Collection, Compilation, and Preliminary Interpretation of Data Used To Characterize the Hydrogeology and Solute Transport of Agricultural Chemicals in Alluvial Deposits near Perkins, Oklahoma

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COLLECTION, COMPILATION, AND PRELIMINARY INTERPRETATION OF DATA USED TO CHARACTERIZE THE HYDROGEOLOGY AND SOLUTE TRANSPORT OF AGRICULTURAL CHEMICALS IN ALLUVIAL DEPOSITS NEAR PERKINS, OKLAHOMA

by

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ABSTRACT

This research project has been a cooperative effort between the National Agricultural Water Quality Laboratory (USDA-ARS), the Oklahoma State University (OSU) School of Geology , OSU Agricultural Experimental Station, and the OSU Agronomy Department. The objective of this research is to assess the impact of agricultural chemicals on groundwater quality. The research was performed at the OSU Agronomy Research Station near Perkins, OK. This report represents a summary of the research and the significant findings for the period between 1986 and 1993. An extensive database of water quality analysis and water level measurements has been documented in a computer database at the USDA-ARS NAWQL in Durant, OK. Important physical and chemical parameters of both the unsaturated and saturated zones have been determined. Hydrologic and water quality responses within the aquifer have been characterized. Computer modeling, geophysics, and tracer studies have been successfully used for simulating agricultural chemical movement in both the unsaturated and saturated zones. It is recommended that future studies include the continuation of field data collection and mathematical models. Emphasis will be placed on the development of appropriate modeling strategies for coupling the USDA Root Zone Water Quality Model with the USGS solute transport model (KONIKOW—MOC, NRC).

INTRODUCTION

This research project has been a cooperative effort between the United States Department of Agriculture—Agricultural Research Service (USDA—ARS), OSU Agricultural Experiment Station, and the OSU Department of Agronomy. The research was performed at the OSU Agronomy Research Station near Perkins, OK. This report represents a collection and compilation of research and a database of pertinent observations for the period between 1986 and 1993.

Increased demand for water in the southwest has intensified the need for information on groundwater quality associated with agricultural practices. Such information has a direct bearing on the environmental and economic well being of the area. The objectives of this study are 1) to relate observed changes in the chemical content in groundwater to land management practices, 2) to establish some indicators of expected water quality changes due to shifts in management practices, such as conservation tillage or fertilization, and 3) to characterize and quantify the transport of applied agricultural chemicals within the saturated and unsaturated zones. Some studies have shown that conservation minimum tillage is projected to represent 70 percent of the United States cropland by the year 2000 (USDA-ARS, 1988). This expansion of conservation tillage acreage requires an improved understanding of potential groundwater quality changes that may occur with such management.

An extensive database of water quality analysis and water level measurements has been created and recorded on a computer database at the USDA- National Agricultural Water Quality Laboratory (NAWQL) in Durant, OK. Important physical and chemical parameters of both the unsaturated and saturated zones have been determined. Hydrologic and water quality responses within the aquifer have been characterized.

The site geology has been characterized through borehole logs, drilling logs and geophysical techniques. The station is underlain by an unconfined aquifer made up of highly permeable Quaternary-aged terrace alluvial deposits. Geophysical techniques, water level measurements and drilling logs have been successfully used to define aquifer boundaries. Direct current (DC) resistivity surface surveys and gamma ray borehole surveys proved to be the most successfully applied techniques. Potentiometric surface contour maps have been constructed on various scales to define groundwater flowpaths as potential pathways for contaminant migration.

Groundwater quality and water levels have been monitored near Perkins, OK in 198 monitoring wells in experimental plots which were cropped to wheat, cotton, beans and orchard and range from about 0.4 to 5.7 ha in size. Some wells are nested to monitor water quality at different depths in the sandy aquifer. An experimental site was selected to represent typical sandy soils associated with the Terrace alluvium in the southern Plains. The site was monitored for two years during which precipitation, well hydrograph and tracer test data, soil moisture profile data and water quality data from the unsaturated and saturated zones were obtained.

BACKGROUND INFORMATION

The Oklahoma State University Perkins Agronomy Research Station (Perkins Station) is found one mile north of Perkins, OK at the intersection of highways 177 and 33 (Fig. 1). The Perkins Station includes all of Section 36, T18N, R2E, Payne County, OK. A regional site map extending from the north side of the Perkins Station to the Cimarron River is depicted in Figure 2. A more localized scale of the station is shown in Figure 3.

Climate

Payne County is hot in summer and cool in winter with generally mild temperatures. The mean temperature at the station is 35 degrees Fahrenheit in winter and 74 degrees Fahrenheit in summer. Total average annual precipitation at the station is 35 inches with 70 percent usually falling between April and September. The growing season for most crops falls within this period. The average seasonal snowfall is infrequent and tornadoes and severe thunderstorms occur occasionally in the area.

Vegetation and Land Use

Vegetation in the area consists mostly of low-lying shrubbery, brush, and prairie grass with small deciduous trees and evergreens. Various grasses, along with cotton, peanuts, wheat, and alfalfa are commonly grown at the station. While up to 20 percent of the land in Payne County is cultivated, nearly 70 percent is pasture and rangeland for cattle.

Approximately 295 acres of the west side of Section 36 (Perkins Station) are used for agronomic research in which 205 acres are used for horticulture research. Large sections are also used by the Forestry and Pathology departments. The entire station serves as a training ground for students of various disciplines.

The types of crops planted on the Perkins Station will be discussed in detail later. Although the method of tillage used on each plot varies, minimum tillage is most commonly used. Residual vegetation can range from 0 to 100 percent depending on the type of implement used in tilling and the number of times that the plot is tilled. No standard is used in minimum tillage on the Perkins Station. Generally, 30 to 40 percent residue is left in a plot after one tilling event.

Physiography

Payne County is in a transitional zone between the Central Redbed Plains and the Northern Limestone Cuesta Plains. The study area has Redbed Plains characteristics of rolling plains with broad hills and valleys formed by nonresistant red shales and lenticular sandstones. The relief is subdued, and the slope of the land is to the southeast.

Surface Waters and Drainage

The Perkins Station occurs within the Cimarron River drainage basin. The Cimarron River flows east-northeast through Payne County approximately a mile and a half south of the station and has the characteristics of both braided and meandering streams. The station is drained by a dendritic pattern of small, ephemeral creeks trending southeasterly to the Cimarron River. Other surface waters include small isolated farm ponds, intermittent creeks, and undesignated wetland areas that occur in low areas where the groundwater discharges at the surface.

Soil Characteristics

The geologic framework of the area exerts a strong influence on soil development. The Teller and Konawa soil groups cover almost 80 percent of the station (Fig. 4) and are cultivated only where the surface is flat and not subject to rapid erosion.

Teller Soil

Teller soils occur on ridge tops and side slopes. These soils are deep, nearly level to gently sloping, and well drained. Typically, the surface layer is reddish brown loam. The subsoil consists of reddish brown loam, yellowish red clay loam, and red fine sandy loam (Fig. 5). These soils are well suited for raising small grains, sorghum, cotton, legumes, and grasses (Henley et. al., 1987).

Konawa Soil

Konawa soil also occurs on ridge tops and side slopes, and is deep, very gently sloping to sloping, and well drained. Typically, the surface layer consists of brown and light reddish-brown, fine, sandy loam (Henley et. al., 1987). The subsoil contains red, sandy, clay loam, and red, fine, sandy loam (Fig. 6).

Geologic Framework

Regionally, Payne County is situated on the stable Northern Oklahoma Platform on which unconformities are common. The Paleozoic depositional environment consists of shallow marine to alluvial sediments.

Quaternary sediments, made up of terrace and alluvial deposits dominate the regional surface geology (Fig. 7a and 7b). In the north portion of the station, the lower Permian Wellington Formation is exposed and the upper Pennsylvanian Doyle shale crops out south of the Cimarron River. Because the surface rock dips gently westward in Payne County, progressively younger beds are exposed in a westward direction. Drilling conducted on the Perkins Station determined that the bedrock is dominated by the Wellington Formation. The unconsolidated Quaternary sediments that overlie the Wellington Formation represent an unconfined water table aquifer.

The unconsolidated sediments represent different stages of deposition in the north and south half of the station (Fig. 8). The terrace alluvial deposits in the north half were deposited by fluvial action and consequentially eroded to some extent before the southern fluvial material was deposited. The cyclic nature of these deposits was caused by fluctuating sea levels that occurred during the alternating glacial and interglacial epochs. Stabilized sand dunes are present on the lower terrace and account for the hummocky appearance of the surface topography. Alluvial sediments dominate the channel and floodplain of the Cimarron River.

Bedrock

Red-brown siltstones, fine-grained sandstones, and thin, interbedded limestones were encountered during drilling at the site. These indurated rock units belong to the Wellington Formation of Permian age and the Oscar Group of Pennsylvanian age. Typically, multi-storied red sandstones are ten to twenty feet thick and separated by red siltstones, clay stones and thinly bedded, one-foot limestones.

Unconsolidated Sediments

The Quaternary deposits of the study area occur as mappable units in the alluvium of the floodplain and terrace deposits of the Cimarron River and along major creeks. These deposits consist of sand, silt, and clay overlain by eolian sand and silt. These alluvial deposits comprise unconfined water table aquifer in the study area and are collectively called the Perkins Terrace Aquifer. The aquifer averages in saturated thickness from 30 feet in the upper terrace to 50 feet in the lower terrace.

The dominant sediments consist of orange and red fine grained sand and tan silty sands separated by isolated and discontinuous lenses of yellow, tan, and gray silty clay (Appendix A). Clean sands occur at the base of the alluvial terrace deposits and are overlain by siltier sands and discontinuous clay lenses.

Previous Investigations

A Ph.D. dissertation project was completed for the study area by Rajeev Lochan Dwivedi in 1989 at Oklahoma State University. His project involved characterizing agricultural impacts on groundwater quality and acquiring input parameters for the simulation of the fate and transport of chemicals in the unsaturated and saturated zones of the Perkins aquifer. This project developed the beginning of a long term data base for the Perkins Station including the monitoring of water level fluctuations and water quality. This work was presented as an invited paper at the American Association for the Advancement of Science (AAAS) in San Francisco (Kent et al., 1989).

A thesis project combining the use of a groundwater tracer test and a groundwater numerical model to characterize solute transport of agricultural chemicals in the saturated zone of the Perkins aquifer was completed by Atef Kamal Farid Saad in 1992 at OSU. Hydraulic conductivities calculated from pumping test analyses were confirmed through tracer test evaluation. Model application was used to show similarities between actual and simulated chemical movement in the saturated zone.

Many published papers have resulted from the Perkins Station research through the cooperative efforts of members of the OSU Geology Department and the USDA Water Quality Laboratory in Durant, Oklahoma. A general description of the Cimarron River alluvium beneath the OSU Agronomy Research Station near Perkins, Oklahoma has been published previously (Naney et al., 1987 and Kent et al., 1987 and 1989). These publications include general descriptions of lithological features encountered during core drilling near potential monitoring well sites on the research station. Descriptions of typical land use and farming practices for plots and small watersheds with corresponding nitrate-N levels in the groundwater have been described in several publications (Naney et al., 1988a, 1988b, 1990, 1991). Specialized research involving computer modeling and tracer studies which were conducted at the station were reported by Kent et al. (1989, 1990), Naney et al. (1988b), Saad (1992) and Dwivedi (1989).

Description of Vadose and Saturated Zones

The geologic profile which extends from the ground surface to the top of the principal water bearing formation or water table, is called the vadose zone (Everett, 1984). The terms "unsaturated zone," "zone of aeration," and "vadose zone" are often used synonymously. The vadose zone at the study site ranges from less than one foot to almost 30 feet below land surface. Because hydraulic properties of the upper four or five feet of the soil profile are of great importance when considering solute movement in the vadose zone, a concise description is warranted. Some methods used to establish such properties will be discussed.

The saturated zone in an aquifer is the zone in which the voids in the rock and soil are filled with water at one atmosphere of pressure or greater (Fetter, 1988). The Perkins Terrace aquifer is an unconfined aquifer bounded by the water table at the top and the Wellington Formation at the base. As noted earlier, this saturated zone is made up of unconsolidated Quaternary alluvial deposits consisting of materials ranging from fine silt to coarse grained sand and gravel with discontinuous clay lenses. Because the saturated zone is the main conduit by which solute transport takes place laterally to areas of discharge or pumping, methods of characterization and hydraulic analysis will be discussed.

METHODOLOGY

Method of Approach

Site assessment of the Perkins Station for characterizing the potential of agricultural contamination of the groundwater was conducted in four different phases: I) preliminary characterization including identification of major cultural, soil, and hydrogeologic parameters (Fig. 9), II) description of soil and geologic materials in the subsurface (Fig. 10), III) measurement of groundwater quality and quantity (Fig 11), and IV) computer modeling (Fig. 12).

Experimental Methods

Once the data for the preliminary characterization was collected, specific experimental methods were developed for the site field analysis of the unsaturated and saturated zones (Fig. 13).

Chemical Analysis

Soil, soil water, and groundwater samples collected from the Perkins Station were analyzed by the USDA National Agriculture Water Quality Laboratory in Durant, OK. Chemical analyses for NO_3-N and NH_4-N were made using standard Lachat methods in the Federal Water Pollution Control Administration Manual (USDA, 1971). Soluble P was determined using the colorimetric method of Murphy and Kiley (1962). Calcium, magnesium, sodium, and potassium were determined by atomic absorption spectrophotometry. Chloride was analyzed by specific ion electrode analysis, and conductivity was measured using a dip cell process. Sulfate content was determined with the use of the Hach Chemical Company Turbidimetric Method. Pesticides were analyzed by gas chromatography (GC), and a second confirming column was run on all samples in which a pesticide was indicated. The publications *Water Quality Criteria, 1972* (U.S. EPA 1973, U.S. EPA 1976); *Water Quality Criteria for Water* and *Chemistry for Sanitary Engineers* (Sawyer and McCarty, 1967) were resources for the water quality standards used above.

Unsaturated Zone

Two test plots, A and B, with areas of 96 and 64 square feet, respectively, were constructed at the pumping test site on the southern edge of the station to facilitate characterizing and monitoring the unsaturated zone. The soil in the immediate area belongs to the Konawa-Daughtery series, and the depth of the unsaturated zone ranges between 12 and 15 feet. Each plot was constructed as an infiltration basin equipped with tensiometers, vacuum lysimeters, and a neutron access tube (Fig. 14). Ten to fifteen centimeters of top soil were removed from each of the two test plots, and eight inch ceramic tiles were placed at the edges of the plots. Boreholes, four inches in diameter, were dug using a hand auger, and neutron access tubes, tensiometers, and lysimeters were installed at several depths (Fig. 13). A slurry of native soil was poured into the holes to ensure contact with the surrounding soil. Water was poured on top of the slurry to compact it. When this water had drained, additional slurry was poured down the hole and the process was repeated to reduce channeling effects. Sixteen lysimeters were installed to obtain soil water samples from depths of 1, 2, 4, 5, 7, and 9 feet.

A vacuum lysimeter system, which allows the extraction of soil water samples was used. The basic design of the sampler consisted of a porous ceramic cup cemented to a plastic pipe to create an airtight and watertight seal. Lysimeters were also constructed with all glass materials, and therefore, the application of any adhesive and glue was eliminated; these lysimeters were used to monitor organic solutes in the field test plots. When placed in the soil, the pores in the cups become an extension of the pore space of the soil. Consequently, the water content of the soil and the cup became equilibrated at the existing soil water pressure. By applying a vacuum to the interior of the cup, the pressure was less inside the cup than in the soil solution, and flow into the cup was induced (Everett, 1984). The sample was pumped to the surface and analyzed for solute concentrations. The cups were rinsed with dilute hydrochloric acid and distilled water to remove dissolved ions present in the cup.

Both solid sampling and solution sampling techniques were used to monitor solute movement in the unsaturated zone. Worst case conditions of chemical transport were simulated in the test plots A and B by ponding both plots with water at a constant head to keep the soil saturated to almost maximum water content. Then different loadings of ammonium-nitrate fertilizer, potassium sulfate, and zinc-chloride were applied as specified here:

Date	Plot A	Plot B
3/6/88	1000 gm NH_4-N (34% total N) 500 gm K_2SO_4	1000 gm NH_4-N (34% total N)
3/16/88	500 gm ZnCl	
4/20/88	1000 gm NH_4-N	3000 gm NH_4-N

Soil moisture was sampled by use of vacuum lysimeters and soil cores were sampled by continuous split-spoon type core samples taken by a truck-mounted Bull soil sampler at six inch intervals to a depth of nine feet within each plot. Nitrate-N (NO_3N), potassium (K), sulfate (SO_4) and chloride (Cl) were extracted from the soil cores and analyzed.

SATURATED ZONE

Monitoring Wells and Piezometers

A network of monitoring wells and shallow piezometers has been installed on the Perkins Station for collecting water quality samples and monitoring the elevation of the water table within the unconfined aquifer. Twenty-two wells of 2-inch diameter and four wells of 4-inch diameter have been installed using the hollow stem auger drilling method. Split spoon samples and cutting samples were taken to characterize the unconsolidated sediments. Although a few wells were drilled deep enough to reach bedrock, all of the monitoring wells were completed within the unconsolidated sediments

Four sets of clustered monitoring wells were designed to track the water quality in both the shallow and deep intervals of the aquifer. A diagram depicting the typical monitoring well cluster design installed in the northern upper terrace deposits is included in Figure 15. Driller's logs of the groundwater monitoring wells are included in Appendix A. All wells were surveyed to establish the top of casing elevation (TOC). The monitoring well statistics (i.e., top of casing elevation and depth to bedrock) are depicted in Table 1.

Eighteen shallow piezometers were also installed by using the Bull soil sampler and hand auger to define the cross sectional perspective of the water table through the ponded and wetland area in the south half of the site. These piezometers were hand slotted and screened with nylon hose. The screened interval was sand packed and capped off to the surface with bentonite. Once proper elevations were established on the piezometers, the nature of the pond as a discharge/recharge area could be determined.

Groundwater level measurements from the monitoring wells have been recorded along with precipitation data for the Perkins Station from March 1986 to the present. Both records are kept on the computer database at the USDA National Agriculture Water Quality Laboratory in Durant, Oklahoma. Examples of recorded field data are included in

Table 1. OSU/ARS monitoring well statistics								
Well ID	TOC-Steel Elev.	Pad Elev.	TOC-PVC Elev.	PVC Casing Stick-up	Surface Elev.	Depth to Bedrock	Bedrock Elev.	Total Depth
1 (D)	971.48	970.09	970.92	1.42	969.5	30	939.5	30
2 (S)	971.49	970.09	971.08	1.38	969.7	N/A	N/A	25
3 (D)	962.93	961.44	962.11	1.5	960.61	25	935.61	25.5
4 (D)	964.86	963.38	963.84	1.46	962.38	46.5	915.88	47
5 (S)	964.83	963.38	964.6	1.39	963.21	N/A	N/A	25
6 (S)	960.31	959.24	959.95	1.2	958.75	N/A	N/A	25
7 (D)	960.34	959.24	959.85	1.2	958.65	39	919.65	39.5
8 (S)	944.66	943.24	943.94	1.4	942.54	N/A	N/A	25
9 (D)	944.53	943.24	943.44	1.27	942.17	35	907.17	35.5
10 (D)	979.15	977.78	978.57	1.4	977.17	39	938.17	39.5
11 (D)	911.11	909.82	910.34	1.29	909.25	51	858.05	51.5
12 (D)	928.05	926.64	927.33	1.55	925.78	51	874.78	51.5
EP (MW18)	914.14	913.89	913.95	0	913.85	57	856.85	58.2
19 (D)	N/A	N/A	919.75	0.61	919.13	40	879.13	34.2
20 (S)	N/A	N/A	910.57	2.71	907.86	50	857.86	25
21 (D)	N/A	N/A	917.22	2.42	914.8	45-50	869.8	40
22 (S)	N/A	N/A	915.53	1.82	913.71	45-50	868.71	35.25
23 (D)	N/A	N/A	915.28	1.13	914.15	36	878.15	36.5
TH24 (D)	N/A	N/A	N/A	N/A	913.27	49	864.27	N/A
W.House	N/A	N/A	917.35	N/A	N/A	N/A	N/A	N/A

(D) - Deep, (S) - Shallow, N/A - Not Available

All Measurements are in feet.

Tables 2 and 3. The water levels have been recorded on a weekly to biweekly basis as depth to water in feet. Water levels have been converted to potentiometric surface elevations for the period between March 1986 and the present using the top of casing elevations. Complete water level measurements, potentiometric surface elevation calculations, and precipitation records are tabulated in Appendix B.

Geophysical Surveys

Both borehole and surface geophysical surveys have been conducted at various sites on the Perkins Station to interpret subsurface stratigraphy and to further define the water table and bedrock configurations of the study area.

Borehole Geophysics

Most of the Perkins Station groundwater monitoring wells were geophysically logged using the natural gamma ray tool. The natural gamma ray signatures provide the best interpretation of lithology and were found to correlate well over short distances. The gamma ray logs conducted on the observation wells at the pumping well site near test plots A and B allowed detailed lithologic interpretation (Fig. 16). Lithologic correlation from use of geophysical logs across the entire station is not possible due to the presence of discontinuous clay lenses and different terrace type deposits exist in the north and

Table 2. Data example—depth to groundwater

Week		MW#1 (960) TOC 970.92		MW#2 (961) TOC 962.11	
	Corrected Aug. 8, '92	DTW (feet)	PSELEV (feet)	DTW (feet)	PSELEV (feet)
14	14	25.89	945.03	25.87	945.21
28	28	23.91	947.01	24.02	947.06
40	40	22	948.92	22.29	948.79
42	42	22.2	948.72	22.3	948.78
47	47	20.27	950.65	20.35	950.73
49	49	19.31	951.61	19.39	951.69
50	50	18.7	952.22	18.75	952.33
59	59	19.77	951.15	19.72	951.36
61	61	19.35	951.57	19.4	951.68
63	63	19.1	951.82	19.2	951.86
66	66	18.55	952.37	18.5	952.58
67	67	18.3	952.9	18.3	952.78
69	69	18.02	953.06	18.03	953.05
73	73	17.86	953.82	17.92	953.16
77	77	17.1	953.47	17.95	953.13
81	81	17.45	953.27	17.75	953.33
82	82	17.65	953.82	17.75	953.33
83	83	17.1	953.23	17.8	953.28
85	85	17.69	952.72	17.85	953.23

Table 3. Data example—precipitation

Precipitation		Monthly Averages			
Week #	Amount (inches)	Week #	Month #	Average (inches)	Cumul. (inches)
1	2.46	4	1	0.99	3.96
2	0.19	8	2	1.47	5.86
3	1.01	12	3	0.87	3.48
4	0.3	16	4	0.48	1.93
5	0.32	20	5	0.84	3.35
6	0.85	24	6	0.13	0.5
7	3.76	28	7	3.04	12.14
8	0.93	32	8	1.36	5.44
9	0.39	36	9	0.65	2.59
10	0.9	40	10	0.31	1.25
11	0.86	44	11	0.38	1.54
12	1.33	48	12	0.42	1.68
13	0.58	52	13	0.8	3.21
14	1.13	56	14	0.19	0.74
15	0	60	15	0.24	0.96
16	0.22	64	16	3	12.02
17	0.19	68	17	1.26	5.05

south halves of the station. Gamma-ray logging (natural-gamma logs) interpretation and application are described in detail by Keys (1988).

Surface Geophysics

Seismic methods. Seismic methods use artificially generated seismic waves to determine the thickness and depth of geologic layers (Driscoll, 1989). A one channel Bison seismic instrument was used in the Perkins Station surveys for recording refracted seismic waves created by a sledge hammer and steel plate. Geologic formations have characteristic seismic velocities for compressional waves (P waves). The wave velocity in each layer of material is directly related to its physical properties such as density and elasticity that are directly affected by the material's porosity, mineral composition, and water content. Energy is easily dissipated in low density, poorly consolidated sediments, while energy is readily transferred through high density, consolidated sediments. Therefore, changes in lithology, especially dramatic changes such as unconsolidated material to bedrock, can be detected. The seismic methods used on the Perkins Station and seismic data interpretation has been described in detail by Van Alstine (1995).

Resistivity methods. The electrical resistivity method of "sounding" was used to determine the depth to the water table and depth to bedrock at the station. Simply stated, resistivity is the inverse of electrical conductivity. Resistivity is the resistance of a geologic medium to current flow when potential (voltage) difference is applied (Driscoll, 1989). Geologic materials provide resistance to the electrical current produced according to their porosity, permeability, and the volume and conductivity of moisture within the pores. Geologic materials do not have characteristic resistivities, but in general, resistivity decreases as porosity, hydraulic conductivity, water content, and salinity increase. The Wenner and Schlumberger resistivity methods have been used on the Perkins Station to define aquifer boundaries. An entire set of resistivity plots for monitoring well #23 including Wenner array and Schlumberger configurations are included in Appendix C. The resistivity methods and data interpretation have been described in detail by Van Alstine (1995).

Ground penetrating radar. A 100-megahertz frequency analog system ground penetrating radar (GPR) tool has been used near the pumping test site on the Perkins Station. GPR is a nondestructive geophysical technique that uses high frequency radio waves to probe the internal structure of the ground. The signal is sent by a transmitting antenna and picked up by a receiver antenna. The radar wave reflections that are detected result from the subsurface interfaces between different lithologies having different electrical properties.

Signals are detected at chosen increments along survey lines, and their output is recorded in digital format. Resolution is controlled by the frequency of the radar and the size of the increments. The data is printed out as continuous lines and can be processed like seismic lines to enhance the recorded data. The depth of penetration of the radar signals is site-specific because penetration is significantly better in dry, sandy conditions than in wet, clay rich materials.

Aquifer Test Methods

Pumping Tests

Pumping tests for the Perkins Terrace water table aquifer have been conducted in the tracer cluster area around the pumping well (Fig. 14). Drawdowns were measured over time in each of the observation wells, while discharge was measured at the flow line terminus that is located downgradient to eliminate the effects of artificial recharge. The field data was then plotted and analyzed using the Jacob and Prickett methods to determine hydraulic values such as transmissivity and storativity.

Slug Tests

Slug tests have been done on most of the monitoring wells installed on the Perkins Station farm using the Cooper, Bredehoeft, and Papadopulos method (Fetter, 1988). This method is a simple, quick, and inexpensive way of estimating hydraulic conductivity in the field using only a single test well and is especially useful in aquifers with permeabilities too low for pumping tests to be conducted. The alternative of this method used on the Perkins Station involves removing a known volume of water (slug) from a well and observing the water level recovery in the monitoring well.

Tracer Tests

Different scenarios of tracer studies have been conducted at the site using inorganic chemical ions and fluorescent dyes. In all cases, a single or slug release of a contaminant source was utilized instead of a continuous release source to realistically replicate field conditions. Agricultural chemicals are applied in bulk at specific times, not gradually over time. Generalized velocity distribution and dispersivity properties were found from these tracer tests. These parameters are essential to understand for accurate prediction of contaminant migration. A schematic for the tracer tests conducted at the pumping well site of the station is shown in Figure 17.

DATA AND INTERPRETATION

Database Description

A computerized database has been established at the USDA—ARS National Agricultural Water Quality Laboratory in Durant, Oklahoma to compile data collected at research sites. Preliminary work on developing such a computerized database was researched in the 1970s through the USDA—ARS. An article was published in *Ground Water* in 1973 on approaching hydrogeologic investigations by using computerized data (Kent et al., 1973). A user's manual for the computerization of hydrogeologic data was also compiled (Naney et al., 1976).

Examples of the types of data stored on the database are precipitation and water level measurements (Appendix B), hydraulic characteristics (Appendix C), and monitoring well locations and statistics (Appendix D). Complete records of water quality analysis for water samples conducted by the Durant lab are also stored on the database. An example of the chemical analysis of a groundwater sample is included in Table 4. Water quality results are given in Appendices E and F.

Table 4. Data example—water quality analysis

USDA-ARS National Agricultural Water Quality Laboratory, Durant, Oklahoma

Samples From: Date Taken: Date Arrived:	Perkins Wells July 14, Aug. 7&8, 1992	Log No.: Completion Date: Analysis By:	1043 Jan. 28, 1993 Pardue

Sample	DTW	Time	NO_3-N	NH_4-N	WS-P	SO_4	Cl	K	Na	Ca	Mg	pH	Cond.
			----ppm----		ppb	----------ppm--------							umhos
Well #6 (071492)	15.72	1330	26.9	0	2.2	39.3	0.9	3.3	12.7	36.8	14.2	7.59	266
Well #1 (080792)	18.51	1645	28.1	0	11.4	62	24.1	1	22.2	65.6	23.6	7.41	496
Well #2 (080792)	18.65	1647	27.4	0	8.4	71.2	20.7	0.9	21.7	66.2	23.6	7.52	568
Well #3 (080792)	15.95	1310	31.1	0	6.8	43.4	4.3	1.7	14.3	43	16.7	7.68	273
Well #4 (080792)	16.12	1620	34.9	0	51.5	33.6	8.8	5.7	28.3	58.8	23.4	7.62	464
Well #5 (080792)	16.83	1622	20.3	0	1.7	26.3	6.8	1.7	17.5	28	10.9	7.72	275
Well #6 (080792)	15.4	1607	25	0	3.4	39.3	1.2	2.2	11.9	37.4	13.4	7.71	345
Well #7 (080792)	15.3	1609	33.9	0	26.4	26.5	7.9	1.5	28.7	52.3	20.1	7.65	510
Well #8 (080792)	14.64	1330	35.3	0	55.2	25.7	3.2	2.9	13.8	48.9	16.9	7.69	437
Well #9 (080792)	14.05	1332	37.2	0	61.6	16.8	10.2	2	30.5	58.8	20.1	7.96	654
Well #10 (080792)	18.3	1320	9.66	0	16	20.1	14.6	1.2	17.8	25.4	12.2	7.91	138
Well #11 (080792)	24.7	1340	4.14	0.03	95.7	15.3	5.9	3.8	11.8	35.8	13.1	7.59	311

Vadose Zone

Vadose Zone Hydraulics

Infiltration plots A and B were constructed within the Konawa soil of the Perkins Station. Using the neutron probe, volumetric soil moisture measurements were made at 0.5-ft intervals to a depth of 7 ft in test plots A and B. Similar measurements were collected and plotted for test plots A and B (Fig. 18 and 19). The composite profile includes one curve representing data collected before ponding (March 25) and four curves representing data collected during drainage (March 26, April 3, 5 and June 6). The composite profile for test plot A shows a greater variability of soil moisture with depth than test plot B. The variability is probably due to the difference in the properties of the two plot locations. A comparison of the composite soil moisture profiles for test plots A and B is depicted in Figure 20. The overall trends of the two sets of curves vary between each other as a function of depth. Although the soil layers in the two plots are similar in grain size, the soil structure and macropores appear to contribute to the difference in curve response.

Before ponding, the upper soil layer undergoes normal infiltration of precipitation and evaporation processes producing low levels of soil moisture. Ponding the test plot with a 3 inch head increases the upper layer soil moisture above that of natural conditions. While the overall soil moisture below 30 cm increases, approximately 9 percent is due to infiltration of the ponded water, the upper 30 cm shows an increase in moisture content of 16 to 27 percent after ponding.

Vadose zone infiltration studies have been conducted by Keisling (1974) on the Teller Soil Series, which is a dominant soil covering the station. Frequent and simultaneous measurements were taken of the soil wetness and matric suction using tensiometers at different depths (Fig. 21). This allows instantaneous fluxes and suction gradients within the profile to be determined. Representative unsaturated hydraulic conductivities at the specific depths were calculated and corrected for actual soil moisture content (Fig. 22). Specific methods of obtaining this data have been described in detail by Hillel (1982) and Davidson et al. (1969).

Unsaturated hydraulic conductivity is a property needed to define in monitoring chemical transport in the vadose zone since soil moisture is the main mechanism of transport. The effectiveness of the solute transport process also depends heavily upon the properties of the solute and soil constituents themselves. Complex processes of sorption onto clay particles and degradation of the contaminant may occur during travel in the vadose zone. Unsaturated hydraulic conductivity does provide a reasonable estimate of the rate at which a conservative tracer such as chloride or bromide will travel. Computer modeling described later in this section uses the values calculated for the Teller loam (Keisling, 1974).

Tracer Transport / Chemical Characteristics of Soil and Soil Moisture

The physical and chemical processes governing contaminant transport is a complex system (Fig. 23). Once a substance is applied to the surface, degradation begins and it may alter into inactive compounds. The fate of a surface-applied chemical includes volatilization into the atmosphere, metabolization by plants or organisms in the soil, leaching through the soil column into the saturated zone, or transport as surface runoff. Once inside the soil column, the substance may adhere to soil particles or dissolve and move downward toward the saturated zone. Therefore, it is important to understand the basic physical/chemical properties operating in the unsaturated zone.

The unsaturated zone monitoring program applied at the test site consisted of characterizing the granular texture of the soils and the solute movement of zinc, nitrate-N, chloride, and sulfate in the vadose zone. The tracer test was designed not only to track the movement of solutes in the unsaturated zone, but also to determine the extent of solute interactions with the soil matrix itself. The final purpose of the tracer was to calculate the approximate time of travel to the saturated zone to determine the impact of the solute loading on the groundwater in the vicinity.

Soil Water Sampling

Before conducting the tracer test, soil water samples extracted from the lysimeters were analyzed to obtain background levels of nitrate-N (NO_3-N), chlorides (Cl), zinc (Zn) and sulfates (SO_4) (Table 5). Because of the low natural occurrence of NO_3-N and Cl, they were chosen to be acceptable choices for tracers. Both NO_3-N and chloride would serve as conservative, inert (regarding soil interaction and adsorption) tracers. However,

Table 5. Background concentration of soil water (modified from Dwivedi, 1989)

		February 20, 1988			
Lysimeter Number	Depth	Cl	NO_3	SO_4	Zn
	-feet-	------ppm------			
L-1	1	7.2	0.1	65.1	0.1
L-14	1	3.2	0.1	76.4	0.5
L-6	2	5.3	0.1	47	0.1
L-8	2.2	1.9	1.1	31.2	0.3
L-13	2.2	3.5	0.7	10.7	0.5
L-3	4	2.1	0.2	19.4	0.3
L-11	4	4.2	0.1	8.4	0.1
L-7	5	3.3	0.1	4	0.1
L-2	7	3.6	0.1	17.6	0.2

Zn soil chemical interactions are complex and usually result in strong Zn retention. Variable chemical interactions would make Zn a poor tracer. Biweekly samples were collected during the 4.25-month tracer test and followed by chemical analysis in the lab (methods of analysis specified previously). A 22-day ponding period followed by two separate scenarios of application on 3/6/88 and 4/20/88. Substantial variability is shown to occur within and between test plots A and B, though the same basic type of soil exists in both infiltration basins (Fig. 24, 25, and 26).

Following the first application to Plot B of 1000 gm ammonium nitrate on 3/6/88, the nitrate-N concentration in soil water in the shallowest suction lysimeters was found to slowly increase to 10 ppm during the first week. The nitrate-N (NO_3 N) pulse did not seem to move very quickly though the entire soil profile was subjected to continuous pond infiltration that began 21 days before the first tracer application (Fig. 24). After the first week, NO_3-N concentration increased significantly within the profile with the maximum concentration reaching the depths of 1, 4, 7, and 9 feet in 16, 20, 22, and 23 days, respectively (Fig. 25). More important, once the nitrate-N pulse had reached a depth of one foot (10 days), the nitrate-N concentration rose in lysimeters at 4, 5, 7, and 9 feet at approximately the same time, 18 days after application (Table 6). The nitrate-N concentration dropped off at all depths at approximately the same time, 38 days after application.

Nitrate-N is considered a conservative tracer material with no chemical retardation slowing its movement through the soil media. Under ideal conditions, the nitrate-N pulse in this tracer would have steadily moved down through the profile with the first arrival times for different depths being spread apart and in chronological order. The nitrate-N pulse in this scenario is delayed for the first week and then seems to break through and manages to reach all of the lysimeters (to 9 feet) within eight days (Fig. 24). Several explanations for this occurrence should be considered.

The silty and clayish nature of the upper layers of the soil in plot B could have slowed the nitrate-N movement during the first week. Macropore effects could then account for the rapid nitrate-N pulse movement to 8 feet in depth within the following eight days.

The pressure within the actual macropore can cause meniscuses to form at the macropore interface with the soil matrix. Macropores of very small area may not conduct solutes at an appreciable rate. If the macropore was large enough, the soil water would overcome such conditions and produce preferential flow. The integrity of the lysimeter installation could be questioned in the Perkins Station tracer case. Dwivedi (1989), has shown that all of the possible precautions to insure reliable results were taken.

Nitrification is also a possible source for the sudden increase of nitrate-N (NO_3-N) concentration in the soil water. At some point after infiltration, the fixation capacity of clays in the profile can be exceeded and relatively immobile ammonium (NH_4) transformed to nitrate-N (NO_3-N). Conditions for nitrification in this tracer test were optimal since plant uptake of nitrogen was not possible due to the lack of vegetation at the surface and oxygen was supplied for nitrification of ammonia at depth by infiltrating water.

Table 6. Tracer arrival times for test plots A and B

Tracer Application 1					
Plot A		Plot B			
Depth (ft)	Peak NO_3	Depth (ft)	First NO_3	Peak NO_3	Peak Cl
1	14	1	10	16	14
3	20	4	14	20	18
5	20	5	18	---	---
9	22	7	18	22	19
		9	18	23	20
		13	24	32	---

Tracer Application 2					
Plot A		Plot B			
Depth (ft)	Peak NO_3	Depth (ft)	First NO_3	Peak NO_3	Peak Cl
1	---	1		28	---
3	---	4	7	28	---
5	---	5	7	---	---
9	---	7	7	29	---
		9	13	29	---
		13	≤ 39	50	---

Note - All tracer arrival times are in days from tracer application

This process may be represented by the elevated concentrations of ammonia and nitrate at depth under natural conditions near monitoring wells 3 and 7. These data are represented in Appendices E and F.

The second loading of 3000 gm of ammonium nitrate to plot B on 4/20/88 rendered responses similar to those of the smaller initial loading (Fig. 24). The nitrate-N pulse concentration at each depth for the second application was on the same order as the first application. The lysimeters seem to respond to the nitrate-N concentration simultaneously (Table 6). The macropore hypothesis is sustained in this second scenario. A wider nitrate-N pulse was noticed for this second heavier application indicating the duration of the concentration that the pulse will have upon leaching into the groundwater.

Analysis of the trend of sulfates (SO_4) in the soil water was too difficult since the natural background levels were very high. Little movement of zinc and chloride was noticed below one foot of depth and is probably due to significant absorption and chemical interactions.

Soil Sampling

Core samples were taken within the infiltration basins of test plots A and B during the unsaturated tracer test. The variations of nitrate-N within the soil profile over time were plotted following chemical analysis (Fig. 27 and 28). Following the first ammonium nitrate-N application on 3/6/88, samples were taken on 3/8, 3/10 and 3/25. Following the second ammonium nitrate N application on 4/20/88, samples were taken on 4/23 and 5/22. A limited number of soil samples were taken; thus, the general trend of the nitrate-N pulses in the soil water discussed in the previous section were difficult to correlate. Nitrate-N and ammonium-N concentrations at all depths within the soil profiles for plots A and B show inverse trends (Fig. 29 and 30). Nitrate-N concentration peaks within the first few feet at 3/8/88 following the first application and steadily decreases through 3/25/88. Nitrate-N concentration increases again on 4/23/88 following the second application and decreases on 5/22/88. The first nitrate-N pulse does not move to depths below 3 feet until the last two sample dates.

Groundwater Sampling

During the tracer test to characterize the unsaturated zone, groundwater samples were taken from monitoring wells beneath test plots A and B. There are two pulses of nitrate-N concentration that correspond to the two separate applications of fertilizer in the test plot B (Fig. 31). The first arrival of the first nitrate-N pulse is detected at approximately 24 days, with the maximum concentration peaking at approximately 32 days (Table 6). The first arrival of the second nitrate-N pulse is detected before 39 days and peaks at approximately 50 days. The first pulse of nitrate-N fertilizer was leaching at a rate of 13 feet/24 days or 0.55 ft/day. This leaching rate further supports the hypotheses that macropores significantly influence higher flow rates in the vadose zone.

Saturated Zone

Geologic Cross-sections

A topographic map for the Perkins Station with the profile locations for the generalized geologic cross-sections—north-south (A-A') and east-west (B-B') is shown in Fig. 32. These cross sections define layers of high hydraulic conductivity and layers that impede or slow saturated flow (Fig. 33 and 34). Generally, the terrace deposits of the north half of the station consist of finer materials than those located in the south half.

Geophysical Surveys

A seismic survey completed on the Perkins Station in the Fall of 1991 showed three layers of material are interpreted, each with a different seismic velocity (Fig. 35 and 36). The first two interfaces are interpreted to represent significant changes in lithology. The saturated zone is characterized by slightly elevated velocities. The third interface is interpreted to be the depth to bedrock surface at the point of the survey.

A DC resistivity survey completed on the Perkins Station shows the water table elevation is interpreted as where the apparent resistivity has decreased by the more conductive saturated zone (Fig. 37). The bedrock elevation is interpreted where the apparent resistivity decreases to a constant value due to encountering more conductive claystone (shales). These elevations were easily validated since this survey was run immediately adjacent to an existing set of monitoring wells (#1 and #2). The resistivity plots aided in identifying the bedrock at a depth deeper than indicated on the driller's log.

Geophysical logs and driller's logs both were used to create the water table and bedrock maps. The driller's logs correlated well with the geophysical surveys for proper elevations of water table and bedrock.

The 100-MHz analog system GPR survey conducted at the pumping test site (MW #18) on the Perkins Station did not result in any clearly defined subsurface interfaces due to the high clay content of the soils. However, higher resolution GPR techniques may be of use for this site in the future.

Bedrock and Potentiometric Surfaces / Groundwater Flowpaths

Potentiometric surface contour maps with predicted groundwater flowpaths have been constructed on regional, local, and detailed scales (Fig. 38, 39, and 40) using available water table data (Appendix D). Computer contouring software was used as an aide in contouring the data using the Kriging technique. The general location and trend of potential pathways for solute migration are important to determine so that prediction of possible environmental and human exposure can be addressed.

The regional geology consisted of a series of terraces built up by the Cimarron River upon bedrock and consequently eroded (Fig. 8). Apparently, the groundwater flowpaths in this area are controlled by tributary bedrock channels. These channels were eroded out of the bedrock by river activity and subsequently buried by terrace deposits. These buried tributary bedrock channels may contain materials of higher permeability such as coarse sands and gravel that explain their preferential conductance of groundwater and solute.

The regional bedrock surface (Fig. 41) controls the configuration of the regional water table (Fig. 38). The regional direction of groundwater flow is southeast toward the Cimarron River. A major buried tributary bedrock channel is evident in the southwestern quarter of Perkins Station. Bedrock channels contribute to local depressions of the potentiometric surface and groundwater divides. The existing groundwater divides and pathways of flow are well defined on the detailed water table map (Figure 40). The dominant direction of groundwater flow from the Perkins Station is to the southwest. A groundwater discharge area exists as a shallow ponded area called Twin Lakes where the flow lines converge from the north and east. This is a sensitive designated wetland area that could be a receptor of elevated concentrations of contaminants. For example, small amounts of the pesticide chemical Lindane (.003 ppm) was detected in pond sediments more than three years after upgradient application had been discontinued.

Aquifer Tests

Discharge rates for individual pumping tests have varied from 30 to 60 gpm. A 1992 pumping test with a discharge rate of 47 gpm rendered highly erratic measurements in the observation wells. The high discharge rate stressed the aquifer to the point that the data was difficult to interpret. A 1989 pumping test using a pumping rate of 32 gpm rendered more reasonable drawdown patterns for the observation wells and has subsequently been used for calculating hydraulic values for the southern alluvial sediments. The data collected from this pumping test is included in Appendix C.

The Jacob and Prickett methods of analysis of pumping test data have been described in detail by Van Alstine, 1995. Typical data plots for Jacob and Prickett analysis with calculations for hydraulic properties for a 1989 pumping test at the Perkins Station (Fig. 42 and 43). Additional data plots for both methods are presented in Appendix C.

The slug tests conducted on the clustered monitoring wells in the northern half of the station are of interest to this project since they are completed in materials of lower conductivity than those aquifer materials in the southern half. Graphical plots of slug test data for the clustered monitoring wells #4 (deep) and #5 (shallow) are shown in Fig. 44 and 45. The pertinent data and graphs used in these analyses are presented in Appendix C.

Hydraulic Variables / Aquifer Coefficients

The portion of the Perkins Terrace aquifer located beneath the Perkins Station has been characterized as to the rate at which groundwater is conducted and the aquifer's storage capacity. Aquifer coefficients were calculated by analyzing pumping test data from the fall of 1989 and the spring of 1992 (Table 7). The slug tests conducted in the upper terrace deposits resulted in transmissivities of 0.28 to 18.9 gpd/ft while pumping tests conducted in the lower terrace deposits rendered transmissivity values ranging from 14,669 to 20,373 gpd/ft (Table 7). Pertinent data and graphs used in these analyses are included in Appendix C.

The significant difference between the transmissivity values for the upper and lower terrace deposits can be accounted for by the much higher silt and clay content of the thinner upper terrace deposits. The lower, thicker terrace deposits have relatively high transmissivity and should be of great concern in the transport of solutes. The storativity of the lower terrace deposits was calculated to range between 0.06 and 0.10 through pumping test analysis (Prickett Method). These values are considered low for an unconfined aquifer that normally ranges between 0.10 and 0.30. A storativity of 0.20 usually represents coarser materials such as those that make up the lower terrace deposits. The calculated storativities may be unnaturally low due to delayed drainage caused by

Table 7. Summary of aquifer coefficients (Spring 1992) (from Saad, 1992)

	MW15	E0	E1	E2	E3
	-----Feet from MW18-----				
	7.65	12.85	20.4	39.5	80.6
Cooper-Jacob					
T	13360	17296	16062	16615	23748
S	0.011	0.018	0.007	0.019	0.002
K	334	432	401	415	593
Theis					
T	1900	N/A	8175	21705	29545
S	0.03	N/A	0.06	0.006	N/A
K	272	N/A	204	542	738
Jacob Straight Line Method					
T	N/A	24137	20114	19200	25000
S	N/A	0.46	0.031	0.003	0.3348
K	N/A	575	479	457	595

T-Transmissivity (gal/day/ft), S-Storativity (unitless), K-Hydraulic conductivity (gal/day/ft^2)

discontinuous impeding layers of clay and silt present at the pumping test site (see cross-section in Figure 16).

Tracer Studies

Tracer tests have rendered specific information on velocity distribution and dispersive properties for the lower terrace deposits of the Perkins Station.

Dispersivity properties. Concentration breakthrough curves are obtained from tracer tests by graphing time versus normalized concentrations of tracer chemicals. A textbook example of a breakthrough curve is shown in Figure 46. In the graph, the concentration increases gently in an S shaped curve rather than an abrupt step function. In a typical velocity-dominated concentration distribution (due to convection alone), a sharp concentration front with concentrations throughout the plume equal to the input concentration is expected (Kent et al., 1986). The influence of natural processes on levels of contaminants detected downgradient from a slug release source are shown in Figure 47. The arrival of the center of mass is the result of advection and sorption, while the spread of the curve is the result of dispersion.

Velocity distribution. Hydraulic conductivity of aquifer materials can be found by calculating velocity distribution based on the arrival times of chemicals in observation wells during tracer tests. There are two basic methods of velocity calculation: Darcian velocity (average linear discharge) and seepage velocity (specific discharge). The actual distribution of velocity in the saturated porous media will be dependent on the various flow paths that create the effect of dispersion. Dispersion can create different arrival times of the solute. This can be noted in the marked differences in travel times as represented by the peaks shown in Figure 48. These differences can be reduced to differences in velocity that can be related to Darcian seepage velocity.

Darcian velocity is an apparent velocity calculated from Darcy's Law that represents the flow rate at which water would flow in an aquifer if the aquifer were an open conduit (Fetter, 1988). Simply stated, when water flows through an open pipe, the discharge is equal to the product of the velocity and the cross sectional area of the pipe.

$$Q = V * A \qquad \text{or} \qquad V = Q / A$$

Darcy's Law (Fetter, 1988) states that:

$$Q = K A (dh / dl)$$

Substituting renders Darcian velocity:

$$V = Q / A = K (dh / dl)$$

Seepage velocity is the rate of movement of fluid particles through the aquifer material (Fetter, 1988) when restricted to the voids. Effective porosity of the aquifer material can be accounted for since water can only move through the pore spaces. Therefore, Darcian velocity must be divided by effective porosity (n) to render seepage velocity.

Seepage velocity :

$$V = (K / n) (dh / dl)$$

Therefore, hydraulic conductivity (K) is the product of the velocity (V) of a chemical in a tracer test and the effective porosity (n) of the aquifer material divided by the gradient obtained during a tracer test.

Calculations of chemical tracer velocities for the tracer test conducted in the spring of 1989 used the arrival times at specific observation wells located in the groundwater flowpath between the source well and the pumping well. The source well (#14) is located

12.85 feet from the pumping well (#18). A gradient of 0.10 was established by a pump test. Resultant velocity (Darcian) was 3 ft/day. The natural gradient in the southern half of the station is 0.01; therefore, the tracer velocity (Darcian) would be reduced to approximately 0.3 ft/day.

The first arrival time of the bromide pulse at the pumping well was 30 hours (see early peak in Fig. 48). The Seepage and Darcian velocity equations were used to calculate hydraulic conductivity values ranging from 231 to 769 gpd/ft^2 for bromide (Fig. 49). Maximum peak arrival time of the bromide pulse at the pumping well was determined to be 90 hours. The Seepage and Darcian velocity equations were used to calculate hydraulic conductivity values ranging from 77 to 257 gpd/ft^2 for bromide (Fig. 50; Table 8).

The hydraulic conductivity calculated for the first arrival of the bromide tracer in MW #18 by the Seepage velocity method correlates closely to the hydraulic conductivity values calculated from aquifer tests (Table 7 and 8). The hydraulic conductivity calculated for the maximum peak arrival of the bromide tracer in MW #18 by the Darcian velocity method correlates closely to the hydraulic conductivity values calculated from aquifer tests (Table 8). It can be concluded from these data that the Darcian velocity is associated with the principle mass of a slug release breakthrough curve (Fig. 47) when the maximum concentration of a tracer chemical is observed in the well. Seepage velocity appears to be associated with the front edge of a slug release breakthrough curve affected by dispersion (Fig. 47; Table 8).

An inverse approach was used in calculating hydraulic values for the 1992 tracer test. Values for hydraulic conductivity were obtained from pumping tests conducted at the tracer site (Table7). Using these values, approximate ranges of expected times of arrival for different chemical pulses at specific observation wells were calculated using the

Table 8. Tracer test results - fall 1989	
Bromide Pulse	
First Arrival MW #18 = 30 hrs	Max Peak Arrival MW #18 = 90 hrs
Darcian Velocity Method K=V/I	
K = 769 gpd/ft2	**K = 257 gpd/ft2**
Seepage Velocity Method K=(V*n)/I	
K = 231 gpd/ft2	K = 77 gpd/ft2

Table 9. Range of time for tracer tests (modified after Saad, 1992)

Well Number	Range **(hrs)**
15	35.4 to 11.8
16	76.6 to 25.5
17	74.16 to 24.7
18	107 to 35.7

Table 10. Matching from tracer tests (modified after Saad, 1992)

Well Number	Fl	Cl	Br	NO_3	K
15	1	1	N/M	1	N/M
16	2	2	N/M	N/M	N/M
17	2	1/2	2	N/M	N/M
18	2	2	2	N/M	2

1 - matching with first peak; 2 - matching with second peak; N/M - no matching.

Seepage and Darcian velocities. These ranges of times of arrival (Table 9) were then found to coincide with principle peaks on tracer test breakthrough curves (Table 10). For example, Table 9 shows that an arrival range of 11.8 to 35.4 hours is expected for observation well #15. The chloride breakthrough curve for observation well #15 is depicted in Figure 51, and the principle peak (peak 2) falls within the expected range of time,using Darcian velocity, as noted in Table 10. This method has been explained in detail by Saad (1992).

These results are similar to those in the 1989 data and support the conclusion that Darcian velocity is associated with the principle mass of the slug (peak 2).

Land Use and Chemical Application

Without question, pesticide and fertilizer development during the twentieth century has improved the quality of life, especially in the area of public health. Devastating diseases such as malaria and typhus, along with agricultural pests such as insects, weeds, and plant diseases have all been controlled so that lives have been saved, crop production has increased, and food prices have not escalated. Pesticide and fertilizer losses from runoff and infiltration cause a monetary loss for farmers and a potential threat to surface and groundwater. The technology exists today to estimate the potential contamination of groundwater by loss of specific agricultural chemicals through these two main pathways (surface runoff and leaching), therefore making it easier for farmers to improve their management strategies. Land management and agricultural chemical management combine to decrease the risk of potential groundwater pollution and to maximize the benefits of fertilizers and pesticides to crops.

Land Use

The use of the land on the Perkins Station is highly complex because it serves projects leaders from several disciplines. Crop type and placement varies from season to season according to individual research and cropping needs. No commodity control for major changes in land use exists on the Perkins Agronomy Research Station. Land use from the spring of 1986 to the present has been recorded in map form included in Appendix G.

Fertilizer Application

Fertilizer is applied during the growing seasons (spring and fall) on the Perkins Station in three basic forms. The first is urea [$CO(NH_2)_2$], which is an organic nitrogen material composed of 45-46 percent NH_4-N. The second is diammonium phosphate (18-46-0), and the third is a mixture of specific percentages of nitrogen (N), phosphate (P_2O_5) and Potash (K_2O). For example, the diammonium phosphate is labeled as18-46-0 suggesting a mixture of 18 percent nitrogen, 46 percent phosphate and 0 percent potash. Seasonal applications since the spring of 1986 have been recorded in map form and can be found in Appendix G.

Herbicide Application

The main pesticides applied at the Perkins Station are herbicides intended to rid the station of unwanted weeds and grasses. Those applied on the station are tabulated in Table 11, including their popular brand names, actual chemical names and specific chemical properties as designated by the chemical database of the Oklahoma State University Agronomy Department. Available records of seasonal application since the spring of 1986 have been recorded in map form and can be found with fertilizer applications in Appendix G.

Precipitation and Water Quality

The main source of recharge to the aquifer in the immediate area is infiltration of precipitation. The area receives a total annual rainfall of 35 inches. Assuming approximately 10 percent of precipitation percolates with the remaining 90 percent lost to evaporation, transpiration, and runoff, the total recharge for the aquifer is between three and 4 inches per year (Table 12). Confirmation of these rates has been provided through calibration using the KONIKOW model (Van Alstine, 1995).

Table 11. Herbicides used on the OSU/ARS site			
Brand Name	Chemical Name	Half-Life	Partition Coeffiecient
		--days--	-mg/gOC-
Attrex	Atrazine	60	100
Banvel	Dicamba	14	2
Blazer	Acifluoren	30	139
Dual	Metolochlor	20	200
Furadan	Carbofuran	50	22
Lasso	Alachlor	15	170
Milogard	Propazine	135	154
Peeper	Experimental	?	?
Princep90	Simazine	75	138
Ramrod	Propachlor	6	80
Sancap	Dipropetryn	30	1180
Treflan	Trifluralin	60	7000
2-4D	2-4D	10	1000
Vernam	Vernolate	12	330
Sorption Coef. (K) = PC (%OM)(0.0058)			

Table 12. Cumulative precipitation and recharge calculations				
	1989	1990	1991	1992
Total precipitation **(inches/year)**	41.00	23.44	25.36	40.44
Estimated recharge **(inches/year)**	6.15	3.52	3.80	6.10
Net recharge = 15% of total precipitation				

The combination of precipitation and potentiometric surface elevation data for the Perkins Station is used to correlate precipitation with water table response and to analyze the effects of water table fluctuation on groundwater nitrate-N concentration (Fig. 52). The hydrographs correlate closely with the frequency and magnitude of the precipitation and show a lag time of only 30 to 60 days between the maximum water level increase and the time of precipitation. Composite hydrographs for the remaining monitoring wells are included in Appendix B.

Pesticides. Integrated Pest Management is an overall pest management strategy being used on agricultural research farms including pest monitoring, biological controls, and pesticide selection. Pesticide selection is based upon various factors including cost, effectiveness, toxicity to nontarget organisms, and solubility and persistence.

While pesticides have been applied to crops intermittently on the Perkins Station, none have been found in appreciable amounts in the groundwater. Cultivated fields located directly upgradient from monitoring wells targeted for pesticide sampling have been divided into sections A - H (Fig. 53). Scenarios of recorded upgradient application of pesticides and the subsequent downgradient concentrations found in groundwater samples taken from corresponding downgradient wells appear in Table 12. Although appreciable amounts of Attrex (Atrazine) and Treflan (Trifluralin) was applied from 1986 to 1989, groundwater samples taken in the spring and fall of 1989 showed no to minimal concentration of these chemicals (Table 13). Use of Lindane was ended on the station after 1986.

Atrazine has a relatively short half-life of 60 days and small partition coefficient, Koc, of 100 mg/g, while Trifluralin has a relatively short half-life of 60 days and a large partition coefficient of 7000 mg/g (Table 11). Rao et al. (1983) give a complete discussion of how these chemical properties show persistence and solubility in soils. These chemicals are considered only moderately persistent with half lives greater than 30 days but less than 100 days. Atrazine is readily adsorbed by organic carbon. It is true that Atrazine's partition coefficient is less than Trifluralin's, but most studies show little (but significant) leaching of atrazine in soils with moderate levels of organic matter.

The apparent lag time between precipitation and corresponding response of the other parameters in the saturated zone is 30-60 days (Fig. 54 and 55). This could suggest that the pesticides could appreciably decay (depending on amount of pesticide applied) by the time they reach the water table and move downgradient within the saturated zone.

Atrazine is more likely to contaminate groundwater due to its small partition coefficient and short half-life while Trifluralin is more likely to contaminate surface runoff due to its large partition coefficient and short half-life. This explains minimal detection of Atrazine in the downgradient groundwater samples and no detection of Trifluralin (Table 12). These chemicals will adsorb on organic matter in soils and probably decay largely before leaching or surface runoff can occur. Lindane, which is not presently used at the site, is much more persistent than Trifluralin and Atrazine (half-life of 400 days). It would therefore be expected to be detected in the groundwater within this span of time. The travel time within the saturated zone would result in a distance of

Table 13. Pesticide application and recovery

Upgradient Pesticide Application

Area C Cotton/Beans/Sroghum	Areas E, F, and G Min-Wheat/Con-Wheat
1986 June Atrazine 1 pint/acre	1986 no applications
1987 April Trifluralin 1 pint/acre	1987 no applications
1988 no data	1988 no data
1989 Atrazine 1.25 qt/acre (May) Trifluralin 1 pint/acre (April) 0.75 pint/acre (June)	1989 Trifluralin 0.75 qt/acre (June)

Downgradient Groundwater Concentration **(mg/l)**

	Well #3	Well#5	Well#6	Well#8	Well#9
May 1989					
Atrazine	0.011	ND	ND	ND	ND
Lindane	0.006	0.002	ND	ND	0.003
September 1989					
Atrazine	ND	ND	ND	ND	trace
Lindane	ND	ND	ND	ND	ND
Trifluralin	ND	ND	ND	ND	ND

ND - Not detectable at < .001 mg/l

120 ft. However, Lindane was detected in both groundwater samples and pond sediments (Table 12).

Solubility and persistence of pesticides are critical elements when the application site is underlain by permeable soils and a shallow aquifer. The Perkins Station has a water table where the depth to water ranges between 10 and 30 feet. The aquifer is composed of permeable terrace deposits and is overlain by sandy loams in the southern half of the station. Chemicals with short half-lives and intermediate to large partition coefficients are preferable in this situation. Atrazine and Trifluralin are ideal pesticides to be used on the Perkins Station and have been effective herbicides.

Fertilizers. Increases in NO_3-N concentration are found in the groundwater where nitrogen fertilizers have been applied to the field surface at the Perkins Station. In general, it has been found that nitrate-N levels in groundwater correspond closely to the water table fluctuations, showing that as infiltrating water recharges the aquifer, it carries dissolved nitrate-N with it. Nitrate-N levels on the station range between 1 and 150 mg/l. Nitrate-N levels change significantly over time with respect to water table fluctuations (Fig. 54 and 55). Similar trends have been noted in other wells on the station.

Research conducted by the OSU Department of Agronomy has shown that land applications of nitrogen fertilizer under 90 lbs/acre do not move beyond a depth of one foot within the soil column (Westerman et al., 1994). Records have shown in the past that the fertilizer applications in some plots on the Perkins Station have exceeded this "threshold" of 90 lbs/acre on occasion.

Computer Modeling

Unsaturated Zone

A qualitative assessment of the possible pollution potential of the pesticides used on the Perkins Station is possible through the joint analysis of the persistence and solubility of each pesticide as discussed previously. Quantitative prediction of pesticide losses that occur through leaching and infiltration is possible through computer modeling. Models that use site-specific information such as soil, climatological, irrigation, application, and crop type data have been developed. Specifically for the Perkins Station, the Chemical Movement in Layered Soils (CMLS) model, developed by Nofziger and Hornsby, 1987, and the EPA's Pesticide Root Zone Model (PRZM) have been used for deciding the extent that herbicides applied to crops will travel through the unsaturated zone. The results help in determining which pesticides have the potential to enter the groundwater of the Perkins Terrace Aquifer beneath the Perkins Station.

The version of the CMLS used was a model for simulating organic chemical movement in layered soils and considered solute movement to be strictly driven by piston flow, without consideration of macropore flow effects. For a detailed description of the model used, refer to the CMLS manual by Nofziger and Hornsby (1987). The PRZM is a compartmentalized model developed to aid the EPA in pesticide exposure assessments and simulates pesticide movement within and below the root zone. However, PRZM requires a much more complex set of input parameters than CMLS. For a detailed description of this model, refer to the PRZM manual (Carsel, 1985). The data that were available from the site were not considered adequate to calibrate and compare the models. The PRZM model was not used because of the lack of data.

Saturated Zone

Modeling studies conducted for the Perkins Station used the two dimensional groundwater flow and solute transport model KONIKOW (MOC, NRC) which was developed by Konikow and Bredehoeft (1978) and later modified by Kent et al. (1985). KONIKOW is a numerical model that uses a finite-difference method to solve both flow and transport equations. Input data and parameters are prepared for the model by use of a preprocessor (KONIM). Because KONIKOW is a numerical model, data along with initial and boundary conditions are specified for each node within the matrices of the preprocessor. Hydrological parameters in the nodes control the output solution. KONIKOW can be used in either a planar or cross-sectional perspective by manipulating the x and y nodes and the aquifer thickness. The cross-sectional configurations were successfully used for model simulations of tracer transport within the saturated zone.

Simulations, including those completed by Saad (1992) and Van Alstine (1995), used basic assumptions of solute transport under both steady state and transient conditions. An isotropic and homogeneous aquifer was assumed. Hydrologic parameters used in the model were determined through aquifer field tests conducted on the Perkins Station to ensure reliable accuracy of simulation results. A few of the variables used for computer simulation are listed below.

Storage: 0.4
Effective porosity: 0.2
Hydraulic conductivity: 433-450 gpd/ft^2 (upper range)
Saturated thickness: 42 ft
Aquifer density: 2.0 g/cm^3
Characteristic length: 75 ft
Ratio of transverse to longitudinal dispersivity: 0.2
Net recharge: 6.1 in. (15% of rainfall)

The basic simulation scenario included a series of four pumping periods designed to simulate the actual field tracer tests conducted at the site. The first pumping period was used to establish a gradient only with an inflow boundary on the north side of the grid as an injection well and a constant head boundary on the south side of the grid. The second pumping period added the downgradient pumping well (MW #18) to the scenario with a discharge rate of 30-32 gpm. The third pumping period served to introduce a tracer plume to the scenario by gradually adding the tracer concentration at an upgradient location over a period of one day at a rate of one gpm. The fourth pumping period lasted 14-20 days to simulate the movement of the tracer plume through the effects of natural gradient plus the downgradient pumping well (MW #18).

Cross-sectional modeling of the bromide tracer and the pesticides Atrazine, Trifluralin, and Lindane were successfully completed. Using the four pumping period scenario, each type of tracer was run with the KONIKOW model and the output concentration matrices analyzed. Concentrations over time for the recovery well (MW #18) were isolated and plotted (Fig. 56, 57, 58, and 59).

Modeling the conservative tracer bromide requires chemical parameters of no decay and no sorption to be used in the simulation. The simulated first arrival peak of bromide was smaller in concentration and delayed in time compared to the observed first arrival peak of bromide (Fig. 56). This indicates that the actual dispersivity occurring within the aquifer is lower than the simulated dispersivity used in this modeling exercise.

To simulate the chemical movement of pesticides, the decay and sorption options within the model must be adjusted to the properties of each pesticide. In each case, decay with a specified half life and linear sorption with Kd values calculated from specified Koc values were used. Each pesticide was also run with no sorption occurring to provide a comparison with linear sorption effects.

	Atrazine	Trifluralin	Lindane
Half life (days)	60	60	400
Koc (mg/l)	100	7000	1100
Kd (mg/l)	0.2	14.0	

Comparing the resulting concentration curves with and without sorption for the recovery well (Fig. 57, 58, and 59) shows that the nonsorption option caused the pesticide tracer to react as a conservative tracer would: a sharp slug peak would occur followed by dropping off gradually over time. In the nonsorption cases, the decay time difference (60 to 400 days) did not noticeably affect the time of first peak arrival (Fig. 58 and 59). On the other hand, linear sorption greatly reduced the simulated concentration levels for all of the pesticides, especially Trifluralin and Lindane.

The modeling study conducted by Saad (1992) consisted of cross-sectional modeling of the bromide, chloride, and nitrate-N and the dye, fluorescein. This study was conducted to try to simulate the actual results from a recent tracer test using all of the chemicals. Using two different simulation scenarios, each type of tracer was run with the KONIKOW model, and the output concentration matrices were analyzed. The above detailed four pumping periods and a simplified scenario of one pumping period of 14 days were used. Concentrations over time for various monitoring wells were isolated as observation wells in the model and plotted. While the output from the complex four pumping periods did not conform to the observed data, the output from the simplified one pumping period scenario did correlate well with the actual field tracer test results (Fig. 60 and 61).

SUMMARY OF SIGNIFICANT FINDINGS

The Perkins Station project has been a long-term site assessment to characterize the potential of agricultural contamination in groundwater. An extensive computerized database of water quality analysis and water level measurements has been created at the

USDA National Agricultural Water Quality Laboratory in Durant, Oklahoma. Important physical and chemical parameters of both the unsaturated and saturated zones have been determined. Hydrologic and water quality responses within the aquifer have been characterized.

The site geology has been characterized through borehole logs, drilling logs, and geophysical techniques. The aquifer underlying the station is an unconfined water table aquifer made up of highly permeable Quaternary aged terrace alluvial deposits of considerable permeability.

Important physical and chemical properties of the unsaturated zone have been determined. Soil moisture profiles have been used to analyze the change in saturation with depth and thus the soil's ability to conduct solutes. Unsaturated hydraulic conductivity values of .18-.33 cm/day have been calculated within the first five feet of the unconsolidated material. Tracer tests have been used to indicate that the silty and clayish nature of the unconsolidated material and macropore flow affects solute transport in the unsaturated zone and that nitrification is a possible contributor to the concentration of nitrate-N at depth after fertilizer application. Unsaturated tracer tests have been used to determine that a conservative tracer such as nitrate-N will leach to the groundwater within 20-30 days of application (approximately 0.55 ft/day). Macropore effects account for this leaching rate exceeding the velocities based on calculated unsaturated hydraulic conductivity.

Geophysical techniques, water level measurements and drilling logs have been successfully used to define aquifer boundaries. The DC resistivity surface surveys and gamma ray borehole surveys proved to be the most successfully applied techniques. Potentiometric surface contour maps have been constructed on various scales to define groundwater flowpaths as potential pathways for contaminant migration.

Important physical and chemical properties of the saturated zone have been characterized by aquifer tests and tracer tests. The upper terrace deposits have been found to have very low transmissivities due to the fine nature of the materials. Therefore, the upper terrace deposits are not likely to conduct contaminants at a rapid rate. The lower terrace deposits have been determined to have very high transmissivities ranging from 14,669 to 20,373 gpd/ft and therefore can rapidly conduct contaminants leached into the aquifer. Tracer tests have been used to suggest that dispersion and convection are the physical processes responsible for solute transport within the aquifer and that values for saturated hydraulic conductivity calculated by aquifer test analysis fall within the range of hydraulic conductivity values determined through the seepage and Darcian velocity methods of tracer test analysis.

Composite hydrographs have been used to show long term correlation of water table elevations with the frequency and magnitude of precipitation. A lag time of 30-60 days exists between the maximum water level increase and the time of precipitation. These results are comparable with rates noted in unsaturated tracer tests.

Water quality has also been found to fluctuate with recharge. All parameters except nitrate-N decrease with an increase in recharge. Nitrate-N has been found to increase with recharge, indicating that fertilizer is leaching to the groundwater and/or nitrification is occurring with depth. Yet, a correlation of the combined effect of land use, tillage, and agricultural chemical application on water quality has not been found.

Though pesticides have been applied to crops annually, none have been detected in appreciable amounts in the groundwater. Thus, the Integrated Pest Management used by this research farm has been successful in selecting effective pesticides that pose little contamination threat to the aquifer. The undesignated wetland area on the southern edge of the Perkins Station may possibly be acting as a site of concentration of pesticides. Lindane was detected in both groundwater and pond sediments three years after its use on the station was discontinued.

During characterizing the unsaturated and saturated zones, parameters required for the simulation of the fate and transport of agricultural chemicals have been determined. Computer modeling has proved a useful tool for simulating chemical movement in both the unsaturated and saturated zones. Tracer tests in the aquifer have been closely replicated. Modeling in the unsaturated zone has indicated that no pesticides are reaching the groundwater in detectable amounts.

RECOMMENDATIONS

In Situ Measurement of Unsaturated Hydraulic Conductivity of Soil Profiles

Application of mathematical theories and models of soil physics to the description or prediction of actual processes in the field requires knowledge of hydraulic characteristics of soils. Functional relations of hydraulic conductivity and matric suction to soil moisture therefore need to be determined for soils of concern. The internal drainage method is a recommended in situ field method of deciding soil characteristics because alteration of soil hydraulics due to disturbance of structure is eliminated. This method should be used on the Perkins Station in the future to better define important variables used in computer modeling of the unsaturated zone.

Hillel et al. (1972) give a detailed description of a simplified procedure for determining the intrinsic hydraulic properties of a layered soil profile in situ. This method requires frequent and simultaneous measurements of soil wetness and matric suction within a soil profile under conditions of drainage alone. With these measurements, instantaneous values of the potential gradients and fluxes within the soil are available. Therefore, unsaturated hydraulic conductivity can be determined.

Portable double-ring infiltration systems could be used to establish temporary internal drainage basins at the Perkins Station. Because the set up is portable and temporary, the test could be conducted at several different sites within the soil type being examined to verify results. The internal drainage basins should be equipped with tensiometers and a soil moisture tube. A hand-held strain gauge pressure transducer (tensiometer) could be used to measure soil moisture suction, while soil wetness could be determined with a neutron moisture probe.

Studies conducted by the USDA have developed a method for determining the unsaturated hydraulic conductivity from tensiometric data alone (Ahuja et al., 1988). This should be considered a complimentary method to be incorporated into future field work.

Unsaturated Zone Modeling of Pesticides with the USDA RZWQM

Most of the modeling conducted in the unsaturated zone of the Perkins Station has been accomplished by the CMLS model developed in the OSU Agronomy department by Nofziger and Hornsby (1987). As previously described in the unsaturated computer modeling section, the CMLS model has an established database of soil parameters and precipitation records for Oklahoma. Unfortunately, the main mechanism for movement of solutes through soil profiles is considered piston flow without macropore flow effects. The USDA Root Zone Water Quality Model (RZWQM) for determining movement and degradation of pesticide residues in the unsaturated zone allows the simulation of solutes by piston flow but also considers preferential flow through macropores (Ahuja and Hebson, 1992; USDA, 1995). Future studies should be conducted at the Perkins Station to track pesticide movement within and below the root zone and to compare the predicted impact by the current version of CMLS and RZWQM on groundwater to actual field results.

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FIGURES 1-61

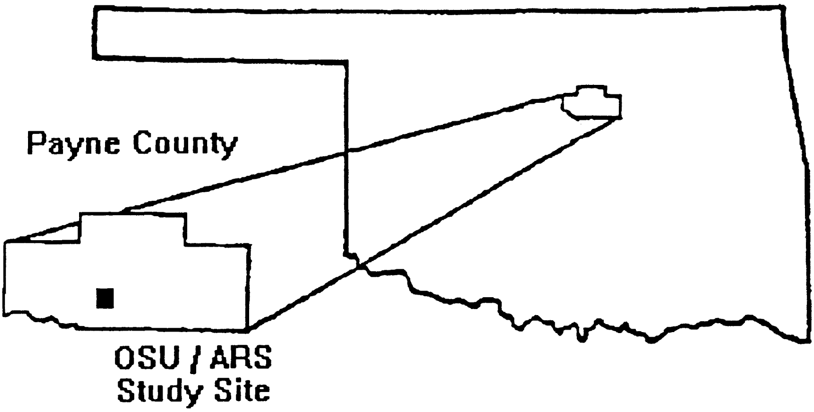


Figure 1. Site location map.

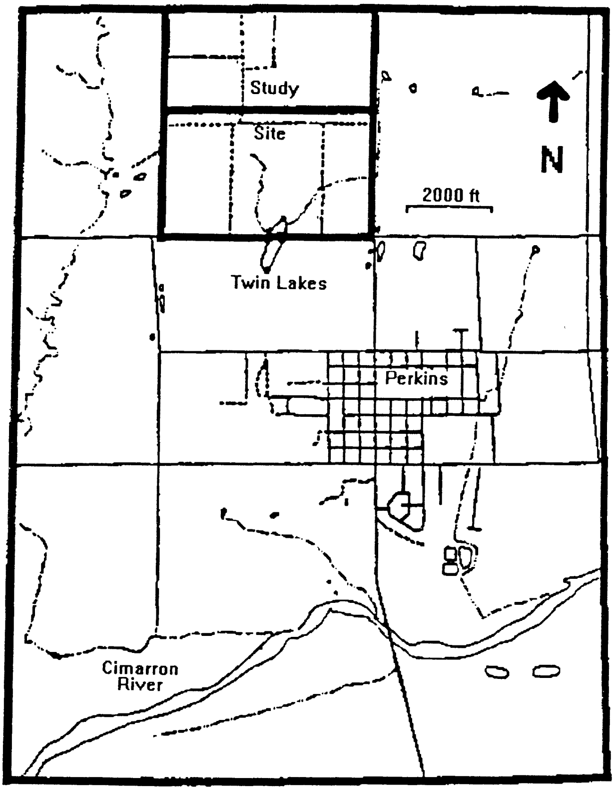


Figure 2. Regional site map.

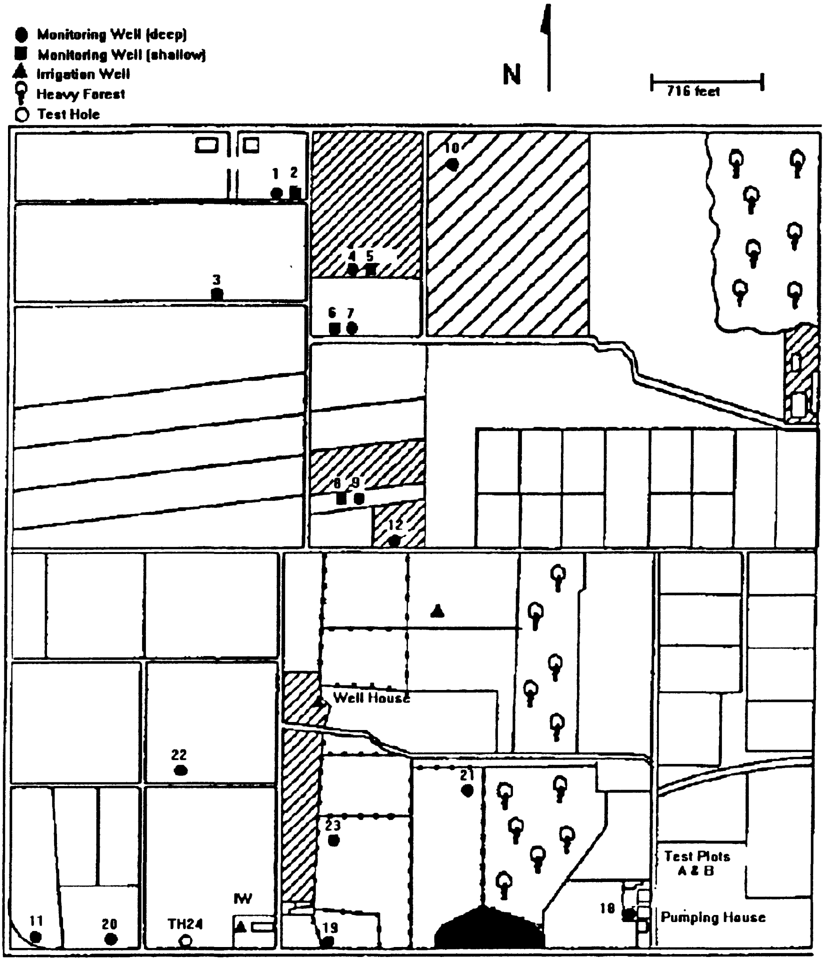


Figure 3. Detailed map of OSU/ARS study site in Section 36T 18N, R2E, Payne Co., Oklahoma.

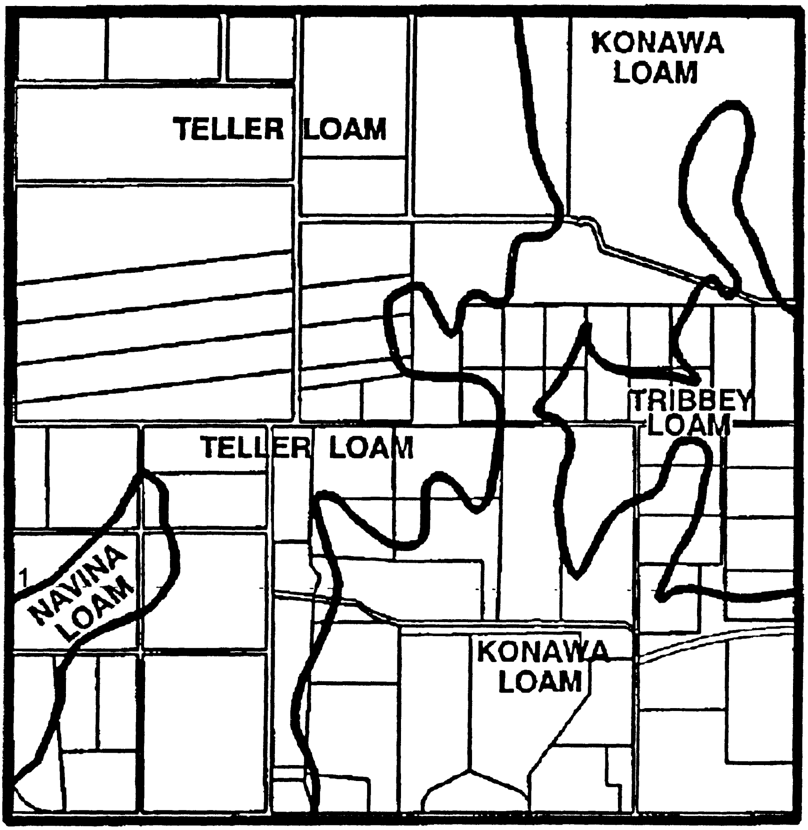


Figure 4. Generalized soil map for the OSU/ARS study site (modified from Henley et al., 1987).

Horizon	Depth (inches)	Description
Ap	0 – 7	Dark brown (10YR 3/3) moist, loam, moderate medium granular structure; very friable when moist; abrupt boundary.
A1	7 – 13	Dark brown (7.5YR 3/2) moist, loam weak medium subangular blocky structure; friable when moist; gradual boundary.
B1	13 – 18	Dark brown (10YR 3/3) moist, loam, mod-erate medium subangular blocky structure; friable when moist; gradual boundary.
B21t	18 – 26	Dark yellowish brown (10YR 4/4) moist loam, strong medium subangular blocky structure; firm when moist; gradual boundary.
B22t	26 – 35	Brown (7.5YR 4/4) moist, sandy clay loam, strong, medium subangular blocky structure; firm when moist; gradual boundary.
B3	35 – 43	Brown (10YR 4/3) moist, sandy loam, weak medium subangular blocky structure; friable when moist; gradual boundary.
C1	43 – 50	Yellowish-brown (10YR 5/4) moist, sandy loam, structureless, single grain; friable when moist; diffuse boundary.
C2	50 – 55	Yellowish -brown (10YR 5/4) moist, sandy loam, old alluvium.

Figure 5. Soil description for Teller loam—0 to 1 percent slope (modified from Henley et al., 1987).

Horizon	Depth (inches)	Description
Ap	0-7	Dark brown (7.5YR 3/2) moist, fine sandy loam, with few distinct red (2.5YR 4.6) mottles; weak medium subangular blocky and weak medium granular; very friable; many fine roots; many worm casts; abrupt smooth boundary.
B21t	7-23	Red (2.5YR 4/6) moist, fine sandy loam moderate coarse prismatic; firm; many fine roots; common worm casts; moderate continuous clay films; gradual smooth boundary.
B22t	23-32	Red (2.5YR 4/6) moist, sandy clay loam compound weak coarse prismatic and weak medium subangular blocky; friable; common fine roots; diffuse smooth boundary.
B31	32-40	Dark reddish brown (2.5YR 4/6) moist, loamy sand with common coarse distinct light brown (7.5YR 5/4) mottles; weak coarse prismatic and weak medium subangular blocky; friable; few roots; diffuse smooth boundary.
B32	40-56	Red (2.5YR 4/6) moist find sandy loam with common coarse distinct light brown (7.5YR 5/4) mottles; friable; diffuse smooth boundary.
C	56+	Mixed red (2.5YR 4/6) moist, and brown (7.5YR 5/4) moist, loamy sand old alluvium.

Figure 6. Soil description for Konawa loam—3 to 5 percent slope, eroded (modified from Henley et al., 1987)

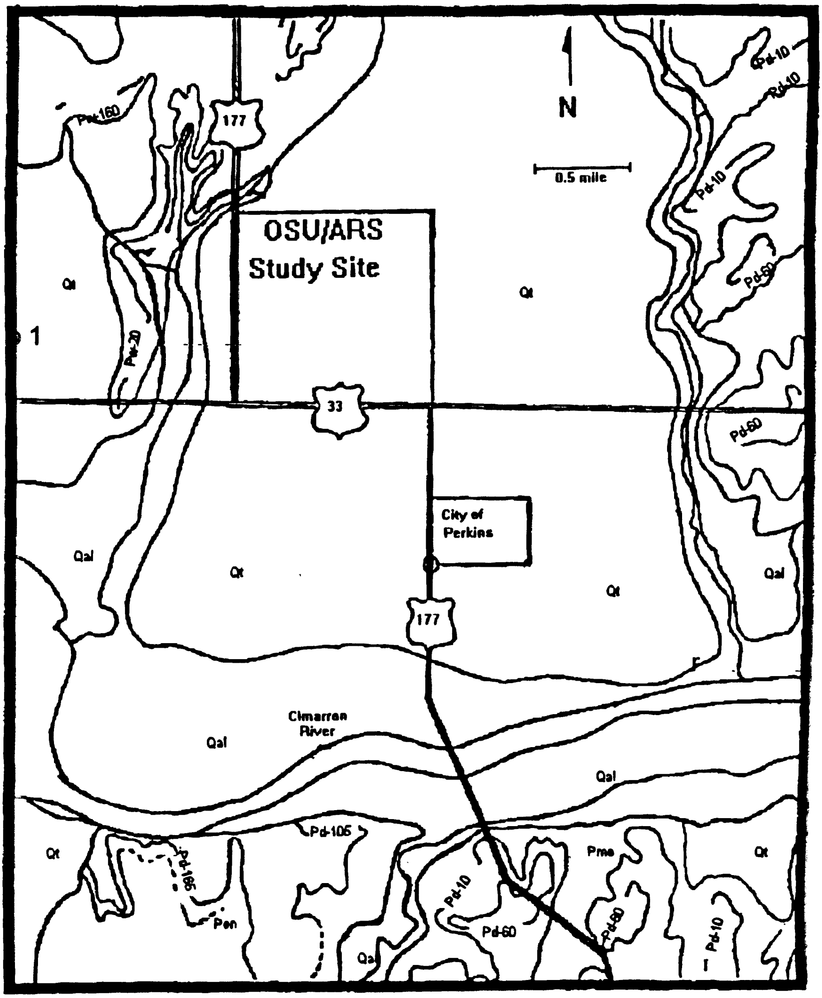


Figure 7a. Regional geology map (from Shelton et al., 1985).

	Q_{al}	Alluvium - Sand, silt, and clay of present streams
	Q_t	Terrace Deposits - sand, silt, and clay with assciated eolian deposits.
	P_w	Wellinton Formation - Red lenticular sandstones and mudrock with thin nodular carbonate beds. Approximately 780 ft of formation crops out in western Payne County. Two key beds divide formation into three units (Pw1, Pw2, and Pw3). Carbonate units are most prominent in upper unit, sandstone is most prominent in middle unit, and mudrock is most prominent in lower unit. The following unnamed beds are mapped.
		Pw-160 Sandstone - 160 ft above base.
		Pw-140 Sandstone - 140 ft above base.
		Pw-120 Sandstone - 120 ft above base.
		Pw-100 Sandstone - 100 ft above base.
		Pw-80 Sandstone - 80 ft above base.
		Pw-60 Sandstone - 60 ft above base.
		Pw-40 Sandstone - 40 ft above base.
		Pw-20 Sandstone - 20 ft above base.
OSCAR		Oscar Group - Red claystone with lenticular sandstone and nodular dolomites IP_n, which is a persistant carbonate unit. Average thickness of Oscar Group is approximately 600 feet. The group contains the following units:
	IP_h	Herington Limestone
	IP_{en}	Enterprise Shale
	IP_{wi}	Winfield Shale
	IP_d	Doyle shale
		IPd -165 Sandstone - 165 ft above base.
		IPd-105 Sandstone - 105 ft above base.
		IPd-90 Sandstone - 90 ft above base.
		IP-60 Sandstone - 60 ft above base.
		IPd-10 Sandstone - 10 ft above base.

Figure 7b. Geologic unit description (modified from Shelton et al., 1985).

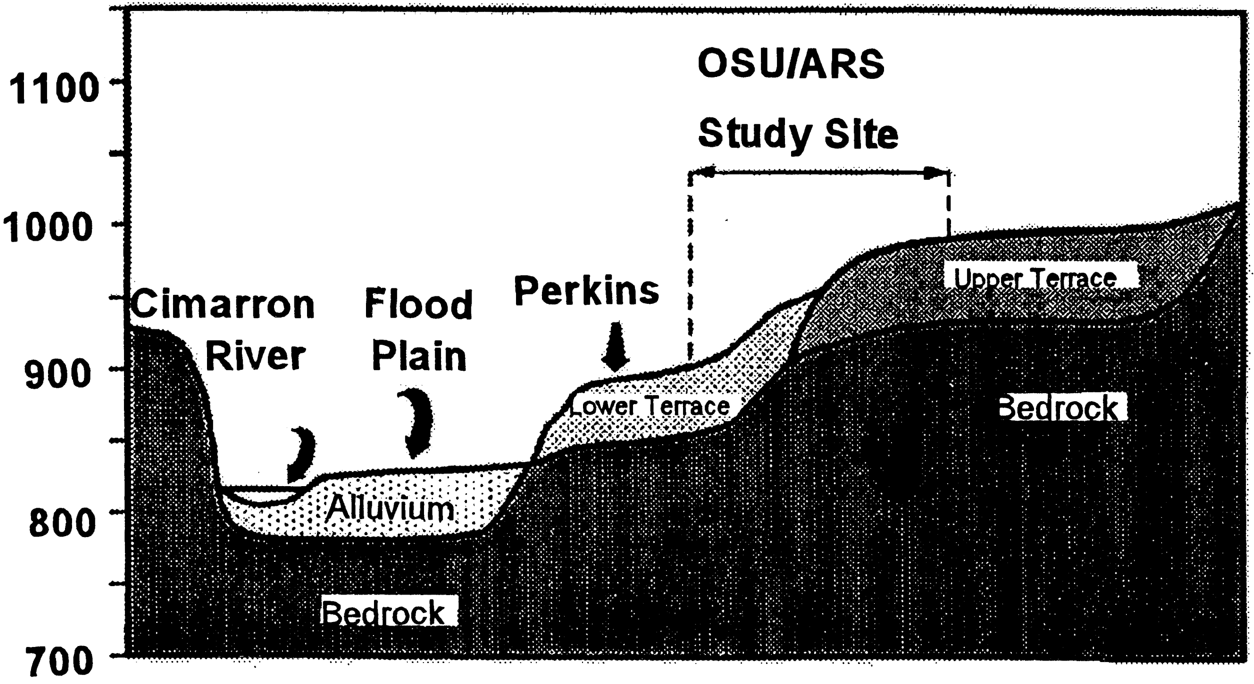


Figure 8. Regional geologic cross-section of study site (horizontal axis not to scale; vertical axis is in feet above mean sea level).

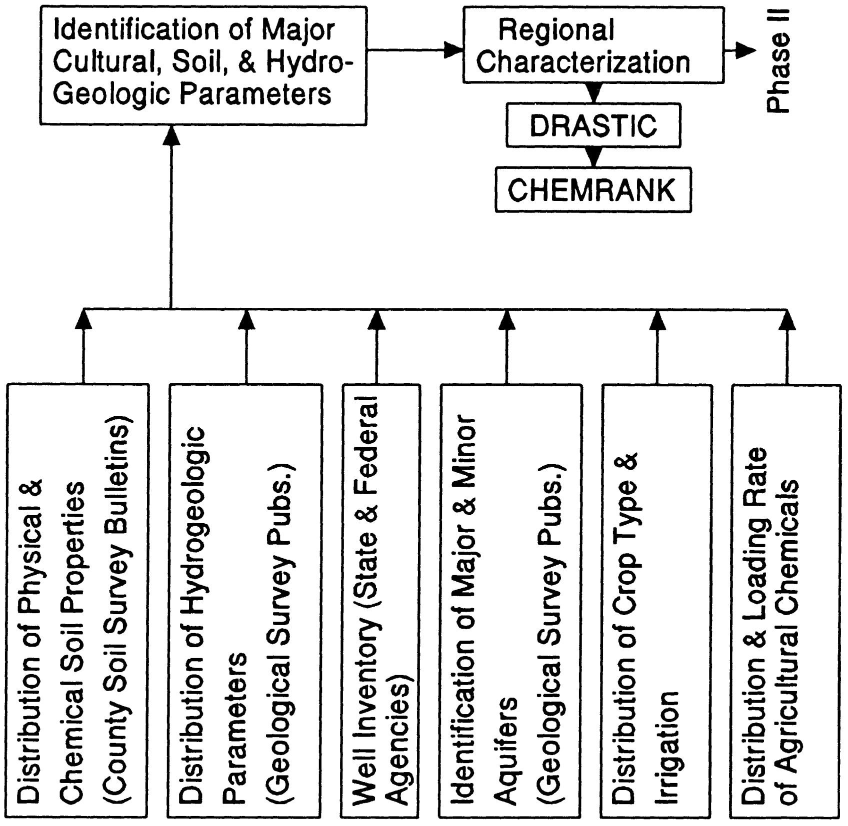


Figure 9. Methodology, Phase I—Preliminary Characterization.

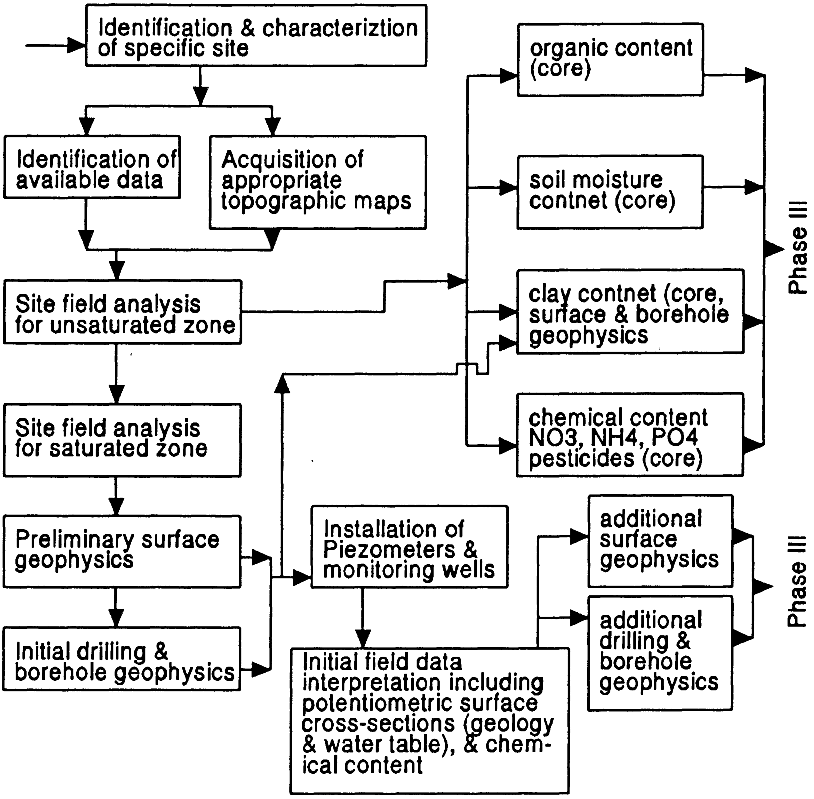


Figure 10. Methodology, phase II—description of soil and geologic materials in subsurface.

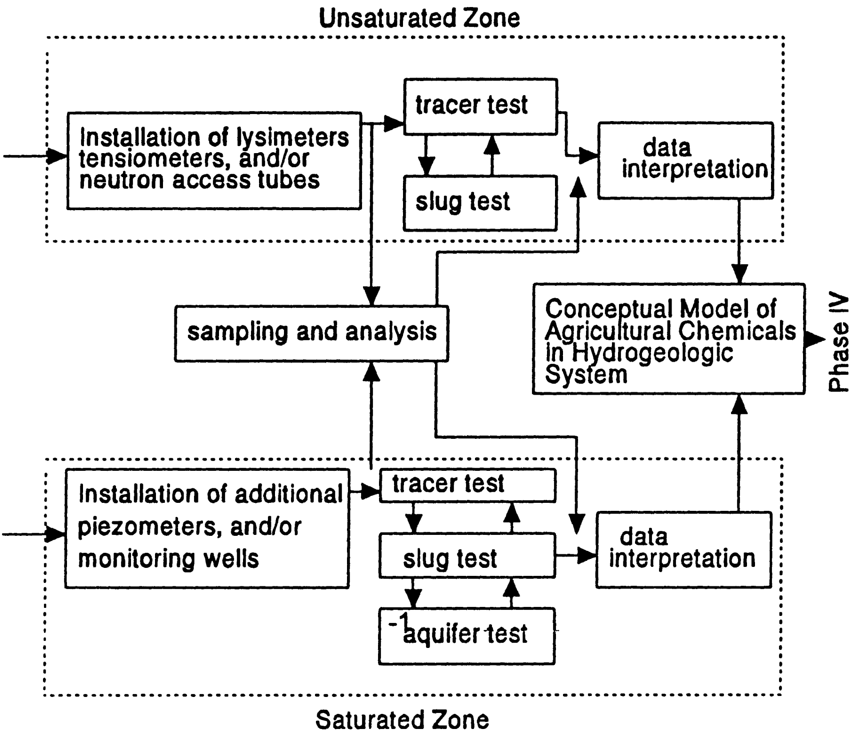


Figure 11. Methodology, phase III—Measurement of groundwater quality and quantity.

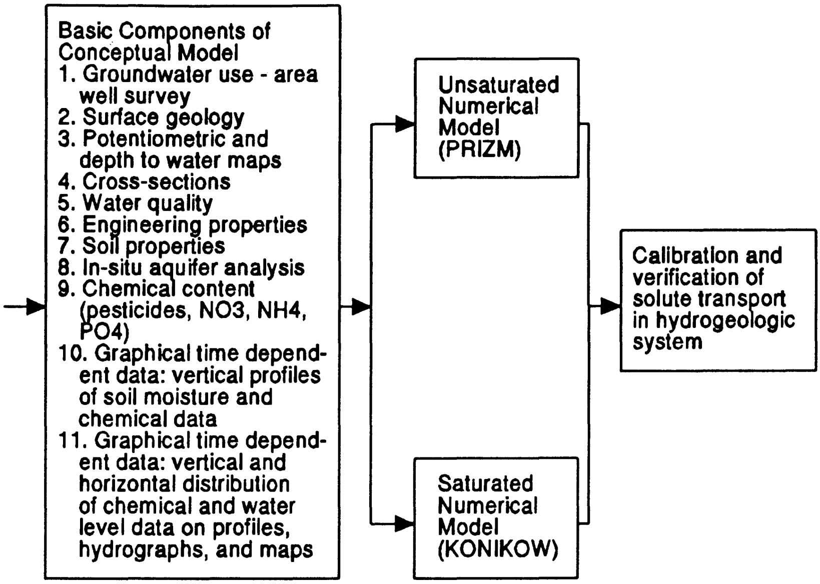


Figure 12. Methodology, phase IV—modeling.

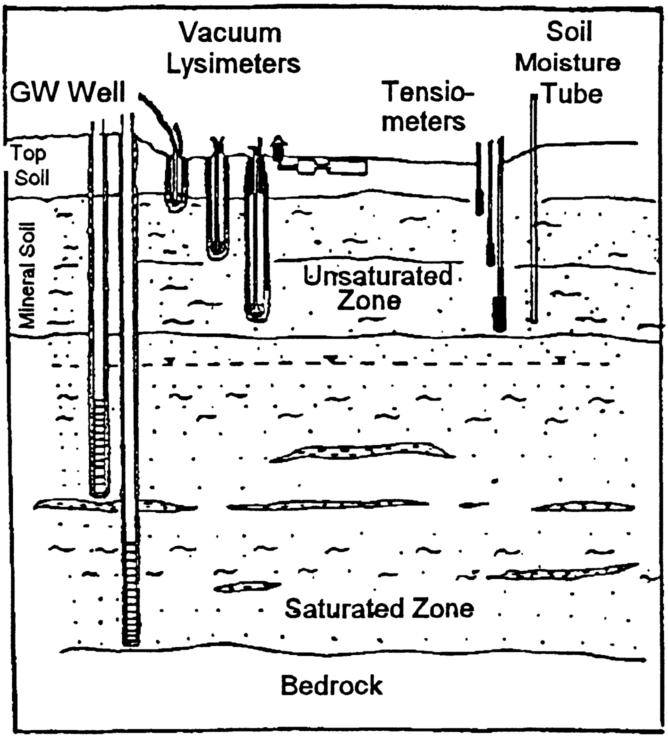


Figure 13. Schematic of unsaturated and saturated zone monitoring system (from Dwivedi, 1989).

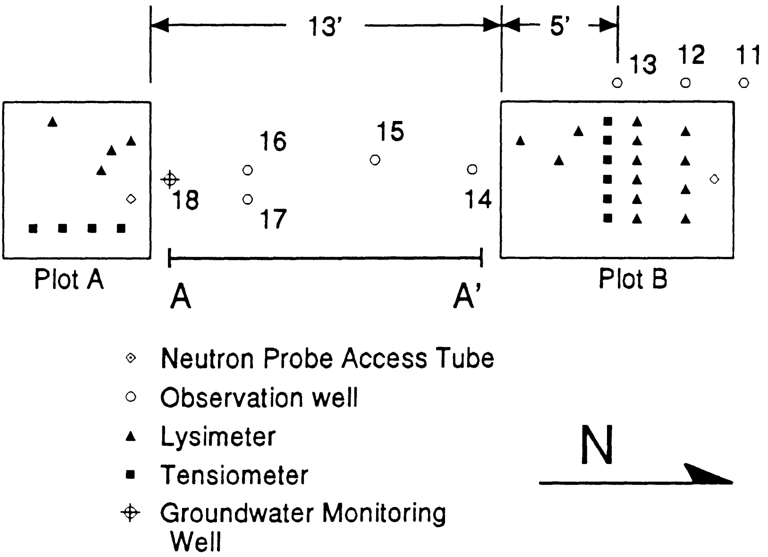


Figure 14. Planar map of saturated and unsaturated monitoring instrumentation near test plots A and B (modified from Dwivedi, 1989).

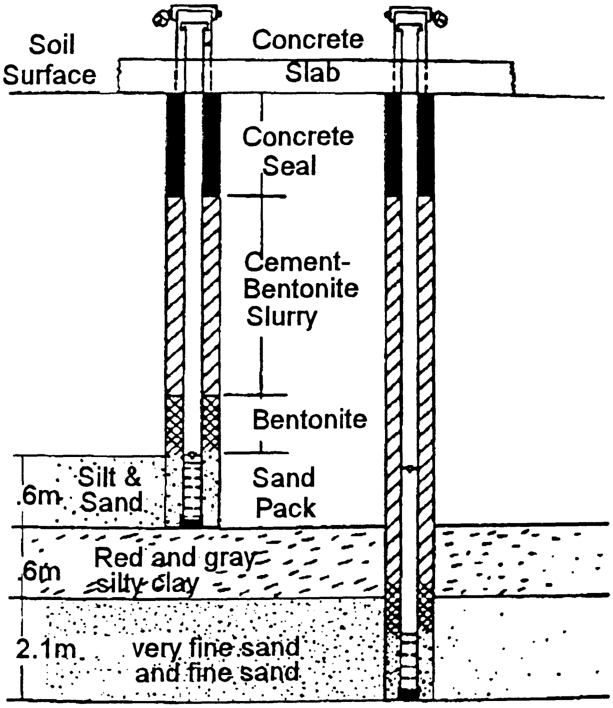


Figure 15. Typical monitoring well design in the northern terrace (modified from Dwivedi, 1989).

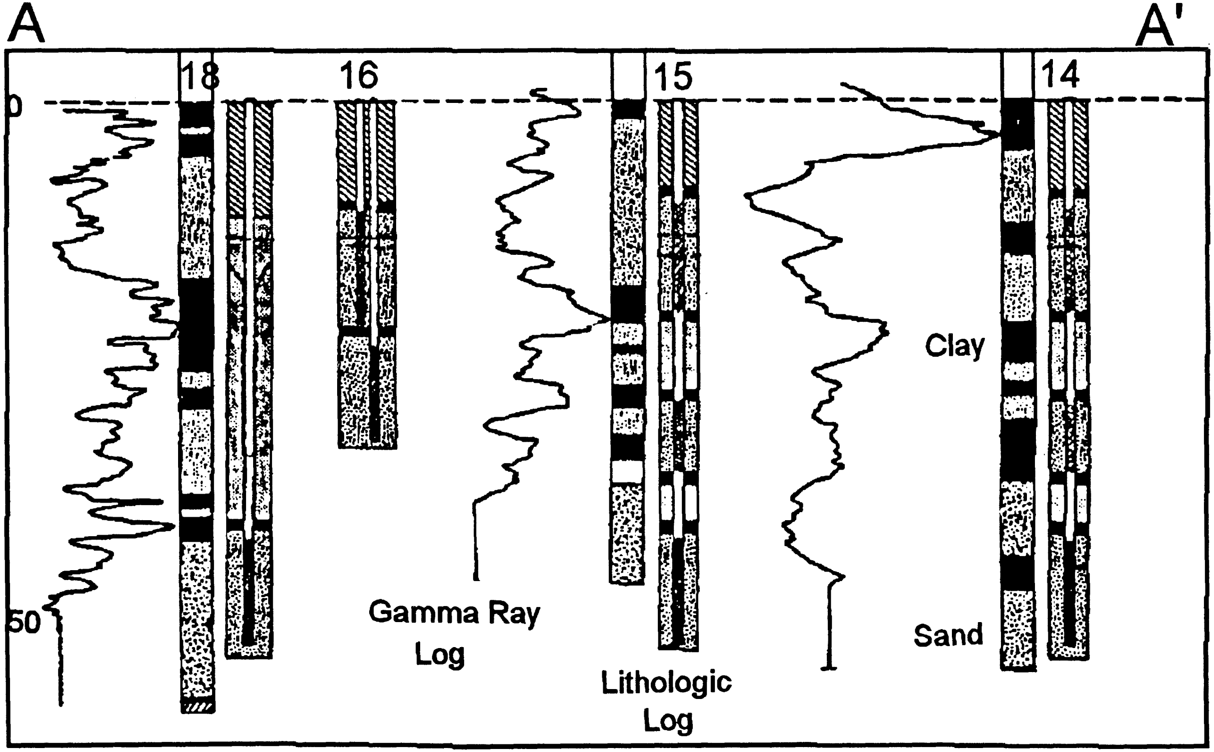


Figure 16. Geologic cross-section A-A' located between test plots A and B (see Figure 14).

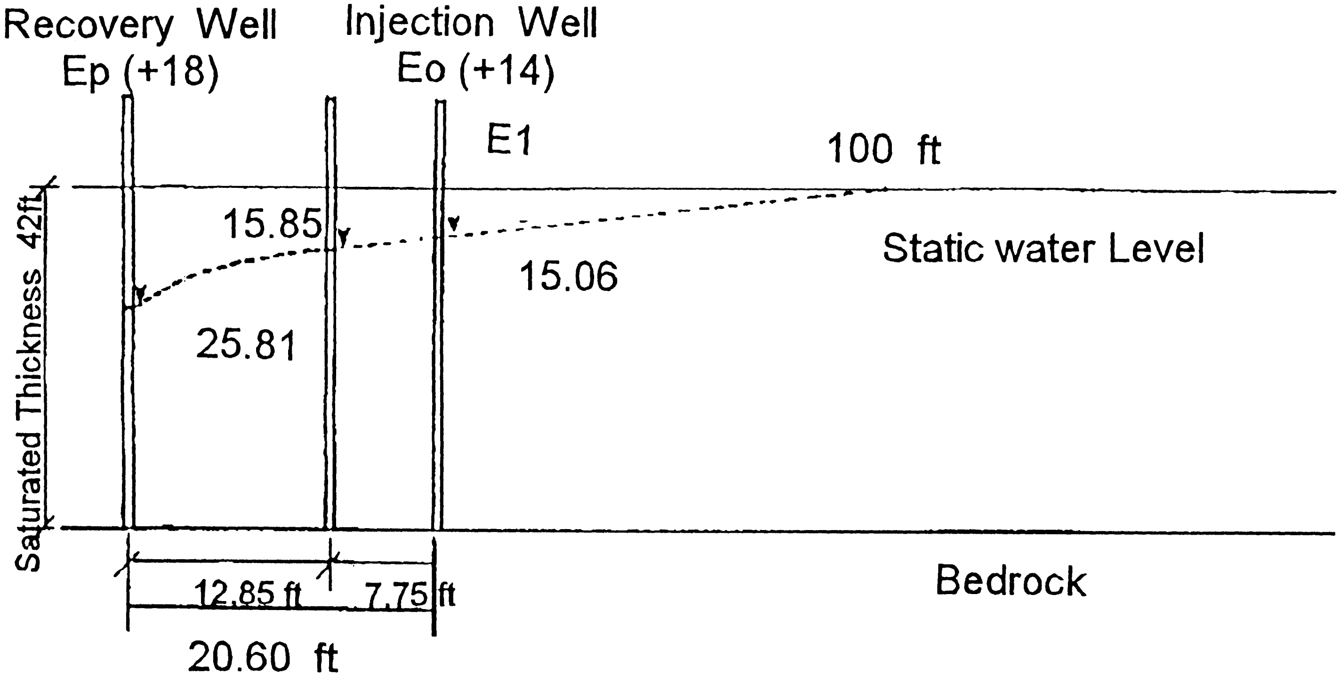
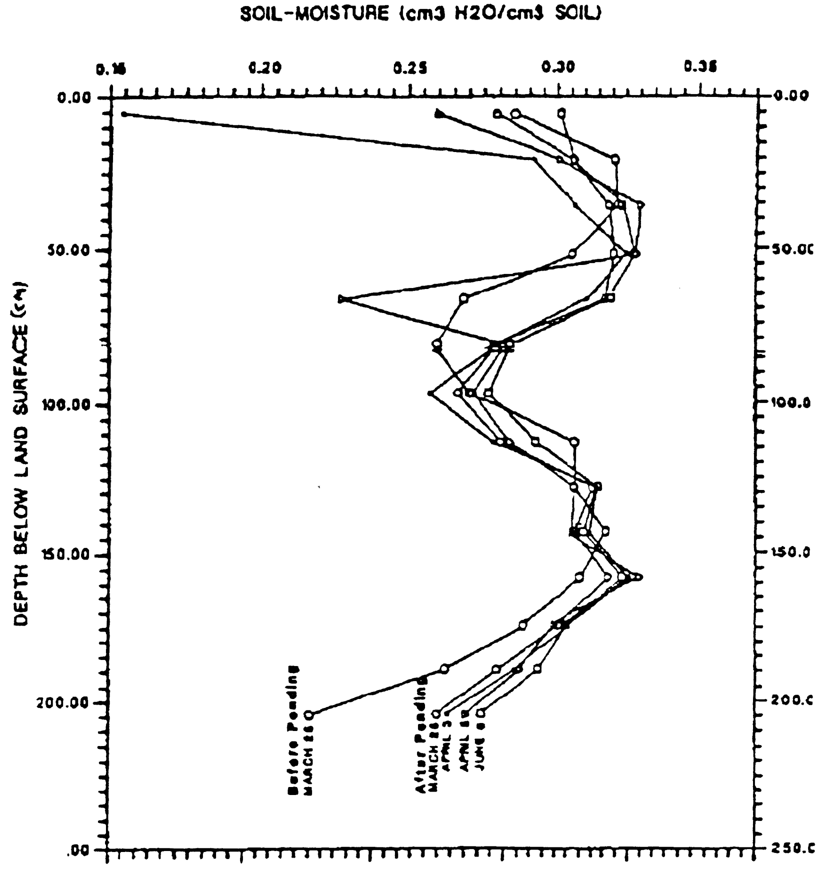
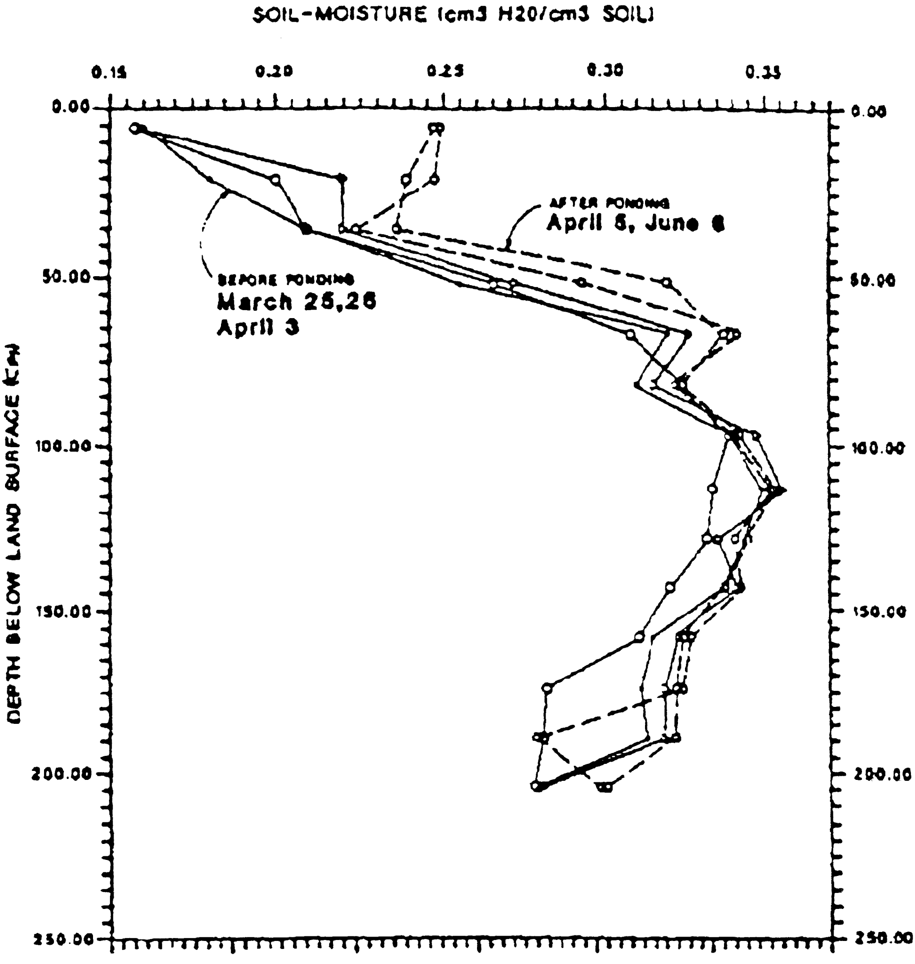


Figure 17. Schematic for tracer test.



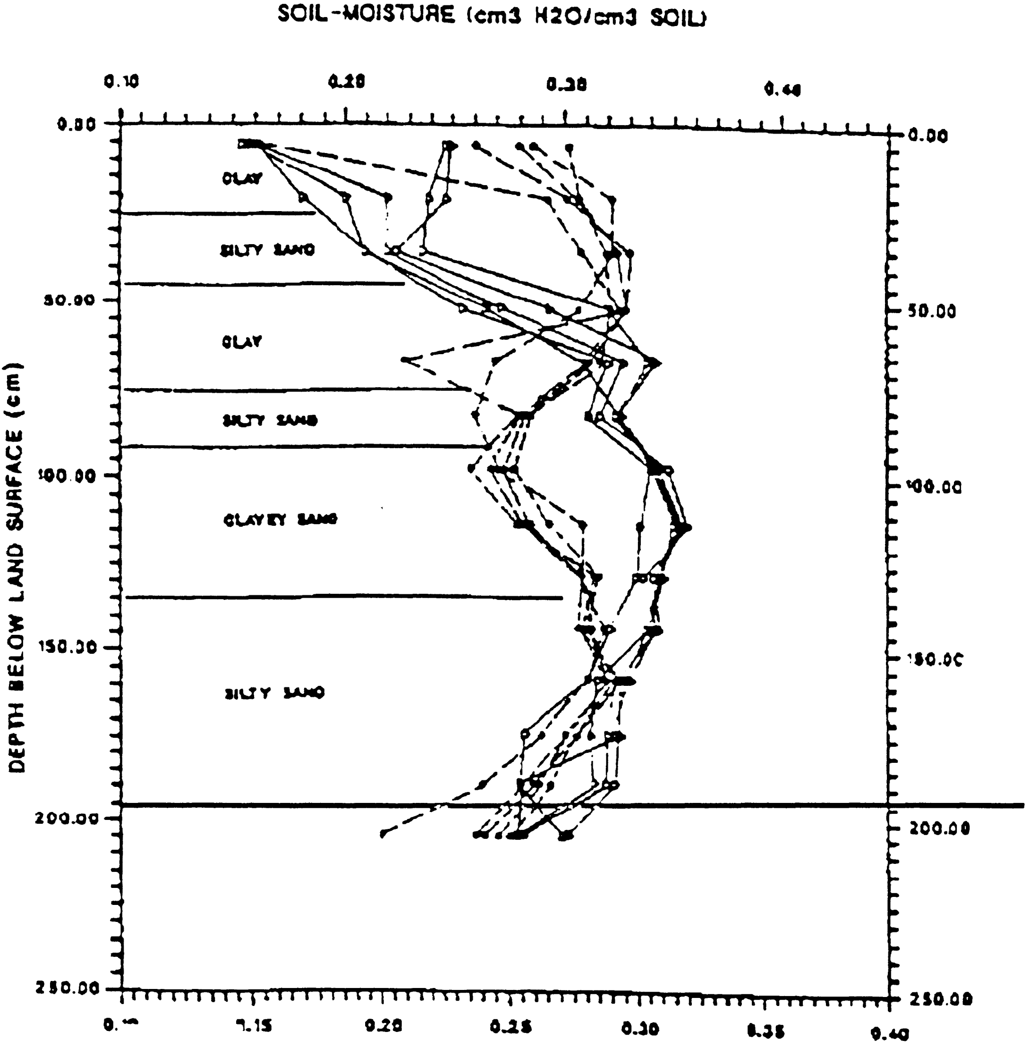
(Modified After Dwivedi, 1989)

Figure 18. Soil moisture profile for test plot A.



(Modified After Dwivedi, 1989)

Figure 19. Soil moisture profile for test plot B.



(Modified After Dwivedi, 1989)

Figure 20. Comparison of soil moisture profiles for test plots A and B.

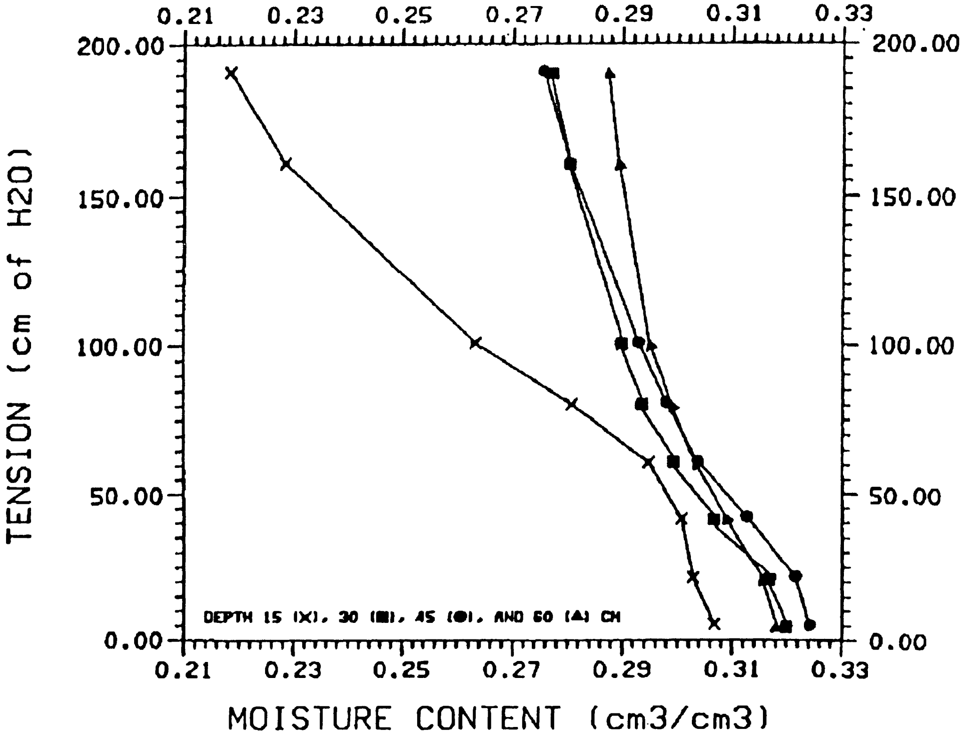


Figure 21. Soil moisture retention curves for different horizons in Teller soil.

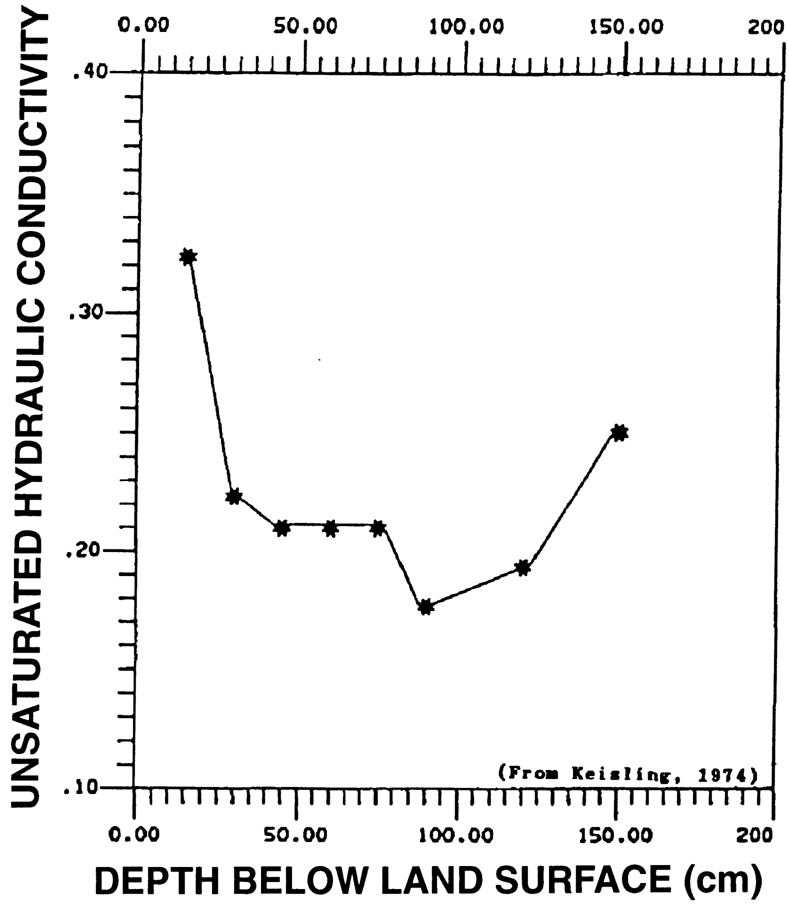


Figure 22. Hydraulic conductivity with depth for the Teller soil.

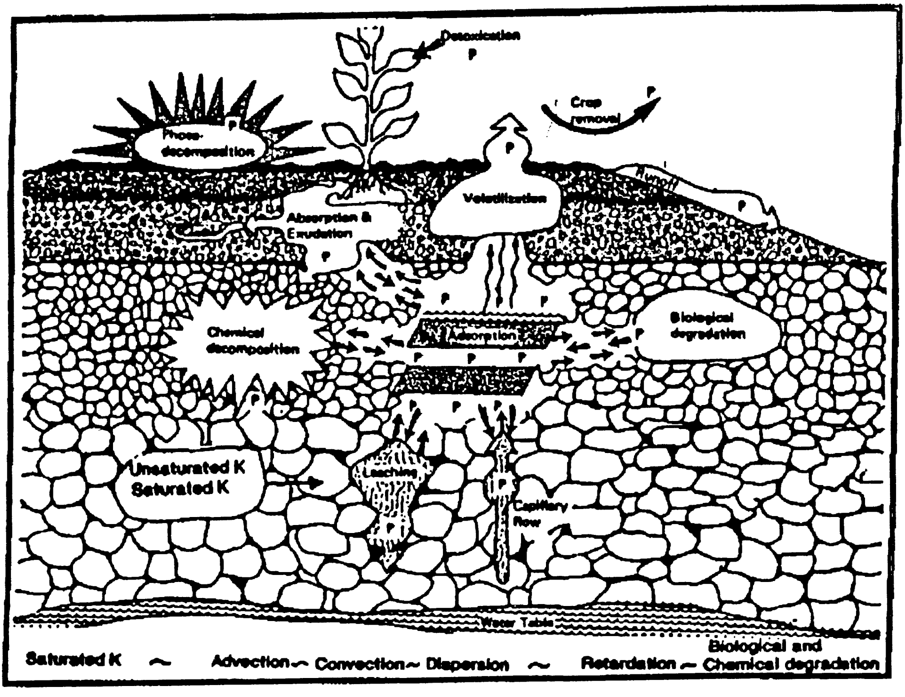


Figure 23. Physical and chemical processes governing contaminant transport in subsurface unsaturated and saturated zone systems.

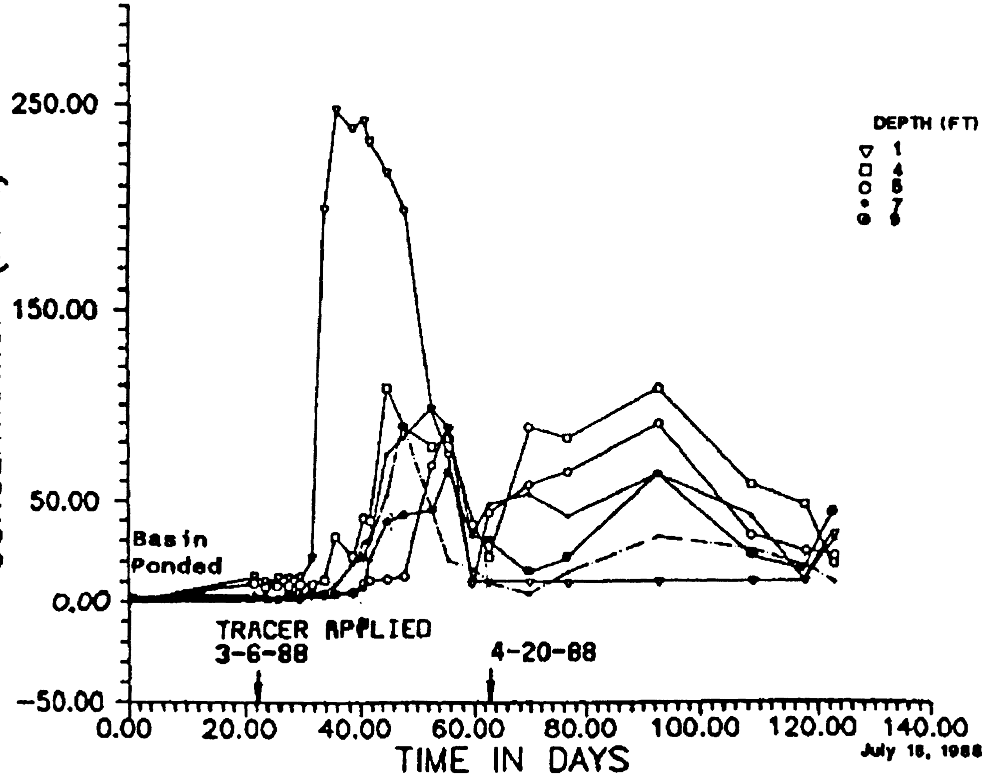


Figure 24. Nitrate-N concentrations at different depths in subsurface with time at test plot B.

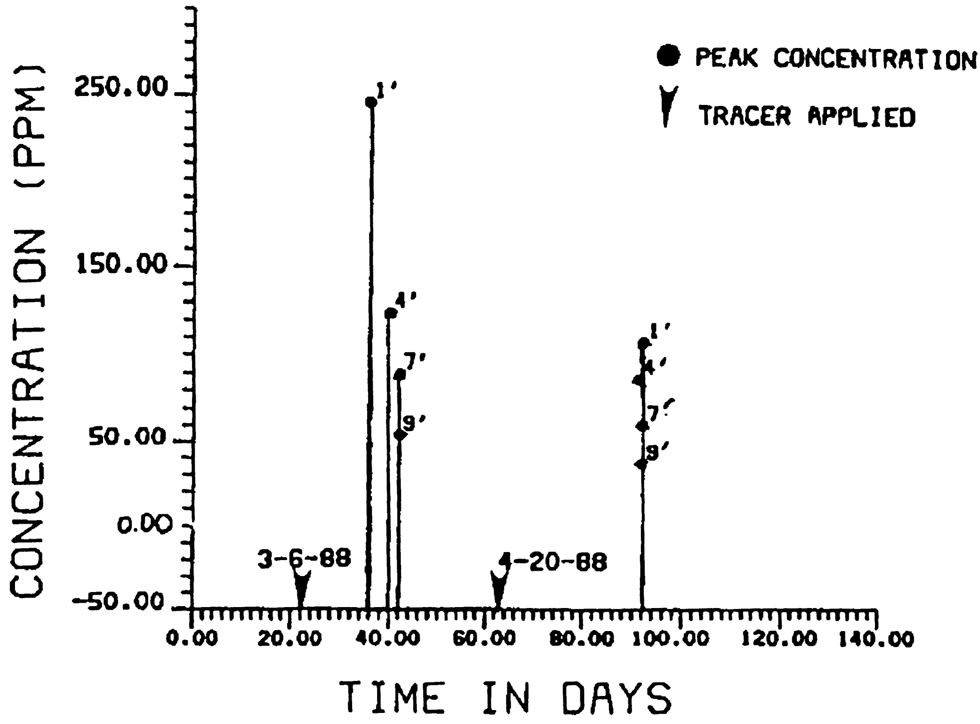


Figure 25. Peak nitrate-N concentrations at different lysimeter depths at test plot B.

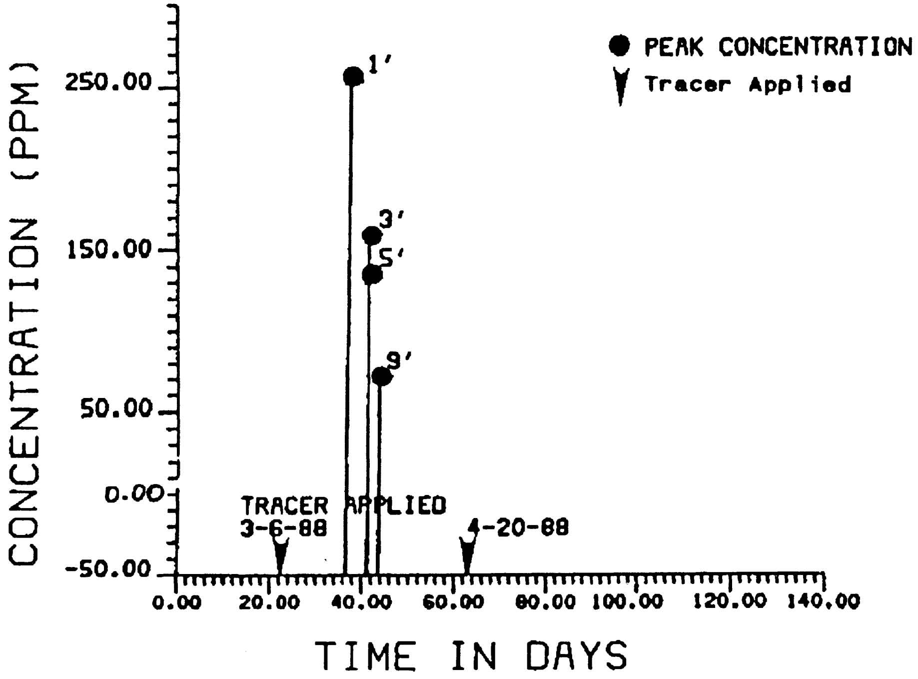


Figure 26. Peak nitrate-N concentrations in different lysimeter depths at test plot A.

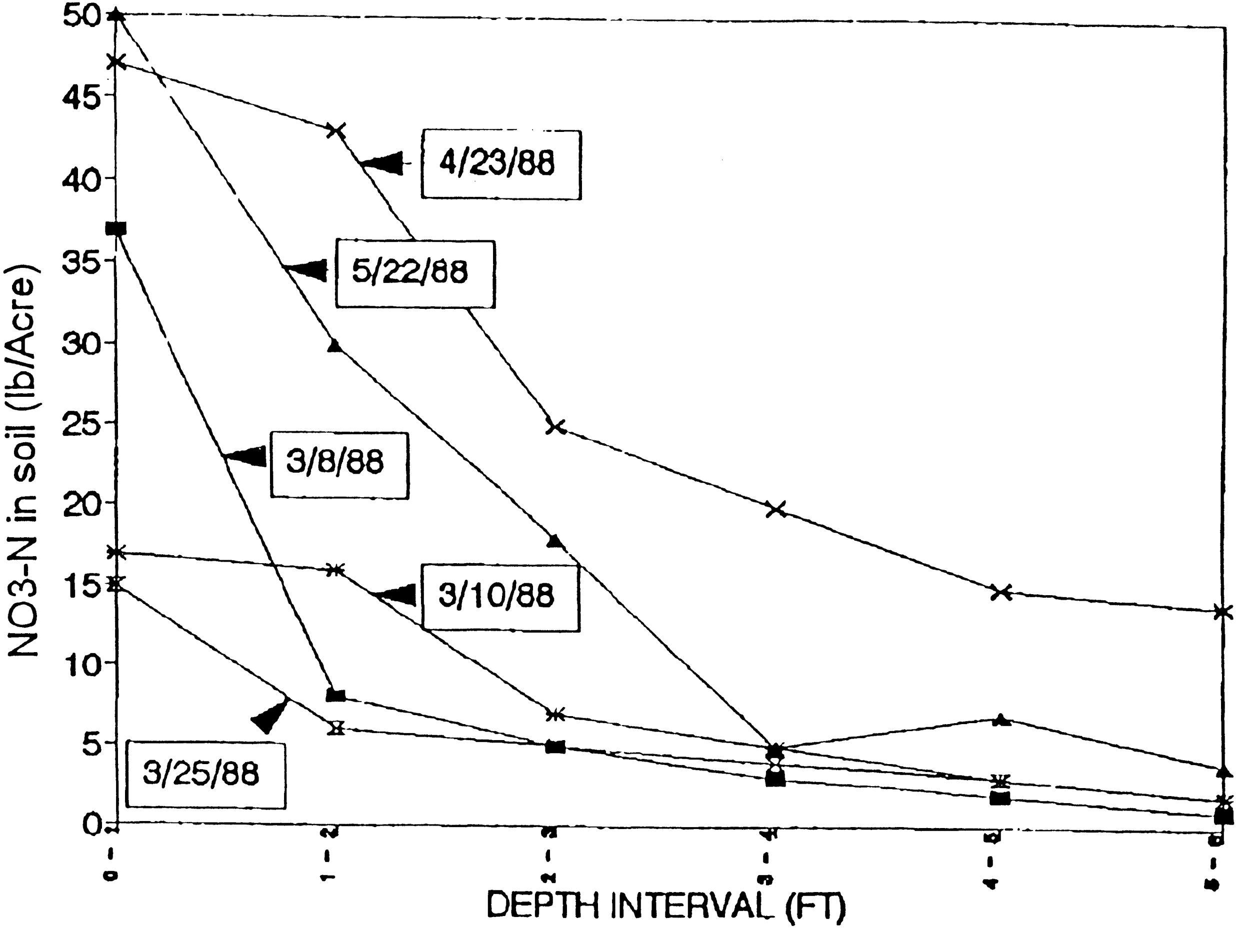


Figure 27. Nitrate-N distribution in soil profile at test plot A.

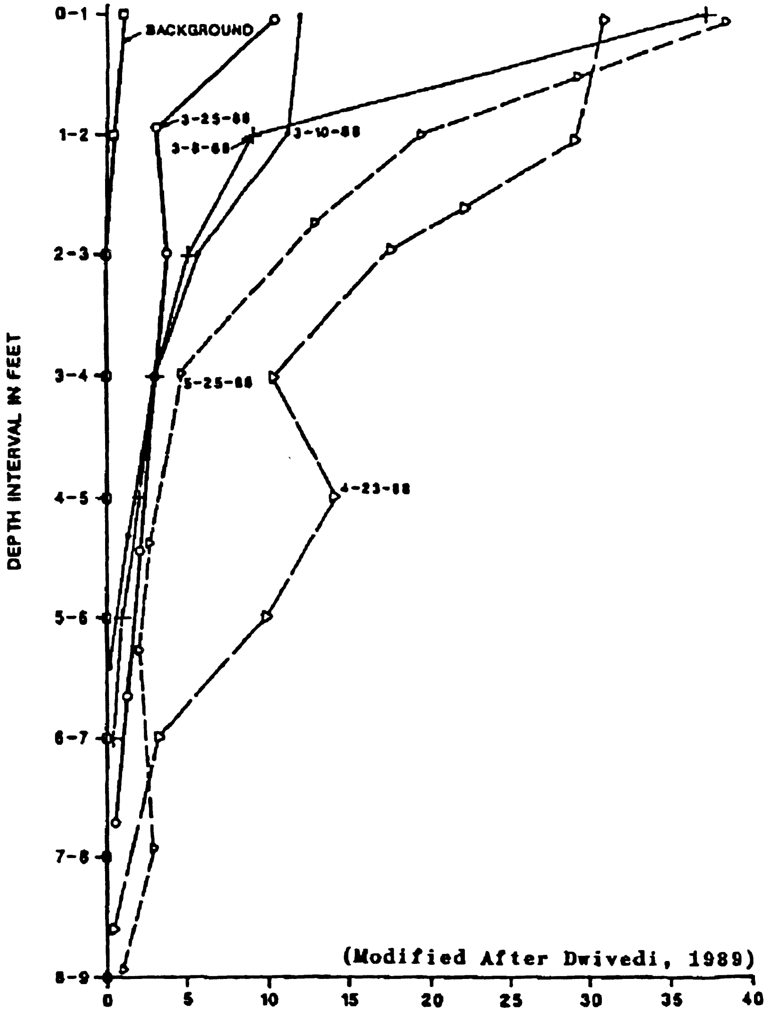


Figure 28. Nitrate-N distribution in soil profile at test plot B.

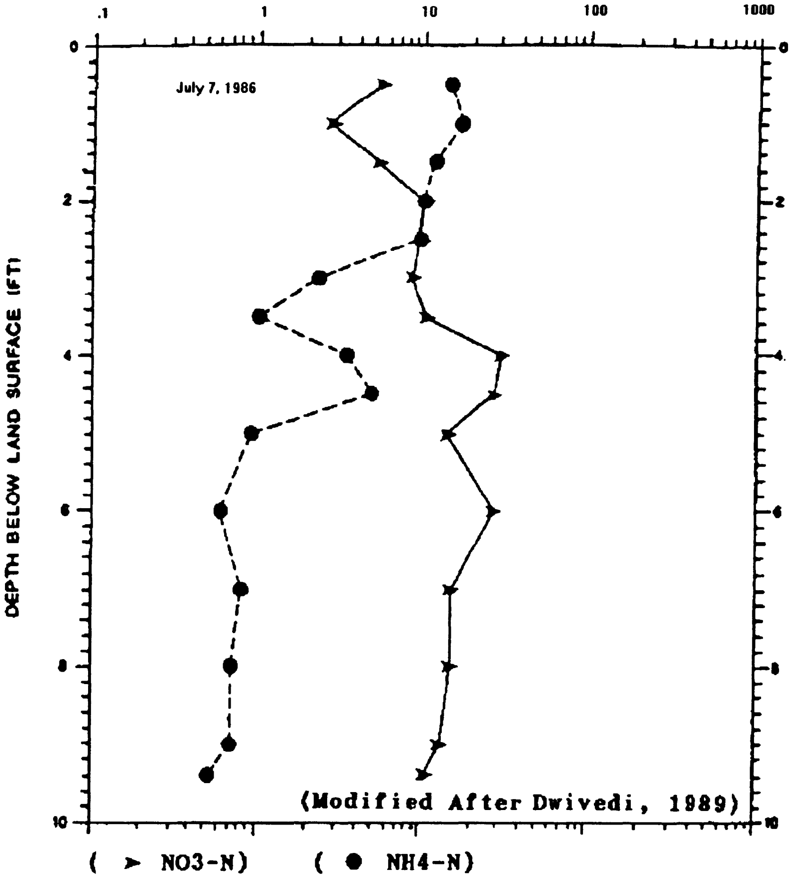
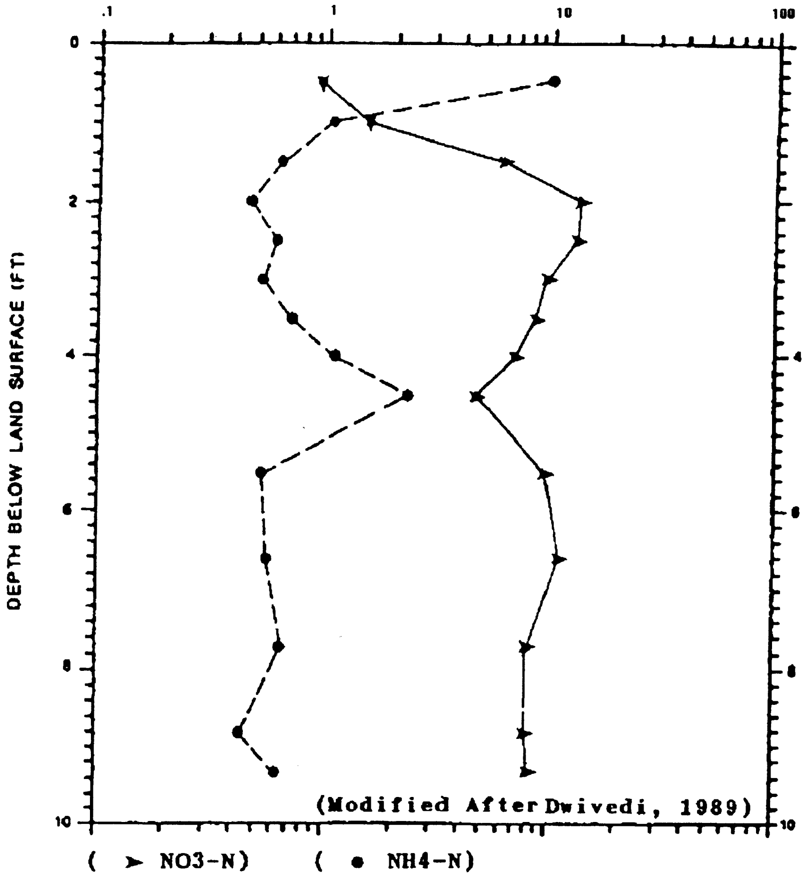


Figure 29. Comparison of nitrate-N and ammonia-N in soil profiles at test plot B.



(Modified After Dwivedi, 1989)

Figure 30. Comparison of nitrate-N and ammonia-N in soil profile at test plot A.

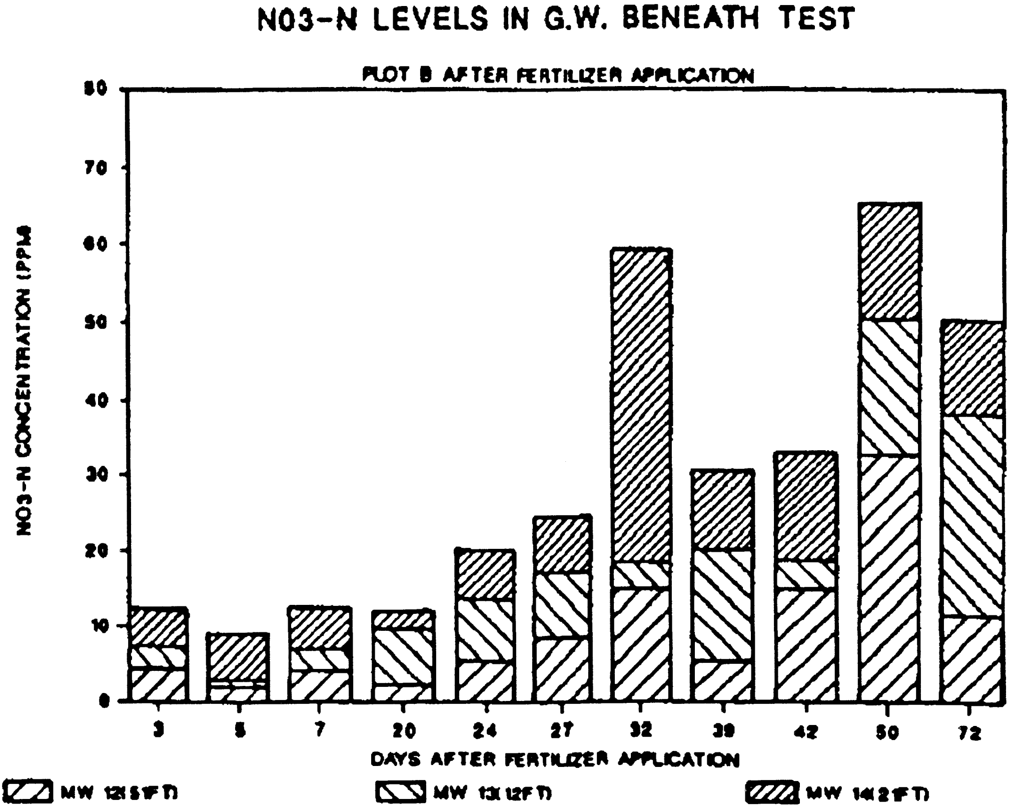


Figure 31. Nitrate-N levels in groundwater beneath test plot B.

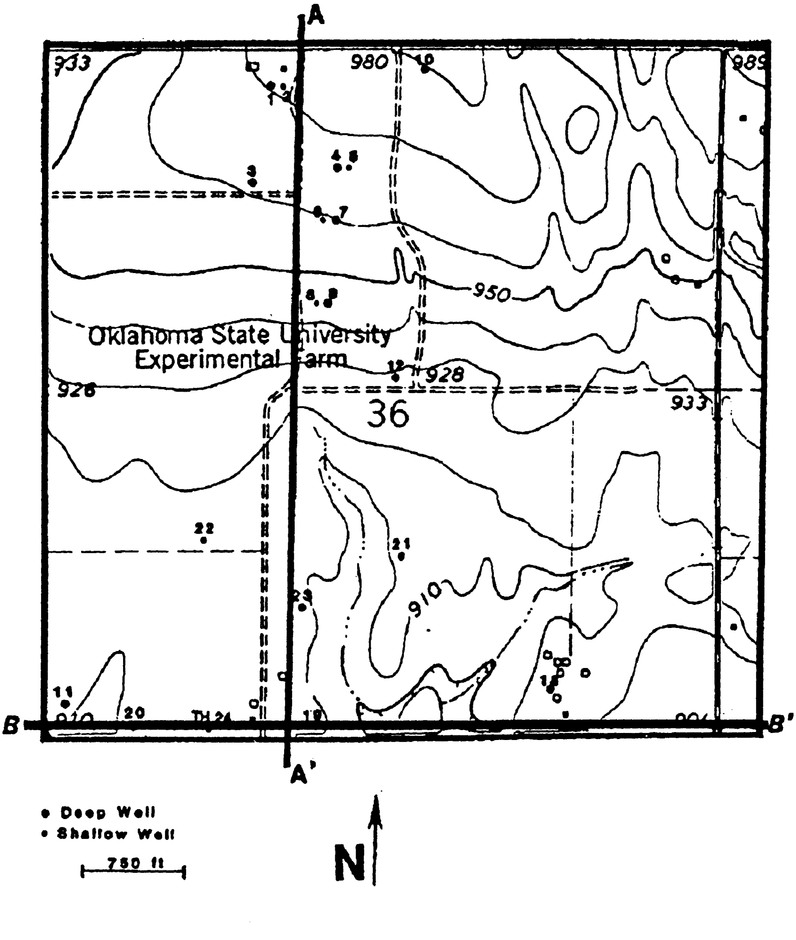


Figure 32. Perkins Station topographic map and location of cross sections in Figures 33 and 34.

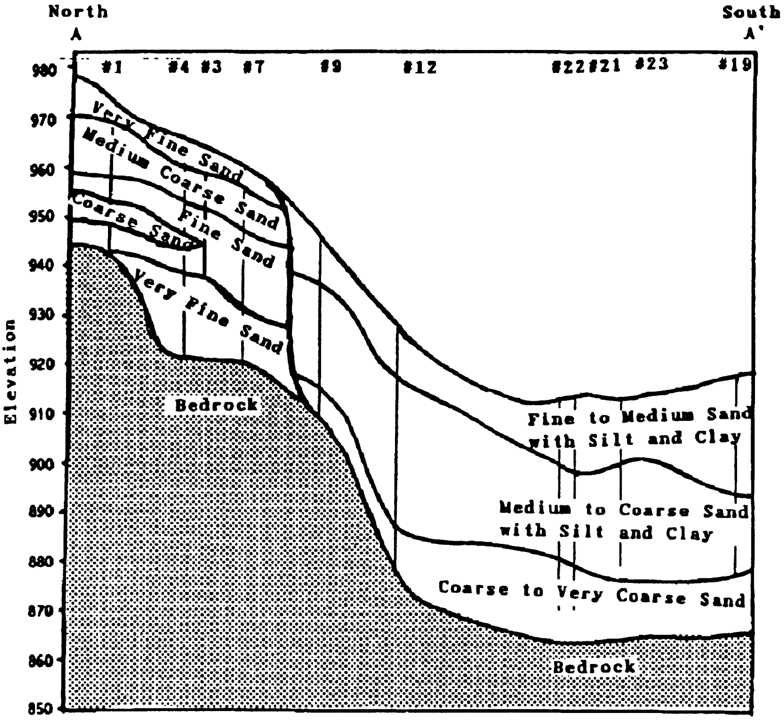


Figure 33. North-south cross section of Perkins Station.

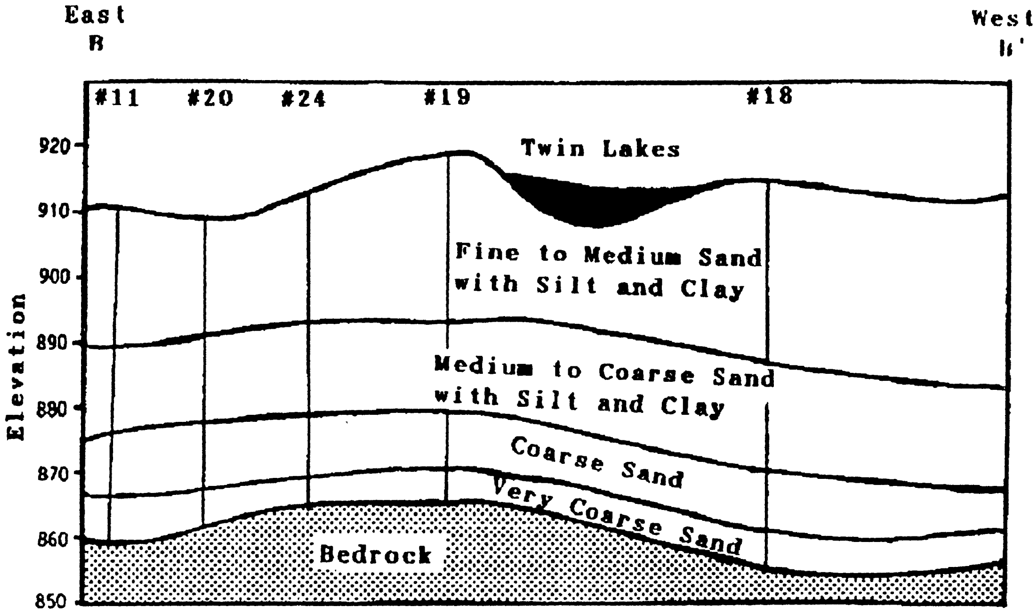


Figure 34. East-west cross-section of Perkins Station.

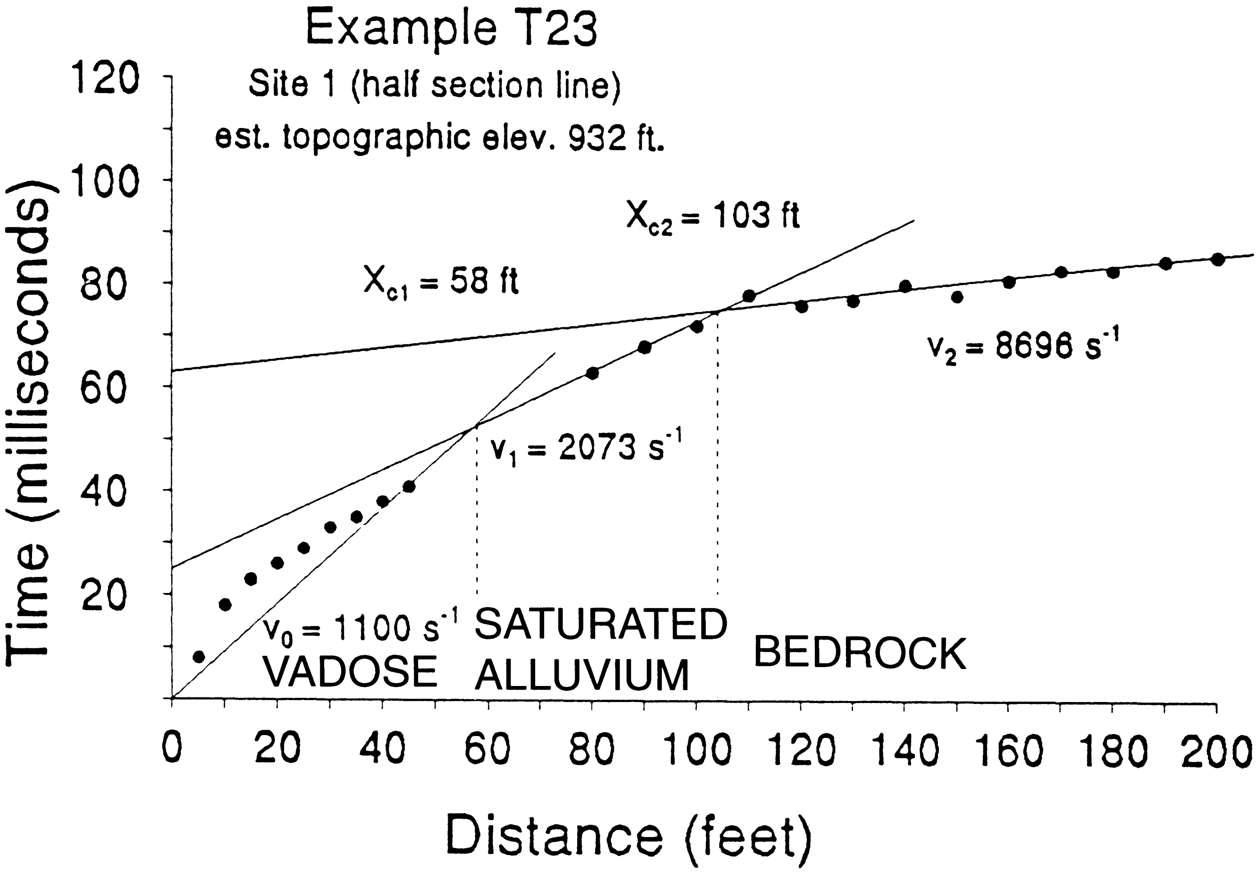


Figure 35. Seismic method example.

<table>
<tr><th colspan="2">Critical Distance Method</th></tr>
<tr><td>$V_0 = 1100\ s^{-1}$
$V_1 = 2073\ s^{-1}$
$V_2 = 8696\ s^{-1}$</td><td>$Xc_1 = 58$ ft
$Xc_2 = 103$ ft</td></tr>
<tr><td colspan="2">$$Z_o = \frac{Xc_1}{2}\frac{\sqrt{v_1 - v_0}}{\sqrt{v_1 + v_0}}$$
Depth to Water = 16.1 feet
Depth to Bedrock = 40.39 + 16.1 = 56.49 feet</td></tr>
<tr><th colspan="2">Y - Intercept Method</th></tr>
<tr><td>$V_0 = 1100\ s^{-1}$
$V_1 = 2073\ s^{-1}$
$V_2 = 8696\ s^{-1}$</td><td>$Ti_1 = 0.025$ s
$Ti_2 = 0.0625$ s</td></tr>
<tr><td colspan="2">$$Z_o = \frac{Ti_1}{2}\frac{v_1 * v_0}{\sqrt{v_1^2 + v_0^2}}$$
Depth to Water = 16.2 feet
Depth to Bedrock =35.55 + 16.2 = 51.8 feet</td></tr>
</table>

Figure 36. Seismic refraction example calculations.

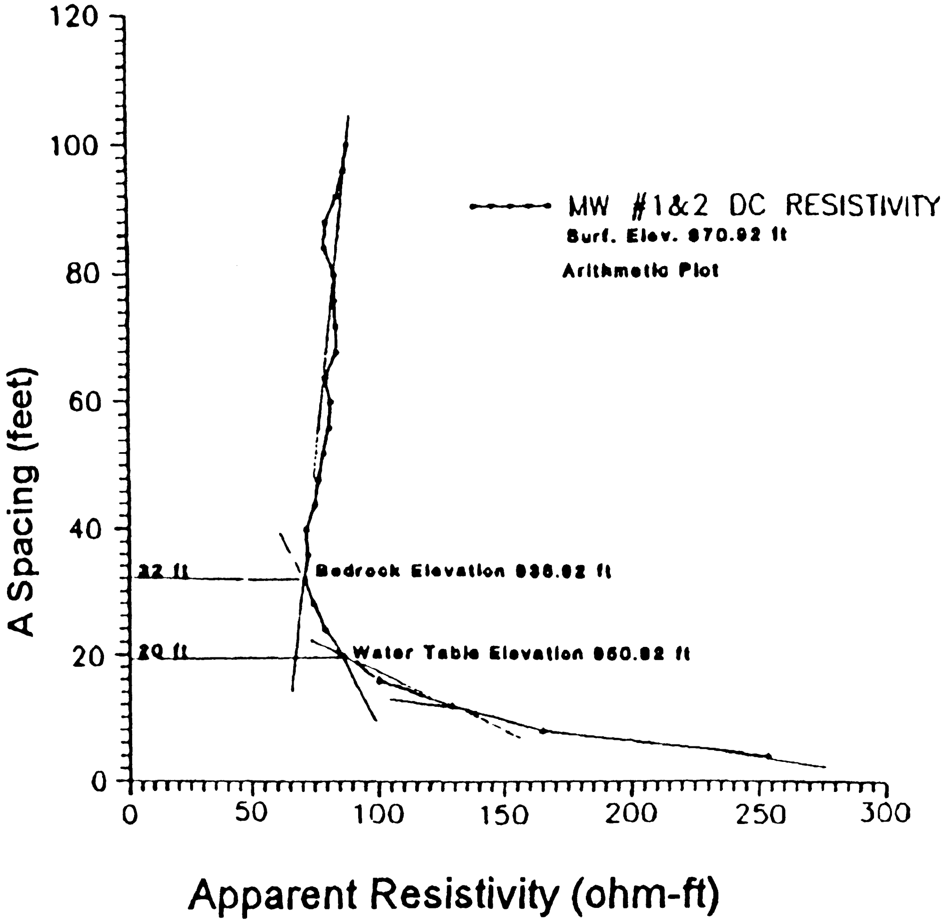


Figure 37. Resistivity method example.

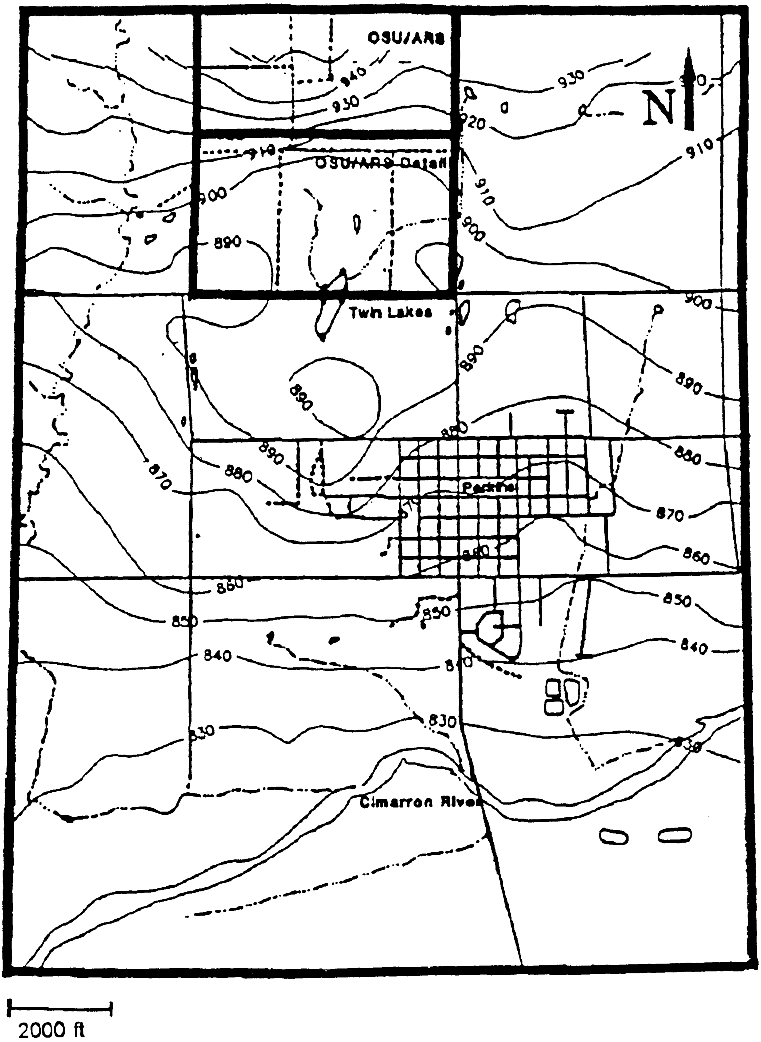


Figure 38. Water table map—regional scale.

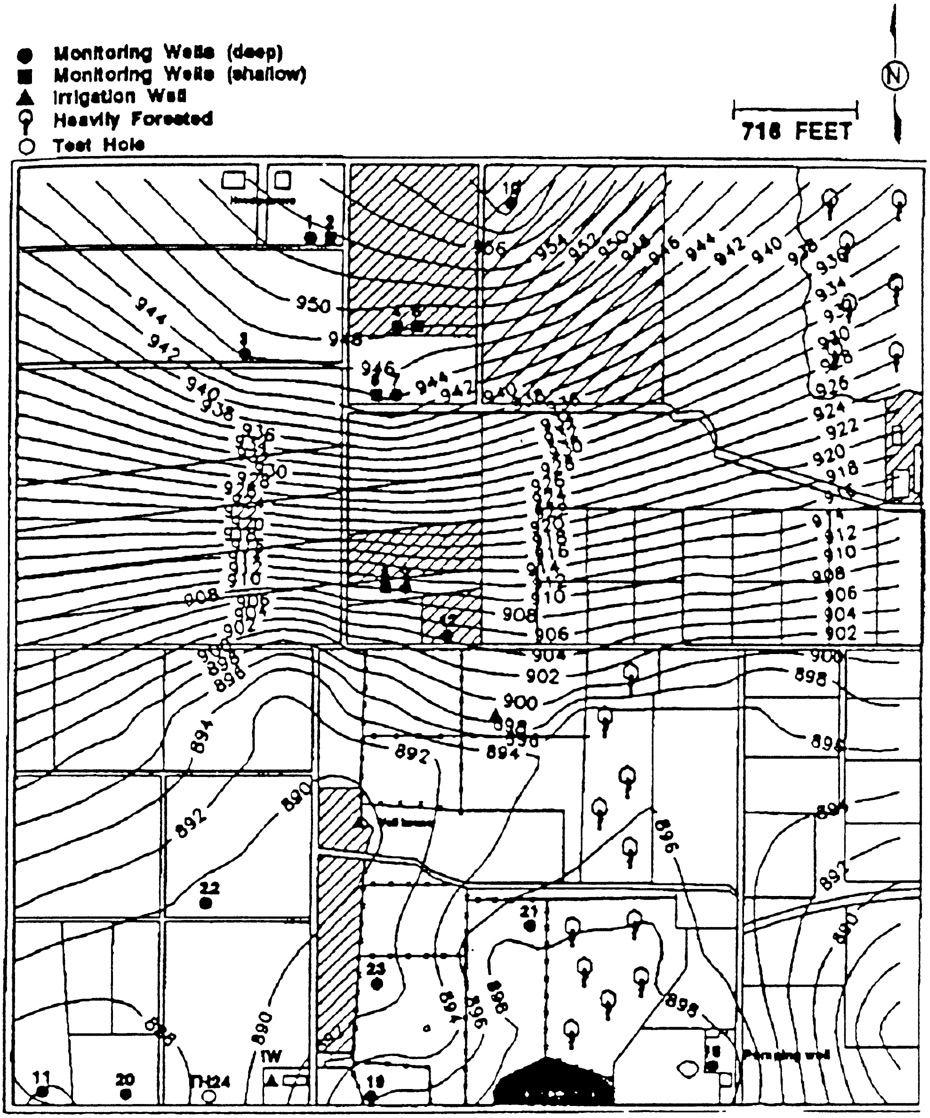


Figure 39. Water table map—local scale.

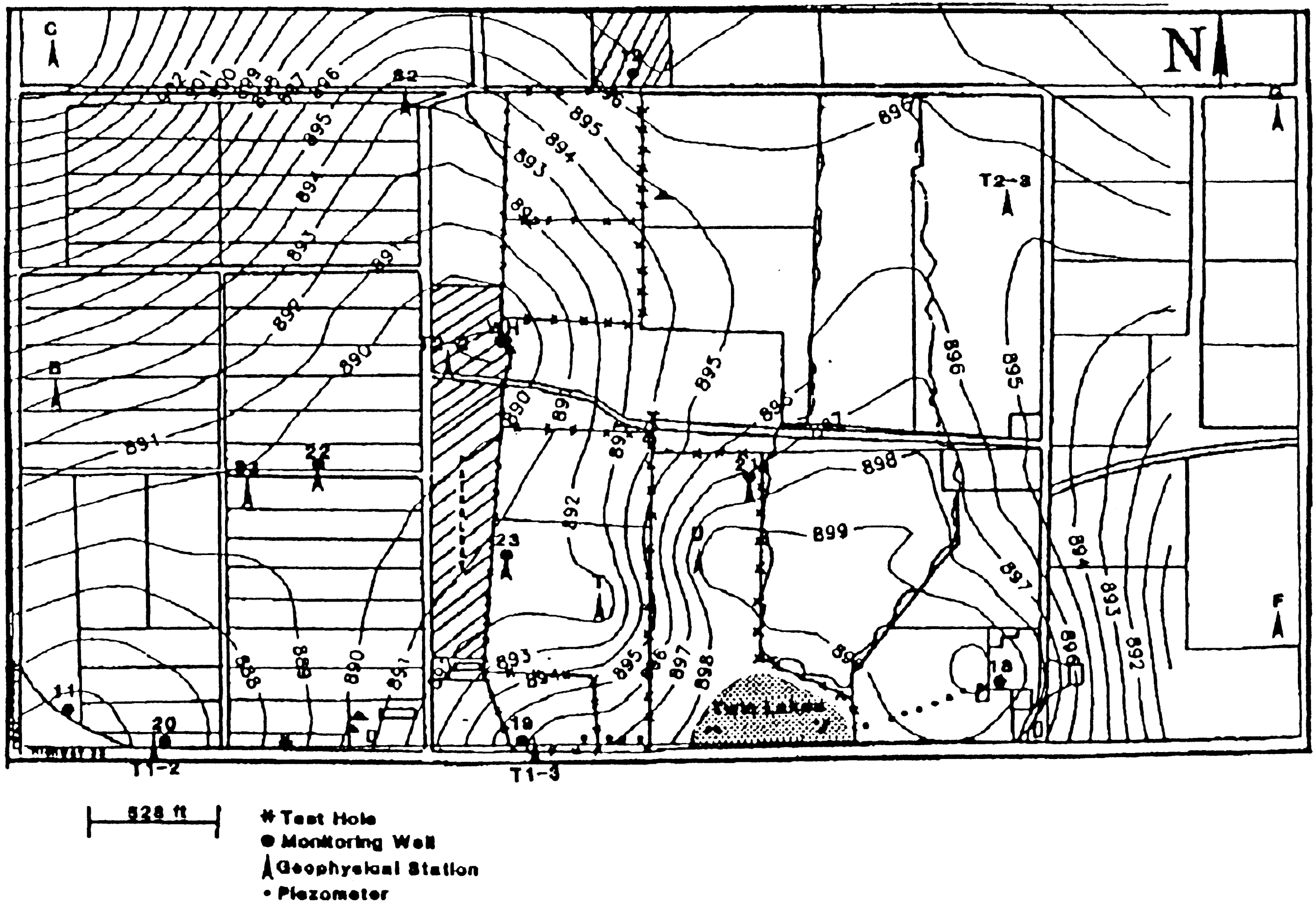


Figure 40. Water table map—detailed scale.

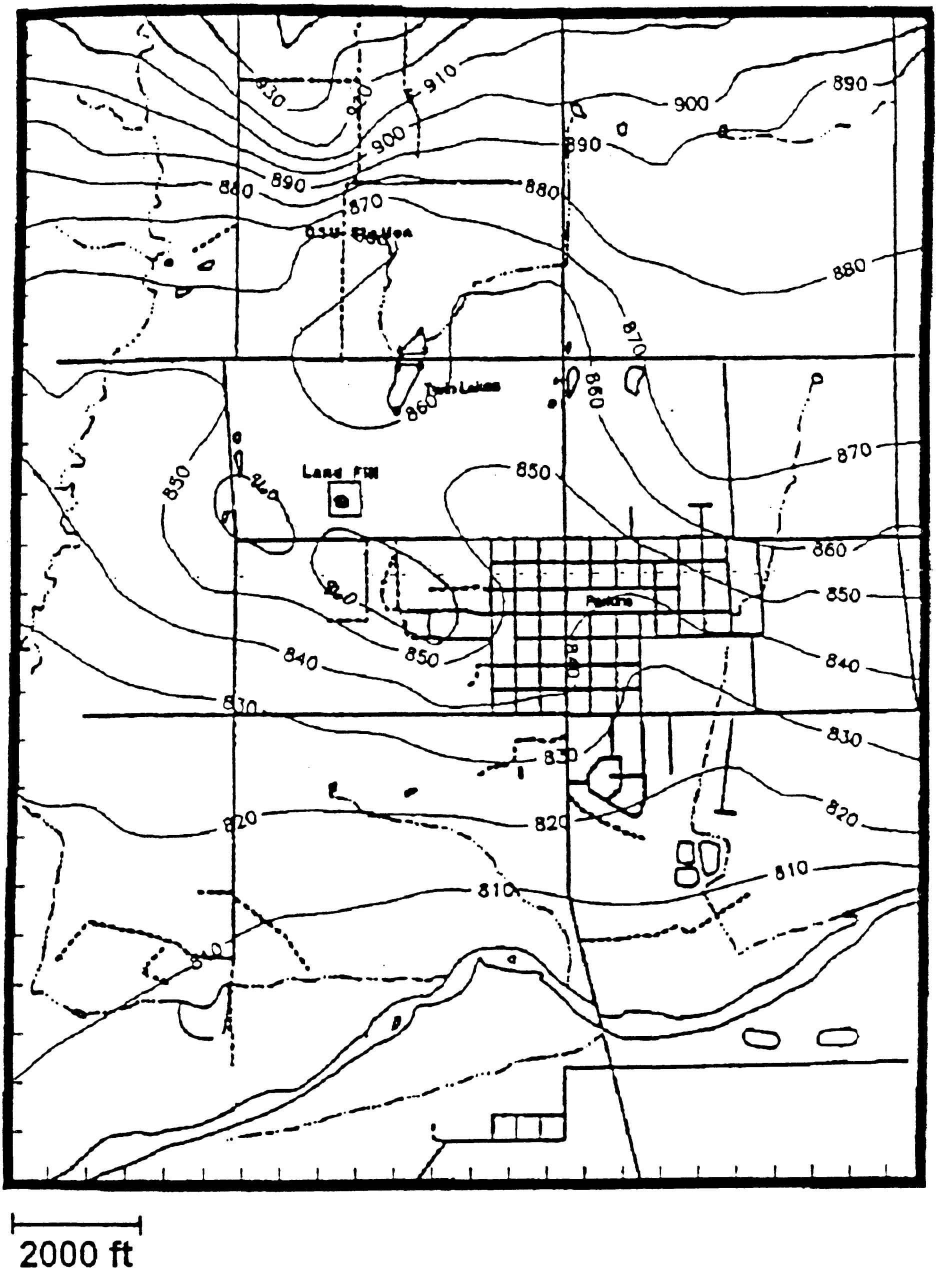


Figure 41. Bedrock elevation map—regional scale.

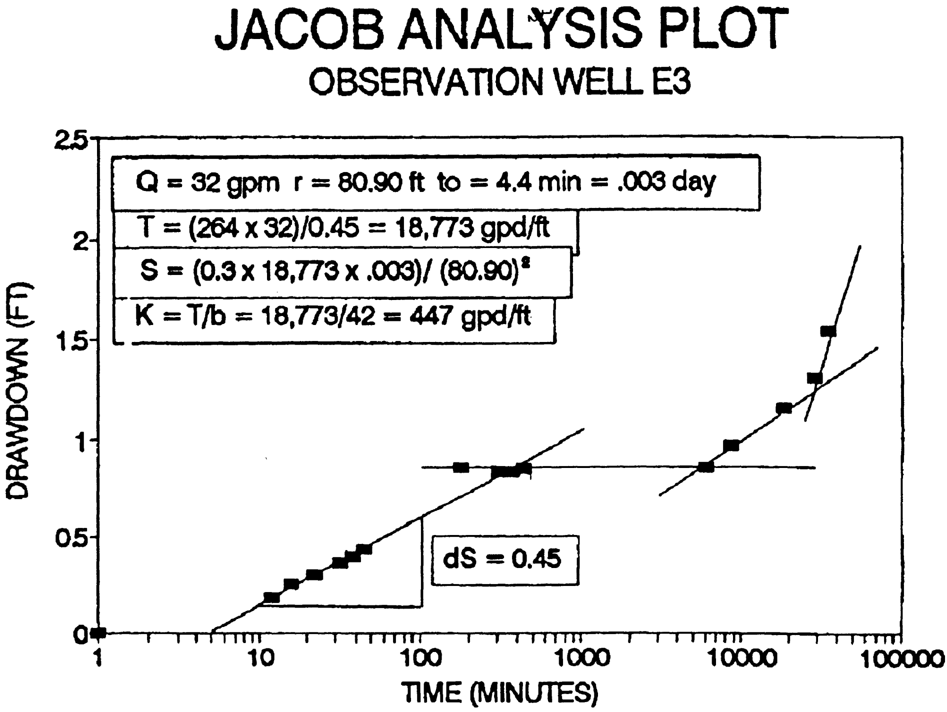


Figure 42. Jacob analysis example.

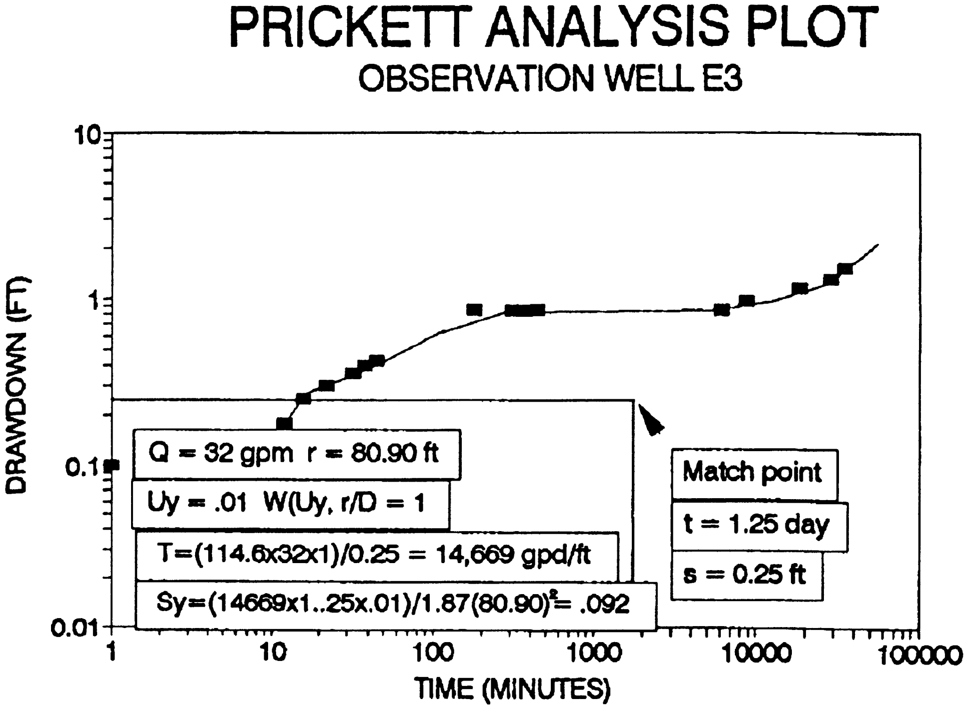


Figure 43. Prickett analysis example.

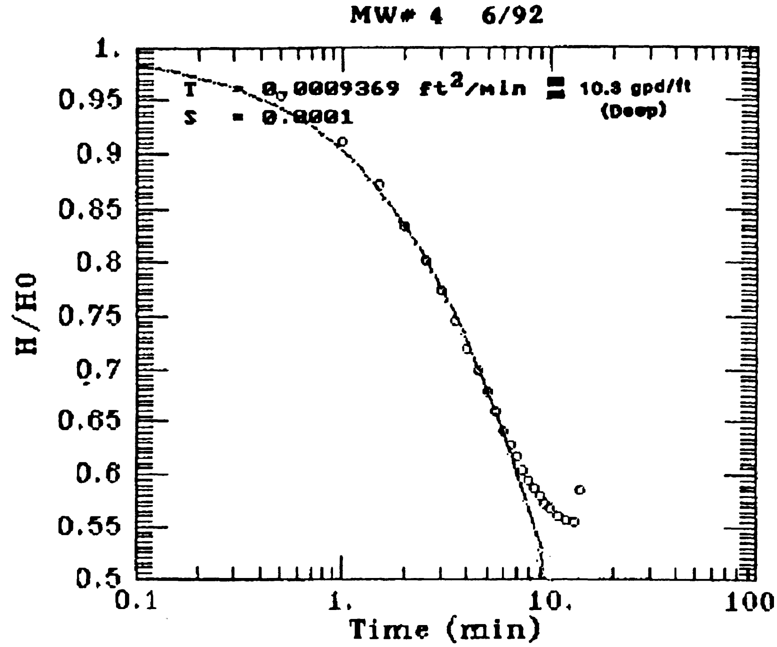


Figure 44. Slug test method example.

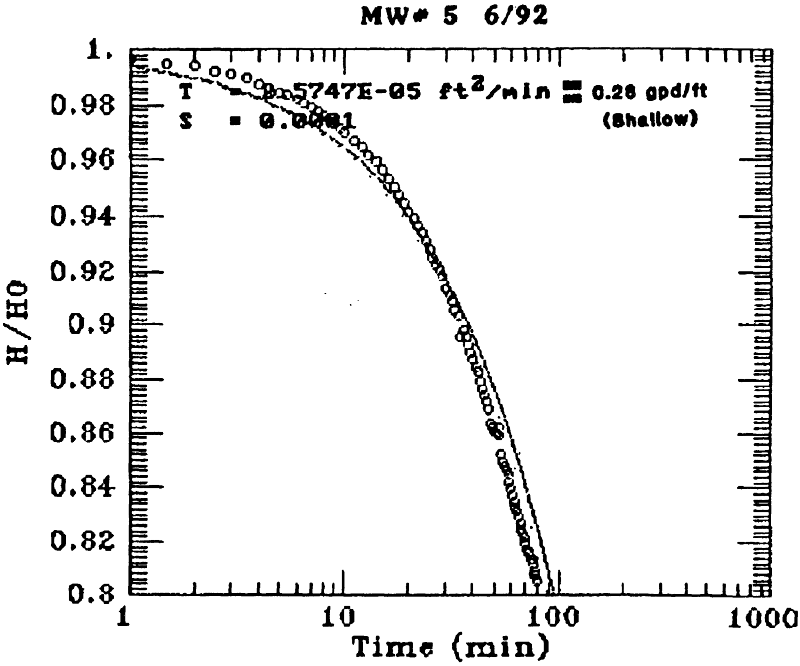


Figure 45. Slug test method example.

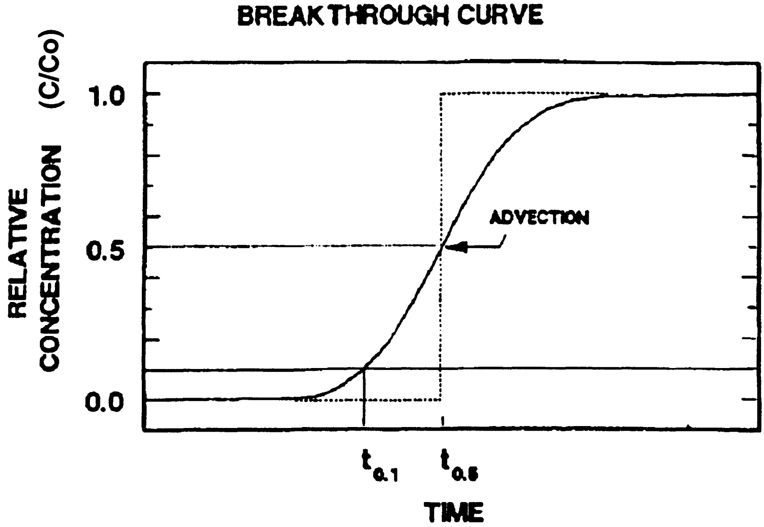


Figure 46. Breakthrough curve (modified after Palmer and Johnson, 1989).

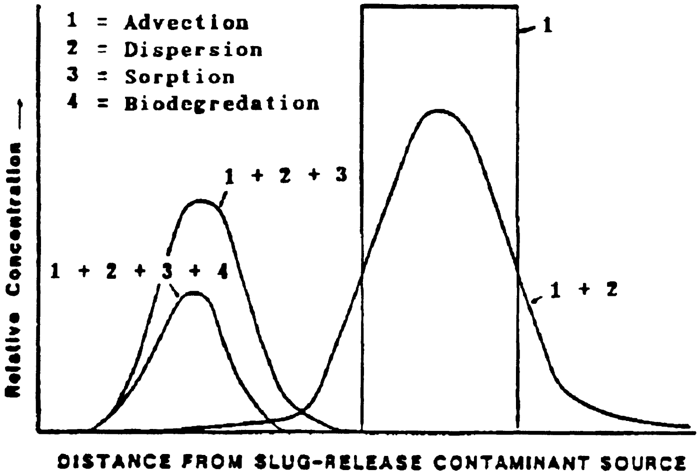


Figure 47. Influence of natural processes on levels of contaminants (modified after Palmer and Johnson, 1989).

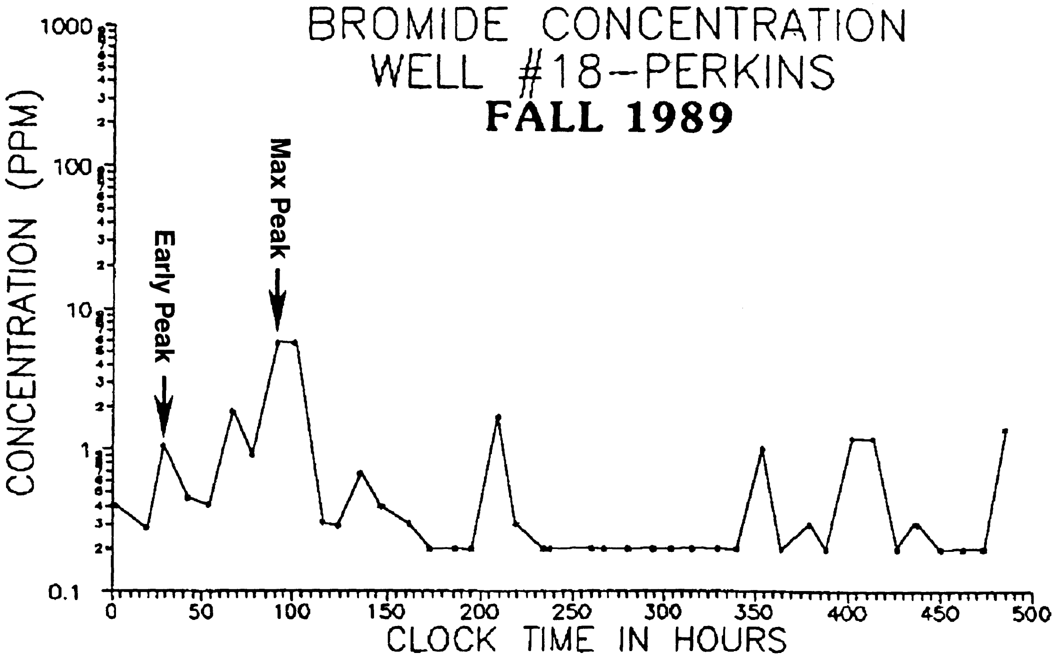


Figure 48. Bromide concentration in Well #18 in fall 1989 tracer test.

First Arrival Time (T)= 30 hours				
Well #	Water Table Depth (ft) (after pumping)		Distance from Recovery Well (ft)	
Ep (MW18)	H0	25.81	L0	0.00
Eo (MW14)	H1	15.85	L1	12.85
E1	H2	15.06	L2	20.60
Groundwater Velocity Calculations				
$V = \frac{L(i+1) - Li}{T}$	$Velocity = \frac{12.85}{30}$		V = 0.428 ft/hr 10.28 ft/day	
Darcian Velocity				
$I = \frac{H2 - H1}{L2 - L1}$	$K = \frac{V}{I}$		K_{dv} = 102.8 ft/day	
Seepage Velocity				
$I = \frac{H2 - H1}{L2 - L1}$	$K = \frac{V}{I} * n$		K_{sv} = 30.84 ft/day	

Figure 49. Travel time for the first arrival of bromide concentration in Well #18.

T = 90 hours dl = 12.85 feet	$V=\frac{dl}{T}$	v = 3.43 feet /day
dh = 0.79 feet dl = 7.75 feet	$I=\frac{dh}{dl}$	I = 0.10 n =0.30
Darcian		
$K=\frac{V}{I}$	K = 34.3 feet/day or *257. gpd/ feet^2	
Seepage		
$K=\frac{V}{I}*n$	K = 7.48 fee/day or *77 gpd/feet^2	
	Measured K from aquifer test ranges:	
	447 gpd/feet^2 Jacob Method	357 gpd/feet^2 Prickett Method
* Note: Numbers converted to gpd/feet^2 by coversion factor 7.48 g/feet^3		

Figure 50. Travel time for maximum peak arrival of bromide concentration in Well #18.

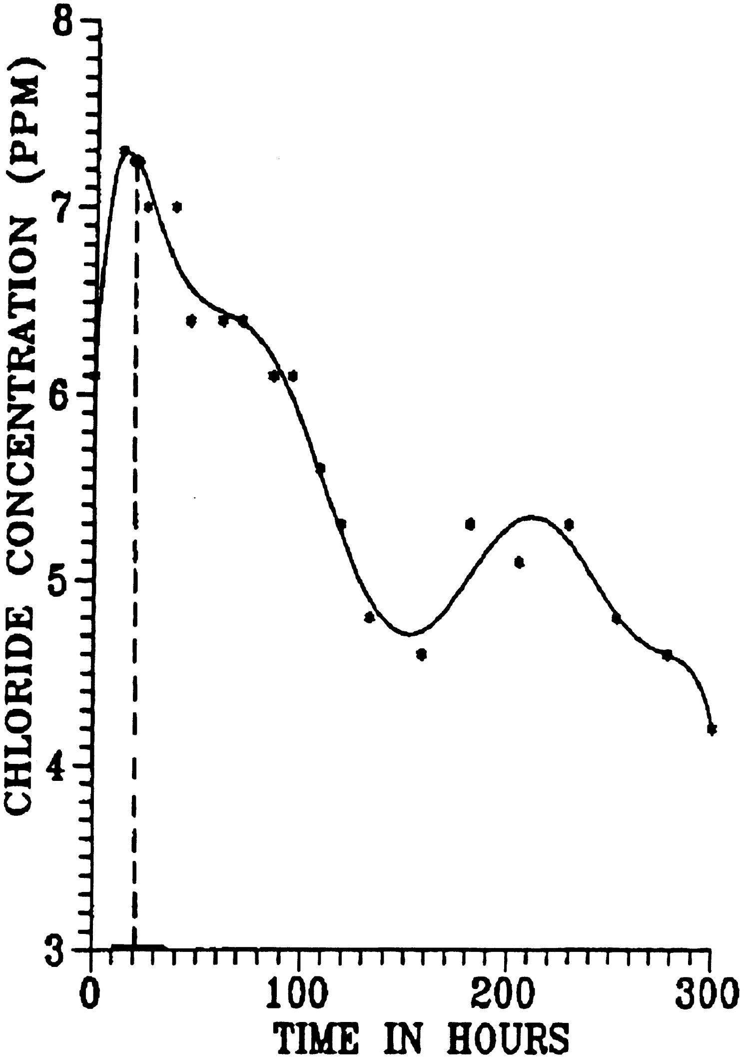


Figure 51. Chlorine breakthrough curve for Well # 15 in 1992 tracer test.

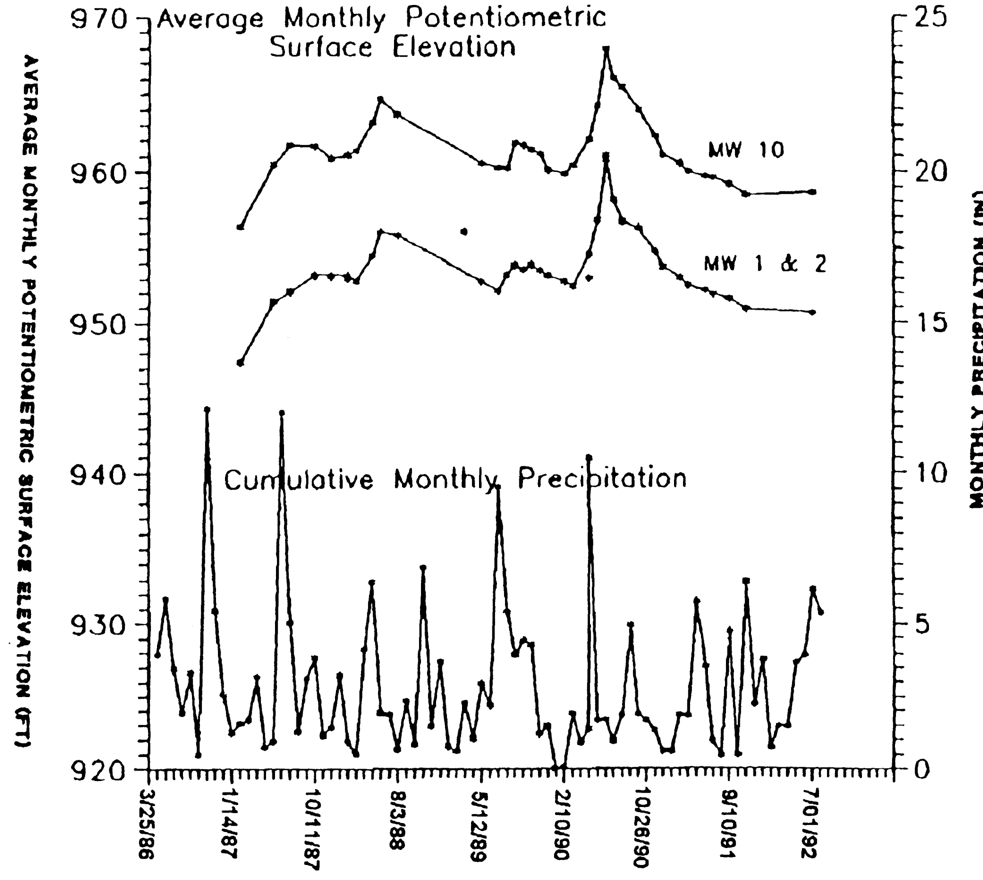


Figure 52. Composite hydrographs for monitoring wells #1, 2, and 10.

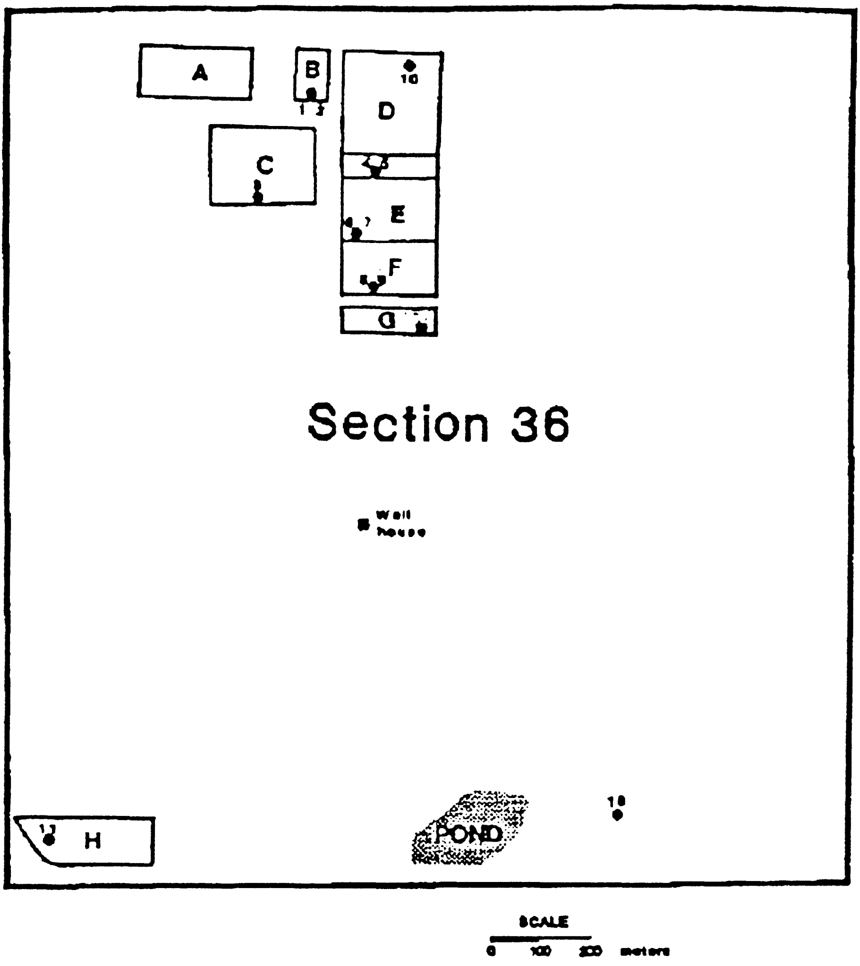


Figure 53. Well locations and application areas on the Agronomy Research Station.

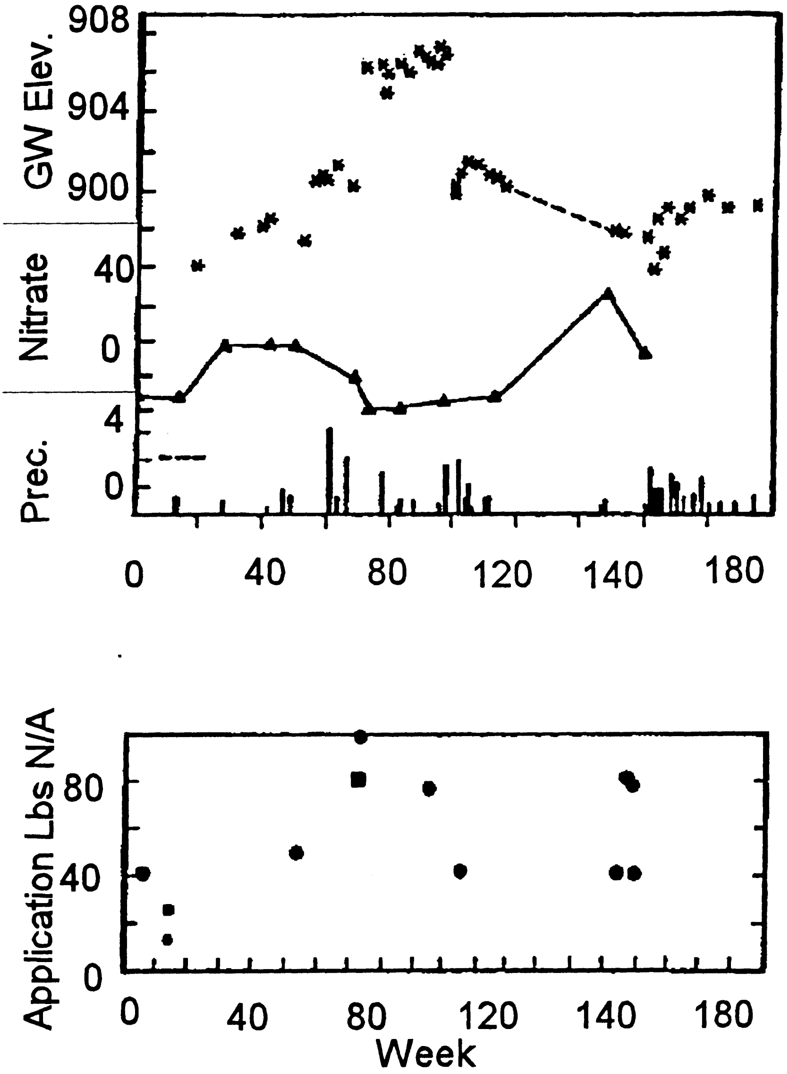


Figure 54. Comparison of water level, nitrate-N level, and precipitation—short term.

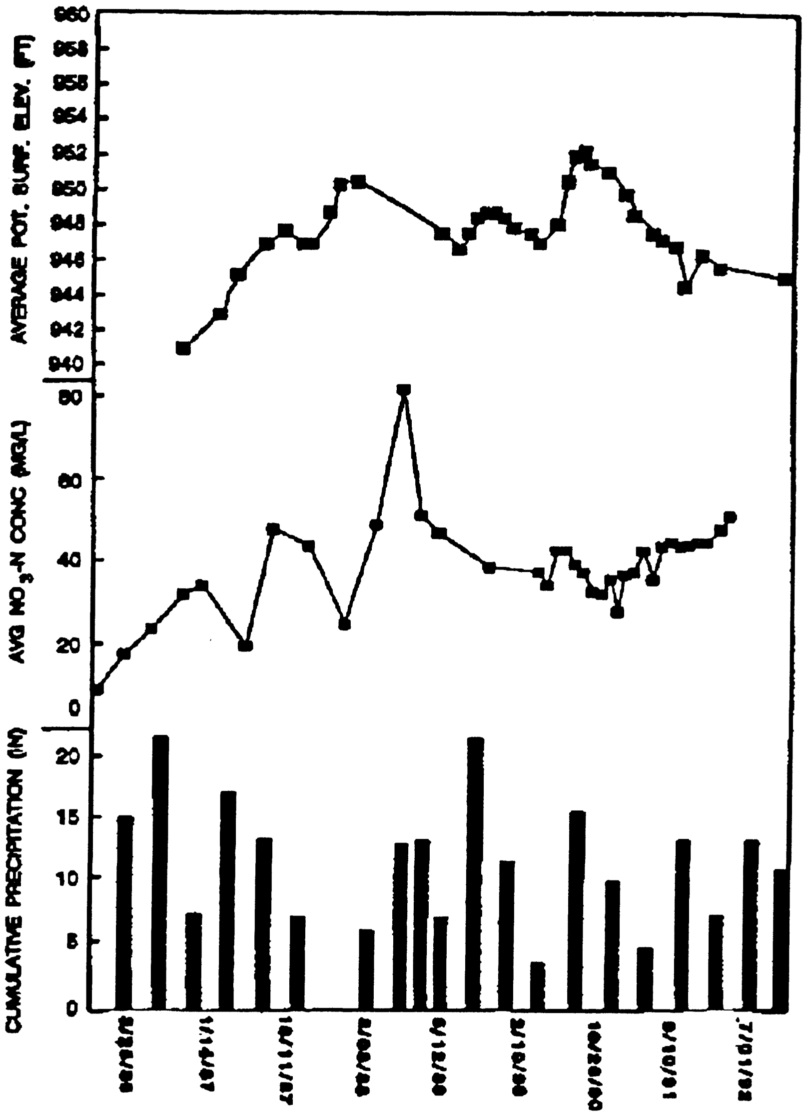


Figure 55. Comparison of water level, nitrate-N level, and precipitation—long term.

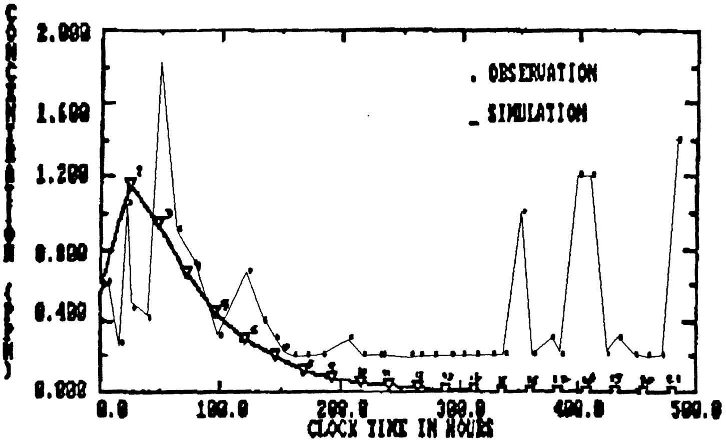


Figure 56. Observed and simulated bromide tracer concentration.

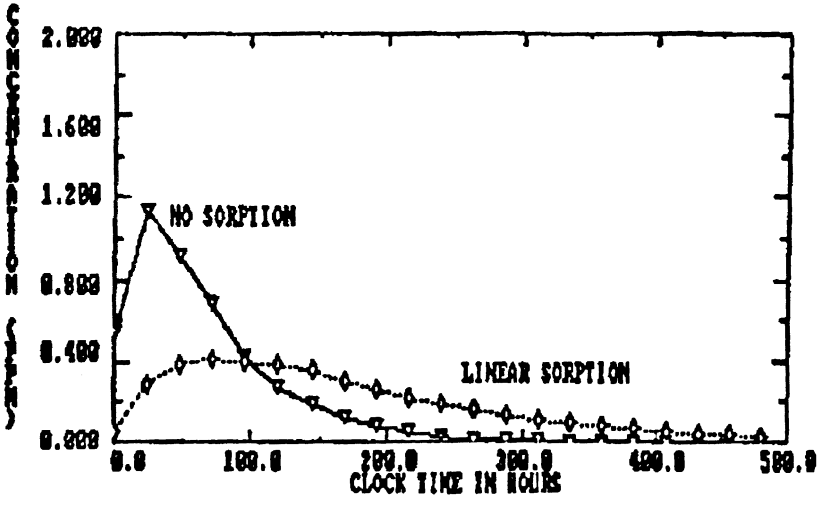


Figure 57. Simulated atrazine tracer concentration.

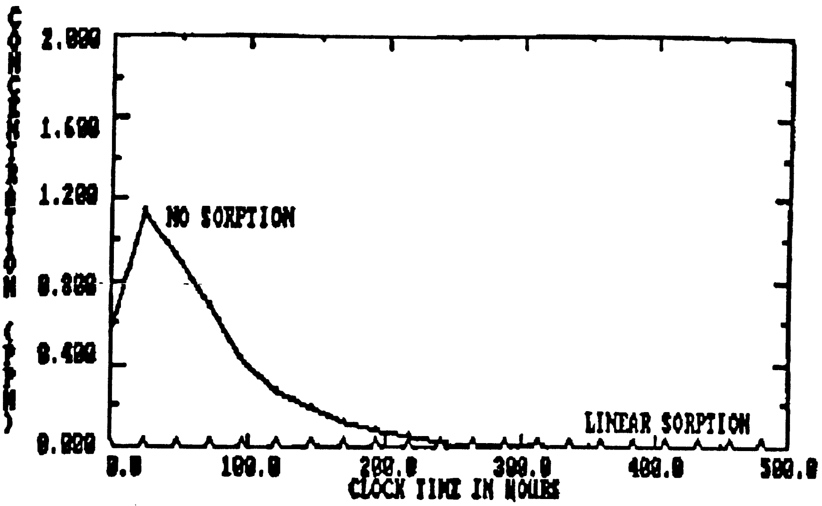


Figure 58. Simulated trifluralin tracer concentration.

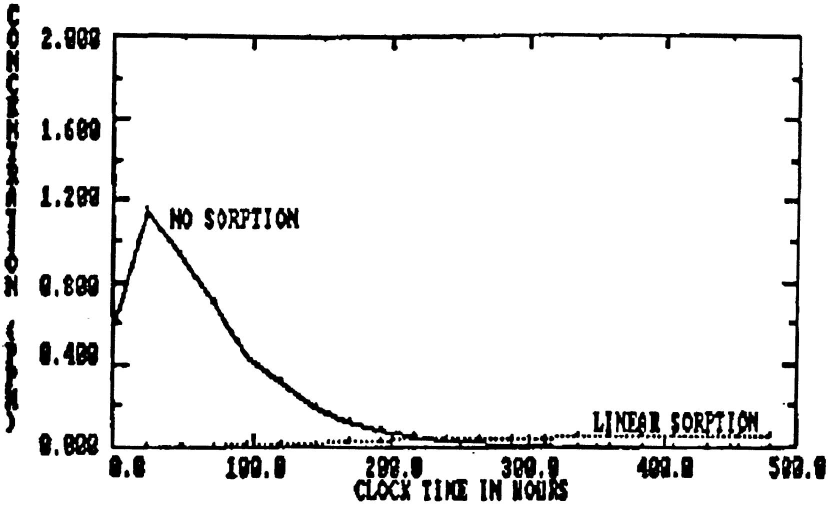


Figure 59. Simulated lindane tracer concentration.

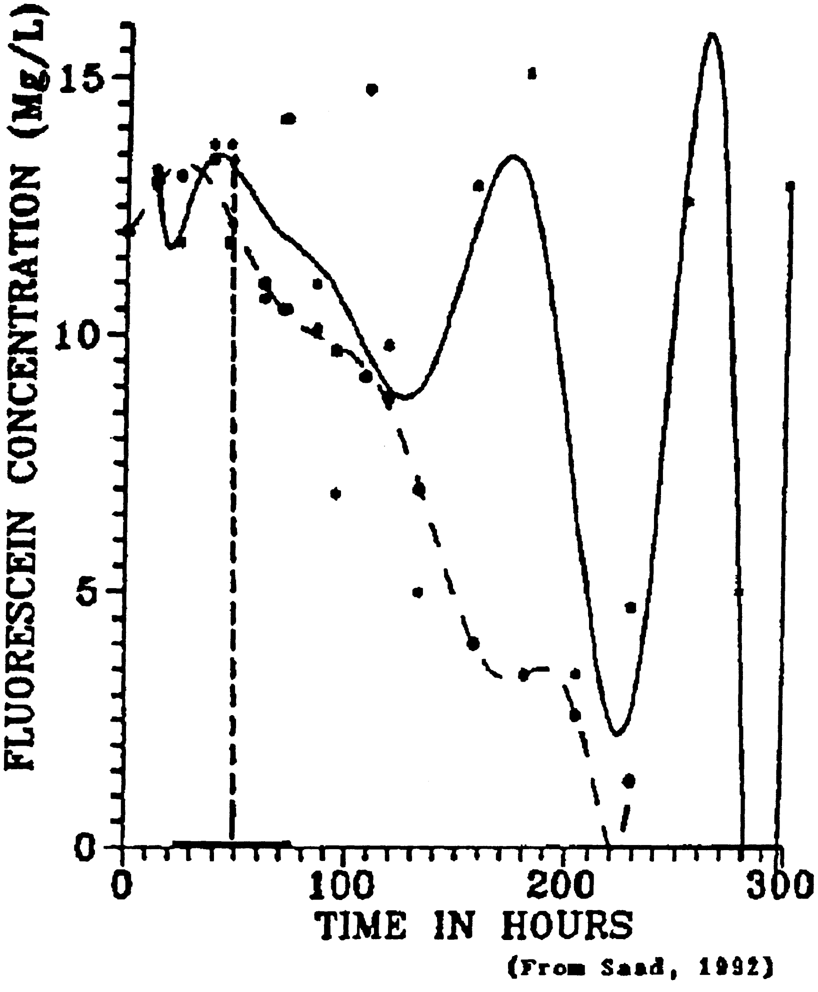


Figure 60. Observed and simulated (solid and dashed) flourescein concentration in 1992 tracer test. Polynomial grade 10 for best fit (solid line).

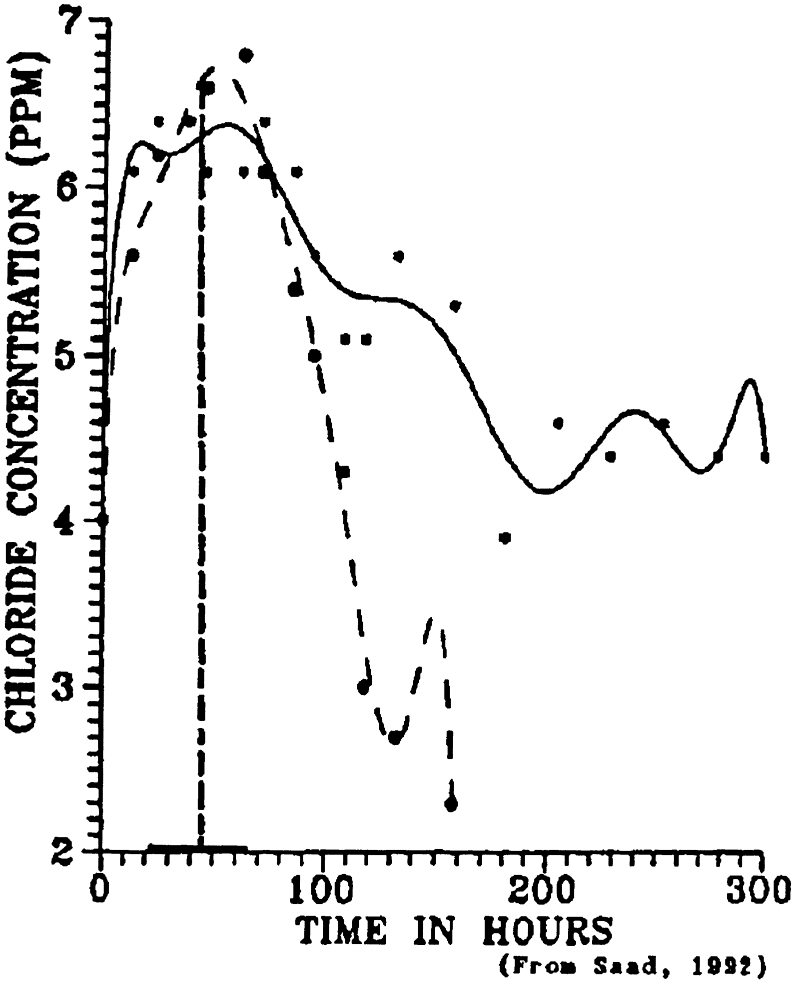


Figure 61. Observed and simulated (solid and dashed) chlorine concentration in 1992 tracer test. Polynomial grade 10 for best fit (solid line).

APPENDIX A
DRILLER LOGS

MONITOR WELL NO. 1

Depth (ft)	Description
0-3	Brown silty clay
3-14	Tan med coarse sd.
14-17	Red silty clay and fine sd.
17-21	Grey silty clay and V. fine sd.
21-23	Tan silt and med coarse sd.
23-25	Red and grey silty clay and fine sand.
25-26	V. Fine sand and tan silt
26-30	Fine sand and silty red clay
30-32	Bed rock

Cased to 23.5' with 25' of 2" Teflon SCREEN 18.0 - 23.0 .010 slot No sand (Hole caved to 8')

J. Naney and S. Bingaman

MONITOR WELL NO. 2

Depth (ft)	Description
0-3	Brown silty clay
3-14'	Tan red coarse sd.
14-17'	Red silty clay and fine sand
17-21'	Grey silty clay and V. fine sand.
21-24.5'	Tan silted and Md. coarse sd.

Cased to 23 ft w/25' of 2" Teflon SCREEN 18-23 ft .010 slot Hole cave no sand added No vol clay or concrete

J. Naney and S. Bingaman

MONITOR WELL NO. 3

Depth (ft)	Description
0-3	Brown silt
3-9'	Tan silt med coarse sd.
Bag sample (8')	
9'-14'	Red silt clay and fine sand
14'-21'	Red and grey silty clay and V. fine sand
Bag (21')	
21'-25'	Red silty clay w/some V. fine sand
25'	Bed Rock

Cased to 24' with 25' of 2" Teflon solid Sub and Points 19-24' SCREEN 14'-19' .010 slot

J. Naney and S. Bingaman

MONITOR WELL NO. 4

Depth (ft)	Description
0-5	Brown silt and v. fine sand
5-11	Tan silt and v. fine sand
11-14	Red silty clay and fine sand
14-19	Med coarse sand and tan silty
19-21	Red and grey silty clay
21-27	Med coarse sand tan silt
27-30	V. Fine sand and silty red clay
30-32	Fine sand and silt
32-34	Piston core (No sample but piston shot)
32-46.5	V. fine sand and red silt bedrock
46.5	Bedrock

Cased to 46.5 w/2" Teflon SCREEN 41-46 Sand 39-46 10-20 Sieve Size Vol Clay 38-39

J. Naney and S. Bingaman

MONITOR WELL NO. 5

Depth (ft)	Description
0-5	Brown silt and fine sand.
6-11	Fine sand and tan silt.
11-23	Red sandy clay and V. fine sand
23-24.5	Med coarse sand and silty fine sd.
24.5	Total Depth

Cased to 24.5' w/2" Teflon SCREEN 19-24' .010 Slot Sand 18.5-24.5 10-25 Sieve Vol clay 17.0-18.5 Concrete 1-17.0

J. Naney and S. Bingaman

MONITOR WELL NO. 6

Depth (ft)	Description
0-17'	Med coarse sand and tan silt.
17-19'	Grey silty clay and V. fine sand.
19-21.5	Red and grey clay and V. fine sd.

Cased to 21.5' w/25' of 2" Teflon SCREEN 16.0-21.0 Saw slot Sand 16-40' Sieve

J. Naney and S. Bingaman

MONITOR WELL NO. 7

Depth (ft)	Description
0-17'	Med coarse sand and tan silt.
2 Bag samples @ 6' and 10'	
17-19'	Grey silty clay and V. fine sand.
19-30'	Red and grey clay and V. fine sand.
30-37'	brown silt and 1/8 quartz gravel chit chatter.
37-39'	Grey clay
39-41.5	Bedrock

Cased tp 41.5 w/45' of Teflon (2") SCREEN 3.60-41.0 .010 slot Sand 16-40 Sieve

J. Naney and S. Bingaman

MONITOR WELL NO. 8

Depth (ft)	Description
0-5	Yellow tan sand clay
5-14	Tan brown silty clay and fine sand.
14-17	Red brown sand
17-21	Red and grey silty clay and very fine sand.
21-23'	Piston core.

Cased to 23' with 25' of 2" Teflon SCREEN 18'23' Sand 17'23' 10-20 Sieve Vol Clay 16'17' Concrete 0-16

J. Naney and S. Bingaman

MONITOR WELL NO. 9

Depth (ft)	Description
0-6'	Yellow tan sandy clay.
6-14'	Fine sand and tan silt.
14-16'	Red brown sand.
16-22'	Grey sandy clay.
22-30'	Tan silty fine sand.
30-33'	Red clayey silt and very fine sand.
33-35'	Very fine sand and tan silt.
TD 35'	Sandstone (Bed Rock) Hard Drilling.

Cased to 35' with 2" Teflon SCREEN 30-35' 0.10 Slot Sand 28-35' 10-20 Seive size Vol Clay pellets 27-28' Concrete 1-27'

J. Naney and S. Bingaman

MONITOR WELL NO. 10

Depth (ft)	Description
0-8'	Medium coarse sand and yellow-tan silt.
8-12'	Medium coarse sand and white silty clay (Drill fluid is tan).
12-19'	Fine sand and red and white silty clay (Drill fluid is tan).
19-27'	Tan silt and very fine sand.
27-39'	Red and white silty clay.
30-40'	Bedrock.

Cased to 30' with 30' of 2" Teflon. 5 more to be added after well sets. Screen 20-30' with .010 slot No sand (Natural Completion)

J. Naney and S. Bingaman

MONITOR WELL NO. 11

Depth (ft)	Description
0-3'	Brown silt and very fine sand.
3-13'	Orange silt and fine sand.
(5' jar sample)	
(10' jar sample)	
13-15'	Piston core.
(15' jar sample)	
13-19'	Medium coarse sand and tan silt.
19-21'	Red silty clay and fine sand.
(stopped for day jar sample 25')	
21-23	Piston core.
(Jar sample 30')	
21-35'	Fine sand and tan silt.
(Jar sample 35')	
35-44'	Medium coarse sand and tan silt.
(Jar sample 40')	
41.5-43.5	Piston corp (would not shoot).
(Jar sample 45')	
44-51'	Very coarse sand.
(Jar sample 50')	
51'	Bedrock

Cased to 46.5 from GSE with 48.5 of 4" pvc Screen 43.5-48.5 1.020 slot. Sand 40-49' 10-20 sieve Vol Clay 38-40. Concrete

J. Naney and S. Bingaman.

MONITOR WELL NO. 12

Depth (ft)	Description
0-4'	Brown silt and fine sand.
4-9'	Yellow-tan silt, white silty clay and fine sand.
9-11'	Red-brown silt and fine sand.

11-21.5	Orange silt and fine sand.
21.5-23.5	Tan silt and fine sand.
41.5-43.5	Piston sample mudded hole overnite.
47.5	Very fine sand w/sm cs sd. and sm clay rd and brown clay @ 48.5 ±
51'	Bedrock

Cased to 50 ft with 52.3' of 4 inch Teflon. Screen 45-50' .020 slot. Sand 43-50 Vol Clay 41-43 Concrete

J. Naney and S. Bingaman

MONITORING WELL #18

Depth (ft)	Description
0-1	red brown silt
1-3	red brown fine sand
3-5	red brown silt
5-17	red brown fine sand
17-18	red brown silty clay lenses
18-20	red brown fine sand
20-21	red brown silty clay
21-22	red brown fine sand
22-23	red brown silt
23-26	red brown fine sand
26-27	red brown silt
27-37	red brown fine sand
37-40	red brown fine sand with silty clay lenses
40-57.5	red brown medium to coarse sand
57.5-62	red brown claystone, red

Cased to 57.5 feet with 5 inch pvc pipe SCREENED from 32 feet - 57.5 feet with 20 slot screen sand packed from 10 - 57.5 feet Bentonite from 8-10 feet Portland cement slurry 2-8 feet Ready mix surface to 2 feet

Jim N., Doug K., Sam B.

MONITORING WELL #19

Depth (ft)	Description
0-4	Brown sandy loam soil.
4-13	Orange silty sand.
13-15	Tan fine sand.
15-16.5	Orange fine sand with silt (split spoon sample).
18-19	Orange fine sand with clay.
19-23	Tan fine sand with silt.
23-25	Tan silty clay.
25-30	Tan silty clay (moist sample).
30-35	Wet sand (no sample).

Cased to TD of 34.2 ft with 2 inch pvc pipe. Screened from 24-34 ft with 20 slot screen. Sand packed from 19.5-34 ft. Bentonite pellets 17.5-19.5 ft. Portland cement Slurry to 17. ft.

Dr. Kent, Yusuf B., Sam B., Roy.

TOC elevation surveyed - 919.74 ft.

MONITORING WELL #20

Depth (ft)	Description
0-5	Reddish brown fine silty sand.
5-10	Fine to medium reddish orange sand with silt and clay (slightly moist).
10-15	Reddish orange brown fine to medium sand with silt and clay (moist).
15-20	Reddish brown silty clay (moist).
20-25	Reddish orange silty clay (moist).
25-30	Reddish orange silty clay (saturated).

Cased to TD of 25 ft with 2 inch pvc pipe.
Screened from 20-25 feet with 20 slot screen.
Sand packed from 13-25 ft.
Bentonite pellets 10.8-13 ft.
Portland cement slurry 2-13 ft.
Ready mix surface-2 ft.

Roy, Sam B., Yusuf B., Shelle V.

At 30 feet, heaving sand problem. Pulled up to complete well at 25 feet.

MONITORING WELL #21

Depth (ft)	Description
0-2.5	Brown fine silty sand
2.5-5	Reddish orange medium silty sand.
5-10	Orange-tan-brow, fine to medium well sorted sand.
10-15	Reddish orange fine to medium clayey.
15-20	Reddish orange very fine to fine clayey sand.
20-21.5	Split spoon sample.
20-25	Orange brown very fine to fine clayey sand.
25-30	Same but saturated.
30-35	Same.
35-40	Same.

Cased to TD of 40 ft with 2 inch pvc pipe. Screened from 32.5-40 ft with 20 slot screen. Sand packed from 21-40 ft. Bentonite from 19-21 ft. Portland cement slurry 2-19 ft. Ready mix surface to 2 ft.

Jim N., Shelle V., Roy, Sam B.

MONITORING WELL #22

Depth (ft)	Description
0-5	Reddish brown very fine to fine clayey sand.
4-5	Very high clay content (easy to roll).
5-10	Grayish very fine to medium clayey sand.
10-15	Orange very fine to fine sand (very high clay content).
20-25	Reddish orange very fine to fine sand with much less clay and some moisture.
25-30	Same but saturated.
35-40	Reddish orange fine sand (saturated).
40-44	Same
44-45	Brown fine sand - very clean, little silt.

Cased to 35.25 ft with 2 inch pvc pipe. Screened from 27.75 to 35.25 with 20 slot screen. Sand packed from 25.7-35.25 ft. Bentonite pellets 23-25.7 ft.

Drilled to 45 ft but auger was filling up with sand inside. Put 45 feet of pvc down hole but felt that sand and silt was moving into the screen. Pulled pvc out, cleaned out screen. Will pull up and complete hole at 35 feet instead of 45 feet.

MONITORING WELL #23

Depth (ft)	Description
0-10	Yellow brown fine to medium sand - very high clay content.
10-15	Red medium to coarse sand - very high clay content.
15-20	Same
20-25	Same but saturated
25-30	" " "
30-35	" " "
36	Bedrock

Cased to TD of 36.5 ft with 2 inch pvc. Screened from 29-36.5 ft with 20 slot screen. Sand packed from 24-36.5 ft. Bentonite pellets 21-24 ft. Cement Bentonite slurry 2-21 ft. Ready mix concrete surface to 2 ft.

APPENDIX B
HYDROGRAPH AND PRECIPITATION DATA

Depth to Water - Perkins Monitoring Wells #1 - #7

Week	MW#1 TOC - 970.92		MW#2 TOC - 971.08		MW#3 TOC - 962.11		MW#4 TOC - 963.84		MW#5 TOC - 964.60		MW#6 TOC - 959.95		MW#7 TOC - 959.85	
	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL
14	25.89	945.03	25.87	945.21	-----------	-----------	-----------	-----------	20.15	944.45	-----------	-----------	17.89	941.96
28	23.91	947.01	24.02	947.06	22.88	939.23	22.70	941.14	21.95	942.65	19.93	940.02	20.04	939.81
40	22.00	948.92	22.29	948.79	20.38	941.73	20.30	943.54	20.19	944.41	18.51	941.44	18.52	941.33
42	22.20	948.72	22.30	948.78	20.37	941.74	20.23	943.61	20.21	944.39	18.53	941.42	18.53	941.32
47	20.27	950.65	20.35	950.73	19.51	942.60	19.70	944.14	19.69	944.91	17.03	942.92	17.04	942.81
49	19.31	951.61	19.39	951.69	19.95	942.16	18.80	945.04	18.80	945.80	17.09	942.86	17.10	942.75
50	18.70	952.22	18.75	952.33	18.85	943.26	17.50	946.34	17.40	947.20	15.70	944.25	15.70	944.15
59	19.77	951.15	19.72	951.36	19.86	942.25	18.51	945.33	18.61	945.99	16.68	943.27	16.69	943.16
61	19.35	951.57	19.40	951.68	17.95	944.16	17.20	946.64	16.92	947.68	16.54	943.41	16.53	943.32
63	19.10	951.82	19.20	951.88	17.52	944.59	16.82	947.02	16.80	947.80	15.30	944.65	15.30	944.55
66	18.55	952.37	18.50	952.58	16.90	945.21	16.15	947.69	16.18	948.42	14.70	945.25	14.70	945.15
67	18.30	952.62	18.30	952.78	16.54	945.57	16.00	947.84	15.95	948.65	14.50	945.45	14.50	945.35
69	18.02	952.90	18.03	953.05	15.89	946.22	16.12	947.72	16.11	948.49	14.35	945.60	14.35	945.5
73	17.86	953.06	17.92	953.16	15.35	946.76	15.52	948.32	15.50	949.10	14.15	945.80	14.18	945.67
77	17.10	953.82	17.95	953.13	15.40	946.71	15.70	948.14	15.65	948.95	14.30	945.65	14.40	945.45
81	17.45	953.47	17.75	953.33	14.70	947.41	14.73	949.11	15.52	949.08	14.28	945.67	13.99	945.86
82	17.65	953.27	17.75	953.33	14.80	947.31	14.87	948.97	15.60	949.00	14.20	945.75	14.50	945.35
83	17.10	953.82	17.80	953.28	14.10	948.01	14.11	949.73	15.80	948.80	14.25	945.70	14.35	945.5
85	17.69	953.23	17.85	953.23	14.00	948.11	14.88	948.96	15.59	949.01	14.29	945.66	14.21	945.64
86	18.20	952.72	18.40	952.68	15.50	946.61	15.55	948.29	16.30	948.30	14.85	945.10	14.80	945.05
87	17.11	953.81	18.13	952.95	15.20	946.91	15.21	948.63	15.11	949.49	14.80	945.15	14.70	945.15
88	18.23	952.69	18.36	952.72	15.45	946.66	15.47	948.37	16.15	948.45	14.90	945.05	14.78	945.07
89	17.31	953.61	17.41	953.67	15.59	946.52	15.80	948.04	16.17	948.43	14.36	945.59	14.33	945.52
94	18.08	952.84	18.29	952.79	15.29	946.82	15.25	948.59	16.00	948.60	14.63	945.32	14.54	945.31
95	17.96	952.96	18.17	952.91	15.25	946.86	15.25	948.59	16.00	948.60	14.58	945.37	14.46	945.39
97	18.08	952.84	18.29	952.79	15.42	946.69	15.42	948.42	16.17	948.43	14.69	945.26	14.58	945.27
99	17.98	952.94	18.17	952.91	15.27	946.84	15.25	948.59	15.94	948.66	14.60	945.35	14.50	945.35
101	18.13	952.79	18.25	952.83	15.33	946.78	15.30	948.54	15.04	949.56	14.54	945.41	14.50	945.35
102	17.22	953.70	17.39	953.69	14.41	947.70	14.83	949.01	15.50	949.10	14.16	945.79	14.03	945.82
104	16.91	954.01	17.05	954.03	13.91	948.20	14.34	949.50	15.12	949.48	13.55	946.40	13.69	946.16
106	15.92	955.00	16.08	955.00	13.24	948.87	-----------	-----------	-----------	-----------	13.02	946.93	12.89	946.96
107	15.45	955.47	15.60	955.48	12.68	949.43	12.83	951.01	13.56	951.04	12.46	947.49	12.39	947.46
108	15.12	955.80	15.33	955.75	12.41	949.70	12.50	951.34	13.15	951.45	12.16	947.79	12.07	947.78
109	14.83	956.09	14.95	956.13	12.03	950.08	12.16	951.68	12.91	951.69	11.66	948.29	11.74	948.11
111	14.58	956.34	14.75	956.33	11.54	950.57	11.79	952.05	12.54	952.06	11.33	948.62	11.25	948.6
113	14.70	956.22	14.83	956.25	11.55	950.56	11.83	952.01	11.61	952.99	11.37	948.58	11.24	948.61
114	14.66	956.26	14.75	956.33	11.44	950.67	11.25	952.59	11.50	953.10	11.33	948.62	11.24	948.61
115	14.62	956.30	14.78	956.30	11.34	950.77	11.70	952.14	12.41	952.19	11.24	948.71	11.15	948.7
119	15.41	955.51	15.58	955.50	12.00	950.11	12.62	951.22	13.28	951.32	11.91	948.04	11.83	948.02
120	15.50	955.42	15.62	955.46	12.00	950.11	12.66	951.18	13.32	951.28	12.07	947.88	11.83	948.02
123	16.07	954.85	16.20	954.88	12.53	949.58	13.20	950.64	13.91	950.69	12.58	947.37	12.50	947.35
154	18.62	952.30	18.80	952.28	15.52	946.59	15.59	948.25	16.32	948.28	14.94	945.01	14.83	945.02
157	18.84	952.08	19.01	952.07	15.74	946.37	15.80	948.04	16.55	948.05	15.20	944.75	15.10	944.75
159	18.90	952.02	19.05	952.03	15.77	946.34	15.81	948.03	16.52	948.08	15.04	944.91	14.92	944.93
164	19.06	951.86	19.21	951.87	15.83	946.28	16.03	947.81	16.78	947.82	15.29	944.66	15.17	944.68
166	18.95	951.97	19.28	951.80	15.81	946.30	15.98	947.86	16.71	947.89	15.22	944.73	15.11	944.74
167	18.48	952.44	18.58	952.50	15.65	946.46	15.75	948.09	16.53	948.07	15.02	944.93	14.95	944.9
168	18.35	952.57	18.50	952.58	15.58	946.53	15.64	948.20	16.36	948.24	14.87	945.08	14.77	945.08
169	18.06	952.86	18.26	952.82	15.33	946.78	15.50	948.34	16.22	948.38	14.74	945.21	14.63	945.22
170	17.79	953.13	17.96	953.12	15.08	947.03	15.26	948.58	16.00	948.60	14.48	945.47	14.37	945.48
171	17.50	953.42	17.47	953.61	14.70	947.41	14.62	949.22	15.46	949.14	14.09	945.86	14.10	945.75
172	17.27	953.65	17.60	953.48	14.35	947.76	14.85	948.99	15.18	949.42	13.67	946.28	13.56	946.29
173	17.12	953.80	17.27	953.81	14.19	947.92	14.19	949.65	14.94	949.66	13.43	946.52	13.38	946.47
174	17.00	953.92	17.13	953.95	13.84	948.27	13.97	949.87	14.67	949.93	13.20	946.75	13.10	946.75
175	16.92	954.00	17.08	954.00	13.80	948.31	14.21	949.63	14.81	949.79	13.28	946.67	13.15	946.7
176	16.96	953.96	17.65	953.43	13.79	948.32	14.11	949.73	14.79	949.81	13.25	946.70	13.14	946.71
177	16.84	954.08	18.22	952.86	13.75	948.36	14.00	949.84	14.75	949.85	13.19	946.76	13.13	946.72

178	17.47	953.45	16.94	954.14	13.61	948.50	13.85	949.99	14.66	949.94	13.22	946.73	13.04	946.81
179	17.02	953.90	17.66	953.42	13.62	948.49	13.95	949.89	14.65	949.95	13.14	946.81	13.08	946.77
181	17.60	953.32	17.17	953.91	13.70	948.41	13.58	950.26	14.77	949.83	13.23	946.72	13.14	946.71
182	17.10	953.82	17.26	953.82	13.72	948.39	13.70	950.14	14.47	950.13	13.12	946.83	13.01	946.84
183	17.10	953.82	16.93	954.15	13.69	948.42	13.03	950.81	15.39	949.21	15.00	944.95	13.00	946.85
184	17.03	953.89	17.19	953.89	13.57	948.54	13.61	950.23	14.35	950.25	12.88	947.07	12.74	947.11
185	17.12	953.80	17.24	953.84	13.61	948.50	13.79	950.05	14.65	949.95	12.98	946.97	12.90	946.95
186	17.24	953.68	17.36	953.72	13.79	948.32	14.03	949.81	14.76	949.84	13.20	946.75	13.10	946.75
187	17.32	953.60	17.44	953.64	13.89	948.22	14.19	949.65	14.83	949.77	13.37	946.58	13.22	946.63
188	17.40	953.52	17.56	953.52	13.96	948.15	14.27	949.57	14.98	949.62	13.49	946.46	13.41	946.44
189	17.50	953.42	17.65	953.43	14.05	948.06	14.35	949.49	15.08	949.52	13.58	946.37	14.41	945.44
190	17.61	953.31	17.73	953.35	14.35	947.76	14.82	949.02	15.01	949.59	13.69	946.26	14.33	945.52
191	17.70	953.22	17.85	953.23	14.62	947.49	15.37	948.47	14.37	950.23	13.86	946.09	13.84	946.01
192	17.76	953.16	17.89	953.19	14.60	947.51	15.12	948.72	15.08	949.52	14.21	945.74	13.88	945.97
193	17.84	953.08	17.94	953.14	14.58	947.53	14.82	949.02	15.45	949.15	14.30	945.65	13.97	945.88
194	17.95	952.97	18.02	953.06	14.68	947.43	15.00	948.84	15.54	949.06	14.32	945.63	14.03	945.82
195	18.03	952.89	18.10	952.98	14.73	947.38	15.03	948.81	15.63	948.97	14.33	945.62	14.15	945.7
196	18.25	952.67	18.27	952.81	14.95	947.16	15.11	948.73	15.83	948.77	14.30	945.65	14.24	945.61
198	18.31	952.61	18.60	952.48	15.10	947.01	15.33	948.51	16.08	948.52	14.67	945.28	14.53	945.32
199	18.40	952.52	18.62	952.46	15.29	946.82	15.46	948.38	16.21	948.39	14.56	945.39	14.52	945.33
200	18.52	952.40	18.70	952.38	15.44	946.67	15.58	948.26	16.33	948.27	14.68	945.27	14.55	945.3
202	18.48	952.44	18.61	952.47	15.37	946.74	15.49	948.35	16.28	948.32	14.61	945.34	14.49	945.36
204	18.45	952.47	18.58	952.50	15.30	946.81	15.42	948.42	16.22	948.38	14.56	945.39	14.40	945.45
206	18.65	952.27	18.80	952.28	15.95	946.16	16.14	947.70	16.85	947.75	15.29	944.66	15.42	944.43
208	15.72	955.20	15.93	955.15	14.23	947.88	15.00	948.84	15.75	948.85	14.78	945.17	14.62	945.23
209	15.53	955.39	15.71	955.37	14.02	948.09	14.76	949.08	15.52	949.08	14.55	945.40	14.39	945.46
210	15.53	955.39	----------	----------	13.05	949.06	13.84	950.00	13.98	950.62	13.24	946.71	13.10	946.75
211	15.70	955.22	15.86	955.22	13.00	949.11	13.72	950.12	14.42	950.18	13.07	946.88	12.97	946.88
212	15.50	955.42	15.65	955.43	12.63	949.48	13.35	950.49	14.10	950.50	12.75	947.20	12.62	947.23
213	14.11	956.81	14.28	956.80	12.14	949.97	12.27	951.57	13.00	951.60	12.30	947.65	12.20	947.65
214	11.23	959.69	11.35	959.73	9.21	952.90	9.32	954.52	10.07	954.53	9.40	950.55	9.32	950.53
215	10.10	960.82	10.24	960.84	11.25	950.86	10.64	953.20	11.67	952.93	11.62	948.33	11.50	948.35
216	9.45	961.47	9.60	961.48	10.16	951.95	9.69	954.15	10.39	954.21	10.26	949.69	10.12	949.73
217	10.21	960.71	10.33	960.75	9.85	952.26	9.70	954.14	10.35	954.25	9.95	950.00	9.84	950.01
218	10.95	959.97	10.08	961.00	9.91	952.20	9.88	953.96	10.59	954.01	9.98	949.97	9.91	949.94
220	11.82	959.10	11.95	959.13	9.77	952.34	9.88	953.96	10.64	953.96	9.84	950.11	9.73	950.12
222	12.74	958.18	12.88	958.20	9.84	952.27	10.25	953.59	11.00	953.60	9.96	949.99	9.87	949.98
223	13.05	957.87	13.22	957.86	10.05	952.06	10.43	953.41	11.15	953.45	10.07	949.88	9.96	949.89
224	13.55	957.37	13.70	957.38	10.20	951.91	10.82	953.02	11.55	953.05	10.37	949.58	10.29	949.56
225	13.84	957.08	14.00	957.08	10.38	951.73	11.03	952.81	11.78	952.82	10.57	949.38	10.48	949.37
226	14.13	956.79	14.30	956.78	10.56	951.55	11.24	952.60	12.00	952.60	10.76	949.19	10.66	949.19
227	14.32	956.60	14.48	956.60	10.75	951.36	11.44	952.40	12.17	952.43	10.91	949.04	10.81	949.04
228	14.51	956.41	14.86	956.22	10.91	951.20	11.60	952.24	12.30	952.30	11.05	948.90	10.97	948.88
230	14.90	956.02	15.05	956.03	11.23	950.88	11.74	952.10	12.90	951.70	11.41	948.54	11.31	948.54
231	14.82	956.10	14.96	956.12	11.12	950.99	11.63	952.21	12.80	951.80	11.35	948.60	11.20	948.65
232	15.38	955.54	15.52	955.56	11.60	950.51	12.39	951.45	13.10	951.50	11.82	948.13	11.72	948.13
234	13.56	957.36	13.68	957.40	10.72	951.39	10.93	952.91	11.15	953.45	10.02	949.93	9.89	949.96
235	15.86	955.06	16.00	955.08	12.07	950.04	12.85	950.99	13.60	951.00	12.30	947.65	12.20	947.65
237	16.10	954.82	16.25	954.83	12.40	949.71	13.11	950.73	13.87	950.73	12.56	947.39	12.46	947.39
239	16.20	954.72	16.45	954.63	12.47	949.64	13.17	950.67	13.92	950.68	11.57	948.38	12.57	947.28
241	16.45	954.47	16.68	954.40	12.76	949.35	13.74	950.10	14.25	950.35	12.11	947.84	12.48	947.37
242	16.70	954.22	16.85	954.23	13.20	948.91	13.92	949.92	14.65	949.95	13.32	946.63	13.22	946.63
245	17.00	953.92	17.30	953.78	13.53	948.58	14.15	949.69	14.95	949.65	14.30	945.65	14.35	945.5
246	17.46	953.46	17.62	953.46	14.20	947.91	14.64	949.20	15.41	949.19	14.08	945.87	14.00	945.85
247	17.61	953.31	17.78	953.30	14.36	947.75	14.84	949.00	15.59	949.01	14.25	945.70	14.18	945.67
248	17.69	953.23	17.85	953.23	14.91	947.20	15.60	948.24	14.44	950.16	14.32	945.63	14.23	945.62
251	17.96	952.96	18.11	952.97	14.74	947.37	15.18	948.66	15.90	948.70	14.57	945.38	14.46	945.39
252	18.10	952.82	18.25	952.83	14.95	947.16	15.31	948.53	16.07	948.53	14.73	945.22	14.63	945.22
254	17.95	952.97	18.07	953.01	14.81	947.30	15.15	948.69	15.92	948.68	14.40	945.55	14.30	945.55
255	18.27	952.65	18.42	952.66	15.15	946.96	15.58	948.26	16.22	948.38	14.93	945.02	14.84	945.01
256	18.30	952.62	18.46	952.62	15.06	947.05	15.42	948.42	16.16	948.44	14.87	945.08	14.78	945.07

257	18.55	952.37	18.61	952.47	15.39	946.72	15.75	948.09	16.50	948.10	15.17	944.78	15.07	944.78
258	18.60	952.32	18.75	952.33	15.57	946.54	15.84	948.00	16.56	948.04	15.22	944.73	15.13	944.72
259	18.58	952.34	18.75	952.33	15.40	946.71	15.72	948.12	16.45	948.15	15.15	944.80	15.06	944.79
260	18.77	952.15	18.92	952.16	15.66	946.45	16.07	947.77	16.80	947.80	15.42	944.53	15.35	944.5
261	18.72	952.20	18.87	952.21	15.49	946.62	15.81	948.03	16.55	948.05	15.25	944.70	15.16	944.69
265	19.00	951.92	19.15	951.93	15.86	946.25	16.15	947.69	16.90	947.70	15.58	944.37	15.49	944.36
266	18.96	951.96	19.12	951.96	15.16	946.95	16.06	947.78	16.78	947.82	15.32	944.63	15.43	944.42
268	18.98	951.94	19.14	951.94	25.76	936.35	16.12	947.72	16.86	947.74	15.40	944.55	15.32	944.53
269	19.05	951.87	19.21	951.87	15.74	946.37	16.40	947.44	16.88	947.72	15.36	944.59	15.27	944.58
271	19.15	951.77	19.30	951.78	15.60	946.51	16.17	947.67	16.93	947.67	15.36	944.59	15.28	944.57
273	19.26	951.66	19.41	951.67	15.57	946.54	16.23	947.61	16.96	947.64	15.44	944.51	15.40	944.45
274	19.31	951.61	19.46	951.62	15.66	946.45	16.34	947.50	17.07	947.53	15.55	944.40	15.46	944.39
276	19.45	951.47	19.61	951.47	16.48	945.63	17.23	946.61	15.81	948.79	15.72	944.23	15.64	944.21
281	19.45	951.47	19.61	951.47	16.48	945.63	17.23	946.61	15.81	948.79	15.72	944.23	15.64	944.21
282	19.79	951.13	19.97	951.11	16.72	945.39	16.82	947.02	17.55	947.05	16.15	943.80	16.10	943.75
284	19.94	950.98	20.09	950.99	16.93	945.18	17.04	946.80	17.80	946.80	16.32	943.63	16.22	943.63
287	20.28	950.64	20.48	950.60	17.00	945.11	17.07	946.77	17.80	946.80	16.45	943.50	16.36	943.49
291	20.25	950.67	20.41	950.67	16.85	945.26	17.39	946.45	18.12	946.48	16.74	943.21	16.63	943.22
295	20.50	950.42	20.64	950.44	17.24	944.87	17.74	946.10	18.52	946.08	17.16	942.79	17.08	942.77
306	20.60	950.32	20.70	950.38	17.23	944.88	17.70	946.14	18.41	946.19	17.00	942.95	16.90	942.95
317	20.80	950.12	20.96	950.12	17.72	944.39	18.05	945.79	18.82	945.78	17.37	942.58	17.25	942.6
321	19.35	951.57	19.60	951.48	17.05	945.06	17.22	946.62	17.94	946.66	16.46	943.49	16.37	943.48
325	18.50	952.42	18.65	952.43	16.30	945.81	16.45	947.39	17.18	947.42	15.72	944.23	15.61	944.24
328	18.51	952.41	18.65	952.43	15.95	946.16	16.12	947.72	16.83	947.77	15.40	944.55	15.31	944.54

TOC - Top of Well Casing (in feet from msl)
DTW - Depth to Water (in feet)
PSEL - Piezometer Surface Elevation (in feet from msl)

Depth to Water - Perkins Monitoring Wells # 8 - #18

	MW #8 TOC - 943.94		MW #9 TOC - 943.44		MW #10 TOC - 978.57		MW #11 TOC - 910.34		MW #12 TOC - 927.33		MW #18 TOC - 913-95	
Week	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL	DTW	PSEL
14	12.02	931.92			23.36	955.21						
28	17.94	926	17.67	925.77	23.4	955.17	25.91	884.43	31.87	895.46		
40	18.18	925.76	16	927.44	20.86	957.71	24.37	885.97	30.12	897.21		
42	16.2	927.74	16.01	927.43	20.87	957.7	24.34	886	30.1	897.23	10.7	903.25
47	16.89	927.05	16.69	926.75	20.11	958.46	26.16	884.18	29.7	897.63		
49	13.18	930.76	13.27	930.17	17.95	960.62	25.51	884.83	29.51	897.82		
50	12.3	931.64	12.12	931.32	16.6	961.97	20.5	889.84			10.7	903.25
59	13.18	930.76	13.29	930.15	17.61	960.96	23.51	886.83	30.41	896.92		
61	12	931.94	12	931.44	17.6	960.97	23.5	886.84	27.67	899.66	12.8	901.15
63	12.68	931.26	12.66	930.78	17.1	961.47	22.92	887.42	27.4	899.93	12.14	901.81
66	12	931.94	12	931.44	16.4	962.17			27.2	900.13	12.1	901.85
67	12.35	931.59	12.15	931.29	16.28	962.29	22.68	887.66	27.1	900.23	11	902.95
69	12.58	931.36	12.34	931.1	16.44	962.13	22.8	887.54	26.71	900.62		
73	13.06	930.88	12.89	930.55	17.2	961.37	23.52	886.82	27.75	899.58		
77	13.5	930.44	13.3	930.14	17.3	961.27	23.65	886.69			12.8	901.15
81	12.1	931.84	12.6	930.84	16.73	961.84	22.83	887.51	21.62	905.71		
82	13.1	930.84	12.55	930.89	16.1	962.47	22.9	887.44	21.85	905.48		
83	13.15	930.79	12.65	930.79	19.72	958.85	22.95	887.39	24.2	903.13		
85	13.27	930.67	12.54	930.9	17.13	961.44	22.1	888.24	21.46	905.87		
86	13.8	930.14	13.2	930.24	17.8	960.77	23.35	886.99				
87	13.54	930.4	12.96	930.48	17.6	960.97	23.1	887.24	21.63	905.7		
88	13.76	930.18	13.21	930.23	17.78	960.79	23.3	887.04	21.82	905.51	13.34	900.61
89	14.08	929.86	13.21	930.23	17.38	961.19	23.55	886.79			13.38	900.57
94	12.92	931.02	12.33	931.11	17.21	961.36	21.29	889.05	20.88	906.45	12.33	901.62
95	12.67	931.27	12.08	931.36	17.17	961.4	22.92	887.42	20.88	906.45	12.29	901.66
97	12.83	931.11	12.29	931.15	17.19	961.38	23.08	887.26	21.08	906.25	12.54	901.41
99	12.92	931.02	12.4	931.04	17.17	961.4	23.13	887.21	21.33	906	12.77	901.18
101	13.17	930.77	12.58	930.86	17.38	961.19	23.21	887.13	21.54	905.79	12.92	901.03
102	12.2	931.74	11.66	931.78	17.2	961.37	23.16	887.18	20.7	906.63	12.92	901.03
104	12.31	931.63	11.73	931.71	15.91	962.66	23.12	887.22	21.03	906.3	13.45	900.5
106					14.34	964.23	23.31	887.03			11.88	902.07
107	10.62	933.32	10.06	933.38	13.87	964.7	23.31	887.03			11.56	902.39
108	10.53	933.41	10.03	933.41	13.7	964.87	22.41	887.93	27.62	899.71	11.54	902.41
109	10.5	933.44	9.91	933.53	13.7	964.87	22.11	888.23	27.11	900.22	11.53	902.42
111	10.5	933.44	9.92	933.52	13.83	964.74	22	888.34	26.67	900.66	11.91	902.04
113	10.76	933.18	10.15	933.29	14.26	964.31	22.07	888.27	26.57	900.76		
114	10.66	933.28	10.07	933.37	14.24	964.33	22.07	888.27	26.55	900.78		
115	10.7	933.24	10.11	933.33	14.34	964.23	22.07	888.27	26.5	900.83		
119	11.45	932.49	10.83	932.61	15.41	963.16	22.91	887.43	27.07	900.26		
120	11.53	932.41	10.91	932.53	15.5	963.07	23.2	887.14	27.2	900.13		
123	12.11	931.83	11.53	931.91	16.24	962.33	23.83	886.51	27.75	899.58	14.7	899.25
154	14.28	929.66	13.68	929.76	18.52	960.05	24.36	885.98	29.58	897.75	13.97	899.98
157	14.42	929.52	13.81	929.63	18.67	959.9	24.54	885.8	29.9	897.43	14.41	899.54
159	14.25	929.69	13.62	929.82	18.6	959.97	24.56	885.78	29.94	897.39	13.94	900.01
160	14.32	929.62	13.71	929.73	18.74	959.83	24.67	885.67	32.13	895.2	14.42	899.53

161	13.84	930.1	13.28	930.16	18.6	959.97	27.27	883.07	30.26	897.07	13.41	900.54
162	13.68	930.26	13.1	930.34	18.03	960.54	24.13	886.21	30.14	897.19	13.04	900.91
163	15.7	928.24	12.91	930.53	17.82	960.75	23.95	886.39	31.86	895.47	14.94	899.01
164	13.35	930.59	12.71	930.73	17.58	960.99	24.01	886.33	29.34	897.99	12.62	901.33
165	13.15	930.79	12.54	930.9	19.51	959.06	23.71	886.63	29.22	898.11	12.51	901.44
166	15.28	928.66	14.73	928.71	17	961.57	23.56	886.78	31.2	896.13	12.31	901.64
167	12.86	931.08	12.27	931.17	19.24	959.33	23.53	886.81	28.95	898.38	12.26	901.69
168	15.03	928.91	12.15	931.29	16.82	961.75	23.52	886.82	28.9	898.43	12.45	901.5
169	12.68	931.26	12.07	931.37	16.66	961.91	23.4	886.94	28.6	898.73	12.39	901.56
170	12.82	931.12	12.2	931.24	16.66	961.91	23.44	886.9	28.52	898.81	12.9	901.05
171	12.74	931.2	12.41	931.03	16.71	961.86	22.89	887.45	28.42	898.91	13.07	900.88
172	12.9	931.04	12.19	931.25	16.78	961.79	23.13	887.21	28.4	898.93	12.83	901.12
173	12.73	931.21	12.14	931.3	16.74	961.83	23.37	886.97	28.28	899.05	12.7	901.25
174	12.7	931.24	12.1	931.34	17	961.57	23.45	886.89	28.13	899.2	12.83	901.12
176	12.72	931.22	12.14	931.3	16.93	961.64	23.62	886.72	28.25	899.08	12.8	901.15
177	12.28	931.66	12.37	931.07	17.32	961.25	23.58	886.76	28.81	898.52	12.77	901.18
178	12	931.94	11.42	932.02	17	961.57	23.08	887.26	29.62	897.71	12.81	901.14
179	12.1	931.84	11.49	931.95	17.12	961.45	23.32	887.02	28.64	898.69	25	888.95
180	12.32	931.62	11.54	931.9	17.28	961.29	23.44	886.9	28.56	898.77	25.3	888.65
181	12.45	931.49	11.86	931.58	17.32	961.25	23.65	886.69	28.16	899.17	25.5	888.45
182	12.59	931.35	12.01	931.43	17.35	961.22	23.68	886.66	28.15	899.18	25.73	888.22
183	12.74	931.2	12.12	931.32	17.49	961.08	23.7	886.64	28.11	899.22	13.77	900.18
184	12.83	931.11	12.2	931.24	17.59	960.98	23.78	886.56	28.2	899.13	13.56	900.39
185	12.98	930.96	12.39	931.05	17.7	960.87	23.92	886.42	28.13	899.2	13.82	900.13
186	13.1	930.84	12.58	930.86	18.83	959.74	24.04	886.3	28.1	899.23	13.91	900.04
187	13.23	930.71	13.09	930.35	18.69	959.88	24.15	886.19	28.09	899.24	13.95	900
188	13.49	930.45	13.78	929.66	18.6	959.97	24.23	886.11	28.15	899.18	14	899.95
189	13.52	930.42	13.63	929.81	18.72	959.85	23.36	886.98	28.17	899.16	13.93	900.02
190	13.56	930.38	13.5	929.94	18.85	959.72	23.67	886.67	28.23	899.1	13.82	900.13
191	13.57	930.37	13.2	930.24	18.91	959.66	23.93	886.41	28.22	899.11	13.7	900.25
193	13.77	930.17	13.17	930.27	18.3	960.27	24.06	886.28	28.3	899.03	13.74	900.21
194	13.85	930.09	13.37	930.07	18.29	960.28	24.12	886.22	28.33	899	13.73	900.22
195	14.05	929.89	13.5	929.94	18.21	960.36	24.4	885.94	28.25	899.08	13.75	900.2
197	13.96	929.98	13.42	930.02	18.15	960.42	24.31	886.03	28.18	899.15	13.68	900.27
199	13.88	930.06	13.37	930.07	18.09	960.48	24.25	886.09	28.09	899.24	13.59	900.36
201	14.1	929.84	13.46	929.98	18.75	959.82	24.4	885.94	29	898.33	12.89	901.06
203	11	932.94	10.42	933.02	16.35	962.22	22.31	888.03	27.89	899.44	11.45	902.5
204	10.74	933.2	10.2	933.24	16.1	962.47	22.01	888.33	27.57	899.76	11.2	902.75
205	10.83	933.11	10.24	933.2	14.95	963.62	23.42	886.92	28.45	898.88	11.5	902.45
206	11.22	932.72	10.65	932.79	15.3	963.27	23.35	886.99	28.4	898.93	11.85	902.1
207	11.05	932.89	10.42	933.02	15.13	963.44	23.15	887.19	28.31	899.02	11.63	902.32
208	10.4	933.54	9.73	933.71	14.86	963.71	22.76	887.58	28	899.33	10.6	903.35
209	8.38	935.56	7.89	935.55	12.01	966.56	19.98	890.36	25.24	902.09	8.89	905.06
210	8.65	935.29	8.15	935.29	13.1	965.47	21.24	889.1	26.86	900.47	9.5	904.45
211	8.74	935.2	8.1	935.34	9.1	969.47	22.1	888.24	26.41	900.92	10.45	903.5
212	8.97	934.97	9.43	934.01	9.9	968.67	21.97	888.37	25.97	901.36	11.1	902.85

213	9.34	934.6	8.75	934.69	10.67	967.9	22.07	888.27	25.68	901.65	11.17	902.78
205	9.51	934.43	8.95	934.49	11.62	966.95	22.09	888.25	25.04	902.29	11.67	902.28
207	9.8	934.14	9.2	934.24	12.55	966.02	22.3	888.04	25.1	902.23	12.15	901.8
208	9.92	934.02	9.35	934.09	12.71	965.86	22.43	887.91	25.05	902.28	12.36	901.59
209	10.21	933.73	9.64	933.8	13.35	965.22	22.81	887.53	25.08	902.25	12.7	901.25
220	10.41	933.53	9.8	933.64	13.01	965.56	22.92	887.42	25.24	902.09	12.81	901.14
221	10.6	933.34	9.95	933.49	12.53	966.04	23.02	887.32	25.4	901.93	13	900.95
222	10.75	933.19	10.17	933.27	12.75	965.82	23.12	887.22	25.55	901.78	13.12	900.83
223	10.84	933.1	10.27	933.17	14.37	964.2	23.26	887.08	25.62	901.71	13.2	900.75
225	11.2	932.74	10.62	932.82	14.85	963.72	23.5	886.84	25.85	901.48	13.45	900.5
226	11.12	932.82	10.51	932.93	14.73	963.84	23.41	886.93	25.76	901.57	13.35	900.6
227	11.55	932.39	10.96	932.48	15.36	963.21	23.82	886.52	26.2	901.13	14.05	899.9
229	9.74	934.2	8.98	934.46	13.46	965.11	21.67	888.67	24.79	902.54	12.88	901.07
230	11.95	931.99	11.36	932.08	16	962.57	23.98	886.36	26.6	900.73	14.05	899.9
232	12.21	931.73	11.57	931.87	16.22	962.35	23.87	886.47	27.05	900.28	13.55	900.4
234	12.24	931.7	11.67	931.77	16.32	962.25	23.92	886.42	27.43	899.9	13.87	900.08
236	12.32	931.62	11.83	931.61	16.66	961.91	24.02	886.32	27.48	899.85	13.91	900.04
237	12.62	931.32			17	961.57	24.13	886.21	27.4	899.93	13.9	900.05
240	13.09	930.85					24.54	885.8	28.11	899.22	14.25	899.7
245	13.6	930.34	13	930.44	17.75	960.82	24.42	885.92	28.1	899.23	14.08	899.87
246	13.76	930.18	13.15	930.29	17.88	960.69	24.45	885.89	28.5	898.83	14.02	899.93
247	13.79	930.15	13.21	930.23	17.91	960.66	24.5	885.84	28.48	898.85	14.05	899.9
250	14.05	929.89	13.44	930	18.15	960.42	24.55	885.79	28.75	898.58	14.24	899.71
252	14.15	929.79	13.54	929.9	18.32	960.25	24.67	885.67	28.99	898.34	14.54	899.41
253	13.97	929.97	13.35	930.09	18.11	960.46	24.48	885.86	30.05	897.28	14.4	899.55
254	13.34	930.6	13.72	929.72	18.51	960.06	24.75	885.59	29.3	898.03	14.44	899.51
256	14.3	929.64	13.68	929.76	18.47	960.1	24.66	885.68	29.17	898.16	14.31	899.64
257	14.53	929.41	13.92	929.52	18.7	959.87	24.92	885.42	29.42	897.91	14.71	899.24
258	14.59	929.35	14	929.44	18.79	959.78	24.92	885.42	29.59	897.74	14.5	899.45
259	14.52	929.42	13.92	929.52	18.76	959.81	24.82	885.52	29.7	897.63	14.41	899.54
260	14.75	929.19	14.15	929.29	18.95	959.62	25.06	885.28	29.06	898.27	14.67	899.28
261	14.61	929.33	14	929.44	18.85	959.72	24.9	885.44	29.9	897.43	14.5	899.45
265	14.9	929.04	14.3	929.14	19.15	959.42	25.15	885.19	29.72	897.61	14.32	899.63
266	14.55	929.39	14.95	928.49	19	959.57	25.1	885.24	30.31	897.02	14.26	899.69
268	14.46	929.48	13.96	929.48	19	959.57	25.05	885.29	31.5	895.83	14.17	899.78
269	14.33	929.61	13.74	929.7	18.92	959.65	25.08	885.26	30.53	896.8	14.15	899.8
271	14.31	929.63	13.7	929.74	19.15	959.42	25.24	885.1	30.15	897.18	14.93	899.02
273	14.46	929.48	13.88	929.56	19.32	959.25	25.56	884.78	30.86	896.47	15.43	898.52
274	14.6	929.34	14	929.44	19.41	959.16	25.69	884.65	30.72	896.61	15.61	898.34
276	14.8	929.14	14.2	929.24	19.55	959.02	25.96	884.38	32.74	894.59	15.7	898.25
281	14.8	929.14	14.2	929.24	19.55	959.02	25.96	884.38	32.74	894.59	16.3	897.65
282	15.23	928.71	14.62	928.82	20	958.57	26.44	883.9	30.8	896.53	16.75	897.2
284	15.45	928.49	14.84	928.6	20.09	958.48	26.44	883.9	30.58	896.75	16.67	897.28
286	15.56	928.38	14.94	928.5	20.22	958.35	26.5	883.84	30.95	896.38	17.31	896.64
290	15.75	928.19	15.15	928.29	20.36	958.21	26.16	884.18	30.65	896.68	16.12	897.83
293	16.12	927.82	15.52	927.92	20.61	957.96	26.31	884.03				
303	16.14	927.8	15.54	927.9			25.56	884.78	30.85	896.48	14.65	899.3
315	16.42	927.52	15.88	927.56			25.62	884.72	31.85	895.48		
319	15.46	928.48	14.86	928.58	19.36	959.21	25.05	885.29			13.24	900.71
323	14.85	929.09	14.26	929.18	18.22	960.35	24.76	885.58	30.18	897.15		

Precipitation Data

Wk	Amt (in)	Wk	Amt (in)	Wk	Amt (in)	Wk	Amt (in)
1	2.46	43	0.24	85	0.00	127	0.00
2	0.19	44	0.00	86	0.69	128	0.82
3	1.01	45	0.00	87	0.72	129	0.00
4	0.30	46	0.00	88	0.00	130	2.77
5	0.32	47	1.68	89	0.00	131	3.40
6	0.85	48	0.00	90	0.80	132	0.73
7	3.76	49	1.30	91	2.45	133	1.13
8	0.93	50	0.15	92	0.00	134	0.00
9	0.39	51	1.38	93	0.83	135	0.31
10	0.90	52	0.38	94	0.00	136	0.00
11	0.86	53	0.00	95	0.11	137	0.00
12	1.33	54	0.15	96	0.00	138	2.40
13	0.58	55	0.16	97	0.04	139	0.00
14	1.13	56	0.43	98	0.00	140	1.30
15	0.00	57	0.00	99	0.46	141	0.00
16	0.22	58	0.21	100	0.00	142	0.35
17	0.19	59	0.00	101	3.25	143	0.20
18.	0.12	60	0.75	102	0.25	144	0.23
19	1.72	61	6.25	103	0.63	145	0.33
20	1.32	62	1.24	104	0.00	146	0.08
21	0.00	63	1.15	105	3.68	147	0.20
22	0.13	64	3.38	106	0.00	148	0.00
23	0.37	65	0.25	107	0.88	149	1.21
24	0.00	66	4.02	108	1.88	150	0.09
25	0.12	67	0.03	109	0.09	151	0.00
26	0.00	68	0.75	110	0.00	152	0.98
27	11.27	69	0.00	111	0.07	153	0.48
28	0.75	70	0.00	112	1.77	154	0.30
29	1.67	71	0.00	113	0.95	155	0.25
30	1.90	72	1.26	114	0.93	156	0.00
31	0.05	73	0.00	115	0.00	157	0.00
32	1.82	74	0.84	116	0.00	158	2.46
33	0.40	75	0.00	117	0.00	159	0.40
34	0.10	76	2.31	118	0.58	160	0.12
35	2.09	77	2.73	119	0.07	161	0.10
36	0.00	78	0.40	120	0.00	162	0.00
37	1.15	79	0.71	121	0.65	163	2.02
38	0.00	80	0.00	122	1.60	164	0.07
39	0.00	81	0.00	123	0.00	165	3.48
40	0.10	82	0.25	124	0.11	166	2.97
41	0.95	83	0.75	125	0.02	167	1.52
42	0.35	84	0.15	126	0.00	168	1.57

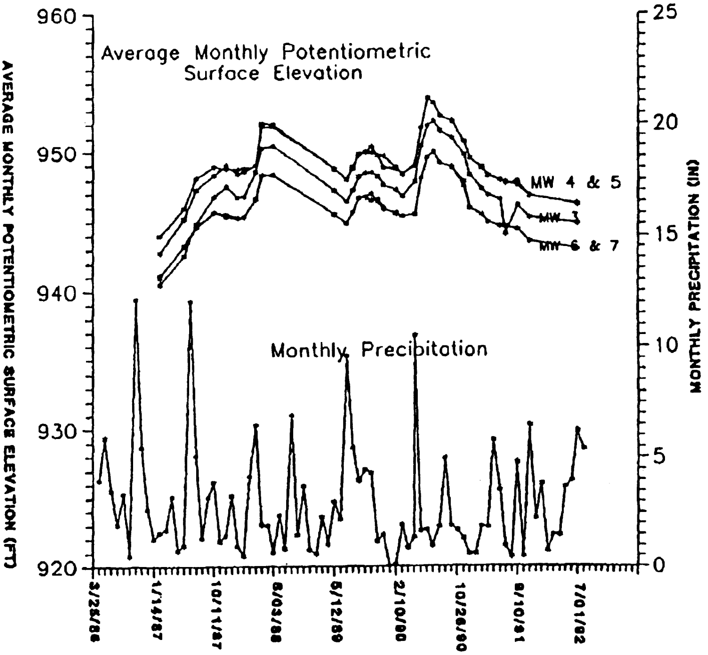
Precipitation Data (cont.)

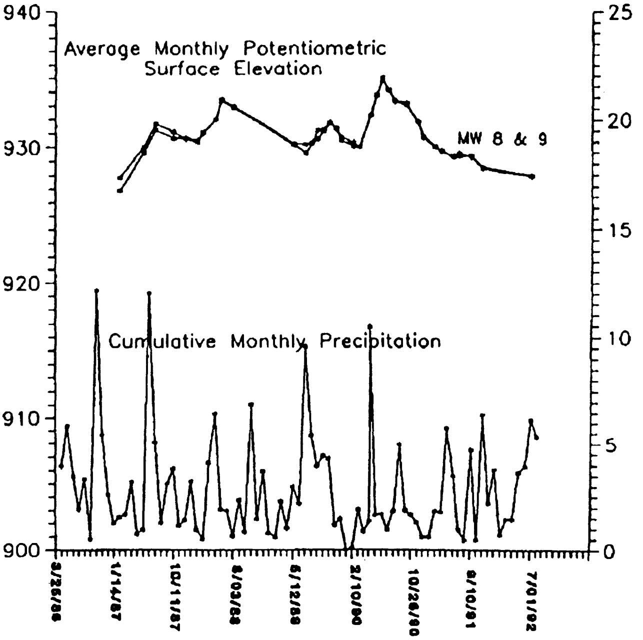
Wk	Amt (in)	Wk	Amt (in)	Wk	Amt (in)	Wk	Amt (in)
169	1.49	212	0.85	255	0.00	298	0.05
170	2.50	213	4.32	256	0.30	299	0.40
171	0.75	214	3.03	257	0.20	300	0.07
172	0.68	215	2.27	258	1.35	301	0.20
173	2.95	216	0.47	259	0.06	302	0.00
174	0.00	217	0.30	260	0.10	303	0.67
175	0.71	218	0.72	261	0.85	304	0.40
176	0.30	219	0.15	262	0.80	305	0.39
177	2.47	220	0.10	263	1.80	306	0.75
178	1.40	221	1.03	264	0.05	307	0.00
179	0.32	222	0.55	265	3.55	308	0.15
180	0.25	223	0.00	266	0.36	309	0.55
181	1.14	224	0.00	267	0.00	310	0.15
182	3.15	225	0.00	268	1.29	311	0.06
183	0.00	226	0.88	269	1.92	312	2.72
184	0.00	227	0.07	270	0.30	313	0.73
185	1.17	228	1.20	271	0.92	314	0.05
186	0.00	229	0.14	272	0.00	315	0.00
187	0.00	230	0.40	273	0.00	316	1.85
188	0.00	231	0.11	274	0.05	317	2.05
189	1.05	232	0.00	275	0.00	318	1.08
190	0.40	233	0.00	276	0.00	319	1.41
191	0.02	234	3.06	277	0.30	320	1.73
192	0.00	235	1.89	278	0.15	321	1.95
193	0.00	236	1.10	279	0.06	322	2.72
194	0.00	237	0.45	280	2.31	323	0.51
195	0.00	238	0.33	281	0.31		
196	0.00	239	0.00	282	2.05		
197	0.00	240	1.25	283	0.48		
198	0.10	241	0.40	284	0.00		
199	0.00	242	0.02	285	0.00		
200	1.42	243	0.00	286	0.00		
201	0.00	244	0.12	287	2.75		
202	0.37	245	0.17	288	2.34		
203	0.11	246	0.93	289	0.10		
204	0.86	247	0.07	290	1.23		
205	0.00	248	0.00	291	0.83		
206	0.00	249	0.25	292	0.00		
207	0.00	250	0.36	293	0.14		
208	0.00	251	0.20	294	1.25		
209	0.50	252	0.06	295	3.17		
210	0.85	253	0.35	296	0.45		
211	0.00	254	0.00	297	0.18		

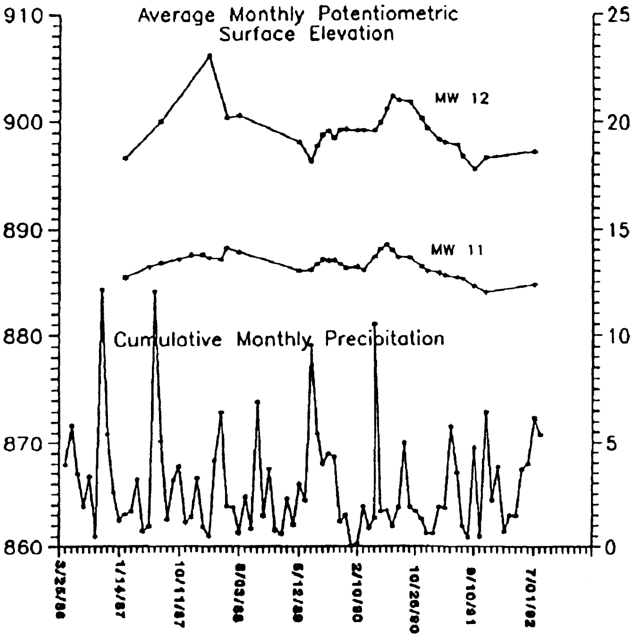
Equivalent Calender Dates for Weekly Designation

WEEK	DATE	WEEK	DATE	WEEK	DATE	WEEK	DATE
1	032586	111	060888	190	121589	236	110990
14	070286	113	062388	191	122089	237	111690
28	100986	115	070788	193	010590	240	120790
40	010187	116	071488	194	011390	245	010991
42	011487	119	080388	195	012090	246	011891
47	021987	132	110588	196	012790	247	012591
49	030787	145	013189	197	020390	248	020191
50	031387	149	030289	198	021090	250	021191
59	051387	152	032589	199	021790	252	022291
61	052587	154	040789	201	030390	253	030191
63	061187	159	051289	202	031090	254	030891
66	062887	161	052389	203	031790	256	032291
67	070787	162	053089	204	032490	257	032991
69	072287	163	060689	205	033190	258	040591
73	082087	164	061489	206	040790	259	041291
77	091787	165	062089	207	041390	260	041991
81	101187	166	062789	208	042090	261	042691
82	102387	167	070589	209	042790	265	052491
83	103087	168	071189	210	050490	266	053191
85	111387	169	071789	211	051690	268	061091
86	111987	170	072589	212	052590	269	061891
87	112887	171	080189	213	053190	271	070391
88	120587	172	080789	215	061390	273	071991
89	121187	173	081689	217	062690	274	072491
90	011688	174	082489	218	070390	276	080791

91	012388	175	090189	219	070990	277	081291
93	013188	177	091589	220	071690	281	091091
95	021488	178	092289	221	072790	282	092091
97	022888	179	092989	222	080390	284	100391
98	031288	180	100689	223	080990	286	102291
100	032688	181	101389	225	082390	288	110591
101	040188	182	102089	226	083090	290	112191
102	040688	183	102789	227	090790	293	121891
103	041388	184	110389	229	092190	297	011892
104	042388	185	110989	230	092790	303	022892
105	043088	186	111889	231	100590	315	052292
107	051488	187	112289	232	101290	319	061692
109	052788	188	113089	234	102690	323	071492
110	052988	189	120889	235	110290		


Average Monthly Potentiometric Surface Elevation
MW 4 & 5
MW 3
MW 6 & 7
Monthly Precipitation
AVERAGE MONTHLY POTENTIOMETRIC SURFACE ELEVATION (FT)
MONTHLY PRECIPITATION (IN)
960
950
940
930
920
25
20
15
10
5
0
3/26/86
1/14/87
10/11/87
8/03/88
5/12/89
2/10/90
10/26/90
8/10/91
7/01/92


Average Monthly Potentiometric Surface Elevation
MW 8 & 9
Cumulative Monthly Precipitation
940
930
920
910
900
25
20
15
10
5
0
3/26/86
1/14/87
10/11/87
8/03/88
5/12/89
2/10/90
10/26/90
8/10/91
7/01/92


Average Monthly Potentiometric Surface Elevation
MW 12
MW 11
Cumulative Monthly Precipitation
910
900
890
880
870
860
25
20
15
10
5
0
3/25/86
1/14/87
10/11/87
8/03/88
5/12/89
2/10/90
10/26/90
8/10/91
7/01/92

APPENDIX C

HYDRAULIC VARIABLES: PUMPING TESTS, SLUG TESTS

Slug Test			
March 6, 1988 Monitor Well #8		TD= 24.63 ft Screen = 14.63 - 24.63 ft Static Water Level = 13.06 ft	
Time (Min)	Depth to Water (FT)	H	H/Ho
0	24.18	11.12	1.00
0.5	24.14	11.08	1.00
1	24.07	11.01	0.99
1.5	24.01	10.95	0.98
2	23.94	10.88	0.98
2.5	23.87	10.81	0.97
3	23.78	10.72	0.96
3.5	23.6	10.54	0.95
4	23.62	10.56	0.95
4.5	23.55	10.49	0.94
5	23.48	10.42	0.94
6	23.39	10.33	0.93
7	23.27	10.21	0.92
8	23.13	10.07	0.91
9	23.03	9.97	0.90
10	22.87	9.81	0.88
12	22.63	9.57	0.86
14	22.38	9.32	0.84
16	22.1	9.04	0.81
18	21.92	8.86	0.80
20	21.67	8.61	0.77
22	21.45	8.39	0.75
24	21.22	8.16	0.73
26	21	7.94	0.71
28	20.76	7.7	0.69
30	20.57	7.51	0.68
35	20.08	7.02	0.63
40	19.6	6.54	0.59
45	19.16	6.1	0.55
50	18.76	5.7	0.51
55	18.3	5.24	0.47
60	17.99	4.93	0.44
70	17.34	4.28	0.38
80	16.78	3.72	0.33
82	16.67	3.61	0.32
84	16.53	3.47	0.31
90	16.5	3.44	0.31
100	15.87	2.81	0.25
110	15.5	2.44	0.22
120	15.19	2.13	0.19
140	14.43	1.37	0.12

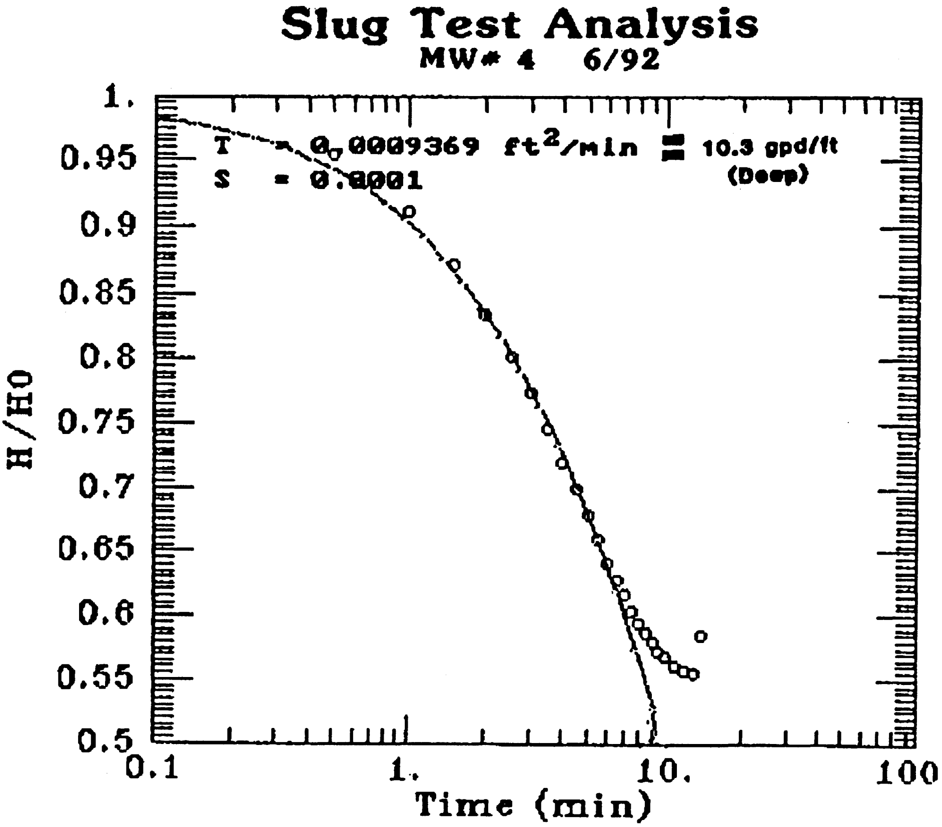
Slug Test

March 17, 1990
Monitor Well #7

Static Water Level = 14.94 ft

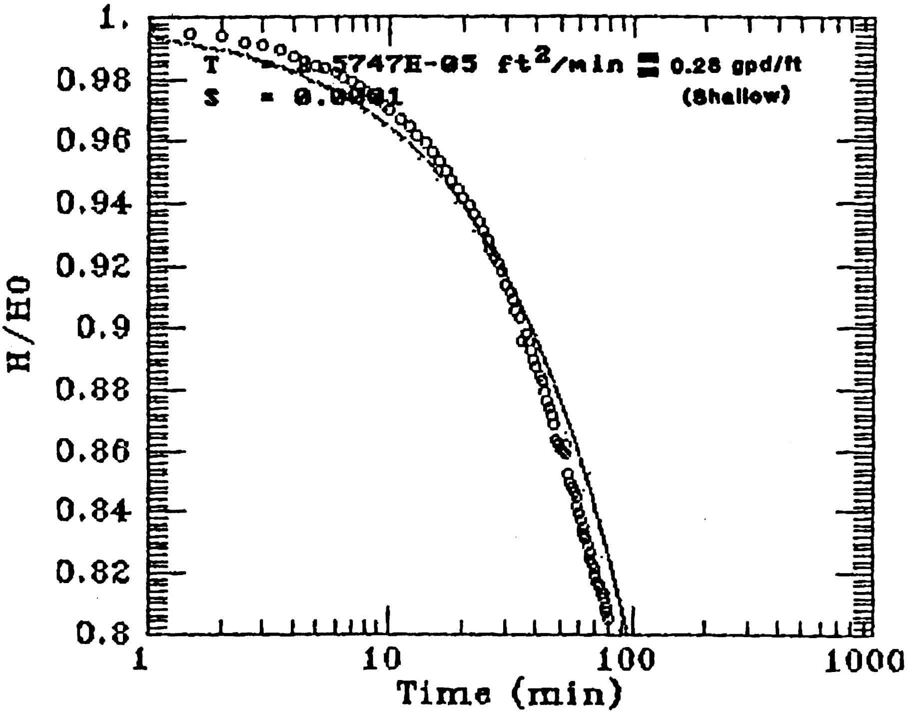
TIME (min)	Depth toWater (ft)	H (ft)	H / Ho
0	24.2	9.26	1
0.5	24.11	9.17	0.99028
1	24.04	9.1	0.98272
1.5	23.97	9.03	0.97516
2	23.89	8.95	0.96652
2.5	23.82	8.88	0.95896
3	23.75	8.81	0.9514
3.5	23.68	8.74	0.94384
4	23.6	8.66	0.93521
4.5	23.54	8.6	0.92871
5	23.47	8.53	0.92117
5.5	23.41	8.47	0.91469
6	23.34	8.4	0.90713
6.5	23.26	8.32	0.89849
7	23.21	8.27	0.89309
7.5	23.15	8.21	0.88661
8	23.08	8.14	0.87905
8.5	23.03	8.09	0.87365
9	22.96	8.02	0.86609
9.5	22.9	7.96	0.85961
10	22.84	7.9	0.85313
11	22.72	7.78	0.84017
12	22.61	7.67	0.82829
13	22.49	7.55	0.81533
14	22.39	7.45	0.80454
15	22.37	7.33	0.79158
16	22.16	7.22	0.7797
17	22.05	7.11	0.76782
18	21.95	7.01	0.75702
19	21.84	6.9	0.74514
20	21.75	6.81	0.73542
21	21.63	6.66	0.71922
22	21.53	6.59	0.71166
23	21.43	6.49	0.70086
24	21.34	6.4	0.69114
25	21.25	6.31	0.68143

26	21.14	6.2	0.66955
27	21.06	6.12	0.66091
28	20.94	6	0.64795
29	20.85	5.91	0.63823
30	20.77	5.83	0.62959
31	20.71	5.77	0.62311
32	20.61	5.67	0.61231
33	20.54	5.6	0.61339
34	20.45	5.51	0.59503
35	20.37	5.43	0.58639
36	20.29	5.35	0.57775
37	20.2	5.26	0.56803
38	20.13	5.19	0.56048
39	20.05	5.11	0.55184
40	19.97	5.03	0.5432
41	19.89	4.95	0.53456
42	19.83	4.89	0.52808
43	19.75	4.81	0.51944
44	19.68	4.74	0.51188
45	19.62	4.68	0.5054
46	19.55	4.61	0.49784
47	19.47	4.53	0.4892
48	19.41	4.47	0.48272
49	19.35	4.41	0.47624
50	19.27	4.33	0.4676
51	19.22	4.28	0.4622
52	19.15	4.21	0.45464
53	19.08	4.14	0.44708
54	19.02	4.08	0.4406
55	18.96	4.02	0.43413
56	18.9	3.96	0.42765
57	18.84	3.9	0.42117
58	18.78	3.84	0.41469
59	18.73	3.79	0.40929
60	18.68	3.74	0.40389


Slug Test Analysis
MW# 4 6/92
T = 0.0009369 ft²/min = 10.3 gpd/ft
(Deep)
S = 0.0001
H/H0
1.
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.1
1.
10.
100
Time (min)

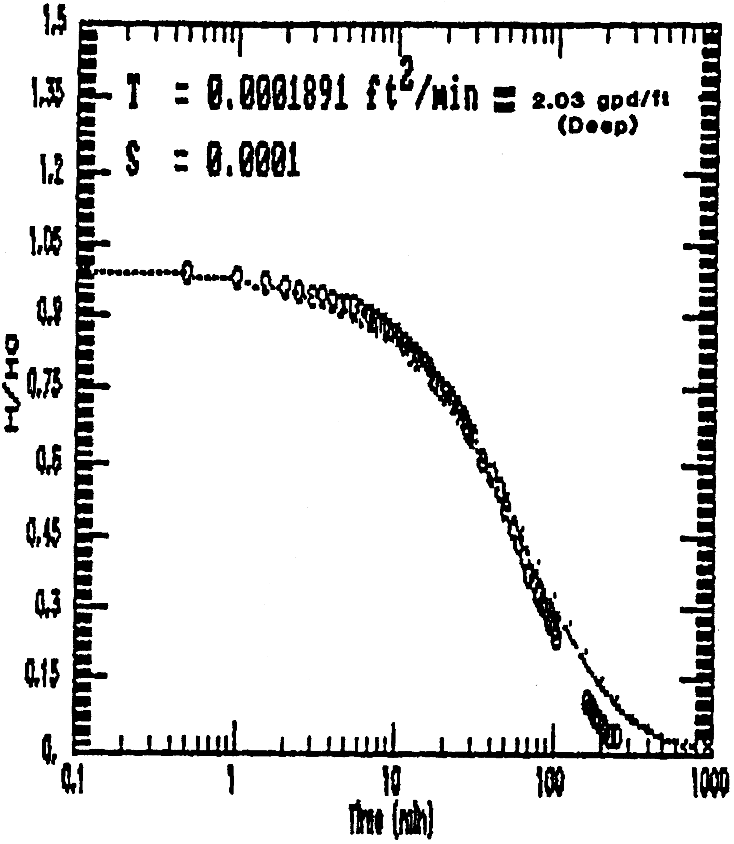
Slug Test Analysis

MW# 5 6/92



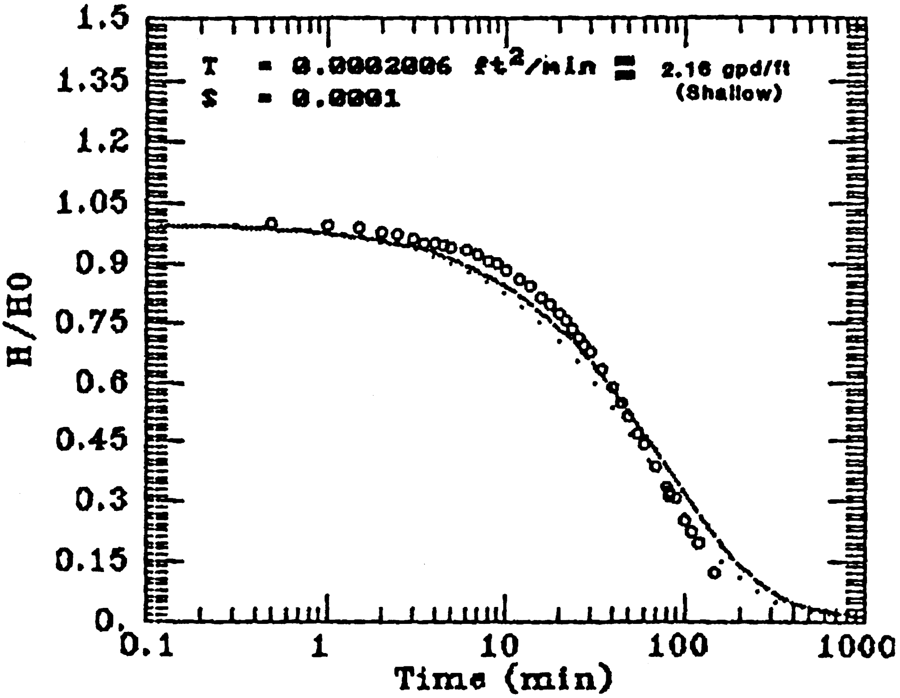
Slug Test Analysis

MW# 7 Fall 1991

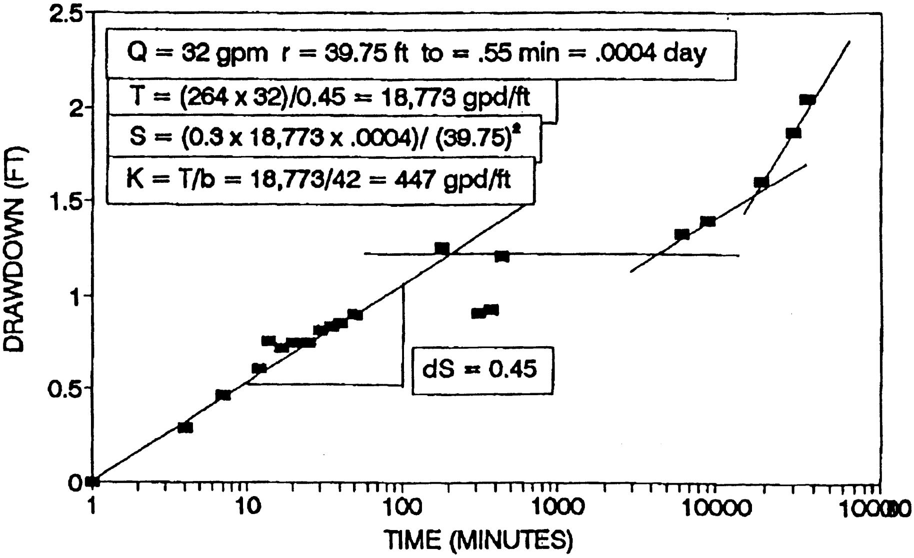


Slug Test Analysis

MW#8 Fall 1991



JACOB ANALYSIS PLOT
OBSERVATION WELL E2


Q = 32 gpm r = 39.75 ft to = .55 min = .0004 day

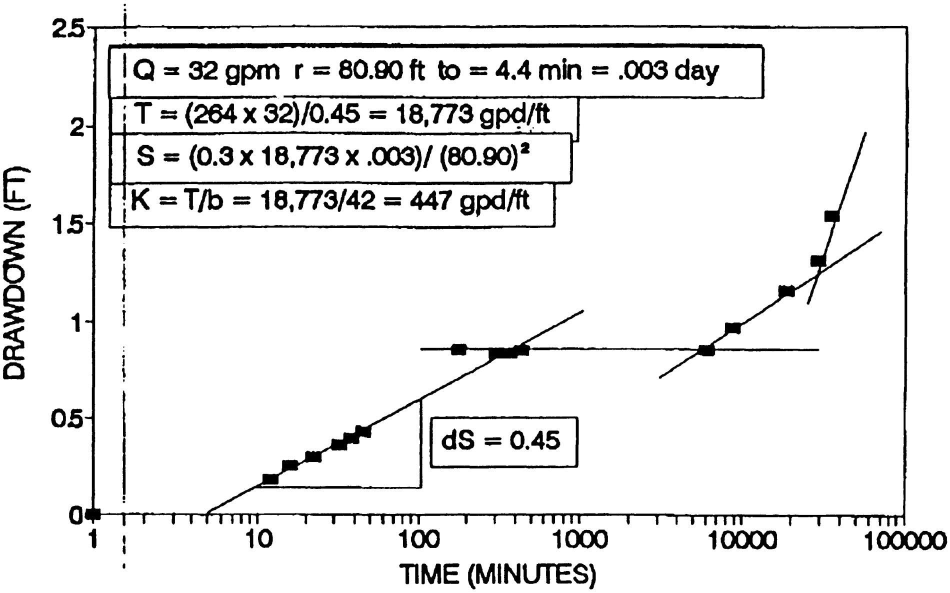
T = (264 x 32)/0.45 = 18,773 gpd/ft

S = (0.3 x 18,773 x .0004)/ $(39.75)^2$

K = T/b = 18,773/42 = 447 gpd/ft

dS = 0.45

JACOB ANALYSIS PLOT
OBSERVATION WELL E3


Q = 32 gpm r = 80.90 ft to = 4.4 min = .003 day

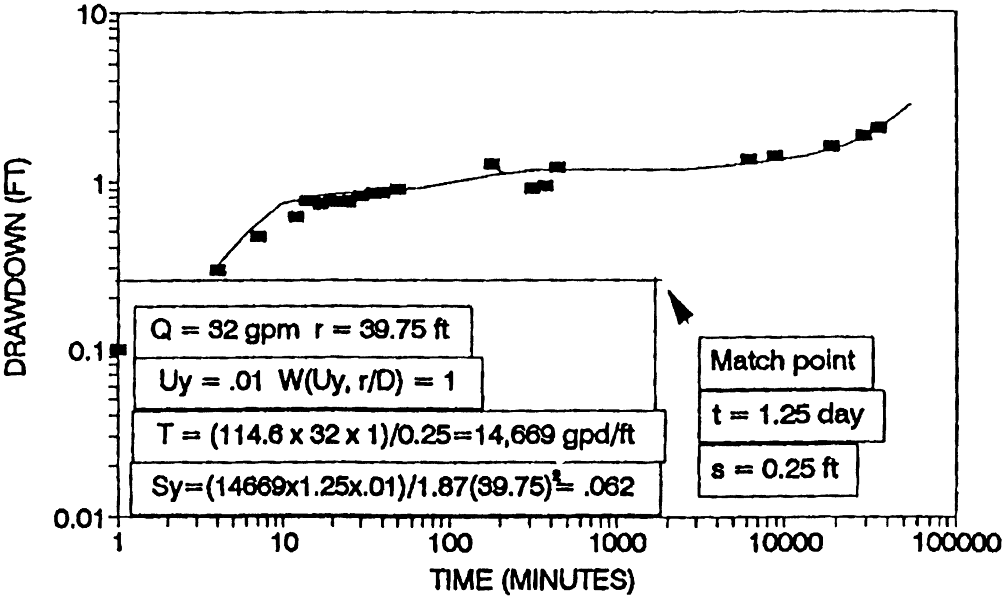
T = (264 x 32)/0.45 = 18,773 gpd/ft

S = (0.3 x 18,773 x .003)/ $(80.90)^2$

K = T/b = 18,773/42 = 447 gpd/ft

dS = 0.45

PRICKETT ANALYSIS PLOT
OBSERVATION WELL E2



Q = 32 gpm r = 39.75 ft

Uy = .01 W(Uy, r/D) = 1

T = (114.6 x 32 x 1)/0.25=14,669 gpd/ft

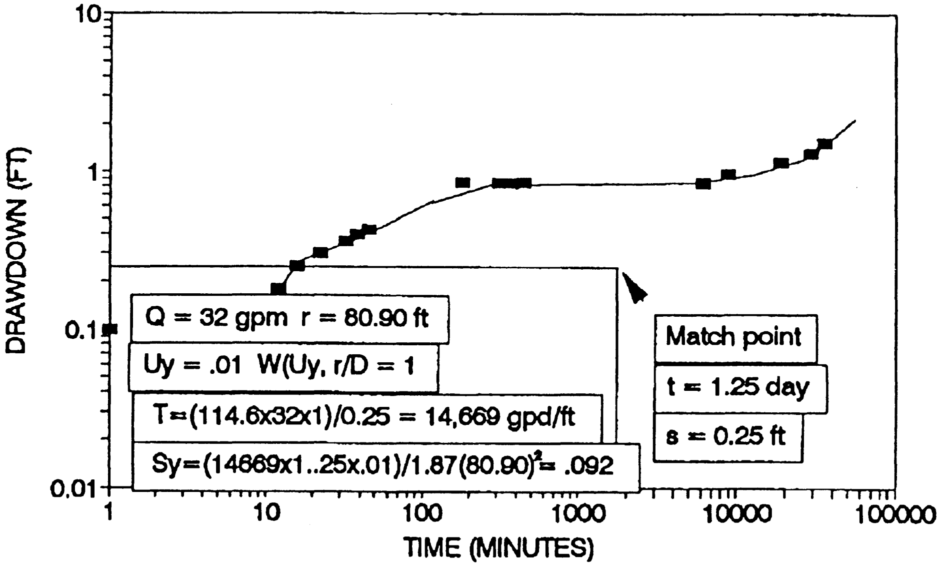
Sy=(14669x1.25x.01)/1.87(39.75)^2= .062

Match point

t = 1.25 day

s = 0.25 ft

PRICKETT ANALYSIS PLOT
OBSERVATION WELL E3



Q = 32 gpm r = 80.90 ft

Uy = .01 W(Uy, r/D = 1

T=(114.6x32x1)/0.25 = 14,669 gpd/ft

Sy=(14669x1..25x.01)/1.87(80.90)^2= .092

Match point

t = 1.25 day

s = 0.25 ft

APPENDIX D

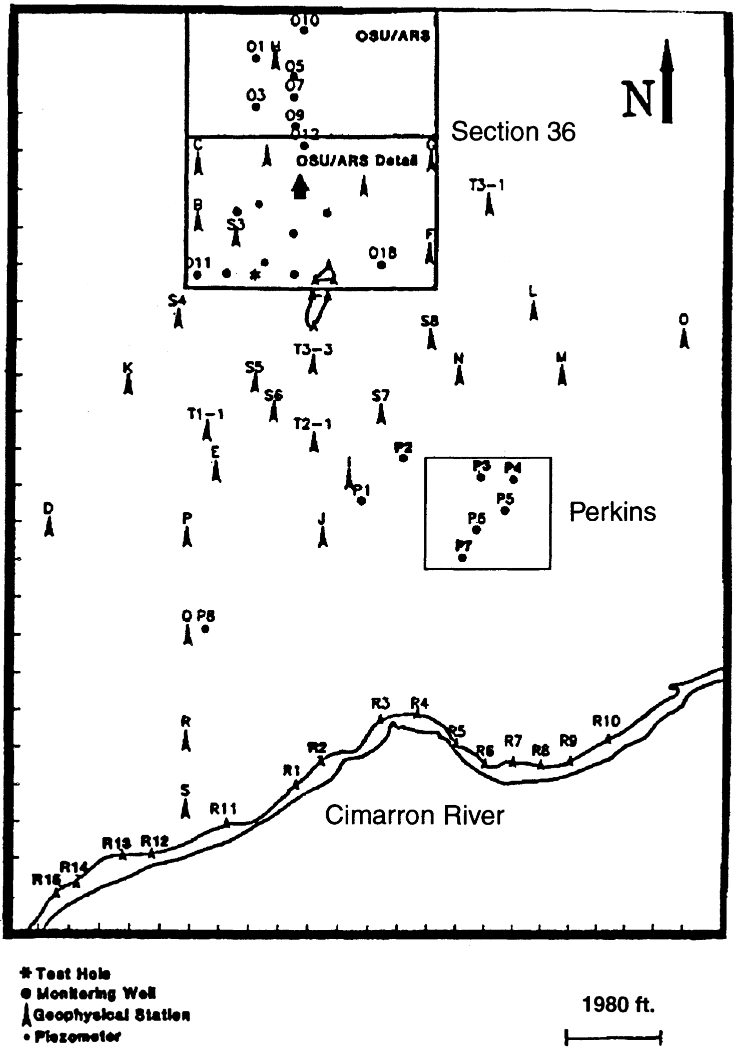
PIEZOMETER, MONITORING WELL, AND GEOPHYSICAL LOCATION AND STATISTICS

OSU/ARS Monitoring Well Statistics.

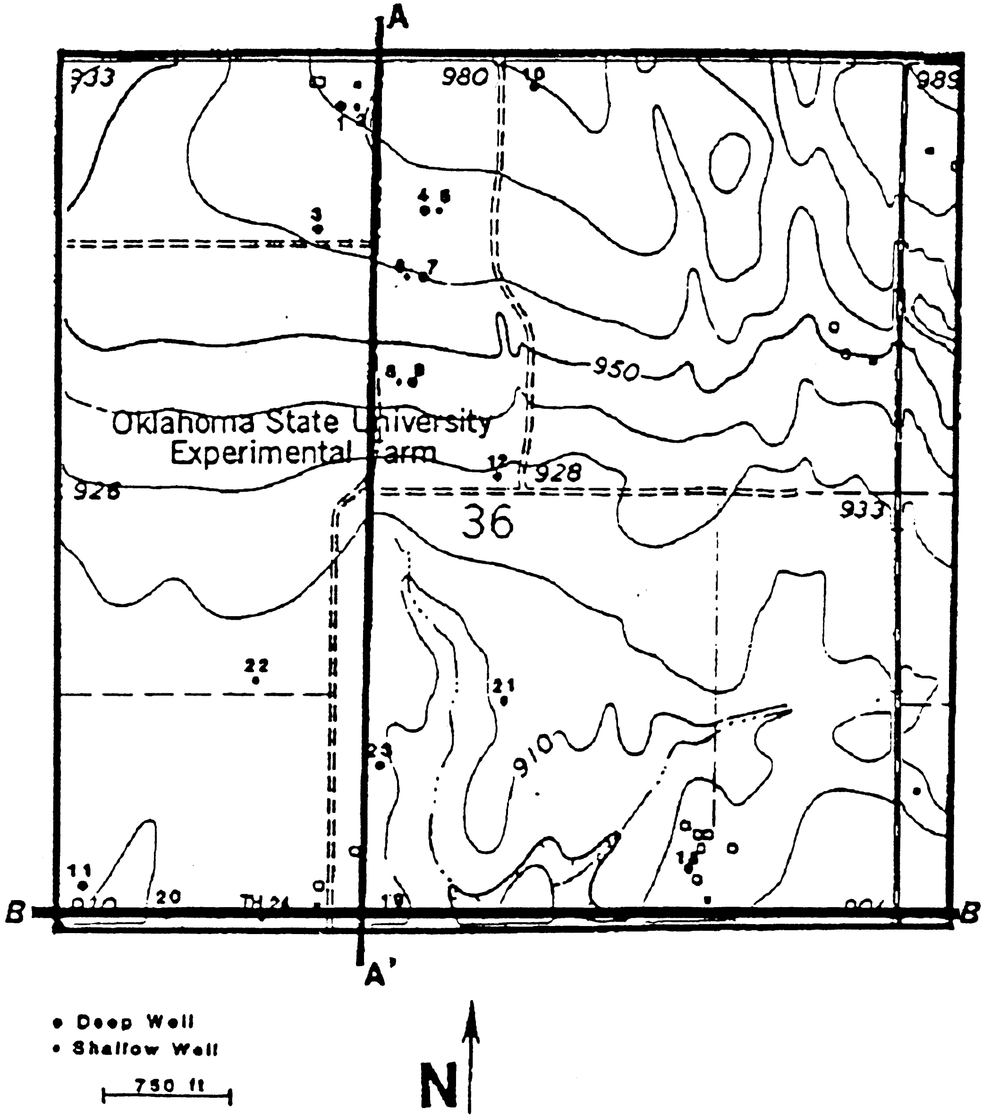
Well ID	TOC-Steel Elev.	Pad Elev.	TOC-PVC Elev.	PVC Casing Stick-up	Surface Elev.	Deth to Bedrock	Bedrock Elev.	Total Depth
1 (D)	971.48	970.09	970.92	1.42	969.5	30	939.5	30
2 (S)	971.49	970.09	971.08	1.38	969.7	N/A	N/A	25
3 (D)	962.93	961.44	962.11	1.5	960.61	25	935.61	25.5
4 (D)	964.86	963.38	963.84	1.46	962.38	46.5	915.88	47
5 (S)	964.83	963.38	964.6	1.39	963.21	N/A	N/A	25
6 (S)	960.31	959.24	959.95	1.2	958.75	N/A	N/A	25
7 (D)	960.34	959.24	959.85	1.2	958.65	39	919.65	39.5
8 (S)	944.66	943.24	943.94	1.4	942.54	N/A	N/A	25
9 (D)	944.53	943.24	943.44	1.27	942.17	35	907.17	35.5
10 (D)	979.15	977.78	978.57	1.4	977.17	39	938.17	39.5
11 (D)	911.11	909.82	910.34	1.29	909.25	51	858.05	51.5
12 (D)	928.05	926.64	927.33	1.55	925.78	51	874.78	51.5
EP (MW18)	914.14	913.89	913.95	0	913.85	57	856.85	58.2
19 (D)	N/A	N/A	919.75	0.61	919.13	40	879.13	34.2
20 (S)	N/A	N/A	910.57	2.71	907.86	50	857.86	25
21 (D)	N/A	N/A	917.22	2.42	914.8	45-50	869.8	40
22 (S)	N/A	N/A	915.53	1.82	913.71	45-50	868.71	35.25
23 (D)	N/A	N/A	915.28	1.13	914.15	36	878.15	36.5
TH24 (D)	N/A	N/A	N/A	N/A	913.27	49	864.27	N/A
W.House	N/A	N/A	917.35	N/A	N/A	N/A	N/A	N/A

(D) - Deep, (S) - Shallow, N/A - Not Available

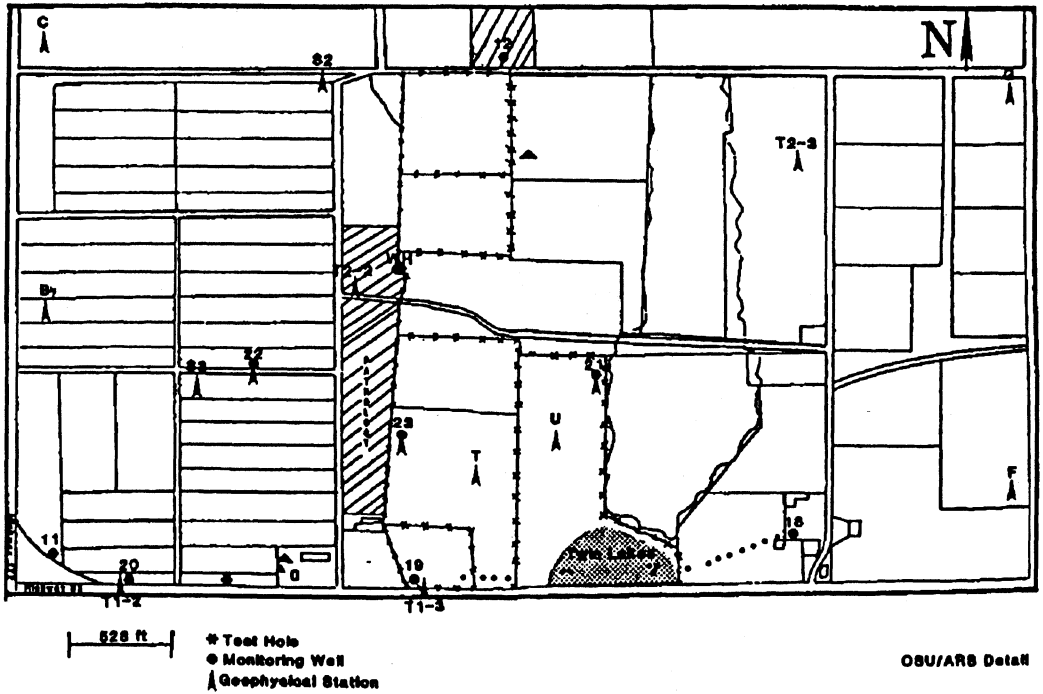
All Measurements are in feet.



Data Locations for Perkins Region



Monitoring Well Location Map of Section 36



Data Locations on OSU Station Detail Map (South Half of Section 36)

ELEVATIONS FOR PERKINS REGION

D = D.C. RESISTIVITY
SU = SURVEYED WITH TRANSIT
Sm = SEISMIC
T = TOPO MAP
L = DRILLER/GAMMA RAY LOG
C = PREVIOUS CLASS DATA
(D) = DEEP WELL (35-50 ft)
(S) = SHALLOW WELL (20-35 ft)
W = COLLECTED DTW DATA CONVERTED TO PSELEV
* = ESTIMATE

A. CONSTANT CONTROL

CONTROL POINT LABEL	TOP OF CASING ELEVATION (ft)	DEPTH TO BEDROCK FROM SURFACE (ft)	TOTAL DEPTH FROM SURFACE (ft)
OSU/ARS MONITORING WELLS			
01 (D)	970.92 SU	30 L	30 L
02 (S)	971.08 SU	N/A	25 L
03 (D)	962.11 SU	25 L	25.5 L
04 (D)	963.84 SU	46.5 L	47 L
05 (S)	964.60 SU	N/A	25 L
06 (S)	959.95 SU	N/A	25 L
07 (D)	959.85 SU	39 L	39.5 L
08 (S)	943.94 SU	N/A	25 L
09 (D)	943.44 SU	35 L	35.5 L
010 (D)	978.57 SU	39 L	39.5 L
011 (D)	910.34 SU	51 L	51.5 L
012 (D)	927.33 SU	51 L	51.5 L
018 (D)	913.95 SU	57 L	58.2 L
019 (D)	919.74 SU	* 40	34.2 L
020 (S)	910.57 SU	* 50	25 L
021 (D)	917.22 SU	* 45-50	40 L
022 (S)	915.53 SU	* 45-50	35.25 L
023 (D)	915.28 SU	36 L	36.5 L
TH24	913.27 SU	49 L	NOT COMPLETED
PIEZOMETERS (CROSS SECTION THROUGH POND)	LOCATIONS INDICATED ONLY ON OSU STATION DETAIL MAP		
P2	912.83 SU	N/A	15 L
P3	911.16 SU	N/A	14 L
P4	905.04 SU	N/A	8 L
P5	902.76 SU	N/A	7 L
P6	902.49 SU	N/A	6.5 L

P7	900.68 SU	N/A	7 L
P8	901.30 SU	N/A	8 L
P11	901.42 SU	N/A	11.5 L
P11b	898.45 SU	N/A	4 L
P11c	898.71 SU	N/A	8 L
P11d	898.72 SU	N/A	6 L
P12	898.73 SU	N/A	8.5 L
P12b	899.96 SU	N/A	2.5 L

CONTROL POINT LABEL	TOP OF CASING ELEVATION (ft)	DEPTH TO BEDROCK FROM SURFACE (ft)	TOTAL DEPTH FROM SURFACE (ft)
P12c	899.95 SU	N/A	4 L
P13	899.80 SU	N/A	12.5 L
P14	900.54 SU	N/A	7.5 L
P15	906.67 SU	N/A	20 L
WELL HOUSE			
WH	917.35 SU	N/A	N/A
IRRIGATION WELL			
IW	912.88 SU	N/A	N/A

B. GEOPHYSICAL CONTROL

CONTROL POINT LABEL	SURFACE ELEVATION (ft)	BEDROCK ELEVATION (ft)	WATER TABLE ELEVATION (ft)
OSU/ARS MONITORING WELLS			
01	970.92 SU	938.92*D	950.92*D
02	971.08 SU	N/A	N/A
03	962.11 SU	937.11*L	N/A
04	963.84 SU	919.84*D	940.84*D
05	964.60 SU	N/A	N/A
06	959.95 SU	N/A	947.85*D
07	959.85 SU	923.85*D	N/A
08	943.94 SU	N/A	927.44*D
09	943.44 SU	907.44*D	N/A
010	978.57 SU	939.57*D	958.57*D
011	910.34 SU	858.34*D	879.34*D
012	927.33 SU	876.33 L	N/A
018	913.95 SU	857.00 L	N/A
019	919.74 SU	N/A	N/A

020	910.57 SU	859.00 L	N/A
021	917.22 SU	N/A	N/A
022	915.53 SU	N/A	N/A
023	915.28 SU	878.78 L	N/A
TH24	913.27 SU	864.27 L	N/A

CONTROL POINT LABEL	SURFACE ELEVATION (ft)	BEDROCK ELEVATION (ft)	WATER TABLE ELEVATION (ft)
GEOPHYSICAL TEAM SITES FALL '91 (TEAM 1 SITE 1 = T1-1)			
T1-1	898.00T	870.00 SM	888.00*D,SM
T1-2	908.00T	858.00D,SM	879.00D
T1-3	920.00T	884.00D,SM	892.00D
T2-1	912.00T	882.00*D	894.00*D
T2-2	912.00T	867.00*D	894.00*D
T2-3	908.00T	878.00*D	902.00*D
T3-1	929.00T	879.00*D	889.00*D
T3-3	899.00T	851.00*D	879.00*D
GEOPHYSICAL STATIONS 1-8 FALL '90			
S1	933.00 SU	881.00 D	903.00*D
S2	914.60 SU	876.60*D	892.60*D
S3	914.60 SU	875.60*D	894.60*D
S4	891.80 SU	851.80*D	873.80*D
S5	906.80 SU	851.80*D	890.80*D
S6	907.09 SU	857.09*D	889.09*D
S7	909.00 SU	854.00*D	889.00*D
S8	908.35 SU	863.35*D	892.35*D
GEOPHYSICAL STATION A TO S FALL '88 - SPRING '91			
B	915.00 C	860.00 C	893.00 C (fall '88)
C	920.00 C	875.00 C	908.00 C " "
D	870.00 C	826.00 C	850.00 C " "
E	895.00 C	847.00 C	865.00 C " "
F	910.00 C	860.00 C	882.00 C " "
G	925.00 C	877.00 C	900.00 C " "
H	960.00 C	912.00 C	940.00 C " "
I	910.00 C	866.00 C	883.00 C " "
J	885.00 C	837.00 C	863.00 C " "
K	895.00 C	846.00 C	873.00 C " "
L	910.00 C	874.00 C	885.00 C " "
M	900.00 C	873.00 C	881.00 C " "

N	910.00 C	850.00 C	883.00 C	" "
O	915.00 C	872.00 C	896.00 C	" "
P	885.00 C	833.00*D	873.00*D	" "
Q	846.00 C	814.00*D	826.00*D	" "
R	840.00 C	810.00 SM	828.00*D	" "
S	838.00 C	806.00*D	822.00*D	" "
T	901.13 SU	866.13 D	891.13 D	(spr. '91)
U	912.13 SU	867.13 D	900.13 D	" "

C. MISCELLANEOUS CONTROL

CITY OF PERKINS WELLS

P1	897.00 C	853.00 L	873.30 C	(fall '88)
P2	905.00 C	N/A	871.00 C	" "
P3	895.00 C	N/A	868.50 C	" "
P4	895.00 C	N/A	861.00 C	" "
P5	886.00 C	824.80 L	858.20 C	" "
P6	884.00 C	839.70 L	860.20 C	" "
P7	875.00 C	N/A	854.00 C	" "
P8	850.00 C	820.00 L	839.00 C	" "

ELEVATIONS TO REPRESENT THE CIMARRON RIVER

R1 TO R15	N/A	805.00 T	825.00 T

ELEVATIONS TO REPRESENT TWIN LAKES

L1 TO L6	N/A	N/A	898.65 (8/92) STAFF GAGE

CONTROL POINT LABEL	TOP OF CASING ELEVATION (ft)	DEPTH TO WATER 7/14/92	8/07/92
OSU/ARS MONITORING WELLS			
01 (D)	970.92 SU	18.50 W	18.51 W
02 (S)	971.08 SU	18.65 W	18.65 W
03 (D)	962.11 SU	16.30 W	15.95 W
04 (D)	963.84 SU	16.45 W	16.12 W
05 (S)	964.60 SU	17.18 W	16.83 W
06 (S)	959.95 SU	15.72 W	15.40 W
07 (D)	959.85 SU	15.61 W	15.30 W
08 (S)	943.94 SU	14.85 W	14.64 W
09 (D)	943.44 SU	14.26 W	14.05 W
010 (D)	978.57 SU	18.22 W	18.30 W
011 (D)	910.34 SU	24.76 W	24.70 W
012 (D)	927.33 SU	30.18 W	29.61 W

018 (D)	913.95 SU	13.29 W	13.22 W
019 (D)	919.74 SU	23.07 W	22.89 W
020 (S)	910.57 SU	24.13 W	24.07 W
021 (D)	917.22 SU	20.17 W	20.24 W
022 (S)	915.53 SU	26.01 W	25.93 W
023 (D)	915.28 SU	23.82 W	23.74 W

CONTROL POINT LABEL	TOP OF CASING ELEVATION (ft)	DEPTH TO WATER	
		7/14/92	8/07/92
PIEZOMETERS (CROSS SECTION THROUGH POND)			
P2	912.83 SU	12.22 W	
P3	911.16 SU	10.85 W	
P4	905.04 SU	5.20 W	
P5	902.76 SU	2.86 W	
P6	902.49 SU	2.65 W	
P7	900.68 SU	1.00 W	
P8	901.30 SU	2.00 W	
P11	901.42 SU	2.74 W	
P11b	898.45 SU	IN POND	
P11c	898.71 SU	IN POND	
P11d	898.72 SU	IN POND	
P12	898.73 SU	UNDER WATER	
P12b	899.96 SU	IN POND	
P12c	899.95 SU	IN POND	
P13	899.80 SU	UNDER WATER	
P14	900.54 SU	UNDER WATER	
P15	906.67 SU	15.32 W	
WELL HOUSE			
WH	917.35 SU	28.60 W	
IRRIGATION WELL			
IW	912.88 SU	26.81	

APPENDIX E

WATER QUALITY DATA

Appendix E: Water Quality Data for Well #1

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
25 March 1986	11.4	NA	832	NA	43	41	4	66	75	38	8.2
9 October 1986	51.8	NA	994	NA	37	62	4	53	122	51	7.6
14 January 1987	93.5	NA	1400	NA	33	57	4	62	138	50	8.2
13 March 1987	149.0	NA	1402	NA	18	85	2	50	149	51	7.9
23 July 1987	78.5	NA	861	NA	48	57	2	38	83	34	7.0
31 October 1987	60.5	NA	797	21	60	5	2	31	88	33	7.3
28 February 1988	66.5	NA	845	NA	43	59	1	31	104	31	6.8
23 June 1988	53.0	NA	790	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	84.0	0.01	834	NA	50	37	2	27	87	29	7.4
31 January 1989	119.0	NA	783	1	46	7	2	29	100	42	6.7
2 March 1989	121.5	NA	800	tr	46	81	17	30	88	34	7.5
8 May 1989	56.8	0.02	858	3	49	58	1	26	159	37	7.1
27 June 1989	56.4	0.03	785	1	59	90	1	29	155	39	7.2
22 September 1989	52.8	NA	839	0	50	56	1	26	101	36	7.5
13 April 1990	48.1	0.01	746	0	43	47	1	25	76	30	7.1
18 July 1990	41.5	0.02	669	1	53	38	1	28	79	31	7.3
28 April 1990	35.8	0.21	629	43	68	154	1	27	79	27	7.3
16 May 1990	37.5	tr	801	4	62	63	1	25	77	26	7.5
25 May 1990	37.9	0.02	760	5	54	77	1	25	74	26	7.6
31 May 1990	41.6	0.05	719	4	53	49	1	25	69	34	7.3
13 June 1990	36.9	0.15	660	7	52	105	1	25	71	28	7.1
29 June 1990	35.1	0.05	677	3	19	43	3	27	72	28	7.2

Appendix E: Water Quality Data for Well #1

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
9 July 1990	36.3	0.03	688	1	24	54	4	28	73	29	7.2
27 July 1990	31.4	tr	648	61	72	28	1	24	66	26	6.9
9 August 1990	34.5	tr	655	19	70	57	1	26	69	27	6.8
9 July 1990	34.1	0.02	705	14	88	47	1	22	68	34	7.1
21 September 1990	34.4	0.01	677	14	81	53	1	21	68	33	6.9
12 October 1990	33.1	tr	604	13	78	47	1	34	71	27	6.7
2 November 1990	33.2	tr	625	10	83	81	1	37	69	27	7.0
16 November 1990	31.1	0.02	634	3	81	77	1	34	70	27	7.4
7 December 1990	31.4	tr	678	11	76	36	1	32	69	27	6.7
17 January 1991	29.5	tr	631	13	81	52	1	33	70	26	6.9
29 January 1991	27.6	tr	656	12	85	13	1	30	74	26	6.6
12 February 1991	28.6	0.02	709	14	76	25	1	31	73	37	7.0
22 February 1991	31.3	tr	719	22	71	26	1	33	71	29	6.4
8 March 1991	28.5	0.02	570	162	85	63	1	36	79	27	6.7
22 March 1991	17.6	tr	432	7	53	16	1	22	56	17	7.4
29 March 1991	29.8	tr	649	13	61	34	1	36	79	28	7.6
5 April 1991	29.6	tr	699	11	57	34	1	34	82	28	6.9
12 April 1991	33.1	tr	701	37	56	36	3	35	82	28	6.9
19 April 1991	32.1	tr	684	14	36	42	1	35	83	29	7.1
26 April 1991	29.7	tr	654	21	59	28	1	34	76	27	6.8
24 May 1991	31.0	0.01	592	11	53	44	1	33	83	28	6.8
31 May 1991	30.1	tr	684	608	32	29	3	34	76	26	6.8

Appendix E: Water Quality Data for Well #1

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
10 June 1991	31.1	tr	559	45	29	52	1	34	74	26	6.7
18 June 1991	31.4	tr	581	8	41	26	1	34	78	27	6.6
3 July 1991	36.2	0.06	728	3477	73	43	5	36	75	27	7.0
19 July 1991	34.3	0.06	566	5	71	42	1	32	78	26	7.2
24 July 1991	34.3	0.06	621	9	71	42	1	33	75	25	7.7
7 August 1991	33.4	0.07	685	3	69	42	1	32	74	29	6.9
12 August 1991	32.9	0.06	772	7	37	42	1	32	79	28	7.0
20 September 1991	33.2	tr	555	2	79	32	3	27	65	27	7.1
22 October 1991	34.4	tr	588	8	83	40	1	27	66	27	7.1

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well # 2

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — — —	— ppm	— —	— — —			
25 March 1986	25.2	NA	NA	NA	81	NA	7	98	64	24	NA
9 October 1986	81.5	NA	982	NA	53	86	4	64	122	47	8.2
14 January 1987	112.0	NA	1388	NA	37	104	3	67	116	41	7.9
13 March 1987	114.0	NA	1230	NA	65	121	2	70	113	41	7.6
23 July 1987	99.0	NA	1005	NA	35	57	1	37	95	40	7.0
31 October 1987	71.8	NA	854	tr	50	49	1	36	95	35	7.3
28 February 1988	65.0	NA	797	NA	47	34	1	32	89	31	6.7
23 June 1988	55.0	NA	756	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	85.5	0.04	803	NA	61	36	1	27	86	29	7.8
31 January 1989	95.0	NA	696	2	66	92	2	27	93	36	7.0
2 March 1989	102.5	NA	733	1	68	78	2	26	75	32	7.5
8 May 1989	50.4	0.01	771	1	67	58	1	24	154	36	7.1
27 June 1989	49.8	0.03	676	0	91	83	1	26	154	37	7.2
22 September 1989	40.8	NA	706	1	81	52	2	25	96	34	7.7
13 April 1990	40.9	0.01	692	tr	55	45	1	25	71	28	7.3
28 April 1990	21.1	0.02	540	1	85	31	2	26	64	24	7.4
16 May 1990	36.3	tr	709	6	67	65	1	25	75	26	7.2
25 May 1990	35.6	0.02	698	177	61	74	1	24	74	27	7.6
31 May 1990	35.5	0.01	714	5	63	58	1	25	60	26	7.7
13 June 1990	33.0	0.11	636	2	53	110	1	25	72	28	6.9
29 June 1990	30.8	0.05	617	1	26	38	1	24	71	27	7.2
9 July 1990	29.0	0.01	634	1	29	37	2	25	68	27	7.2

Appendix E: Water Quality Data for well # 2

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — — ppm — — — — — —						
18 July 1990	34.3	0.01	612	9	66	37	1	26	74	29	7.7
27 July 1990	30.8	tr	608	57	90	27	1	24	65	26	6.8
9 August 1990	26.6	0.02	578	18	84	49	1	24	65	26	6.8
21 September 1990	27.6	0.01	644	12	93	45	2	21	66	31	6.9
12 October 1990	28.3	tr	608	10	104	47	1	32	71	26	6.8
2 November 1990	25.7	0.01	569	13	99	59	1	30	63	25	6.9
16 November 1990	29.9	0.02	608	3	91	77	1	34	67	26	7.7
7 December 1990	23.6	tr	599	6	109	33	1	29	61	24	6.8
17 January 1991	22.9	tr	577	9	110	43	1	35	63	25	6.8
29 January 1991	23.6	tr	610	8	115	23	1	30	70	25	6.5
12 February 1991	27.4	tr	643	9	94	26	1	30	68	89	7.2
22 February 1991	24.8	tr	647	20	101	24	1	30	68	25	6.4
8 March 1991	25.6	tr	589	35	83	24	1	34	77	28	6.7
22 March 1991	9.1	tr	290	1	53	12	0	13	41	11	7.4
29 March 1991	25.3	tr	654	6	89	33	1	33	75	27	6.9
5 April 1991	25.1	tr	684	10	85	33	1	32	81	28	7.4
12 April 1991	23.8	tr	671	18	86	36	1	31	77	27	6.9
19 April 1991	23.6	tr	656	15	68	26	1	33	78	27	7.2
26 April 1991	21.9	tr	489	8	87	21	1	30	61	22	6.8
24 May 1991	26.8	tr	568	9	95	21	1	31	79	27	6.8
31 May 1991	27.1	tr	601	18	102	29	1	31	75	26	6.8
10 June 1991	28.9	tr	604	6	100	55	1	32	77	27	6.6

Appendix E: Water Quality Data for well # 2

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
18 June 1991	28.4	tr	544	8	92	30	1	31	77	27	6.6
3 July 1991	35.8	0.06	714	132	73	45	2	32	78	27	7.1
19 July 1991	31.7	0.07	653	4	78	41	1	34	81	27	7.0
24 July 1991	27.4	0.07	606	6	98	37	1	33	76	25	7.3
7 August 1991	29.1	0.07	656	6	80	38	1	31	76	30	7.1
12 August 1991	29.5	0.07	714	6	51	39	1	31	80	29	7.1
20 September 1991	34.6	tr	538	1	84	49	1	25	69	27	7.7
22 October 1991	34.4	tr	582	5	92	54	1	26	70	28	7.6

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E; Water Quality Data for well #3

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
25 March 1986	7.3	NA	546	NA	33	26	9	60	34	12	7.8
2 July 1986	16.7	NA	546	NA	46	37	8	53	59	19	8.2
9 October 1986	23.4	NA	607	NA	65	48	5	44	65	24	7.8
14 January 1987	32.0	NA	751	NA	55	55	3	44	57	21	8.1
13 March 1987	33.8	NA	626	NA	57	55	2	43	56	22	8.0
23 July 1987	43.8	NA	513	NA	36	23	2	23	56	19	7.9
31 October 1987	48.0	NA	549	tr	38	13	3	31	58	22	7.7
28 February 1988	43.8	NA	548	NA	32	17	2	26	56	21	7.9
23 June 1988	37.0	NA	482	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	49.0	tr	516	NA	44	10	4	213	49	18	7.8
31 January 1989	82.0	NA	491	tr	37	58	3	20	64	24	7.3
2 March 1989	77.8	NA	499	1	36	47	2	18	215	25	7.7
8 May 1989	45.8	0.07	529	tr	29	33	2	17	81	22	7.2
27 June 1989	36.9	0.03	418	1	44	37	2	16	72	21	7.3
22 September 1989	37.1	NA	498	1	46	18	4	21	58	20	7.7
13 April 1990	40.8	0.09	520	1	44	11	3	19	47	20	7.2
28 April 1990	42.8	0.03	552	tr	61	7	3	36	50	21	7.4
16 May 1990	42.0	tr	537	2	42	18	2	28	48	19	7.2
25 May 1990	40.8	0.08	551	2	46	14	2	27	50	19	7.6
31 May 1990	41.6	0.04	553	1	44	17	2	27	45	19	7.9
13 June 1990	39.6	0.03	545	1	40	42	2	24	46	19	7.0
29 June 1990	35.5	tr	487	4	15	9	2	25	48	20	7.2

Appendix E; Water Quality Data for well #3

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — — ppm — — — — — —						
9 July 1990	29.3	0.03	458	31	62	9	3	20	39	17	7.2
18 July 1990	34.5	0.09	474	0	61	12	3	20	48	20	7.4
27 July 1990	36.1	tr	451	5	49	4	2	24	41	18	6.8
9 August 1990	31.6	0.01	425	10	50	7	2	23	40	17	7.0
21 September 1990	31.2	0.19	456	70	53	15	3	19	40	18	7.1
12 October 1990	34.1	tr	445	58	53	17	4	27	48	20	6.8
2 November 1990	25.8	tr	400	6	54	14	3	23	36	17	6.9
16 November 1990	26.4	tr	391	8	52	16	3	27	37	17	7.5
7 December 1990	31.3	tr	448	2	48	12	3	23	42	19	6.9
17 January 1991	39.0	tr	475	5	42	21	2	23	47	20	7.1
29 January 1991	35.8	tr	466	3	46	12	2	22	48	20	6.7
12 February 1991	34.6	tr	488	5	42	15	2	22	47	19	7.1
22 February 1991	41.9	tr	523	22	35	16	2	23	50	21	6.5
8 March 1991	47.9	tr	549	50	32	37	33	29	59	22	6.8
22 March 1991	16.8	tr	249	22	17	8	2	12	24	10	7.1
29 March 1991	42.3	tr	542	17	30	18	2	25	55	21	7.2
5 April 1991	42.9	tr	570	7	26	20	2	24	59	22	7.0
12 April 1991	41.6	tr	547	15	27	24	2	24	56	21	6.9
19 April 1991	40.8	tr	545	13	19	18	2	25	59	21	7.2
26 April 1991	43.5	tr	461	19	34	17	2	27	53	21	6.9
24 May 1991	42.9	0.01	467	23	34	15	2	24	58	21	6.8
31 May 1991	43.3	tr	469	15	39	13	2	23	55	20	6.7

Appendix E; Water Quality Data for well #3

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
10 June 1991	41.9	tr	451	7	33	34	2	26	54	20	6.7
18 June 1991	42.8	tr	424	5	32	17	2	24	52	19	6.7
3 July 1991	43.0	0.06	497	60	33	14	2	22	49	20	7.4
19 July 1991	42.0	0.06	496	2	33	14	2	23	54	20	7.2
24 July 1991	43.4	0.06	504	5	33	14	2	23	52	19	7.1
7 August 1991	43.4	0.07	513	1	32	15	2	23	52	22	6.9
12 August 1991	43.0	0.1	590	12	23	14	2	22	54	19	6.9
20 September 1991	43.3	tr	358	tr	37	24	2	18	40	21	7.3
22 October 1991	46.4	tr	459	tr	34	20	2	19	46	23	7.2

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP Soluble Phosphorus

Appendix E: Water Quality Data for well #4

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
25 March 1986	15.1	NA	585	NA	28	34	5	57	42	15	7.8
2 July 1986	35.3	NA	666	NA	32	39	5	58	77	27	8.3
9 October 1986	41.8	NA	684	NA	36	54	3	40	79	33	7.7
14 January 1987	36.8	NA	878	NA	39	52	4	42	76	29	8.1
13 March 1987	44.3	NA	733	NA	36	55	2	40	72	29	8.0
23 July 1987	35.0	NA	607	NA	30	24	5	34	61	22	8.0
31 October 1987	35.3	NA	586	35	27	4	2	35	65	23	7.6
28 February 1988	34.6	NA	625	NA	33	20	1	35	49	23	7.8
23 June 1988	30.6	NA	577	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	45.0	0.04	583	NA	29	18	4	30	54	22	7.6
31 January 1989	61.3	NA	557	25	31	51	5	31	66	29	7.7
2 March 1989	58.8	NA	580	20	32	40	5	30	55	24	7.8
8 May 1989	27.6	0.02	540	2	33	29	1	27	127	27	7.4
27 June 1989	28.1	0.02	509	6	37	38	1	28	128	29	7.6
22 September 1989	27.8	NA	566	16	30	26	4	29	94	28	7.9
18 July 1990	27.6	0.01	573	38	36	22	4	30	54	22	7.3
18 July 1990	26.8	0.01	528	44	28	21	3	30	56	23	7.4
18 July 1990	27.1	0.04	519	54	29	16	2	30	57	23	7.4
28 April 1990	27.1	0.01	483	38	32	21	1	31	56	23	7.4
16 May 1990	31.0	tr	606	44	24	42	2	29	56	22	7.7
25 May 1990	30.3	0.02	616	72	25	37	3	30	59	22	7.6
31 May 1990	30.1	0.01	545	42	24	34	3	30	54	26	7.7

Appendix E: Water Quality Data for well #4

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — — ppm — — — — — —						
13 June 1990	29.4	0.01	623	24	23	69	6	31	53	23	7.4
29 June 1990	28.6	0.01	574	43	11	18	5	31	59	24	7.2
9 July 1990	28.9	0.02	565	21	14	19	6	32	56	24	7.2
27 July 1990	31.5	tr	579	45	30	12	7	30	52	23	7.3
9 August 1990	31.5	tr	558	56	27	21	7	30	54	23	7.2
9 July 1990	30.6	0.02	612	57	38	22	7	26	55	27	7.3
21 September 1990	30.7	0.01	612	47	39	27	9	29	59	27	7.6
12 October 1990	31.7	tr	585	42	37	30	7	42	60	25	6.9
2 November 1990	30.2	0.01	565	43	38	35	6	38	55	24	7.0
16 November 1990	31.1	tr	589	38	41	33	7	40	57	25	7.3
7 December 1990	28.9	tr	594	43	41	20	7	42	57	25	8.0
17 January 1991	30.6	tr	598	58	38	25	4	39	60	25	7.2
29 January 1991	29.8	tr	580	50	41	12	4	36	62	25	7.0
12 February 1991	31.3	0.03	654	48	33	14	4	38	62	24	7.4
22 February 1991	32.6	tr	627	45	35	12	2	38	60	26	6.7
8 March 1991	34.3	tr	593	91	33	18	2	42	70	27	7.1
22 March 1991	16.6	tr	355	50	18	7	1	24	52	15	7.7
29 March 1991	32.3	tr	636	58	34	17	2	43	71	27	7.6
5 April 1991	30.9	tr	597	63	28	17	2	39	68	25	7.5
12 April 1991	30.5	tr	629	67	26	17	2	41	70	26	7.3
19 April 1991	30.8	tr	650	72	20	14	2	39	71	25	8.0
26 April 1991	30.3	tr	540	73	35	13	2	42	66	26	7.3

Appendix E: Water Quality Data for well #4

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
24 May 1991	31.4	0.01	560	73	34	12	3	59	70	25	7.1
31 May 1991	32.1	tr	553	69	40	14	3	40	67	24	7.1
10 June 1991	31.3	tr	557	62	35	22	2	41	66	25	7.0
18 June 1991	32.0	0.44	550	61	42	11	3	40	65	25	7.1
3 July 1991	34.3	0.06	618	65	33	14	3	38	62	25	7.4
19 July 1991	32.6	0.07	572	51	31	15	3	38	67	25	7.6
24 July 1991	24.8	0.07	384	5	31	9	2	26	35	13	7.0
7 August 1991	31.5	0.07	602	39	33	15	3	38	65	25	7.2
12 August 1991	29.9	0.07	664	44	18	14	4	38	63	22	7.9
20 September 1991	21.4	tr	314	19	24	14	4	21	28	16	7.9
22 October 1991	35.8	tr	539	37	34	17	5	32	52	26	7.5

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #5
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Date	NO3-N	NH4-N	EC	SP	SO4t	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — —	— — ppm	— —	— —	— —	— —	
25 March 1986	55.0	NA	832	NA	33	29	3	61	73	27	7.9
2 July 1986	92.5	NA	873	NA	18	24	4	56	101	25	8.1
9 October 1986	91.0	NA	839	NA	21	36	4	39	98	39	7.4
14 January 1987	73.5	NA	891	NA	29	26	3	36	65	25	7.9
13 March 1987	60.0	NA	685	NA	28	28	2	33	69	22	8.0
23 July 1987	42.0	NA	519	NA	28	17	2	25	51	21	7.8
31 October 1987	64.1	NA	656	tr	15	26	3	35	73	24	7.6
28 February 1988	43.5	NA	553	NA	20	20	2	25	56	20	7.3
23 June 1988	45.5	NA	533	NA	NA	NA	NA	NA	NA	NA	NA
31 January 1989	112.0	NA	572	1	23	56	3	26	71	28	7.5
2 March 1989	118.8	NA	581	1	20	43	2	26	146	24	7.7
8 May 1989	60.3	0.01	613	1	19	29	2	23	131	27	7.2
27 June 1989	59.2	0.05	552	0	22	42	2	24	128	27	7.5
22 September 1989	58.3	NA	675	1	16	23	3	25	156	31	7.8
18 July 1990	50.0	0.1	549	0	21	19	3	26	51	20	7.4
18 July 1990	49.0	0.01	519	0	15	18	3	25	49	20	7.4
13 April 1990	52.3	0.06	566	tr	13	15	2	25	51	20	7.5
18 July 1990	48.3	0.02	522	3	15	14	2	26	53	20	7.4
28 April 1990	49.5	0.04	508	0	17	18	2	26	50	19	7.3
16 May 1990	54.3	tr	589	3	9	38	2	25	50	18	7.4
25 May 1990	51.4	0.07	564	3	8	35	2	25	53	19	7.6
31 May 1990	50.8	0.03	517	1	9	33	2	24	47	19	7.8

Appendix E: Water Quality Data for well #5

Date	NO3-N	NH4-N	EC	SP	SO4t	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — —	— — ppm	— —	— —	— —	— —	
13 June 1990	49.5	0.06	616	2	8	58	2	24	60	19	7.4
29 June 1990	41.6	0.01	486	4	6	13	3	26	49	19	7.2
9 July 1990	43.4	0.02	486	tr	6	14	3	25	47	18	7.2
27 July 1990	48.1	tr	476	5	9	8	2	24	42	17	7.0
9 August 1990	41.6	tr	468	5	13	15	2	25	43	18	6.8
9 July 1990	43.0	0.02	508	10	27	17	3	23	43	18	7.2
21 September 1990	41.1	0.01	484	6	26	21	3	22	41	17	7.2
12 October 1990	39.9	tr	458	1	21	21	2	31	46	18	7.0
2 November 1990	37.9	tr	416	1	24	27	2	29	38	16	7.2
16 November 1990	35.9	tr	441	8	24	25	2	30	38	16	7.0
7 December 1990	34.5	tr	447	1	24	13	2	29	37	16	7.5
17 January 1991	33.8	tr	426	6	27	16	2	29	39	16	7.2
29 January 1991	34.8	tr	420	5	26	11	2	28	40	16	6.9
12 February 1991	36.6	0.01	456	14	22	12	2	27	41	16	7.2
22 February 1991	34.1	tr	424	24	22	3	2	27	37	15	6.6
8 March 1991	34.3	tr	395	17	20	8	2	32	42	16	7.0
22 March 1991	11.2	tr	184	18	11	4	1	12	16	6	7.6
29 March 1991	29.8	tr	426	34	19	13	2	30	47	15	7.2
5 April 1991	28.1	tr	407	24	17	11	2	28	43	15	7.1
12 April 1991	29.3	tr	421	24	16	14	2	28	43	15	7.1
19 April 1991	28.3	tr	432	9	7	11	2	28	42	16	7.8
26 April 1991	31.3	tr	354	14	20	10	2	32	39	15	6.9

Appendix E: Water Quality Data for well #5

Date	NO3-N	NH4-N	EC	SP	SO4t	Cl	K	Na	Ca	Mg	pH
	ppm		µmhos	ppb	ppm						
24 May 1991	31.1	0.06	370	12	19	8	2	29	39	14	7.2
31 May 1991	31.6	tr	345	14	27	10	2	27	39	15	7.0
10 June 1991	31.5	tr	370	12	25	14	2	28	37	14	6.8
18 June 1991	31.4	tr	376	11	17	8	2	27	39	14	6.8
3 July 1991	27.6	0.06	398	6	19	9	2	27	36	15	7.5
19 July 1991	26.2	0.07	350	3	19	9	2	26	36	14	7.1
24 July 1991	32.6	0.07	564	46	18	15	4	39	62	23	7.3
7 August 1991	24.6	0.06	400	2	18	9	2	27	36	16	7.0
12 August 1991	23.2	0.07	423	3	13	9	2	24	34	12	7.2
20 September 1991	25.5	tr	303	tr	22	11	2	20	23	13	7.4
22 October 1991	25.6	tr	331	6	22	11	2	21	24	14	7.2

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #6

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — — — — —		ppm	— — — — — —			
25 March 1986	32.9	NA	601	NA	30	25	3	43	54	19	7.9
2 July 1986	31.3	NA	437	NA	25	14	3	25	50	18	8.0
9 October 1986	26.0	NA	406	NA	32	18	3	17	48	18	7.7
14 January 1987	26.0	NA	446	NA	37	15	3	15	38	15	8.0
13 March 1987	27.5	NA	399	NA	28	17	2	17	42	15	7.9
23 July 1987	34.7	NA	467	NA	26	11	2	17	39	16	7.9
31 October 1987	35.8	NA	402	7	21	13	2	18	43	15	7.7
28 February 1988	28.5	NA	407	NA	26	9	2	18	41	15	7.7
23 June 1988	28.6	NA	383	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	35.8	tr	337	NA	25	6	2	14	32	13	7.6
31 January 1989	47.9	NA	331	206	34	30	2	15	45	17	7.5
2 March 1989	48.1	NA	332	0	26	21	2	14	34	14	7.7
8 May 1989	22.8	0.05	364	tr	30	14	2	14	66	16	7.4
27 June 1989	23.1	0.04	287	tr	34	19	1	15	63	15	7.6
22 September 1989	23.6	NA	336	1	30	11	3	14	35	15	7.7
28 April 1990	25.6	0.02	342	6	26	9	3	15	34	14	7.4
16 May 1990	29.1	tr	388	3	27	19	2	17	37	14	7.3
25 May 1990	28.4	0.03	403	1	27	24	2	17	37	14	7.6
31 May 1990	27.0	0.05	359	1	26	19	2	16	34	15	7.8
13 June 1990	39.3	0.02	641	19	14	63	3	31	57	24	7.3
29 June 1990	25.4	0.01	361	1	8	7	2	17	34	14	7.3
9 July 1990	30.3	0.02	389	66	40	9	3	15	33	15	7.0

Appendix E: Water Quality Data for well #6

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — —	— — — ppm	— — —	— —	— —	— —	
18 July 1990	24.8	0.01	340	0	23	6	2	16	34	14	7.5
27 July 1990	28.2	0.01	359	5	12	4	2	16	32	14	7.0
9 August 1990	27.7	0.01	360	6	27	6	2	15	32	14	6.8
21 September 1990	28.7	0.22	388	72	39	11	3	14	35	14	7.0
12 October 1990	29.4	tr	366	60	34	10	3	18	30	14	6.9
2 November 1990	28.9	tr	347	35	36	12	3	17	32	15	7.1
16 November 1990	28.8	tr	357	19	37	11	3	17	33	16	7.0
7 December 1990	26.6	0.01	367	6	38	6	3	17	33	15	7.5
17 January 1991	26.8	tr	350	8	38	6	3	16	35	16	7.0
29 January 1991	26.6	tr	369	6	42	3	3	23	36	15	6.9
12 February 1991	27.4	tr	363	6	33	5	2	17	36	16	7.2
22 February 1991	21.8	tr	376	15	41	4	2	20	35	15	6.5
8 March 1991	27.4	0.01	348	144	35	3	2	25	41	15	7.0
22 March 1991	11.0	tr	194	41	19	2	1	10	18	7	7.4
29 March 1991	24.8	tr	381	38	36	5	2	20	40	15	7.4
5 April 1991	26.1	tr	359	26	33	6	2	19	40	15	7.2
12 April 1991	26.3	tr	386	16	35	4	2	19	41	16	7.2
19 April 1991	26.0	tr	399	14	25	5	2	19	44	16	7.5
26 April 1991	25.4	0.14	287	10	40	5	3	22	40	16	7.2
24 May 1991	25.9	0.41	327	11	38	2	3	19	41	16	7.1
31 May 1991	26.5	tr	308	13	40	3	3	17	39	15	7.2
10 June 1991	24.8	tr	339	9	9	5	2	19	37	15	6.7

Appendix E: Water Quality Data for well #6

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — — ppm — — — — — — —						
18 June 1991	25.9	0.02	337	9	36	2	2	19	39	15	6.7
3 July 1991	25.7	0.06	365	4	37	3	2	18	35	15	7.5
19 July 1991	23.9	0.06	338	2	39	4	2	20	38	14	7.2
24 July 1991	23.3	0.07	353	2	36	3	2	20	37	14	6.9
7 August 1991	23.2	0.07	393	2	39	3	3	20	35	15	7.0
12 August 1991	22.9	0.08	423	4	34	3	3	18	36	13	7.2
20 September 1991	26.8	tr	298	1	40	6	3	14	25	15	7.1
22 October 1991	26.9	tr	326	1	42	4	3	14	26	16	7.1

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #7

p-1 Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — —	— — —	— ppm	— —	— —	— —	
25 March 1986	21.1	NA	559	NA	28	43	3	52	42	15	7.7
2 July 1986	50.8	NA	718	NA	28	37	4	55	73	29	8.2
9 October 1986	50.3	NA	673	NA	29	59	4	40	73	29	7.4
14 January 1987	48.8	NA	827	NA	33	50	3	42	59	23	8.0
13 March 1987	48.8	NA	701	NA	30	62	2	43	68	28	8.0
23 July 1987	47.8	NA	640	NA	28	34	6	35	78	26	7.6
31 October 1987	42.9	NA	637	12	27	32	5	40	66	24	7.5
28 February 1988	39.5	NA	615	NA	31	22	5	43	67	22	7.7
23 June 1988	36.2	NA	582	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	63.8	0.07	612	NA	23	20	2	34	58	24	7.4
31 January 1989	84.3	NA	568	16	24	58	5	33	67	30	7.4
2 March 1989	87.0	NA	571	21	23	47	3	32	59	24	7.8
8 May 1989	41.0	0.04	577	1	28	33	2	31	136	38	7.4
27 June 1989	42.0	0.04	519	0	27	43	5	34	122	27	7.3
22 September 1989	39.1	NA	570	10	23	26	7	32	63	23	7.8
28 April 1990	37.5	0.01	560	7	22	23	3	14	52	22	7.3
16 May 1990	38.5	tr	620	21	19	49	2	33	56	21	7.7
25 May 1990	40.5	0.01	625	6	18	47	2	34	59	22	7.6
31 May 1990	42.4	0.01	653	14	21	40	2	34	53	25	7.6
13 June 1990	27.3	0.01	390	3	25	37	2	16	31	13	7.3
29 June 1990	36.9	0.06	562	1	9	18	4	15	56	21	7.2
9 July 1990	38.0	0.01	589	35	31	25	3	33	49	23	7.1

Appendix E: Water Quality Data for well #7

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — — — —			ppm — — — — — —			
18 July 1990	39.0	0.02	575	17	21	17	2	34	55	22	7.4
27 July 1990	35.1	0.09	565	26	29	14	3	32	47	21	7.2
9 August 1990	40.3	0.07	561	5	22	25	3	34	56	22	7.2
21 September 1990	38.4	0.02	587	30	33	26	4	28	51	22	7.1
12 October 1990	36.1	tr	555	22	27	36	3	95	50	21	6.9
2 November 1990	37.8	tr	551	23	27	35	4	40	52	21	7.0
16 November 1990	37.6	tr	564	21	29	35	4	41	53	22	7.1
7 December 1990	36.4	0.01	558	17	30	21	4	39	51	22	7.5
17 January 1991	35.3	tr	550	22	29	24	3	41	55	23	7.4
29 January 1991	34.5	tr	576	19	29	10	3	38	57	22	7.0
12 February 1991	30.5	0.02	582	20	24	15	3	39	55	23	7.5
22 February 1991	37.0	tr	595	28	25	10	2	38	54	22	6.7
8 March 1991	32.1	tr	535	41	25	10	2	44	63	24	7.2
22 March 1991	34.4	tr	564	28	24	9	2	43	62	24	7.5
29 March 1991	35.1	tr	599	21	23	11	2	42	60	23	7.4
5 April 1991	35.8	tr	580	21	22	14	2	41	63	23	7.3
12 April 1991	36.0	tr	607	24	21	10	2	41	61	23	7.3
19 April 1991	35.9	tr	606	26	14	14	2	42	65	23	7.7
26 April 1991	33.0	tr	504	22	25	14	6	39	62	22	7.4
24 May 1991	38.4	0.02	501	27	35	7	2	39	61	23	7.3
31 May 1991	33.6	tr	449	27	30	13	2	41	59	22	7.1
10 June 1991	36.4	tr	506	31	30	13	2	41	58	22	7.1

Appendix E: Water Quality Data for well #7

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
18 June 1991	33.4	0.01	522	32	27	10	2	41	57	22	7.0
3 July 1991	36.8	0.07	543	24	26	14	3	40	57	22	7.4
19 July 1991	36.6	0.09	545	3	23	15	3	40	58	21	7.5
24 July 1991	35.0	0.05	531	11	30	15	3	41	55	21	8.0
7 August 1991	33.7	0.05	573	26	24	15	3	38	54	22	7.5
12 August 1991	34.0	0.06	607	28	12	15	3	38	56	20	7.3
20 September 1991	35.8	tr	429	15	27	15	3	31	43	21	8.1
22 October 1991	36.5	tr	480	18	27	16	3	31	44	22	7.4

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #8

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — —	— — —	ppm	— — —	— — —		
25 March 1986	16.8	NA	774	NA	101	36	4	119	32	12	7.9
2 July 1986	17.5	NA	511	NA	49	22	5	80	35	11	8.3
9 October 1986	13.6	NA	464	NA	49	28	4	65	30	10	8.0
14 January 1987	22.7	NA	662	NA	41	26	3	64	35	11	8.2
13 March 1987	27.1	NA	539	NA	32	34	2	56	40	17	8.1
23 July 1987	34.9	NA	473	NA	29	21	3	34	62	15	7.8
31 October 1987	35.0	NA	460	1	33	18	3	25	51	17	7.6
28 February 1988	38.3	NA	595	NA	61	13	3	14	57	19	7.9
23 June 1988	27.0	NA	421	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	48.0	0.01	469	NA	22	10	3	18	48	16	7.6
31 January 1989	72.0	NA	453	1	24	35	3	18	61	22	7.5
2 March 1989	74.5	NA	451	tr	25	29	3	17	48	18	7.9
8 May 1989	35.8	0.03	439	2	26	20	2	17	77	18	7.4
27 June 1989	30.5	0.05	361	1	31	20	3	14	69	16	7.6
22 September 1989	38.5	NA	476	1	24	12	4	16	52	18	7.7
13 April 1990	35.3	0.04	454	0	22	7	3	15	50	16	7.4
28 April 1990	32.7	tr	417	NA	22	8	3	16	48	16	7.4
16 May 1990	38.8	tr	506	3	19	26	3	17	53	18	7.7
25 May 1990	39.3	0.02	521	1	23	18	3	17	53	17	7.7
31 May 1990	39.9	0.03	515	2	22	20	3	16	49	18	7.6
13 June 1990	37.4	0.04	515	2	16	43	3	18	52	19	7.2
29 June 1990	38.3	0.01	497	0	6	7	3	19	51	18	7.2

Appendix E: Water Quality Data for well #8

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
9 July 1990	39.4	0.03	490	0	12	11	4	18	52	19	7.2
18 July 1990	32.3	0.05	428	3	30	10	3	16	51	17	7.4
27 July 1990	36.8	0.01	457	4	24	6	3	17	52	19	7.0
9 August 1990	40.6	0.08	443	22	21	10	2	16	46	28	6.9
21 September 1990	37.3	0.04	487	10	30	9	4	14	49	16	7.2
12 October 1990	37.1	tr	436	13	28	19	3	19	46	17	7.1
2 November 1990	36.4	tr	482	-1	31	16	3	18	52	19	7.2
16 November 1990	36.8	tr	475	6	34	16	3	19	53	19	7.2
7 December 1990	40.5	0.01	504	2	32	11	4	20	59	21	7.5
17 January 1991	44.9	tr	473	7	28	12	3	22	57	21	7.3
29 January 1991	46.5	tr	553	5	30	10	3	22	62	23	7.0
12 February 1991	45.1	0.01	586	7	23	10	3	23	60	24	7.3
22 February 1991	47.3	tr	585	10	23	7	3	25	57	22	6.6
8 March 1991	44.8	0.01	534	129	21	6	3	30	67	23	7.1
22 March 1991	28.8	tr	350	38	13	6	2	17	39	15	7.5
29 March 1991	48.4	tr	602	9	15	8	3	28	64	23	7.5
5 April 1991	47.9	tr	590	12	17	12	3	25	66	22	7.3
12 April 1991	47.4	tr	597	12	18	10	3	26	67	22	7.1
19 April 1991	46.0	tr	605	18	9	10	3	26	69	23	7.6
26 April 1991	46.4	tr	485	20	21	8	4	25	67	22	7.2
24 May 1991	46.6	0.43	512	20	19	5	3	24	65	23	7.2
31 May 1991	46.6	tr	444	26	15	8	3	24	63	21	7.1

Appendix E: Water Quality Data for well #8

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
10 June 1991	46.1	tr	476	9	23	9	3	23	57	20	6.8
18 June 1991	40.6	tr	439	18	33	5	3	21	54	19	7.4
3 July 1991	45.4	0.07	467	31	21	5	3	22	53	20	7.4
19 July 1991	46.2	0.08	500	3	22	7	4	22	57	19	7.3
24 July 1991	46.0	0.08	522	2	22	6	3	23	57	21	7.1
7 August 1991	46.9	0.07	539	6	21	5	3	22	54	21	7.0
12 August 1991	47.2	0.06	572	4	11	6	4	23	58	19	7.7
20 September 1991	47.8	tr	409	tr	24	7	3	18	45	20	7.6
22 October 1991	43.6	tr	443	2	30	8	3	16	49	21	7.4

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #9

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — — — — —			ppm — — —	— — —		
25 March 1986	23.7	NA	471	NA	12	45	20	66	19	1	9.8
2 July 1986	36.3	NA	491	NA	8	33	13	56	39	12	8.1
9 October 1986	31.1	NA	361	NA	16	52	17	43	18	1	7.7
14 January 1987	32.0	NA	471	NA	14	41	18	47	10	2	8.0
13 March 1987	32.2	NA	421	NA	13	46	15	48	21	4	8.0
23 July 1987	37.6	NA	596	NA	13	33	6	39	90	12	7.9
31 October 1987	37.3	NA	622	45	16	37	4	41	69	19	7.6
28 February 1988	36.1	NA	661	NA	14	26	3	46	75	21	8.1
23 June 1988	39.0	NA	621	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	57.0	0.03	617	NA	10	28	3	36	59	21	7.9
31 January 1989	84.0	NA	611	51	10	69	3	36	76	26	7.5
2 March 1989	79.5	NA	625	47	11	63	3	35	62	22	7.9
8 May 1989	41.3	0.04	592	229	14	53	3	34	93	23	7.4
27 June 1989	41.1	0.03	578	35	16	65	2	36	95	28	7.5
22 September 1989	41.8	NA	641	36	13	44	3	35	68	23	8.0
13 April 1990	35.4	0.06	643	21	12	32	3	16	64	23	7.5
28 April 1990	36.2	tr	623	25	17	32	5	37	64	23	7.4
16 May 1990	27.4	tr	593	48	27	38	30	49	40	13	7.9
25 May 1990	36.3	0.05	691	39	15	51	13	42	60	19	7.7
31 May 1990	38.8	0.08	701	50	13	55	8	39	61	21	8.3
13 June 1990	29.1	0.01	698	47	8	105	5	37	65	22	7.6
29 June 1990	36.3	0.02	654	37	6	27	5	36	68	23	7.2

Appendix E: Water Quality Data for well #9

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— —	— —	— —	ppm	— —	— —	
9 July 1990	35.2	0.01	616	42	13	31	8	35	62	20	7.2
18 July 1990	37.7	0.05	585	60	14	32	3	38	61	23	7.3
27 July 1990	36.9	tr	626	52	23	30	5	37	57	21	7.4
9 August 1990	39.2	tr	623	61	18	46	3	36	60	23	7.3
21 September 1990	37.8	0.02	657	72	17	36	3	32	64	24	7.4
12 October 1990	36.4	tr	610	65	17	62	2	50	61	23	7.1
2 November 1990	38.0	tr	446	13	34	17	3	19	52	17	7.3
17 January 1991	37.3	tr	565	77	18	42	2	45	64	23	7.4
29 January 1991	37.8	tr	627	71	20	15	2	41	70	23	7.3
12 February 1991	39.8	0.01	673	72	14	27	2	39	70	31	7.5
22 February 1991	39.6	0.01	682	63	19	17	2	43	65	24	6.9
8 March 1991	39.9	0.03	604	90	16	17	2	45	71	24	7.2
22 March 1991	21.2	tr	397	50	11	10	1	27	51	14	7.9
29 March 1991	37.6	tr	695	72	10	17	2	47	75	24	7.8
5 April 1991	37.8	tr	700	64	12	28	2	45	78	24	7.5
12 April 1991	37.3	tr	682	68	13	21	2	45	77	24	7.7
19 April 1991	34.4	tr	708	72	tr	21	2	46	81	24	7.9
26 April 1991	37.5	tr	560	66	16	14	2	42	74	23	7.5
24 May 1991	37.4	0.02	536	69	14	18	2	43	75	24	7.4
31 May 1991	36.9	tr	586	73	14	26	2	42	68	22	7.3
10 June 1991	37.8	tr	524	64	15	29	2	46	67	23	7.2
18 June 1991	37.1	tr	597	67	14	19	2	45	69	23	7.8

Appendix E: Water Quality Data for well #9

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
3 July 1991	36.8	0.07	568	70	14	20	2	42	61	22	7.7
19 July 1991	38.4	0.06	582	44	16	21	2	43	66	22	7.8
24 July 1991	37.7	0.06	634	45	16	21	2	44	66	23	7.5
7 August 1991	37.3	0.08	688	94	13	21	2	42	62	23	7.9
12 August 1991	36.8	0.05	676	63	2	20	2	42	65	20	7.4
20 September 1991	41.7	tr	496	32	tr	17	2	34	54	21	8.1
22 October 1991	42.4	tr	544	35	tr	24	2	32	56	21	8.1

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #10

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
25 March 1986	23.7	NA	471	NA	12	45	20	66	19	1	9.8
2 July 1986	36.3	NA	491	NA	8	33	13	56	39	12	8.1
9 October 1986	31.1	NA	361	NA	16	52	17	43	18	1	7.7
14 January 1987	32.0	NA	471	NA	14	41	18	47	10	2	8.0
13 March 1987	32.2	NA	421	NA	13	46	15	48	21	4	8.0
23 July 1987	37.6	NA	596	NA	13	33	6	39	90	12	7.9
31 October 1987	37.3	NA	622	45	16	37	4	41	69	19	7.6
28 February 1988	36.1	NA	661	NA	14	26	3	46	75	21	8.1
23 June 1988	39.0	NA	621	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	57.0	0.03	617	NA	10	28	3	36	59	21	7.9
31 January 1989	84.0	NA	611	51	10	69	3	36	76	26	7.5
2 March 1989	79.5	NA	625	47	11	63	3	35	62	22	7.9
8 May 1989	41.3	0.04	592	229	14	53	3	34	93	23	7.4
27 June 1989	41.1	0.03	578	35	16	65	2	36	95	28	7.5
22 September 1989	41.8	NA	641	36	13	44	3	35	68	23	8.0
13 April 1990	35.4	0.06	643	21	12	32	3	16	64	23	7.5
28 April 1990	36.2	tr	623	25	17	32	5	37	64	23	7.4
16 May 1990	27.4	tr	593	48	27	38	30	49	40	13	7.9
25 May 1990	36.3	0.05	691	39	15	51	13	42	60	19	7.7
31 May 1990	38.8	0.08	701	50	13	55	8	39	61	21	8.3
13 June 1990	29.1	0.01	698	47	8	105	5	37	65	22	7.6
29 June 1990	36.3	0.02	654	37	6	27	5	36	68	23	7.2

Appendix E: Water Quality Data for well #10

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
9 July 1990	35.2	0.01	616	42	13	31	8	35	62	20	7.2
18 July 1990	37.7	0.05	585	60	14	32	3	38	61	23	7.3
27 July 1990	36.9	tr	626	52	23	30	5	37	57	21	7.4
9 August 1990	39.2	tr	623	61	18	46	3	36	60	23	7.3
21 September 1990	37.8	0.02	657	72	17	36	3	32	64	24	7.4
12 October 1990	36.4	tr	610	65	17	62	2	50	61	23	7.1
2 November 1990	38.0	tr	446	13	34	17	3	19	52	17	7.3
17 January 1991	37.3	tr	565	77	18	42	2	45	64	23	7.4
29 January 1991	37.8	tr	627	71	20	15	2	41	70	23	7.3
12 February 1991	39.8	0.01	673	72	14	27	2	39	70	31	7.5
22 February 1991	39.6	0.01	682	63	19	17	2	43	65	24	6.9
8 March 1991	39.9	0.03	604	90	16	17	2	45	71	24	7.2
22 March 1991	21.2	tr	397	50	11	10	1	27	51	14	7.9
29 March 1991	37.6	tr	695	72	10	17	2	47	75	24	7.8
5 April 1991	37.8	tr	700	64	12	28	2	45	78	24	7.5
12 April 1991	37.3	tr	682	68	13	21	2	45	77	24	7.7
19 April 1991	34.4	tr	708	72	tr	21	2	46	81	24	7.9
26 April 1991	37.5	tr	560	66	16	14	2	42	74	23	7.5
24 May 1991	37.4	0.02	536	69	14	18	2	43	75	24	7.4
31 May 1991	36.9	tr	586	73	14	26	2	42	68	22	7.3
10 June 1991	37.8	tr	524	64	15	29	2	46	67	23	7.2
18 June 1991	37.1	tr	597	67	14	19	2	45	69	23	7.8

Appendix E: Water Quality Data for well #10

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
3 July 1991	36.8	0.07	568	70	14	20	2	42	61	22	7.7
19 July 1991	38.4	0.06	582	44	16	21	2	43	66	22	7.8
24 July 1991	37.7	0.06	634	45	16	21	2	44	66	23	7.5
7 August 1991	37.3	0.08	688	94	13	21	2	42	62	23	7.9
12 August 1991	36.8	0.05	676	63	2	20	2	42	65	20	7.4
20 September 1991	41.7	tr	496	32	tr	17	2	34	54	21	8.1
22 October 1991	42.4	tr	544	35	tr	24	2	32	56	21	8.1

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #11

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
25 March 1986	8.3	NA	832	NA	49	85	4	46	69	24	8.1
9 October 1986	5.1	NA	436	NA	24	42	5	32	47	16	7.8
14 January 1987	4.5	NA	522	NA	25	42	4	30	41	1	8.2
13 March 1987	4.5	NA	441	NA	22	48	3	30	42	16	8.0
23 July 1987	5.3	NA	420	NA	18	36	4	26	49	20	7.9
31 October 1987	5.7	NA	384	65	18	35	5	24	44	13	7.8
28 February 1988	5.2	NA	390	NA	20	26	4	24	42	12	8.0
23 June 1988	4.4	NA	339	NA	NA	NA	NA	NA	NA	NA	NA
5 November 1988	6.5	0.04	347	NA	11	20	4	20	36	13	7.6
31 January 1989	9.8	NA	337	49	13	63	5	20	47	18	7.3
2 March 1989	10.6	NA	351	66	13	49	4	20	39	14	7.8
8 May 1989	3.1	0.05	374	71	13	29	4	16	69	16	7.6
27 June 1989	3.4	0.02	327	46	16	35	4	17	65	16	7.4
22 September 1989	3.7	NA	360	76	13	32	5	17	41	16	8.0
13 April 1990	3.4	0.03	368	79	13	22	4	18	39	14	7.8
28 April 1990	3.5	0.03	327	84	14	24	5	19	39	15	7.4
16 May 1990	3.6	tr	388	95	8	31	5	18	34	14	7.6
31 May 1990	3.6	0.01	374	190	7	34	4	18	36	15	8.3
13 June 1990	3.3	0.02	392	80	6	69	5	19	39	15	7.3
29 June 1990	3.0	tr	323	92	22	17	5	18	37	15	7.3
9 July 1990	3.0	0.02	339	87	14	15	5	19	38	15	7.3
18 July 1990	4.0	0.12	336	72	15	31	5	20	40	15	7.4

Appendix E: Water Quality Data for well #11

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — — ppm — — — — — — —						
9 August 1990	3.1	0.01	331	95	11	21	4	18	35	15	7.1
12 October 1990	2.5	tr	327	8	17	32	4	21	33	14	7.1
2 November 1990	2.8	tr	333	98	14	33	4	20	40	14	7.0
16 November 1990	2.3	tr	345	21	19	28	4	20	35	14	6.9
7 December 1990	3.1	0.02	338	97	17	23	4	19	38	14	7.1
17 January 1991	3.2	tr	283	105	15	22	4	20	35	14	6.8
29 January 1991	3.2	tr	352	105	19	20	4	20	38	15	7.0
12 February 1991	3.3	0.01	364	104	10	23	4	20	37	17	7.4
22 February 1991	3.0	0.01	351	106	12	17	4	19	38	15	6.8
8 March 1991	2.7	tr	300	115	11	19	5	17	42	15	7.2
22 March 1991	1.2	tr	174	81	-1	7	2	8	27	7	7.8
29 March 1991	1.8	tr	320	107	4	21	4	18	40	15	7.4
5 April 1991	2.4	tr	357	120	7	26	4	16	42	15	7.2
12 April 1991	2.5	tr	343	114	tr	20	4	18	45	16	7.3
19 April 1991	2.4	tr	358	122	tr	17	4	18	45	15	7.3
26 April 1991	2.9	tr	265	121	10	17	5	17	42	15	7.1
24 May 1991	2.7	0.02	308	134	11	14	5	15	41	15	7.1
31 May 1991	2.4	tr	302	115	29	17	4	16	39	14	7.0
10 June 1991	2.4	tr	302	119	13	20	4	15	39	14	7.0
18 June 1991	2.4	0.01	306	121	8	14	4	15	40	14	6.9
3 July 1991	2.5	0.12	301	108	11	13	4	14	37	14	7.5
19 July 1991	2.6	0.09	298	105	13	14	4	17	39	14	7.7

Appendix E: Water Quality Data for well #11

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — — ppm — — — — — —						
24 July 1991	3.4	0.07	305	112	13	14	4	15	37	15	7.7
7 August 1991	3.2	0.06	371	128	10	14	4	14	38	15	7.1
12 August 1991	2.9	0.06	343	126	6	14	4	14	38	13	7.4
20 September 1991	3.7	0.4	270	51	tr	23	8	12	27	14	7.1
22 October 1991	2.8	0.1	292	71	tr	9	4	12	26	14	7.0

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #12

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		µmhos	ppb	— — — — — — ppm — — — — — —						
25 March 1986	6.8	NA	406	NA	17	34	2	44	25	8	8.1
2 July 1986	6.7	NA	344	NA	17	25	3	50	33	7	8.2
9 October 1986	36.0	NA	495	NA	17	42	4	36	48	17	7.7
14 January 1987	36.7	NA	636	NA	17	37	3	36	43	16	8.0
13 March 1987	36.8	NA	539	NA	17	40	2	38	47	16	8.0
31 October 1987	0.2	NA	546	NA	17	19	18	30	55	18	7.7
28 February 1988	3.7	NA	401	NA	21	21	2	41	18	9	8.2
23 June 1988	6.4	NA	355	NA	NA	NA	NA	NA	NA	NA	NA
2 March 1989	67.0	NA	486	tr	14	56	3	37	40	15	7.9
8 May 1989	32.8	0.05	484	tr	17	45	3	35	67	16	7.7
27 June 1989	50.5	0.02	531	1	15	37	3	28	80	22	7.4
22 September 1989	50.5	NA	590	1	12	30	3	26	59	21	7.7
13 April 1990	48.8	0.06	592	0	11	21	3	29	59	21	7.8
28 April 1990	45.3	0.02	578	7	12	20	3	29	56	21	7.3
16 May 1990	48.3	tr	629	6	8	40	3	28	56	20	7.6
25 May 1990	47.1	tr	615	3	7	35	3	28	57	20	7.9
31 May 1990	41.8	0.02	602	4	7	34	3	28	55	20	8.2
13 June 1990	40.9	tr	621	5	5	56	3	28	55	19	8.0
29 June 1990	38.4	0.03	528	7	13	14	3	28	52	18	7.2
9 July 1990	35.4	0.01	534	6	14	13	4	28	50	18	7.2
18 July 1990	42.1	tr	555	8	11	23	2	29	54	20	7.4
27 July 1990	38.8	0.01	506	12	14	13	3	31	49	17	8.2

Appendix E: Water Quality Data for well #12

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm — —		μmhos	ppb	— — — — — — ppm — — — — — —						
9 August 1990	34.5	0.03	481	14	13	17	3	29	48	18	8.3
21 September 1990	37.5	0.02	526	14	18	21	4	26	46	16	8.1
12 October 1990	30.6	tr	404	13	19	29	4	33	36	13	7.3
2 November 1990	15.4	tr	338	23	13	62	2	26	32	15	7.3
16 November 1990	27.5	tr	419	29	21	24	4	32	36	13	7.2
7 December 1990	26.3	0.01	383	19	21	17	4	30	36	11	7.4
17 January 1991	32.3	tr	384	17	20	18	4	34	42	14	7.4
29 January 1991	25.5	tr	380	21	20	13	4	28	36	11	7.4
12 February 1991	28.9	0.02	408	23	18	17	4	30	37	17	7.7
22 February 1991	29.9	0.01	475	25	17	11	4	32	44	16	7.5
8 March 1991	32.1	tr	444	42	15	13	4	35	52	15	7.3
22 March 1991	11.2	tr	174	17	4	6	1	12	21	6	7.9
29 March 1991	33.0	tr	520	36	11	13	4	38	54	17	7.8
5 April 1991	34.1	tr	500	46	13	17	4	36	55	16	7.8
12 April 1991	34.4	tr	510	59	tr	14	4	36	54	17	7.8
19 April 1991	32.0	tr	529	51	tr	12	4	36	57	17	7.9
26 April 1991	37.1	0.05	462	47	15	14	4	35	61	18	7.5
24 May 1991	36.3	tr	522	49	13	11	3	34	65	21	7.4
31 May 1991	40.1	tr	448	31	19	15	3	33	61	19	7.3
10 June 1991	36.5	tr	502	36	18	18	3	33	61	19	7.2
18 June 1991	40.4	0.01	455	34	13	6	3	32	59	19	7.2
3 July 1991	42.8	0.06	485	36	16	13	3	31	57	20	7.4

Appendix E: Water Quality Data for well #12

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — —	— — —	— — ppm	— — —	— —	— —	
19 July 1991	43.5	0.07	509	30	16	13	3	30	59	18	7.4
24 July 1991	41.8	0.07	511	31	17	13	3	43	55	18	7.3
7 August 1991	41.7	0.06	599	25	13	13	3	29	57	19	7.3
12 August 1991	40.8	0.06	581	26	7	13	3	29	57	18	7.3
20 September 1991	39.7	tr	400	12	tr	19	3	23	44	18	7.8
22 October 1991	42.7	tr	481	19	tr	15	3	27	41	19	7.3

tr - Trace Amount; NA - Not Available; EC - Electrical Conductivity; SP - Soluble Phosphorus

Appendix E: Water Quality Data for well #18 (ep)

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — —	— — ppm	— —	— —	— —	— —	
14 January 1987	4.9	NA	382	NA	33	31	2	37	21	6	8.0
13 March 1987	4.9	NA	352	NA	20	35	1	40	24	9	8.1
5 November 1988	8.4	0.02	328	NA	16	14	1	36	26	9	7.7
31 January 1989	10.0	NA	310	138	19	38	2	35	33	11	7.4
2 March 1989	9.4	NA	329	75	19	37	2	35	27	10	7.9
8 May 1989	4.5	0.04	331	92	17	27	1	32	55	10	7.6
27 June 1989	6.4	0.02	294	62	18	30	2	34	52	11	7.8
22 September 1989	4.8	NA	321	90	15	26	2	33	29	13	7.9
13 April 1990	6.5	0.03	337	85	14	23	2	34	27	10	7.9
28 April 1990	6.9	0.06	324	83	13	24	2	36	26	10	7.4
16 May 1990	8.5	tr	365	76	8	37	2	34	29	9	7.6
25 May 1990	7.0	tr	366	78	10	34	1	35	23	9	7.8
31 May 1990	6.0	tr	359	92	11	31	2	37	25	9	7.9
13 June 1990	5.8	0.01	387	163	9	66	1	36	30	10	7.8
29 June 1990	7.4	0.01	330	89	16	19	3	36	26	10	7.3
9 July 1990	6.4	0.01	345	121	20	31	2	30	25	10	7.3
18 July 1990	8.3	0.04	314	50	13	23	2	36	27	10	7.4
27 July 1990	5.7	tr	325	89	14	18	1	35	24	10	7.3
21 September 1990	6.5	0.02	369	107	19	29	2	34	26	10	7.3
12.October 1990	5.9	tr	319	103	19	47	2	46	22	10	7.2
2 November 1990	6.2	0.37	346	115	20	43	2	46	25	11	7.2
16 November 1990	5.7	tr	348	108	21	40	2	48	24	10	7.3

Appendix E: Water Quality Data for well #18 (ep)

Date	NO3-N	NH4-N	EC	SP	SO4	Cl	K	Na	Ca	Mg	pH
	— — ppm	— —	µmhos	ppb	— — — —	— — —	— ppm —	— —	— —	— —	
7 December 1990	6.1	0.01	343	105	18	29	2	61	25	11	7.2
17 January 1991	6.8	tr	303	96	19	31	2	65	25	10	7.1
29 January 1991	7.3	tr	357	171	20	18	2	42	27	10	7.0
12 February 1991	7.2	0.03	373	144	14	21	2	43	28	11	7.3
22 February 1991	8.3	0.02	383	92	16	3	2	44	29	14	6.8
8 March 1991	9.2	tr	322	96	19	21	2	47	31	11	7.1
22 March 1991	4.5	tr	249	81	7	10	1	30	27	7	7.9
29 March 1991	10.7	tr	388	95	12	17	1	48	30	11	7.7
5 April 1991	10.3	0.08	370	93	tr	19	1	45	31	11	7.2
12 April 1991	10.7	tr	379	92	tr	17	1	45	31	11	7.2
19 April 1991	9.9	tr	395	92	tr	17	2	45	31	11	7.4
26 April 1991	9.9	0.01	304	91	16	17	2	42	31	11	7.3
24 May 1991	9.8	tr	320	90	16	18	2	44	33	13	7.2
31 May 1991	8.7	tr	309	84	17	27	2	47	32	11	7.1
10 June 1991	8.9	tr	353	86	18	27	2	47	32	11	7.1
18 June 1991	8.3	tr	362	87	14	14	2	47	33	12	7.0
3 July 1991	3.4	0.07	332	81	17	17	2	44	28	11	7.3
19 July 1991	4.8	0.06	351	92	17	16	2	42	30	11	7.3
24 July 1991	3.5	0.06	364	85	18	16	2	43	27	11	7.3
12 August 1991	2.5	0.07	386	89	13	16	2	43	28	10	7.5
20 September 1991	9.9	tr	317	84	tr	25	2	36	22	11	7.5
	— — ppm	— —	µmhos	ppb	— — — —	— — —	— ppm —	— —	— —	— —	
22 October 1991	10.0	tr	333	89	tr	20	2	37	20	11	7.4

tr - Trace Amount; NA - Not available; EC - Electrical Conductivity; SP - Soluble Phosphorus

USDA-ARS National Agricultural Water Quality Laboratory
Durant, Oklahoma

Samples From: Perkins Wells
Date Taken: 7792/7892
Date Arrived:

Log. No. : 1043b
Completion Date:
Analysis By: Naney

Sample	Time	DTW	NO3-N	NH3-N	WS-P	SO4	Cl	K	Na	Ca	Mg	pH	Cond. umhos
			-------ppm-------		ppb	----------------------		ppm	----------------------				
Well #19	—	—	1.48	ND	24.6	42.8	9.7	—	—	—	—	—	—
Well #20	—	—	9.27	ND	2.9	29.9	16.1	—	—	—	—	—	—
Well #21	—	—	12.6	ND	56.3	19.8	10.8	—	—	—	—	—	—
Well #22	—	—	16.8	0.04	17.4	20.0	14.6	—	—	—	—	—	—
Well #23	—	—	0.20	ND	95.3	32.3	2.6	—	—	—	—	—	—

ND--Not Detectable

USDA-ARS National Agricultural Water Quality Laboratory
Durant, Oklahoma

Samples From: Perkins Wells
Date Taken: 71492/71592
Date Arrived: July 30, 1992

Log. No. : 1028
Completion Date: Dec. 1, 1992
Analysis By: Pardue

Sample	Time	DTW	NO3-N	NH3-N	WS-P	SO4	Cl	K	Na	Ca	Mg	pH	Cond.
			-------ppm-------		ppb	---------------------------ppm------------------------------							umhos
Well #1	1405	18.50	26.9	0.02	7.7	72.1	21.8	0.9	24.7	65.8	23.6	7.86	657
Well #2	1407	18.65	23.9	0.02	3.4	98.9	19.7	0.9	22.4	63.0	23.3	7.89	608
Well #3	1417	16.30	33.3	ND	1.6	43.1	5.9	1.7	16.6	47.1	17.8	7.96	497
Well #4	1355	16.45	33.5	0.02	40.4	36.1	6.8	3.4	31.1	60.5	23.7	7.90	595
Well #5	1357	17.18	19.5	0.03	0.7	28.8	4.8	2.9	19.6	30.8	11.5	8.16	385
Well #7	1332	15.61	31.3	ND	27.3	29.4	7.2	1.4	31.6	54.4	20.5	7.99	613
Well #8	1315	14.85	33.4	0.02	9.0	27.5	1.8	2.9	16.1	51.1	17.2	8.09	502
Well #9	1317	14.26	35.9	0.02	57.9	19.9	8.4	1.5	23.6	36.7	14.4	7.96	650
Well #10	1345	18.22	11.9	ND	12.6	21.9	10.2	2.0	31.3	52.9	18.6	8.16	369
Well #11	1310	24.76	4.2	ND	102	15.3	8.8	3.8	12.9	35.4	12.8	8.06	361
Well #12	1305	30.10	26.7	0.02	22.3	16.0	5.6	2.2	18.8	42.5	13.3	8.06	465
Well #19	1415	23.07	0.4	ND	23.2	25.5	6.8	2.4	97.3	42.0	15.6	8.02	683
Well #20	1330	24.13	9.7	0.02	3.9	44.8	5.3	1.9	15.2	54.4	16.9	7.99	471
Well #21	1400	20.17	11.3	0.03	69.0	30.1	11.9	1.5	38.7	49.4	13.4	8.13	532

ND--Not Detectable

USDA-ARS National Agricultural Water Quality Laboratory
Durant, Oklahoma

Samples From:	**Perkins Wells**	**Log. No. :**	**1065**
Date Taken:	**101392/101592**	**Completion Date:**	**12 Mar. 1992**
Date Arrived:	**November 5, 1992**	**Analysis By:**	**Pardue**

Sample	Time	DTW	NO3-N	NH3-N	WS-P	SO4	Cl	K	Na	Ca	Mg	pH	Cond.
			-------ppm-------		ppb	---------------------------ppm					-------------------------------		umhos
Well #19	1330	23.20	0.34	0.0	34.5	13.8	15.2	2.6	24.2	33.2	12.6	7.93	343
Well #20	1245	24.06	10.1	0.0	5.1	41.0	25.2	1.6	22.8	48.0	16.5	8.00	451
Well #21	1215	20.13	0.14	0.0	1.1	29.6	27.4	1.5	41.7	46.4	13.5	8.02	467
Well #22	1310	25.80	13.8	0.0	67.8	17.4	29.8	2.4	33.0	36.3	9.7	8.01	391
Well #23	1230	20.64	0.07	0.0	130	3.2	4.2	3.8	183	9.0	2.6	8.31	687

APPENDIX F
WATER QUALITY ANALYSIS OF CORE SAMPLES

PERKINS CORE SAMPLES (4-13-90) WATER EXTRACTIONS FOR NO_3, NH_3-N AND CONDUCTANCE

		NO3-N		NH3-N		COND
SITE	DEPTH	EXTRACT	SOIL	EXTRACT	SOIL	
(mw)	(ft.)	----------ppm----------		----------ppm----------		(umhos/cm)
3	0-1	0.820	4.10	0.705	3.53	21.9
3	1-2	0.775	3.88	0.820	4.10	23.7
3	2-3	0.700	3.50	1.215	6.08	30.5
3	3-4	0.475	2.38	0.420	2.10	19.7
3	4-5	0.270	1.35	0.180	0.90	21.3
3	5-6	0.305	1.53	0.080	0.40	24.0
3	6-7	0.260	1.30	0.885	4.43	27.7
3	7-8	0.270	1.35	1.105	5.53	32.2
3	8-9	1.015	5.08	0.890	4.45	23.2
3	9-10	4.270	21.35	4.970	24.85	23.3
3	10-11	1.830	9.15	3.150	15.75	28.8
3	11-12	0.975	4.88	0.890	4.45	22.3
3	12-13	0.695	3.48	0.595	2.98	22.2
4	0-1	0.470	2.35	0.920	4.60	26.4
4	1-2	0.435	2.18	0.675	3.38	14.1
4	2-3	0.545	2.73	0.890	4.45	22.3
4	3-4	0.320	1.60	0.880	4.40	20.8
4	4-5	0.295	1.48	0.460	2.30	16.4
4	5-6	0.345	1.73	0.510	2.55	20.3
4	6-7	0.380	1.90	0.615	3.08	22.9
4	7-8	0.160	0.80	0.280	1.40	21.3
4	8-9	0.295	1.48	0.380	1.90	20.0
4	9-10	0.320	1.60	0.450	2.25	24.8
4	10-11	0.490	2.45	0.625	3.13	19.6
4	11-12	0.130	0.65	0.260	1.30	23.3
4	12-13	0.515	2.58	0.565	2.83	21.4
4	13-14	0.235	1.18	0.325	1.63	24.7
4	14-15	0.295	1.48	0.460	2.30	24.3
4	15-16	0.395	1.98	0.475	2.38	25.0
4	16-17	0.270	1.35	0.385	1.93	32.2
4	17-18	0.485	2.43	0.610	3.05	23.1
4	18-18.2	0.365	1.83	0.290	1.45	21.0
7	0-1	1.610	8.05	0.750	3.75	43.0
7	1-2	0.860	4.30	0.800	4.00	41.4
7	2-3	0.505	2.53	0.705	3.53	22.0
7	3-4	0.650	3.25	0.653	3.18	20.0
7	4-5	1.030	5.15	1.925	9.63	25.5
7	5-6	2.850	14.25	0.658	3.29	42.4
7	6-7	9.590	47.95	0.000	0.00	100
7	7-8	10.000	50.00	0.000	0.00	106

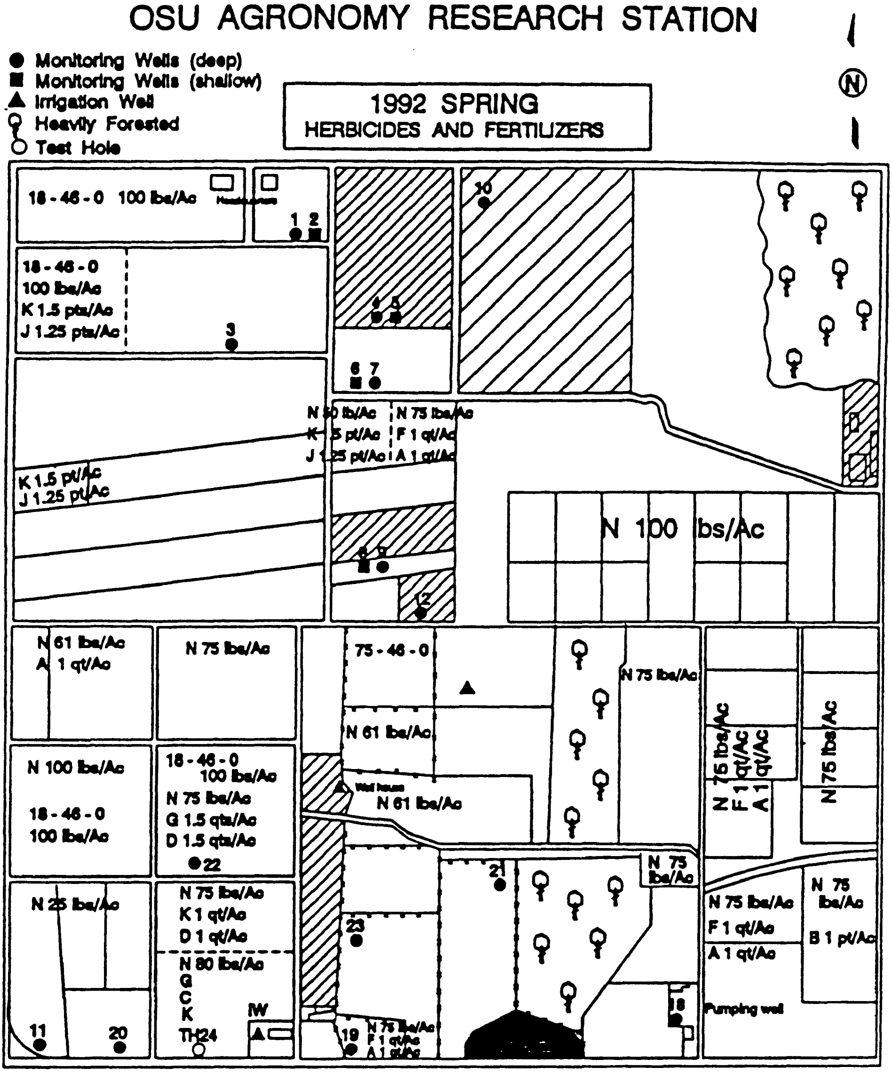
8	0-1	2.120	10.60	1.330	6.65	44.8
8	1-2	0.660	3.30	2.250	11.25	25.5
8	2-3	0.635	3.18	0.625	3.13	25.8
8	3-4	1.220	6.10	1.340	6.70	26.0
8	4-5	0.645	3.23	0.390	1.95	19.4
8	5-6	0.405	2.03	0.120	0.60	25.2
8	6-7	0.270	1.35	0.015	0.08	31.8
8	7-8	0.415	2.08	0.000	0.00	31.8
8	8-8.85	0.215	1.08	0.055	0.28	26.3
12	0-1	0.590	2.95	0.720	3.60	15.1
12	1-2	0.530	2.65	0.905	4.53	12.8
12	2-3	0.525	2.63	0.745	3.73	15.1
12	3-4	0.950	4.75	1.245	6.23	21.6
12	4-5	0.895	4.48	1.300	6.50	22.0
12	5-6	0.350	1.75	0.405	2.03	18.7
12	6-7	0.050	0.25	0.080	0.40	24.8
12	7-8	0.175	0.88	0.160	0.80	25.4
12	8-9	0.425	2.13	0.540	2.70	26.8
12	9-10	0.010	0.05	0.010	0.05	65.5
12	10-11	0.100	0.50	0.075	0.38	24.9
12	11-12	0.325	1.63	0.255	1.28	19.3
12	12-13	0.255	1.28	0.220	1.10	23.0

Procedure Used: Samples were air-dried and passed through a 2.00 mm sieve. 10.0 g of soil was extracted with two 25-ml aliquots of distilled, deionized water, and the unfiltered extract was run for NO_3-N and NH_3-N and on the Technicon AA II.

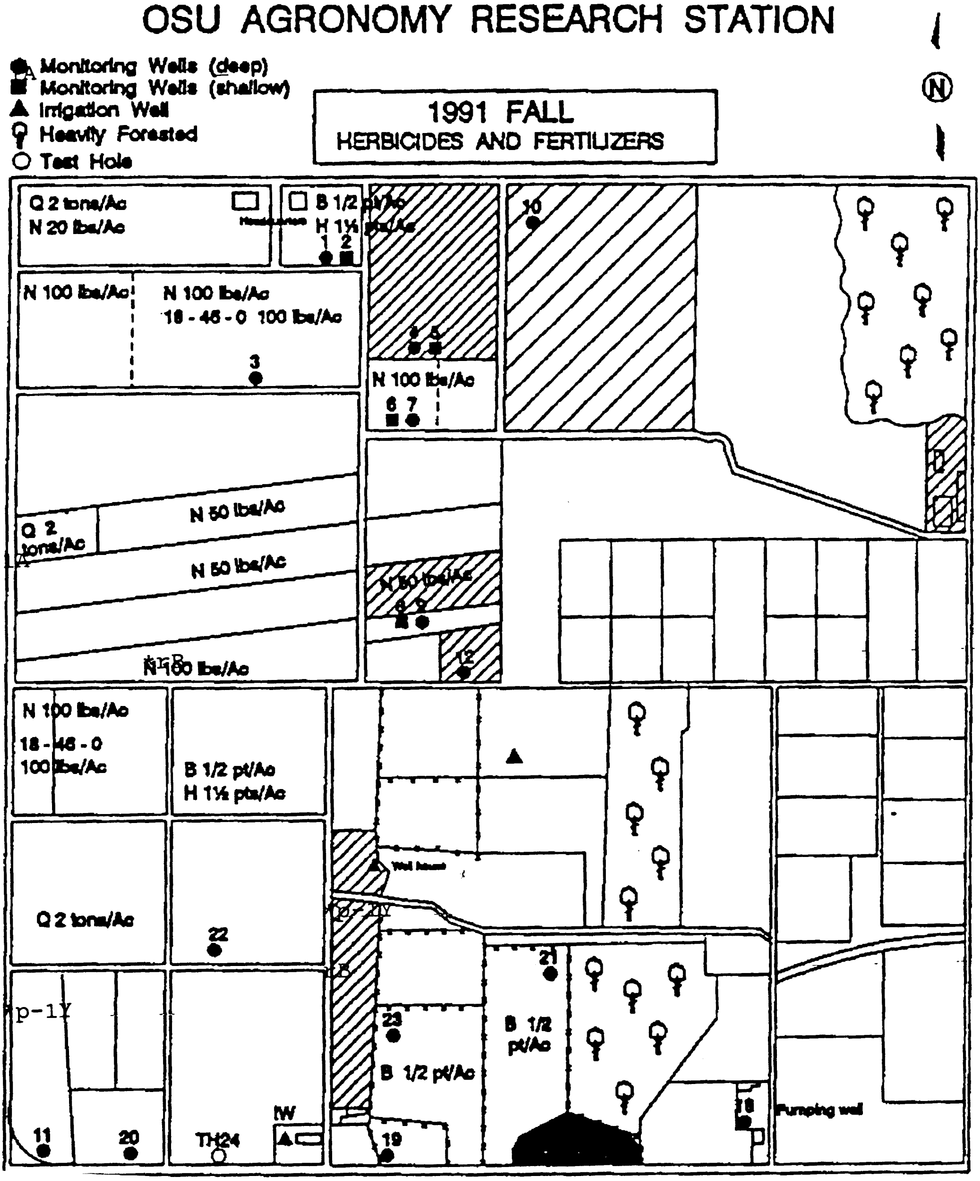
APPENDIX G

PLANTINGS AND CHEMICAL APPLICATION MAPS

OSU AGRONOMY RESEARCH STATION

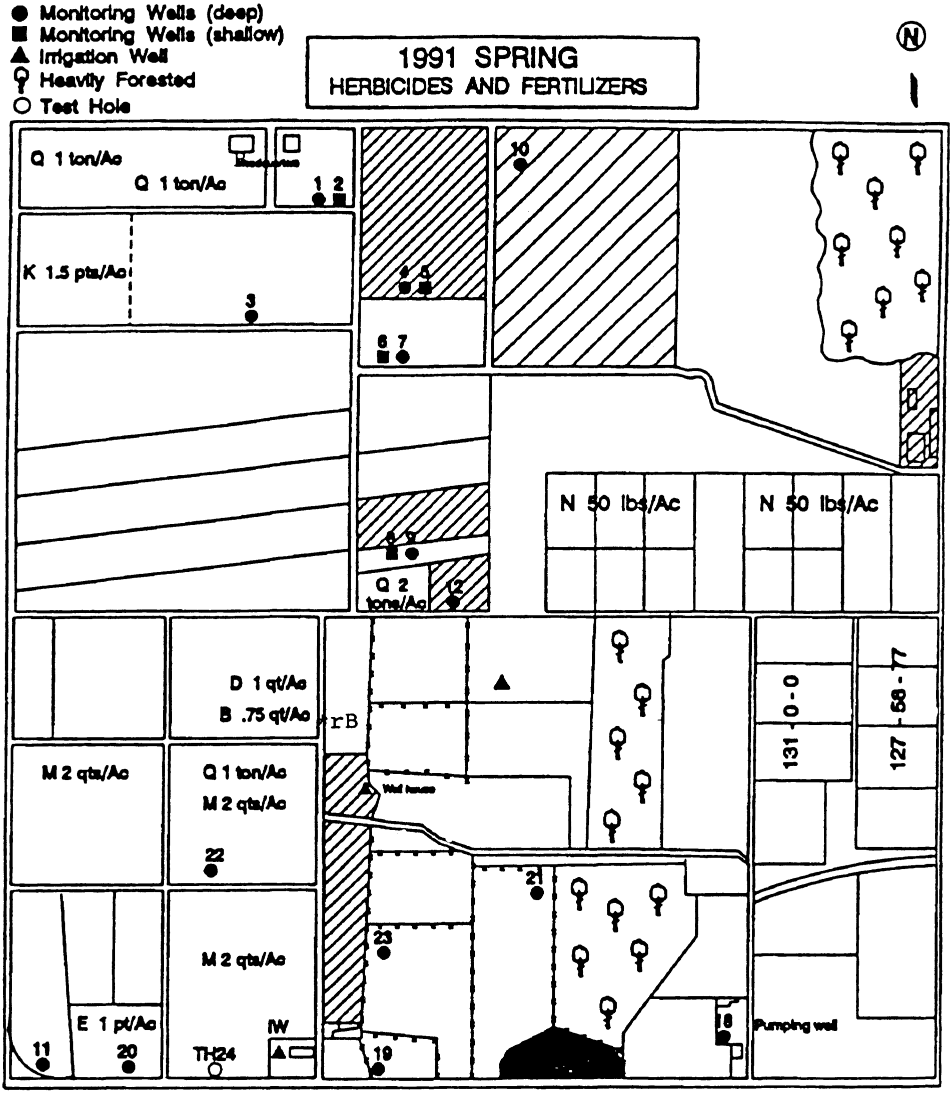


OSU AGRONOMY RESEARCH STATION



OSU AGRONOMY RESEARCH STATION

1991 SPRING
HERBICIDES AND FERTILIZERS



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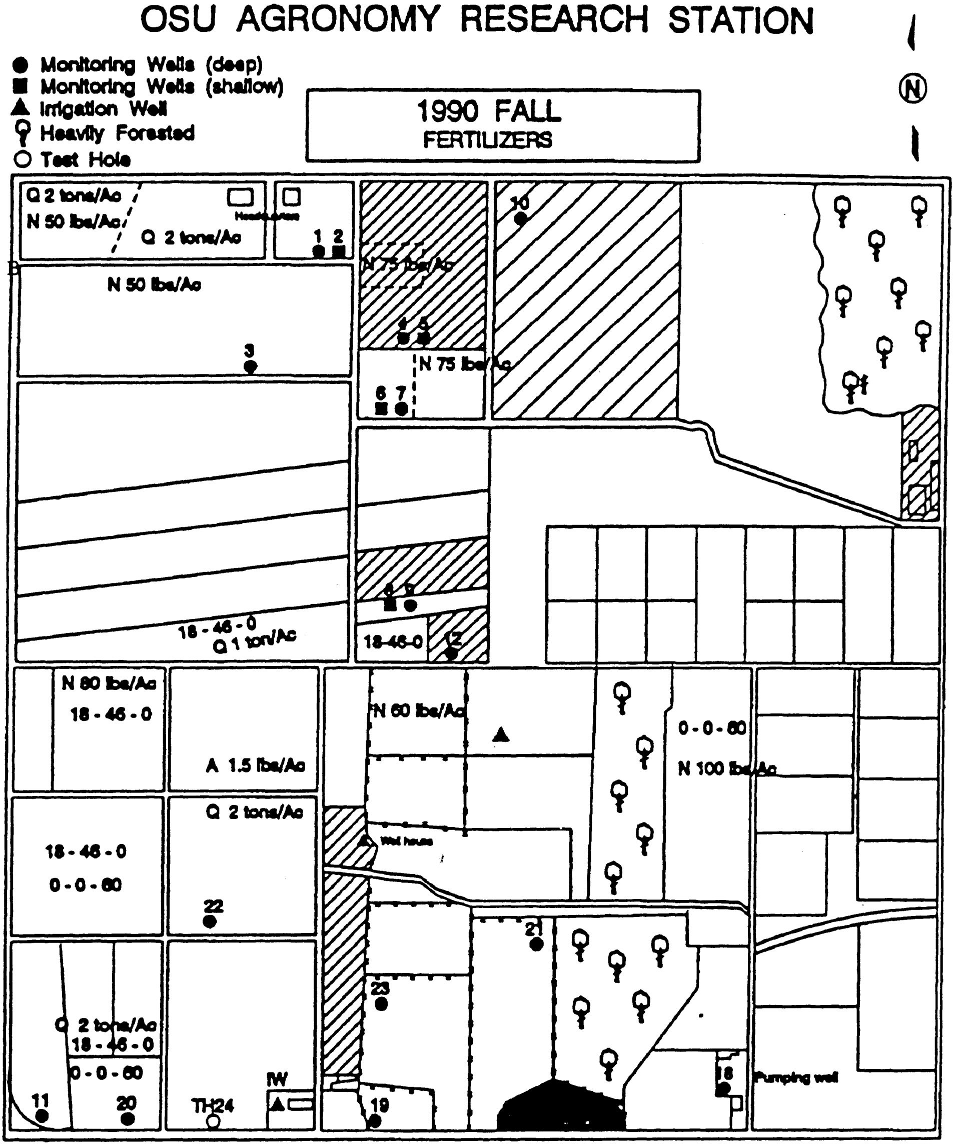

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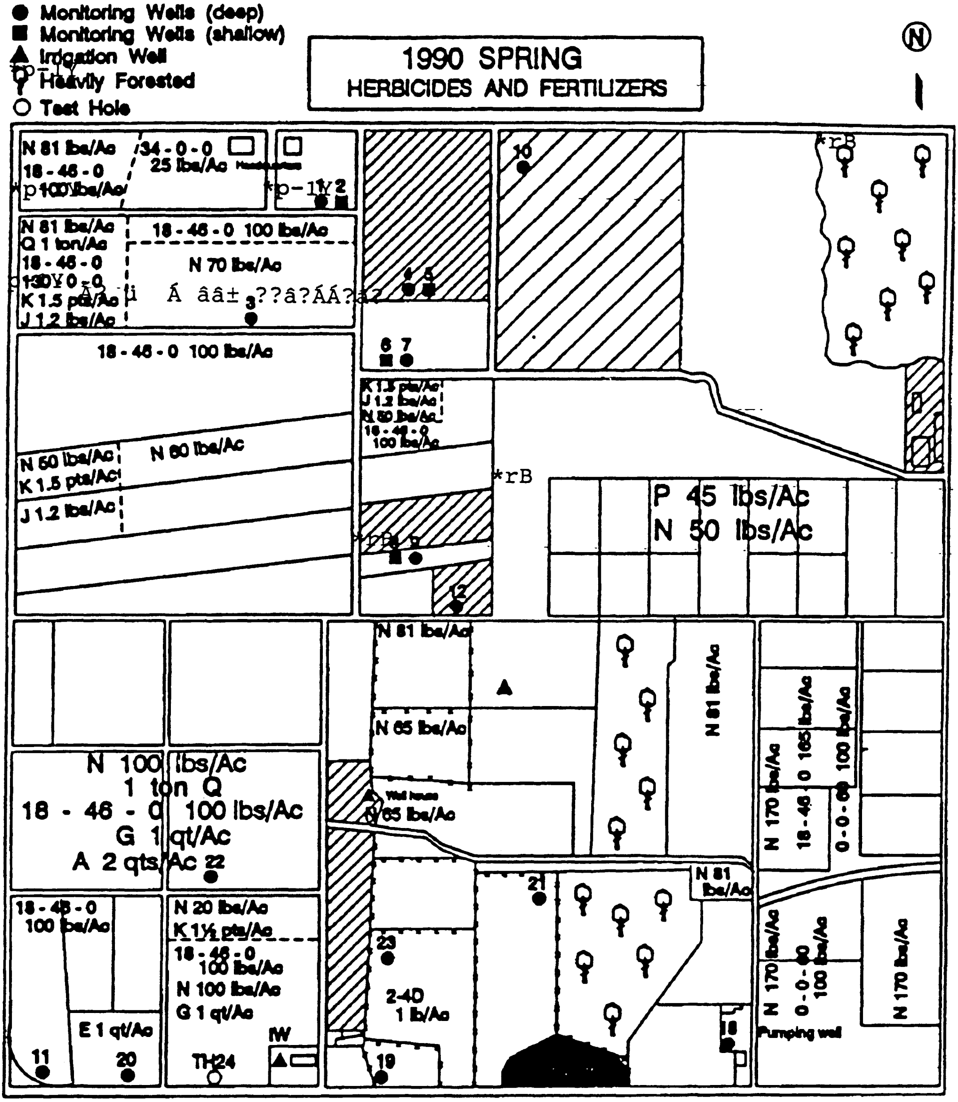
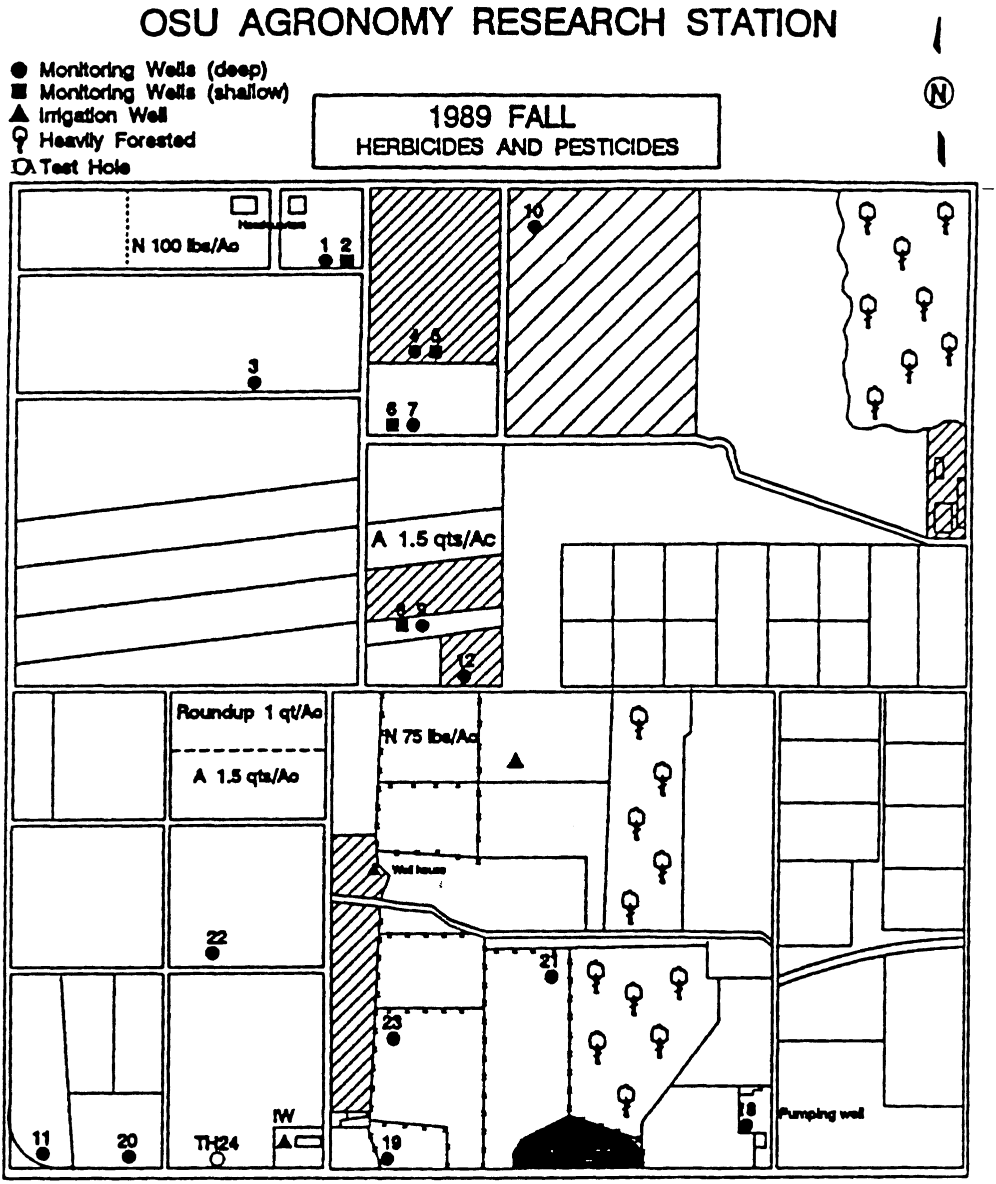
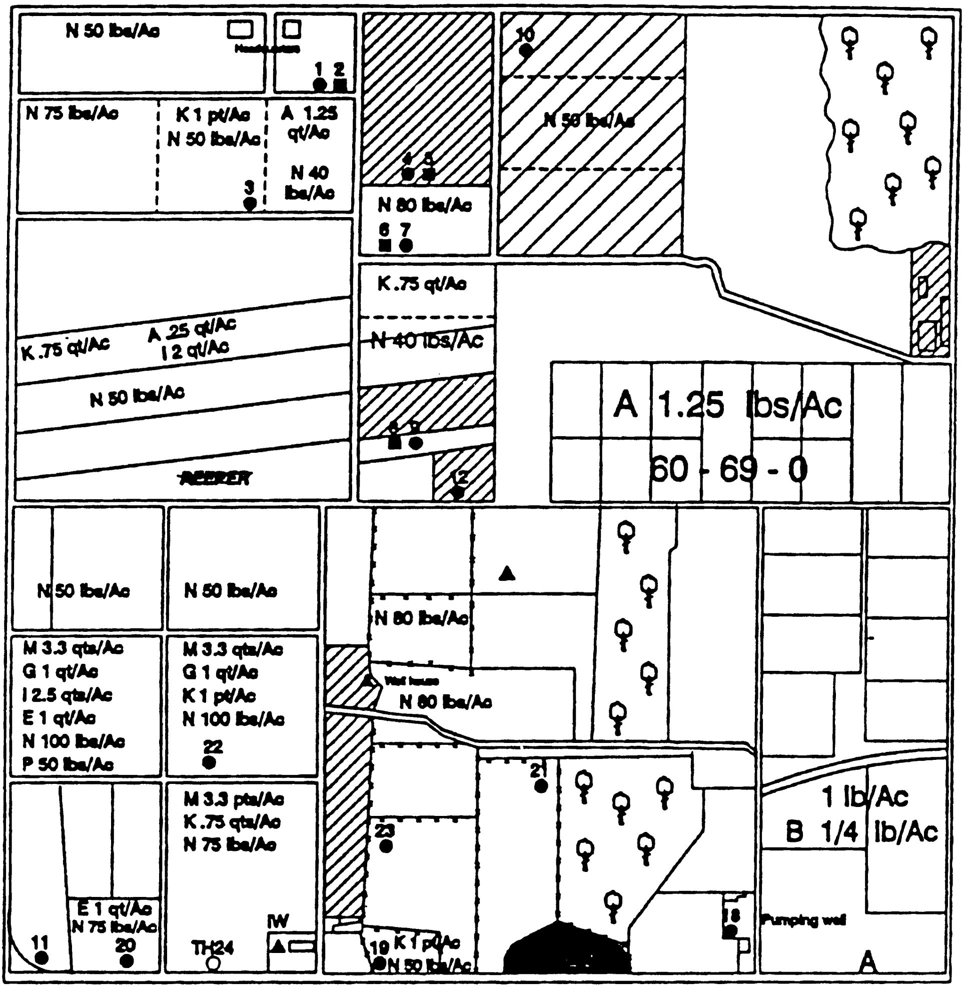



OSU AGRONOMY RESEARCH STATION
● Monitoring Wells (deep)
■ Monitoring Wells (shallow)
▲ Irrigation Well
Heavily Forested
Test Hole
N
1989 FALL
HERBICIDES AND PESTICIDES
Headquarters
N 100 lbs/Ac
1
2
3
4
5
6
7
10
A 1.5 qts/Ac
8
9
12
Roundup 1 qt/Ac
A 1.5 qts/Ac
N 75 lbs/Ac
Well house
22
21
23
IW
11
20
TH24
19
18
Pumping well

OSU AGRONOMY RESEARCH STATION

- ● Monitoring Wells (deep)
- ■ Monitoring Wells (shallow)
- ▲ Irrigation Well
- Heavily Forested
- ○ Test Hole

1989 SPRING
HERBICIDES AND PESTICIDES



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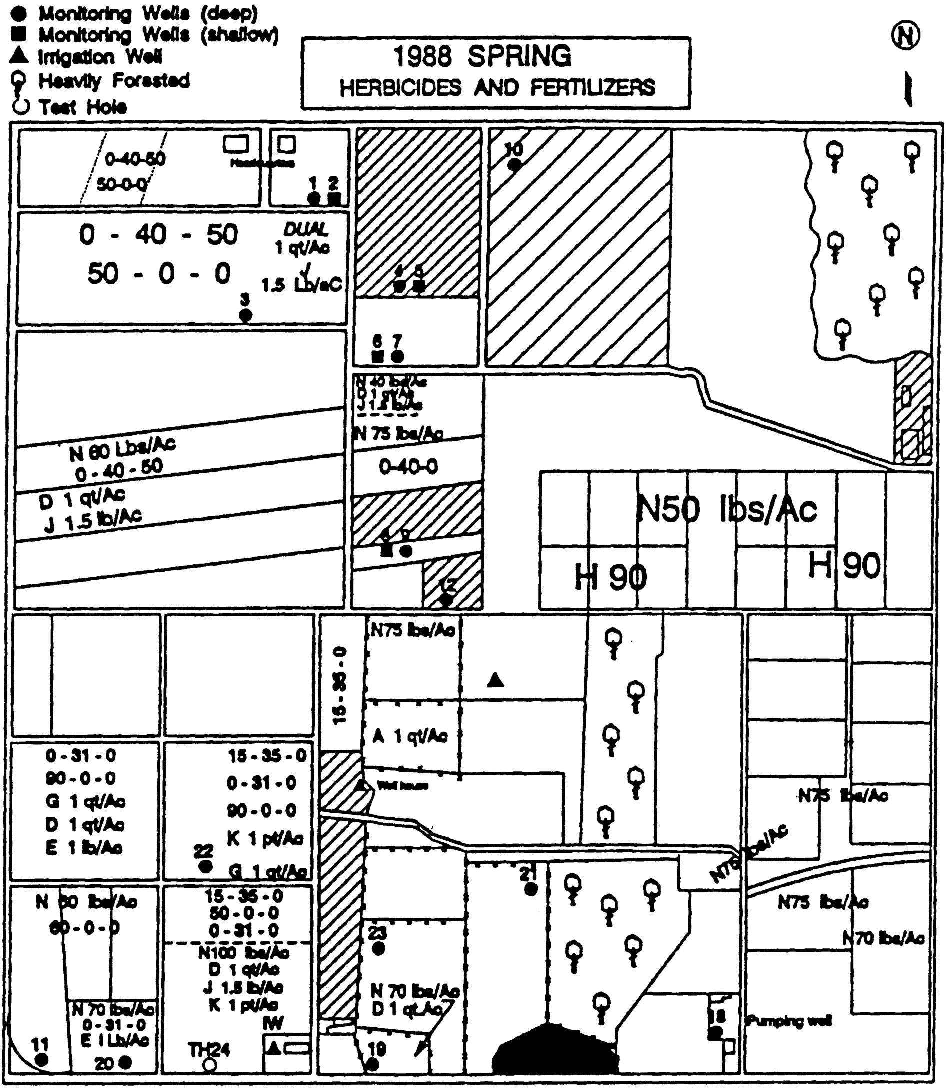

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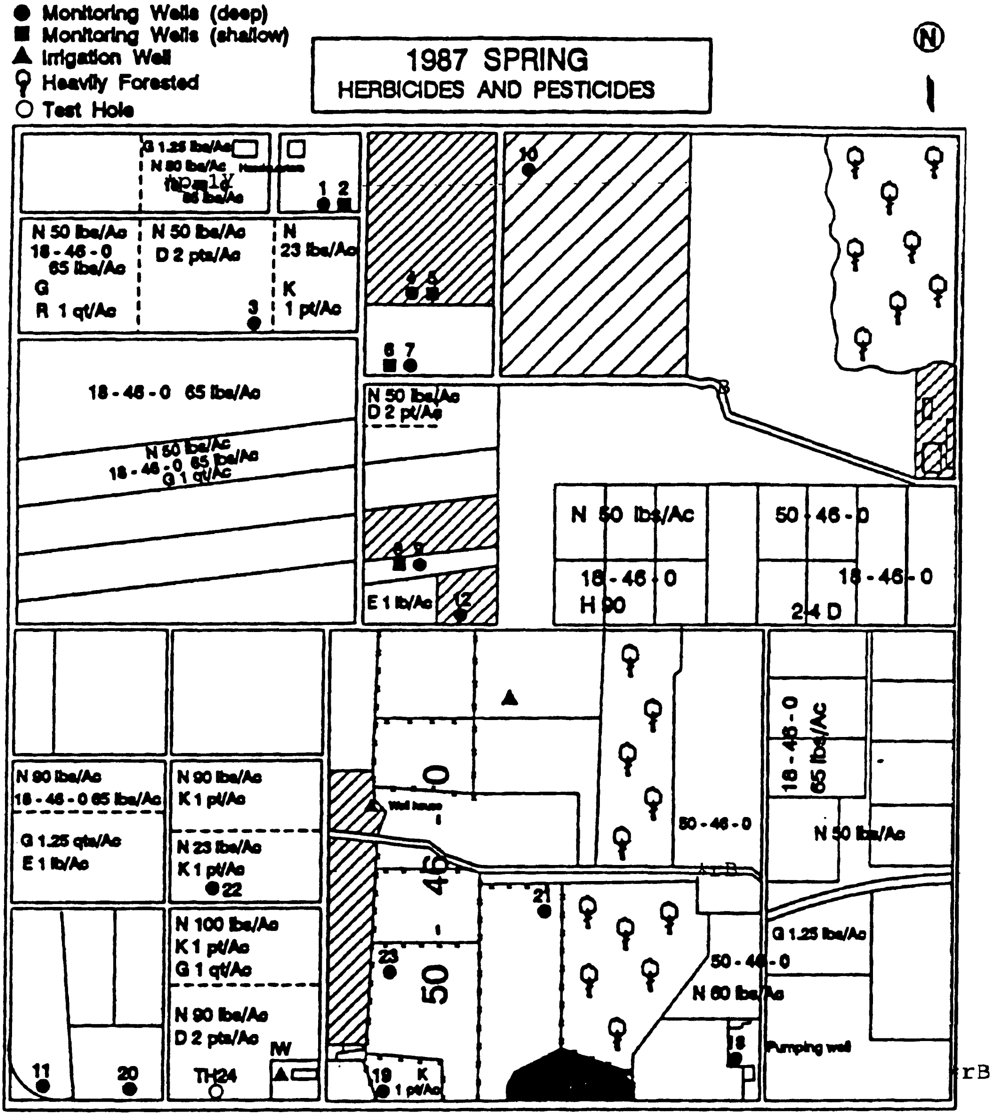

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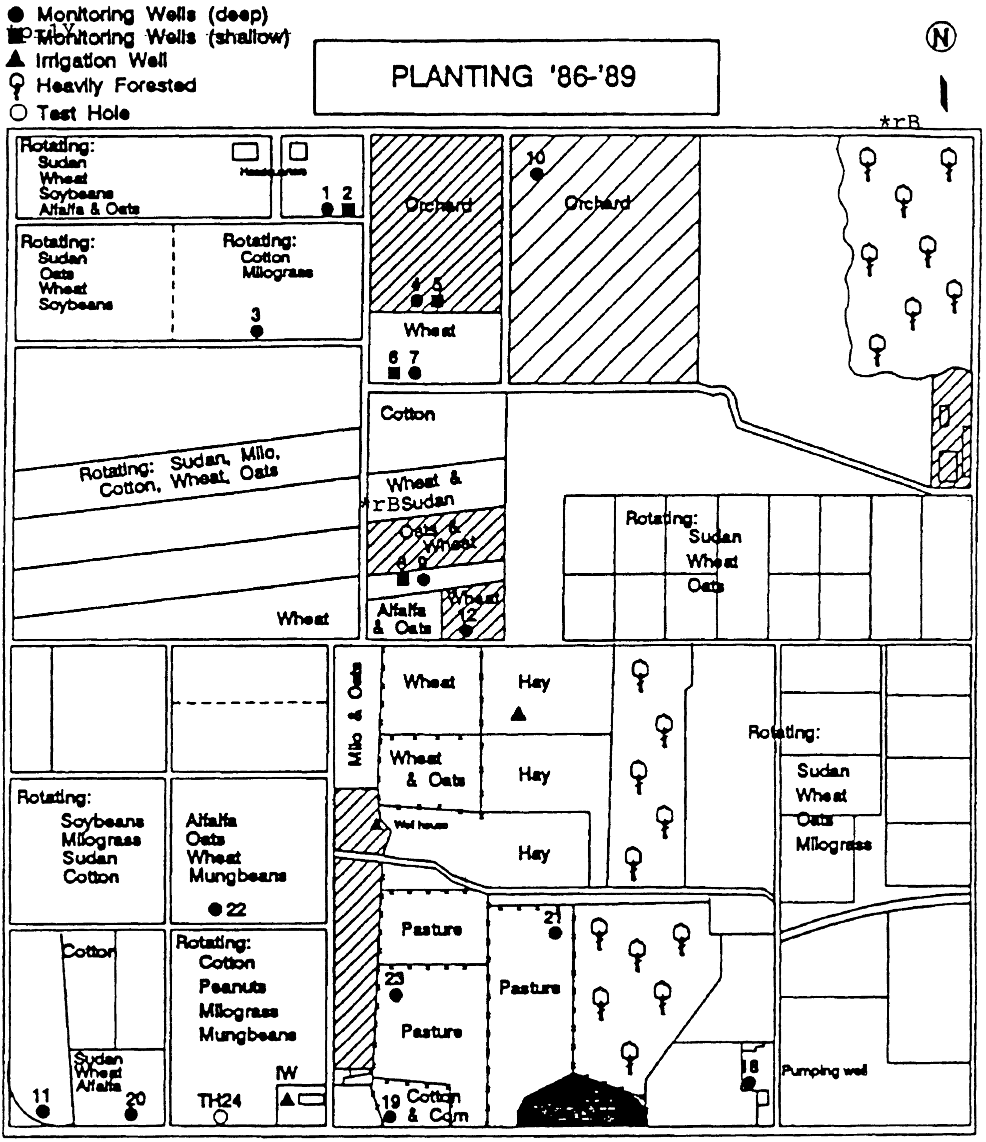

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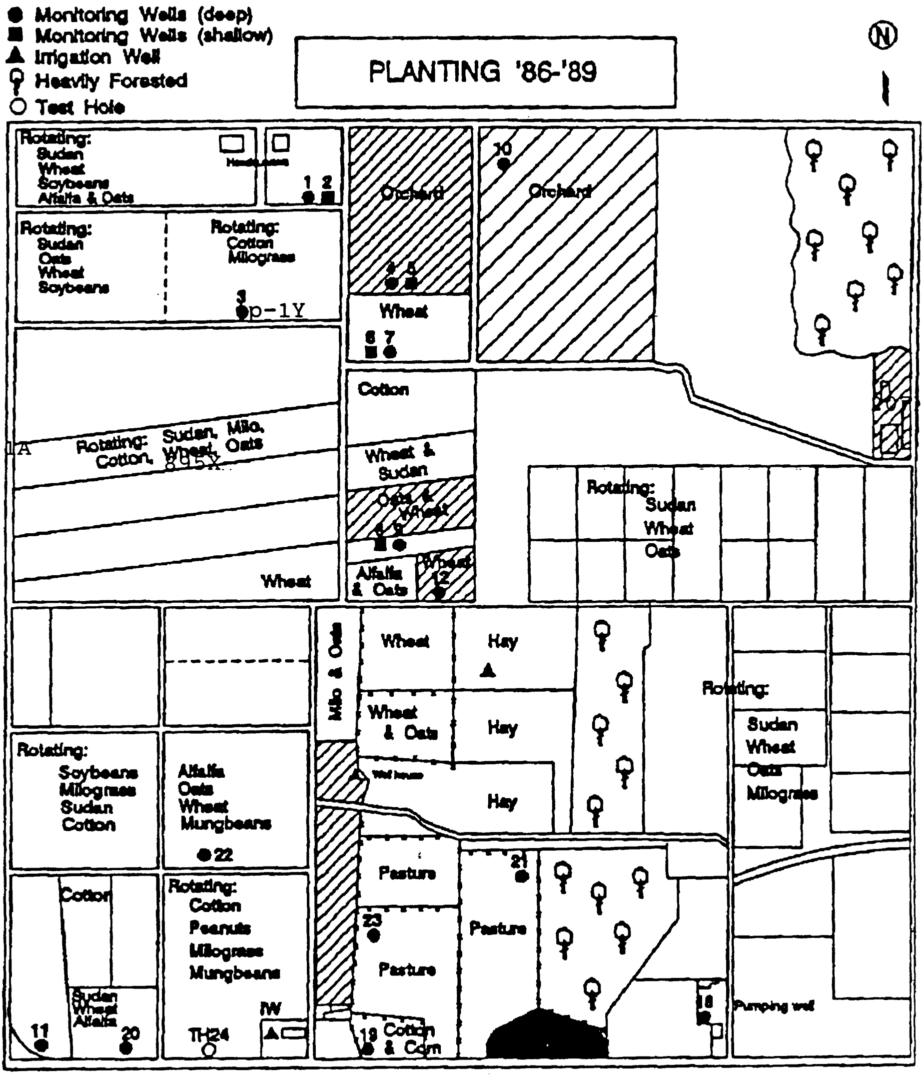

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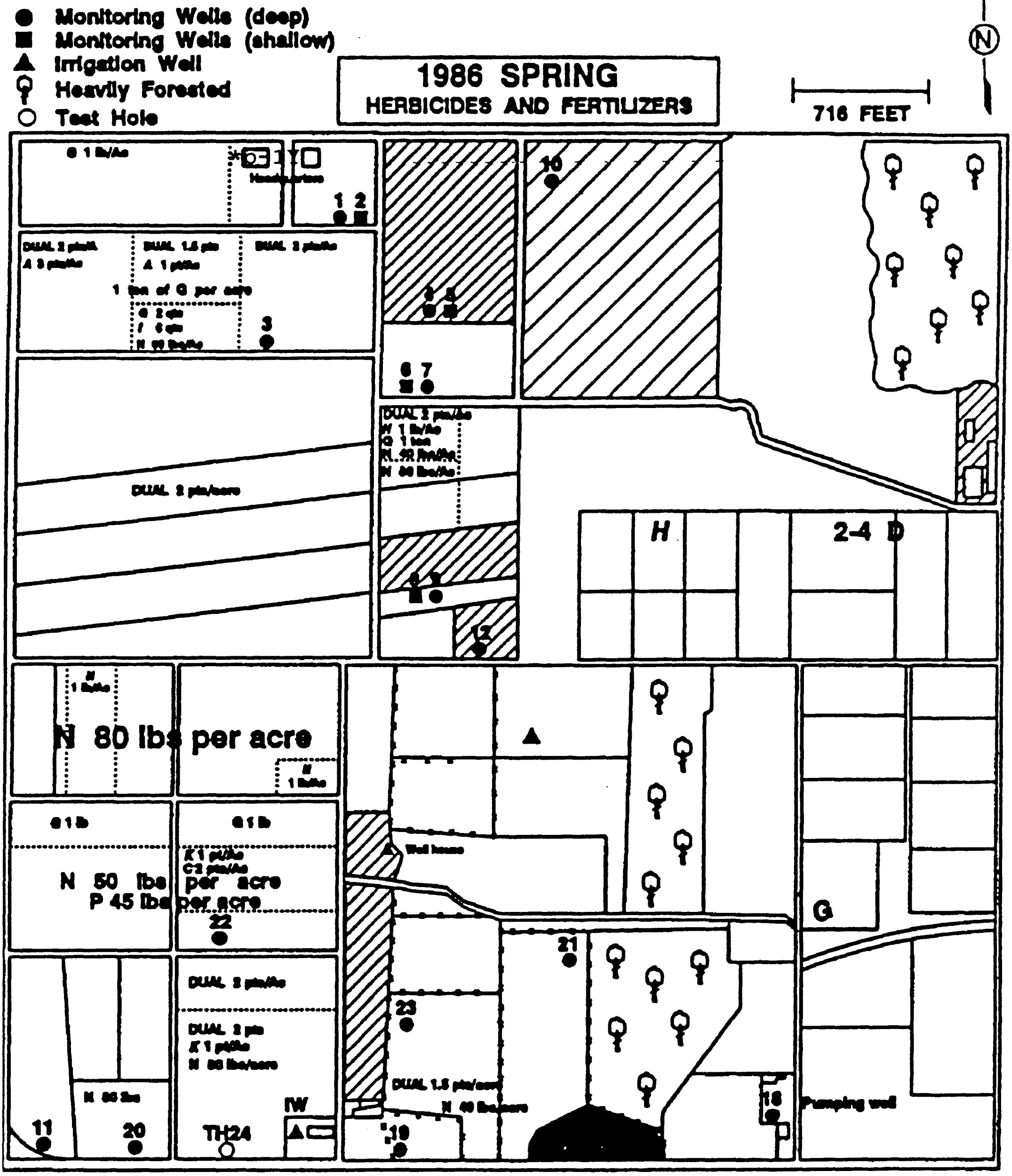

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