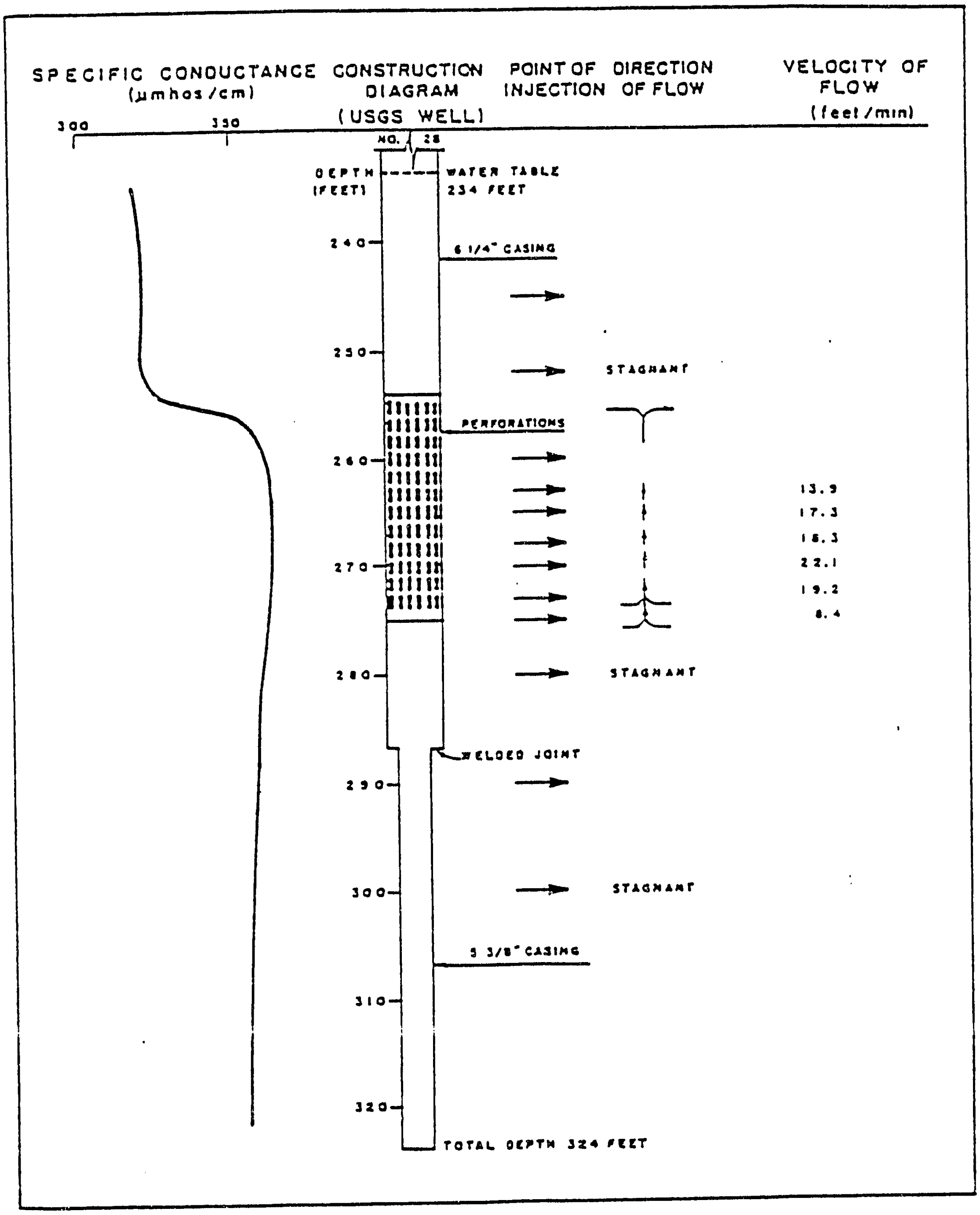


Figure 9, Showing direction and velocity of flow in USGS 28 well (Morris, 1964).

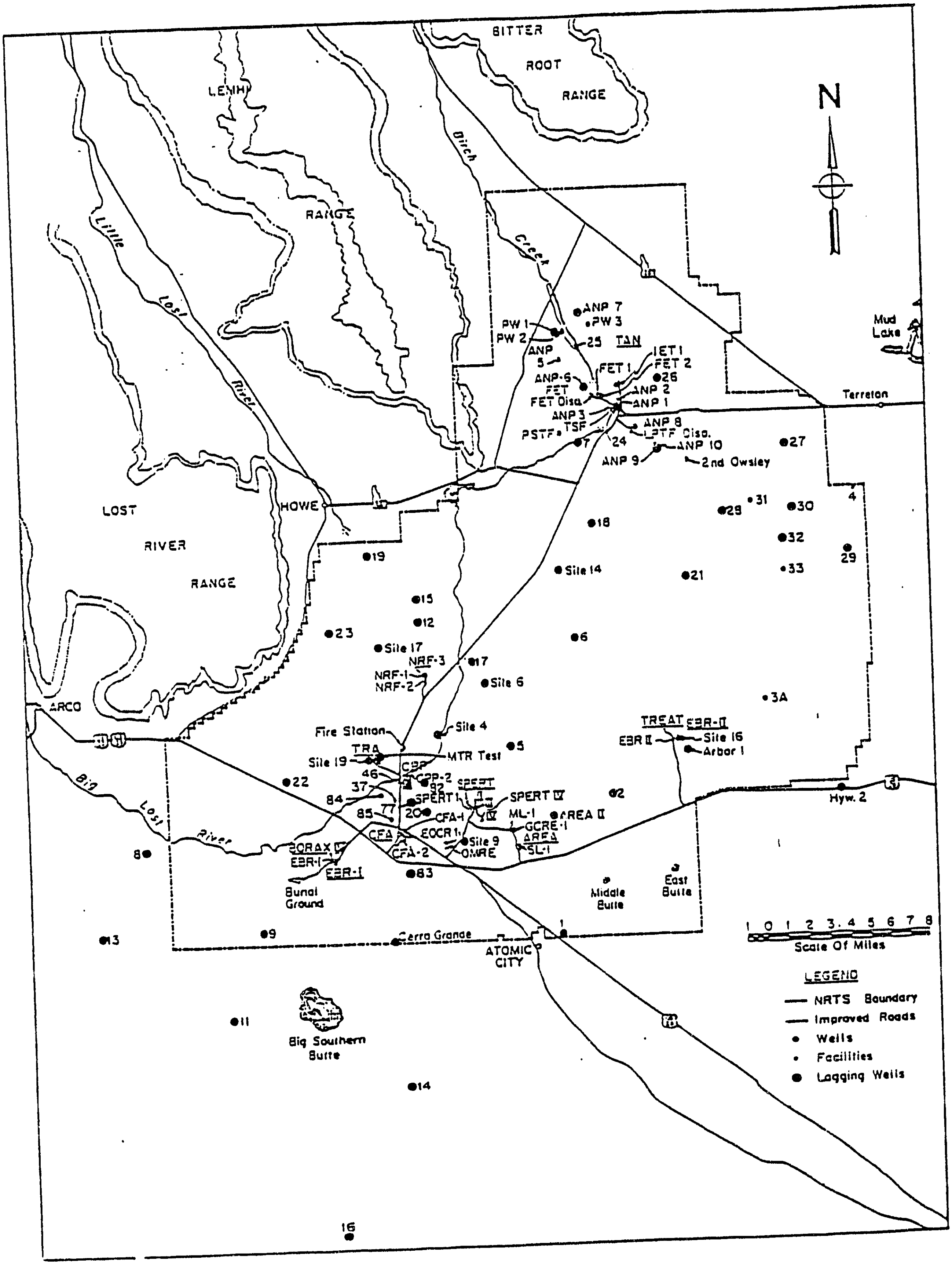


Figure 10, Map showing the wells logged by Morris et al 1964.

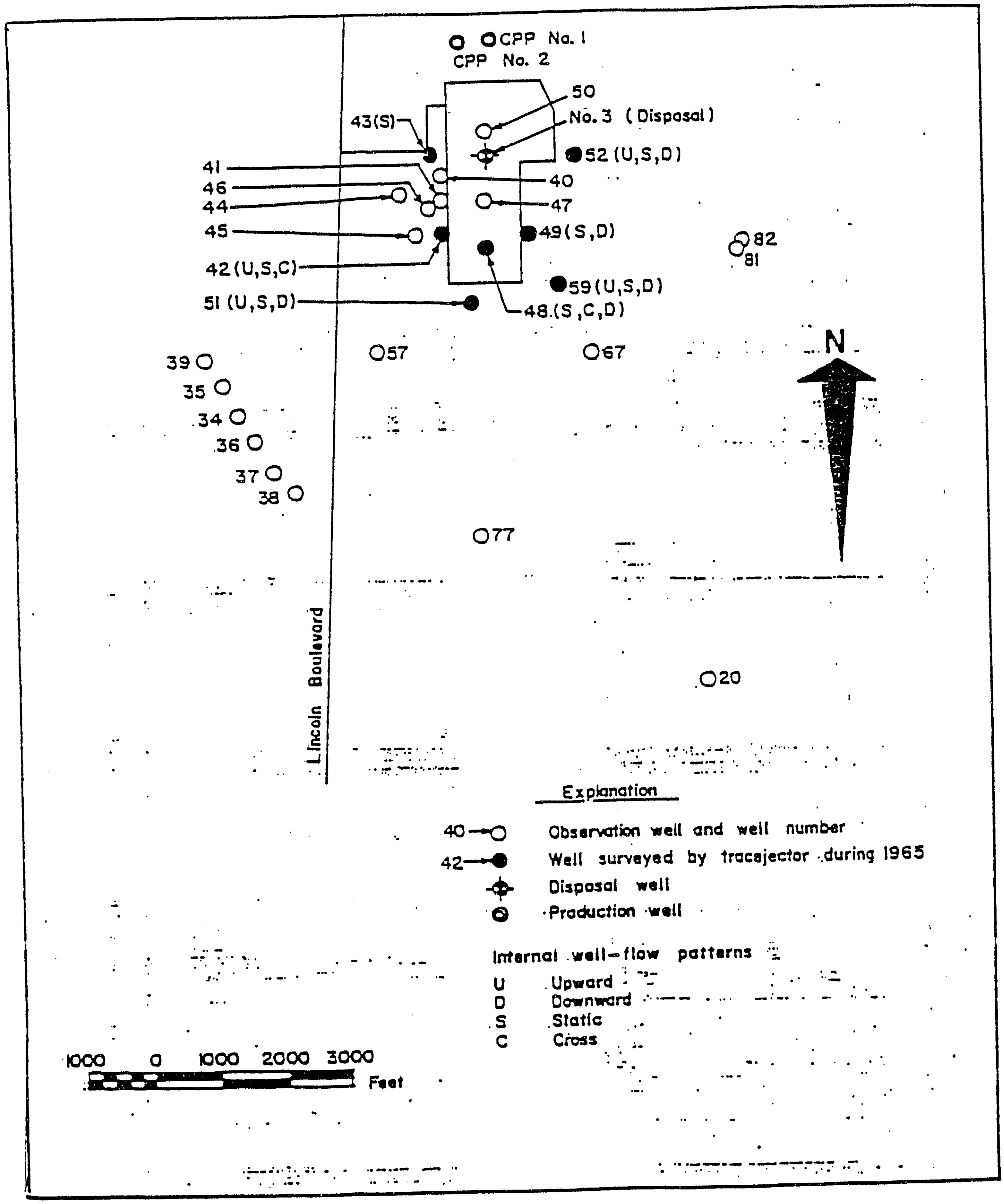


Figure 11. Map of the ICPP area showing the locations of the wells surveyed by the Tracejector and directions of flow (Barraclough, 1965).

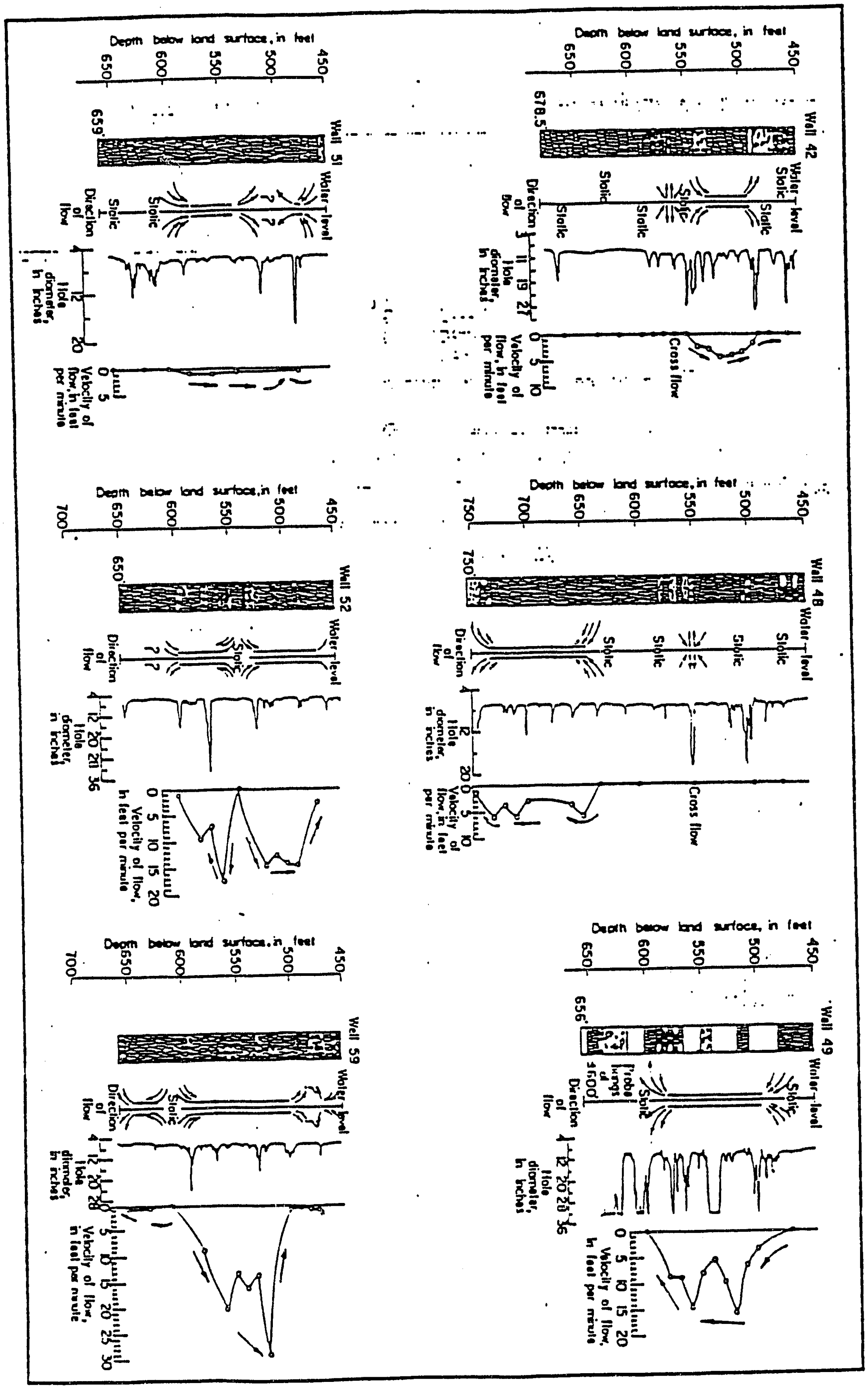


Figure 12, Graph of six wells in the ICPP area showing lithology, directions of flow, hole diameter, and velocity of flow (Barraclough, 1965).

Figure 13, Geophysical Logs ran on wells USGS 44 & 46.

USGS 44:

Caliper resolution about .2 inches (5 mm)

Casing-collar locator .10 feet (30 mm)

Thermistor .5 F (.2 C)

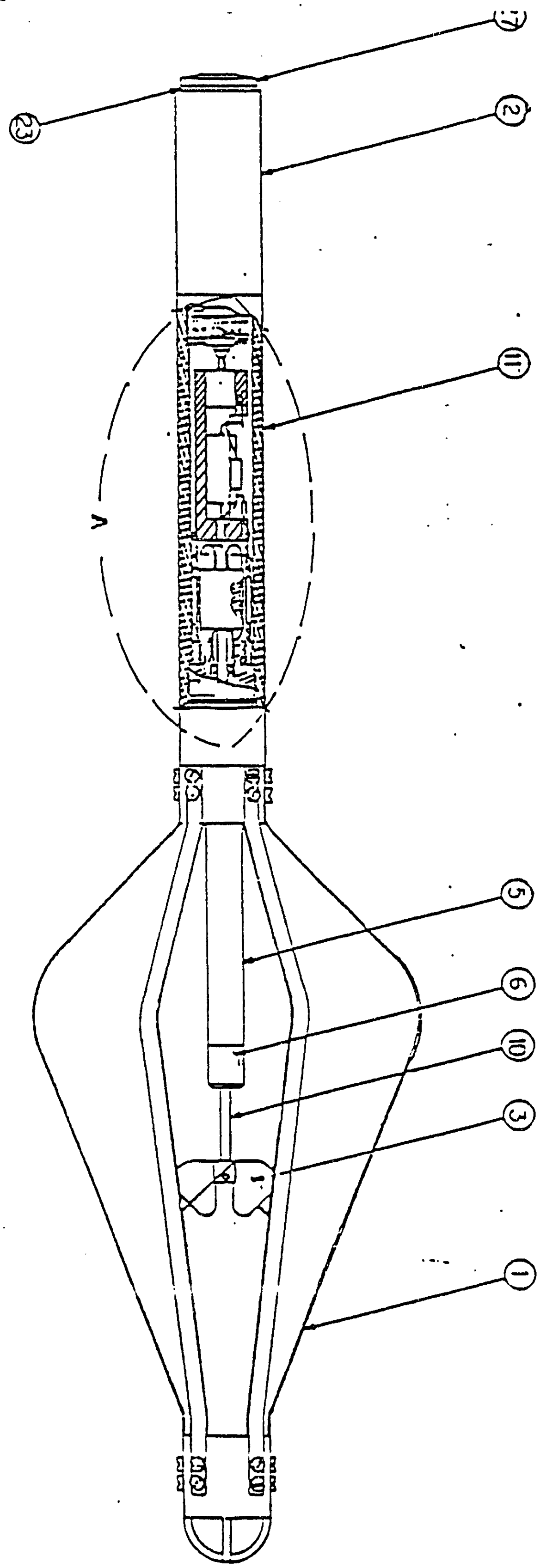
Natural Gamma tool

Impeller Flowmeter

USGS 46:

Caliper

Impeller Flowmeter



1: CENTRALIZER BASKET ASSY.

2: TOP SUB ASSY.

3: BLADE ASSY.

5: SPINNER HEAD BODY

6: LOWER BEARING RETAINER

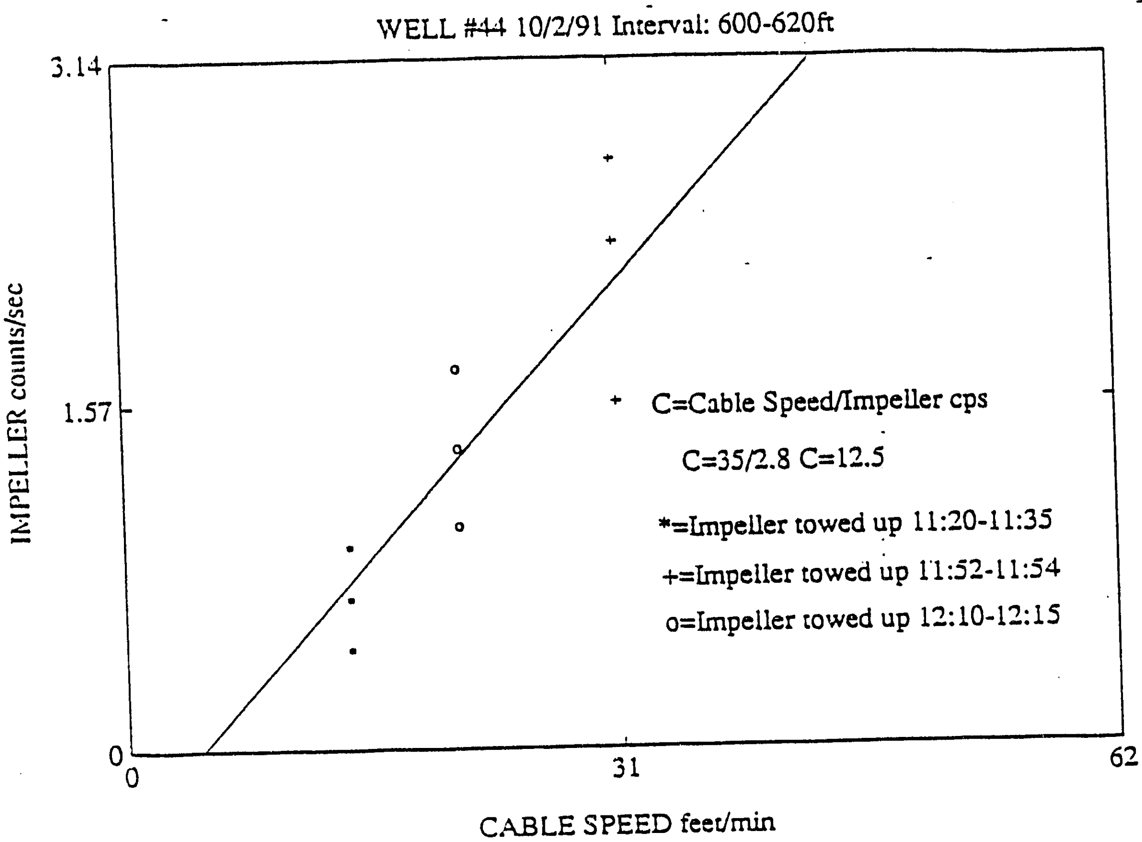
10: SHAFT

11: HOUSING 1 7/16x7 VOLTAGE INHIBITO

23: THREAD PLUG GASKET

27: THREAD PLUG

Figure 14, Showing a Mineral Logging Systems, Inc. 1 7/16 Impeller-flowmeter with a voltage inhibitor.



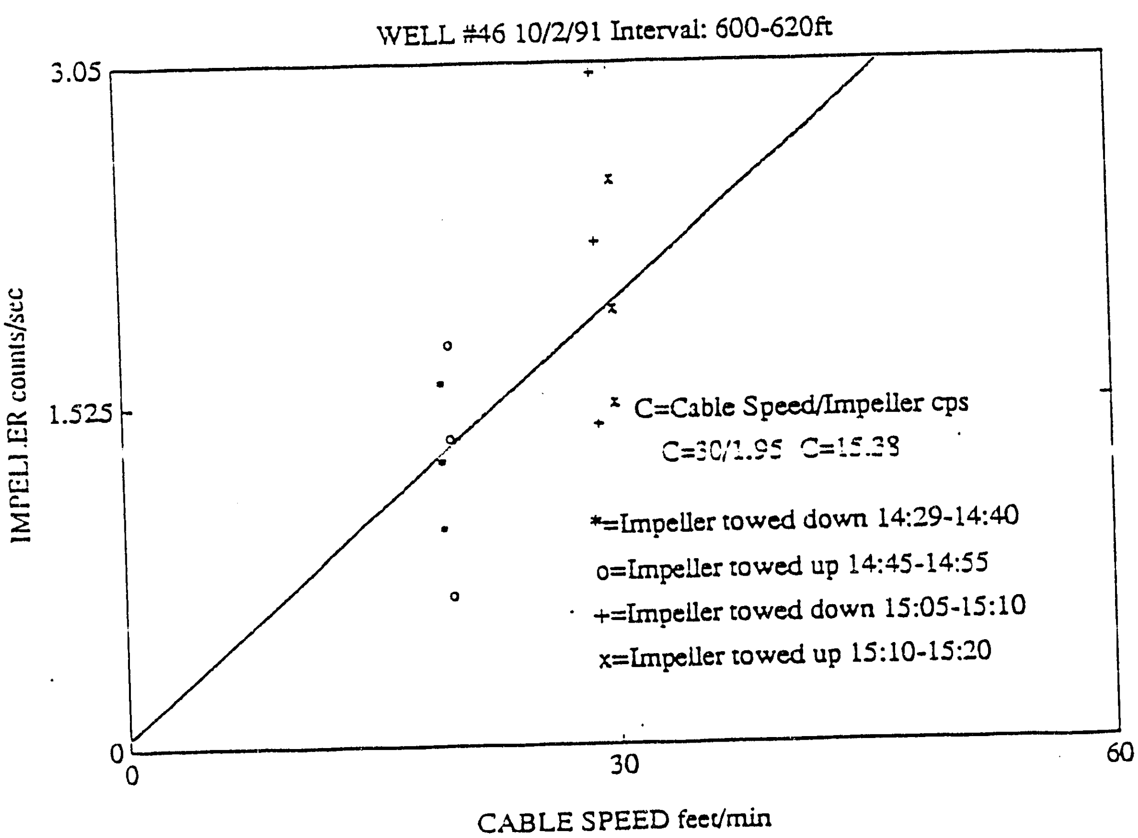


Figure 15. Calibration curves for USGS well #44 & 46. *cable speed — C*counts/sec = flow velocity.*

USGS WELL #44 ALL MEASURE

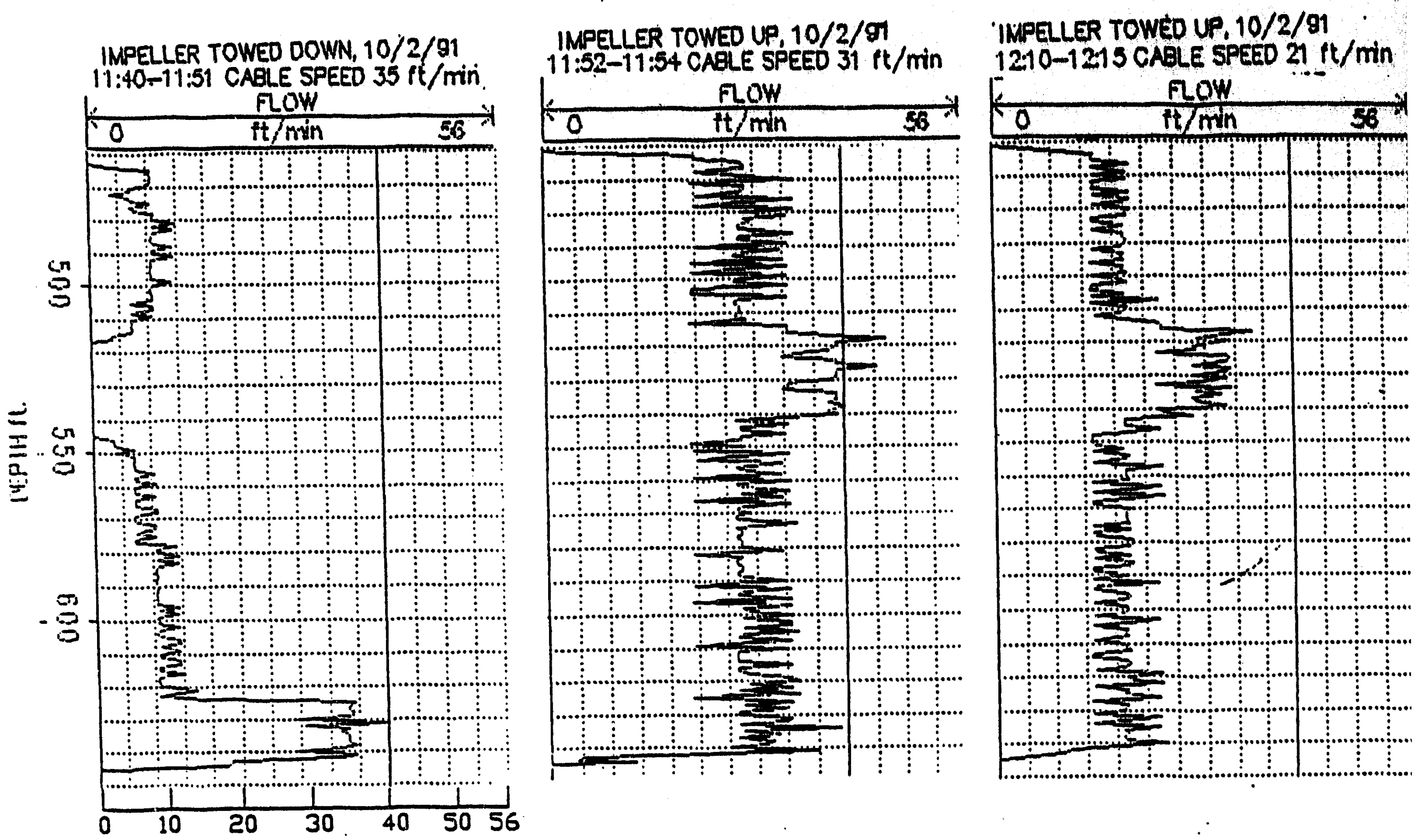
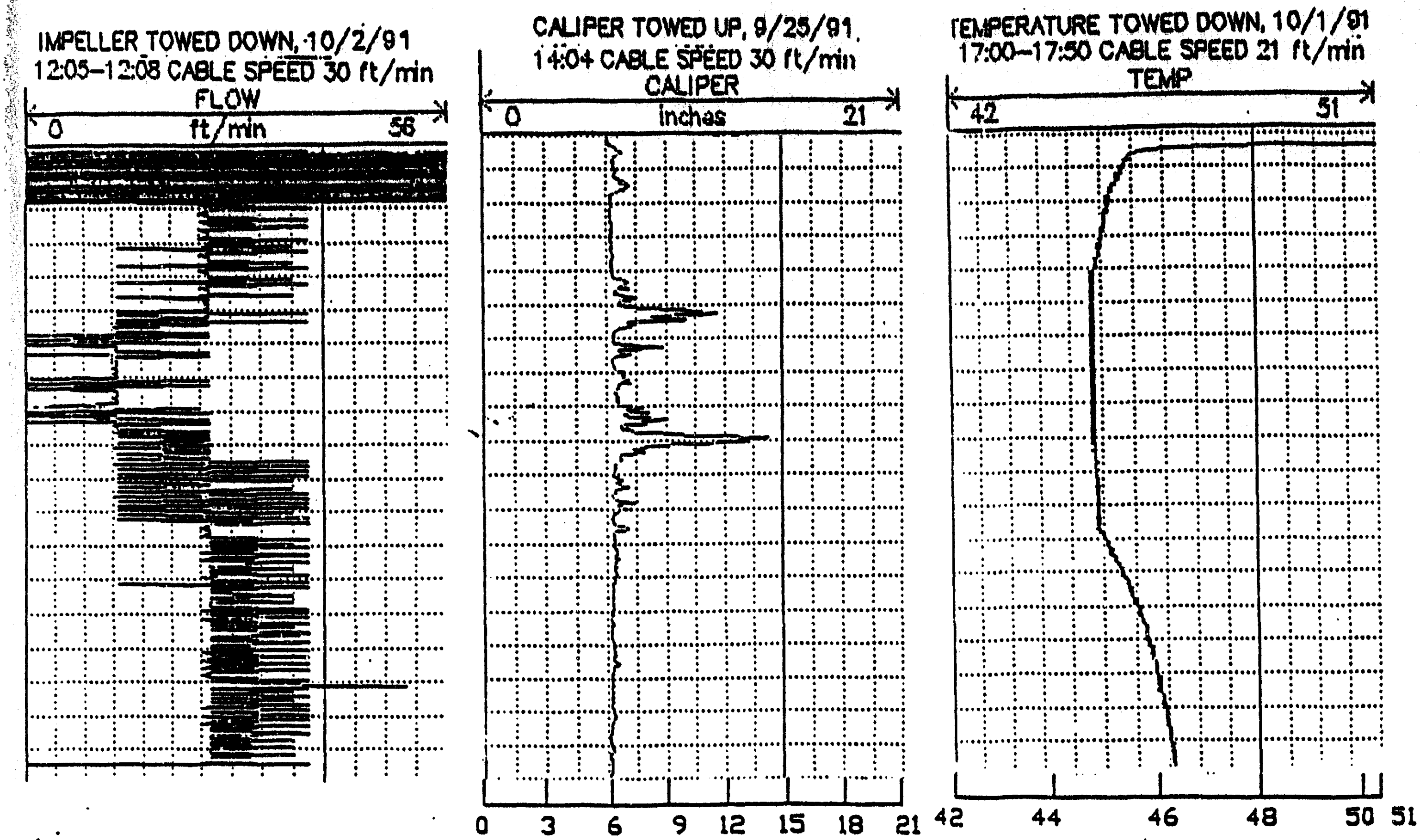


Figure 16, Showing Impeller-flowmeter runs, flo
for USGS

ENTS FROM TOP OF CASING 19"



velocity, hole diameter, and temperature log
ell #44.

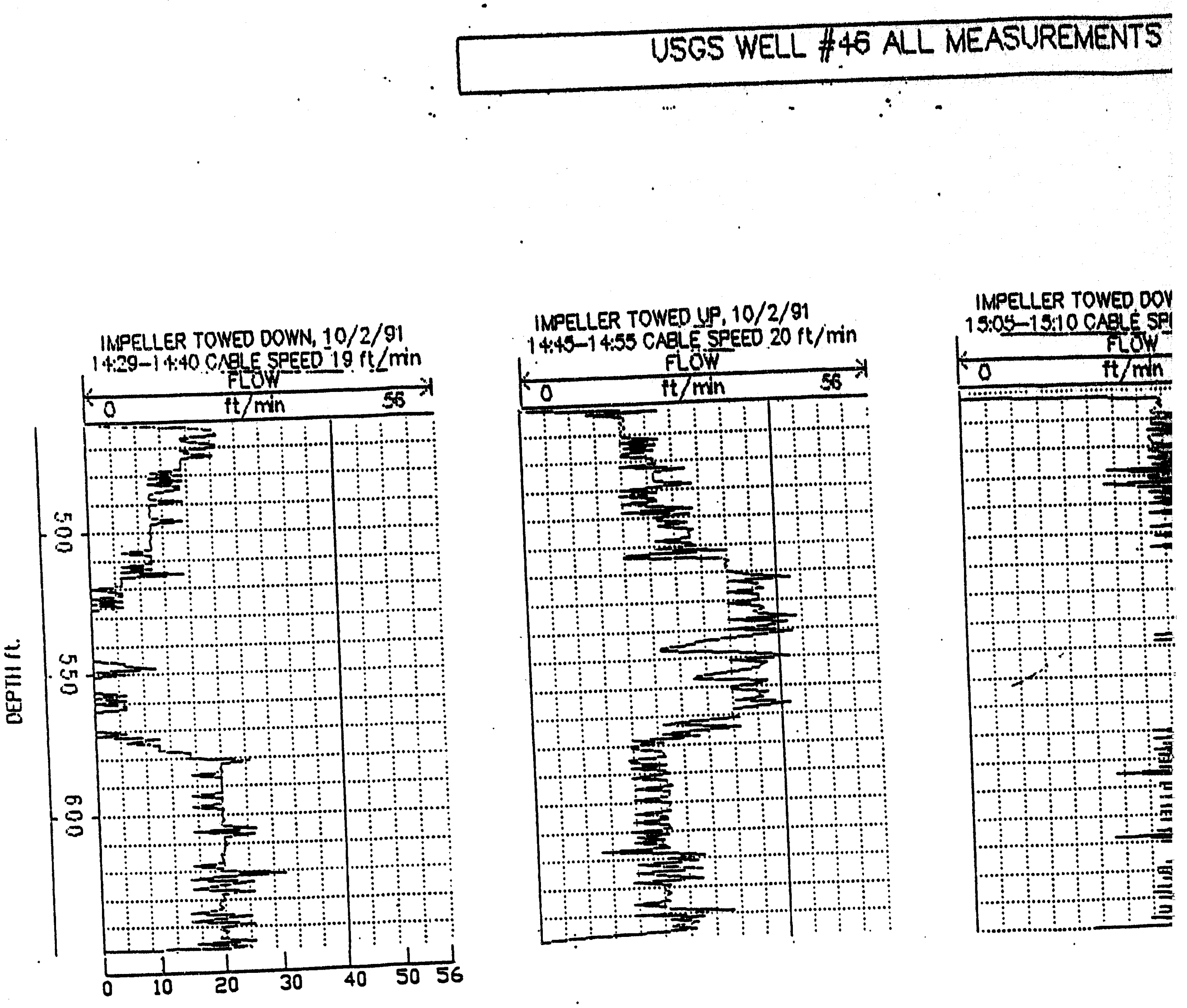
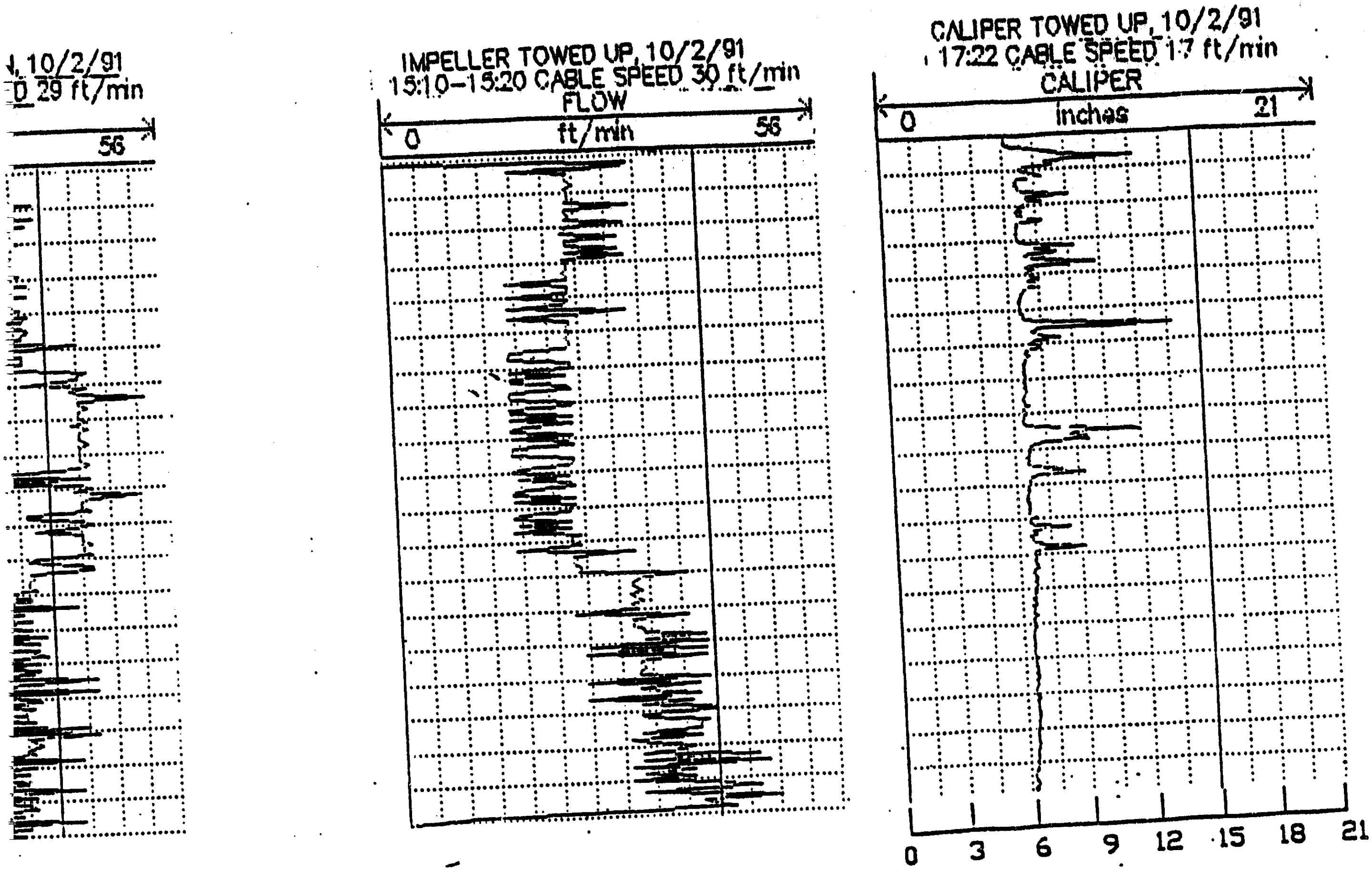


Figure 17. Showing Impeller-flowmeter runs, flow velocity, a
#46.

ROM TOP OF CASING 19.6"



d hole diameter for USGS well

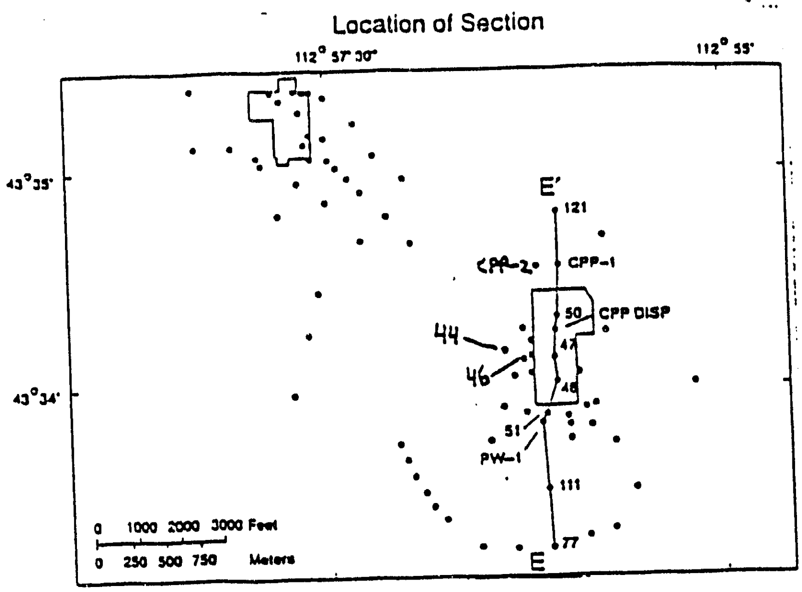
EXPLANATION

BASALT — Basalt-flow group composed of one or more related flows. Letter, B, indicates sequence of group from top to bottom of section. Locally includes cinders and thin layers of sediment

CLAY, SILT, SAND, AND GRAVEL — Major sedimentary interbed between basalt-flow groups. Locally includes cinders and basalt rubble

GEOLOGIC CONTACT — Queried where uncertain

WELL — Entry, 48, is local well identifier. Dashed line indicates measured or estimated water level in aquifer in 1990. Lower arrow indicates measured water level in aquifer in 1989 or 1990. Upper arrow indicates measured water level of perched ground water in 1989 or 1990. Number 651, at bottom of well is total depth of well in feet below land surface



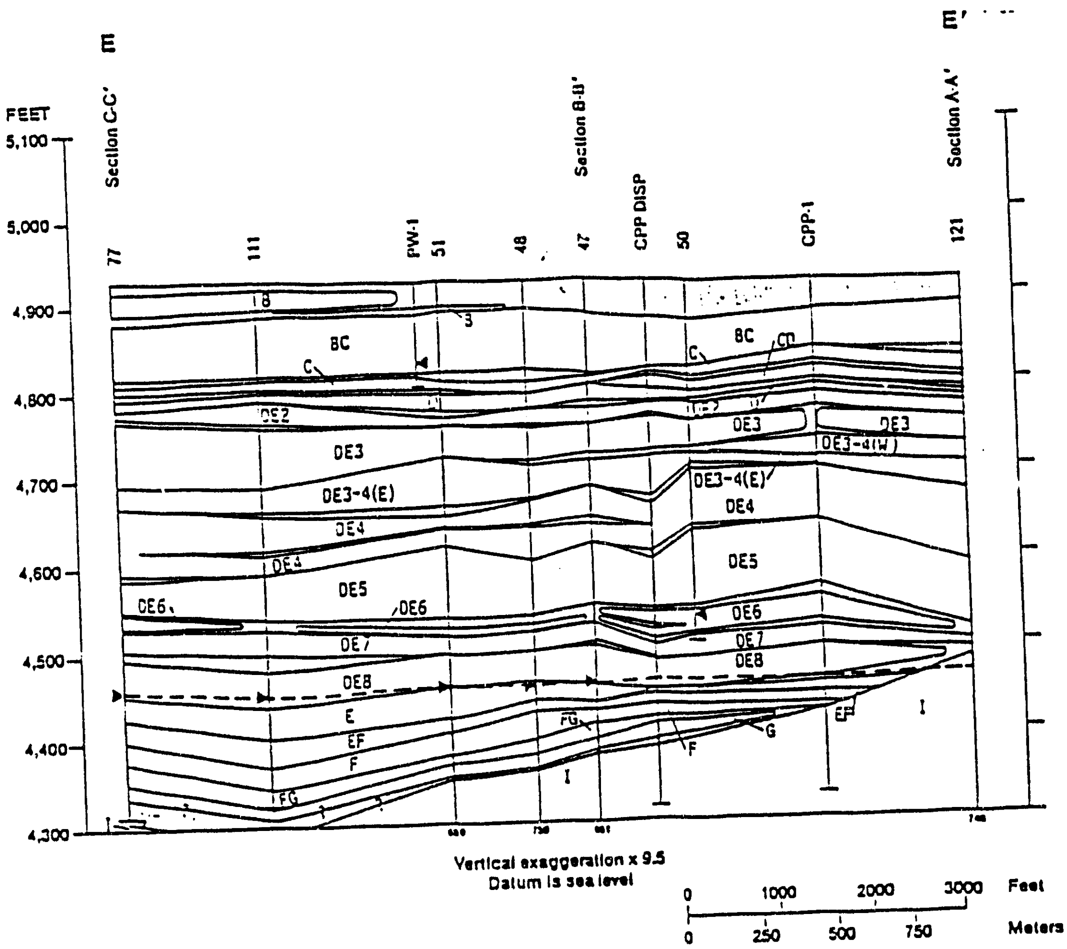


Figure 18, Geologic section E-E' at the ICPP & TRA area showing the I basalt flow group, and location of production well CPP-2 (500 ft west of CPP-1), and wells 44 and 46, west of well 47 from Anderson (1991).

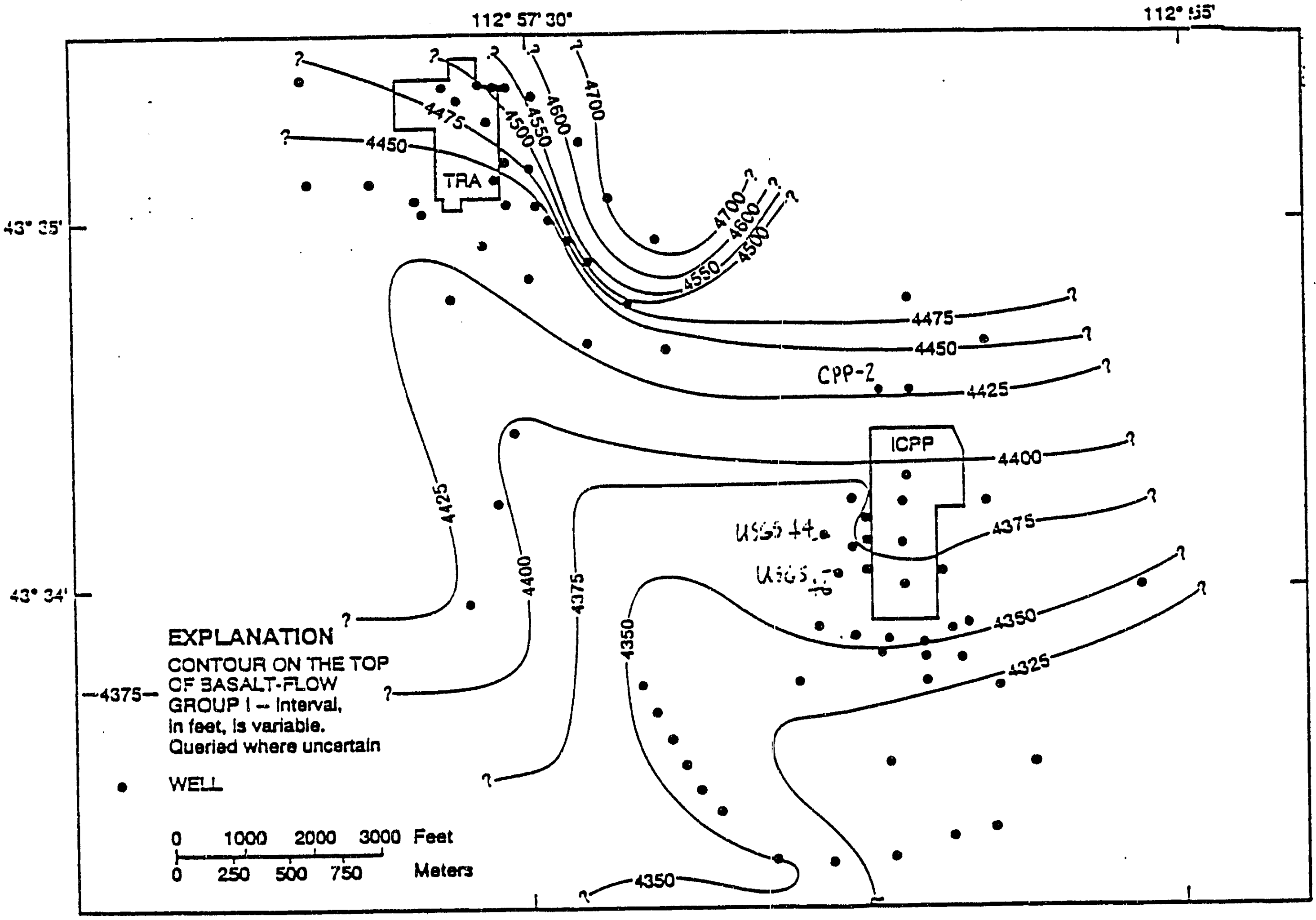


Figure 19. Altitude of the top of basalt-flow group I at the ICPP & TRA area from Anderson (1991).

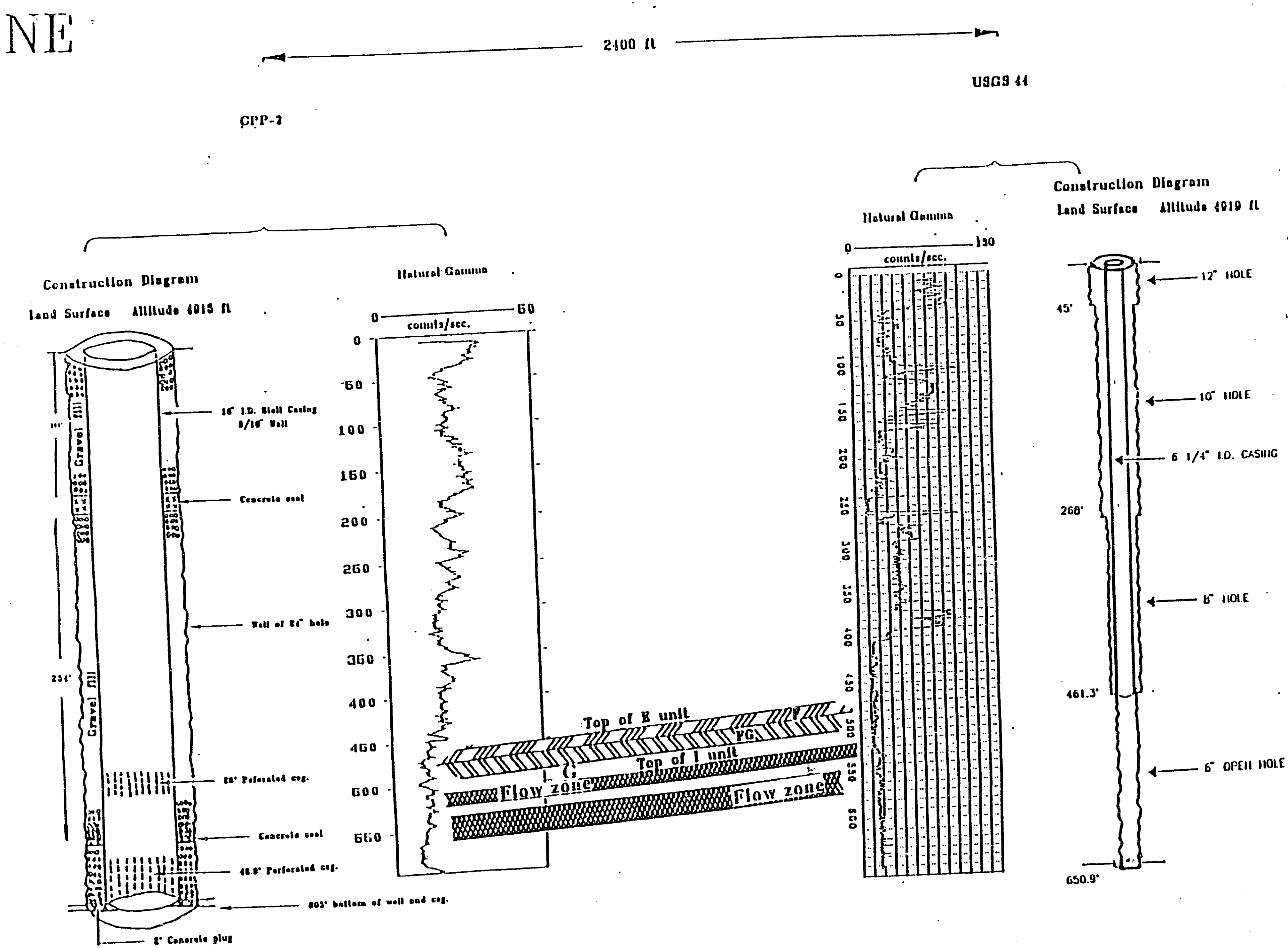


Figure 20, Showing where the transmissivity value from well CPP-2. Correlation by gamma logs of the zone to well USGS 44 is also shown. Flow zones in USGS 44 occurs between 500 and 550 ft.

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