GEOHYDROLOGY OF A COAL-MINING AREA, SOUTHWESTERN BATES COUNTY, MISSOURI

By T.O. Mesko

U.S. GEOLOGICAL SURVEY

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CONVERSION FACTORS

For readers who prefer to use metric (International system) units, conversion factors for terms used in this report are listed below:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
square foot (ft^2)	0.0929	square meter (m^2)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	4.047×10^{-3}	square kilometer (km^2)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.0283	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.0631	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.207	liter per second per meter [(L/s)/m]

To convert degrees Celsius (°C) to degrees Fahrenheit (°F) use the following:

$$°F = 9/5\ °C + 32.$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

DEFINITION OF TERMS

Anisotropy--A characteristic of an aquifer where the hydraulic conductivity at a point varies with the direction measured from that point.

Aquifer--A formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield substantial quantities of water to wells and springs.

Aquifer test--A method of obtaining aquifer characteristics in which a well is pumped at a constant rate and water-level measurements are made from it and, where possible, from nearby observation wells penetrating the same aquifer. Values of drawdown or recovery versus time are used in mathematical formulas to derive aquifer characteristics, such as transmissivity and storage coefficients.

Base flow--Sustained minimum flow in a stream.

Cone of depression--The depression of a water-level surface around a pumping well caused by the withdrawal of water.

Confined aquifer--An aquifer in which water is under sufficient pressure to rise in a well above the water-yielding bed. The pressure can be sufficient to cause water levels to rise above land surface, resulting in a flowing artesian, well.

Confining bed--A body of relatively impermeable material overlying or underlying an aquifer, that restricts vertical water movement into and out of the aquifer.

Drawdown--The difference between the static (pre-pumping) water level and the water level measured while a well is being pumped.

Evapotranspiration--The movement of water into the atmosphere by the combined processes of direct evaporation and transpiration by plants.

Hydraulic conductivity--The capacity of a material to transmit water, expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Permeability--A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Potentiometric surface--An imaginary surface that represents ground-water static head. As related to an aquifer, it is defined by the level to which water will rise in tightly cased wells.

Recharge--The addition of water to the zone of saturation. Infiltration of precipitation is a form of natural recharge.

Secondary permeability--Increased capacity of rocks to transmit water, because of bedding planes, fractures, or solution cavities in the rock.

Specific capacity--The rate of discharge of water from a well, divided by the drawdown of water level within the well. If a well yields 500 gallons per minute, with a drawdown of 25 feet, its specific capacity is 500/25, or 20 gallons per minute per foot.

Specific conductance--A measure of the capacity of water to conduct a current of electricity, expressed in microsiemens per centimeter at 25 °Celsius. Specific conductance varies with the quantity of dissolved mineral constituents, their degree of ionization, and water temperature. It is useful in indicating the approximate concentration of mineral matter in water.

Storage coefficient--The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change in hydraulic head.

Transmissivity--The rate at which an aquifer can transmit water, expressed as feet squared per day. Transmissivity is the volume of water per day that can move through a 1-foot-wide vertical aquifer section extending the full saturated thickness under a hydraulic gradient of 1 foot/foot at the prevailing temperature of the water.

Theis assumptions--(1) The aquifer is homogeneous and isotropic, (2) the aquifer has infinite areal extent, (3) the discharging well penetrates the entire thickness of the aquifer, (4) the well has an infinitesimal diameter, and (5) the water removed from storage is instantaneously discharged with decline in hydraulic head.

Water table--That surface in an unconfined ground-water body at which the water pressure is equal to the atmospheric pressure. It is defined by the level at which water stands in wells that penetrate the aquifer just far enough to hold standing water.

Well-bore storage--The open space of volume in and near a well bore where the aquifer characteristics do not apply. This includes the volume inside the well casing or open hole and the gravel pack outside the casing.

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ABSTRACT

A study was made to describe the geology and hydrology of an abandoned surface coal mine and coal-refuse disposal area in southwestern Bates County, Missouri, during and after reclamation. Before reclamation, two streams and a spring draining the area had degraded water quality caused by acidic run-off and leachate from the mine area.

Dissolved-solids concentrations of area streams ranged from about 600 to about 5,200 milligrams per liter. During reclamation, the spring discharged 0.32 to 0.58 cubic foot per second and was directly affected by precipitation. After reclamation, continuous gage-height data from March to September, 1986 indicated discharge ranged from 0.09 to 0.14 cubic foot per second, and precipitation no longer affected discharge. Dissolved-solids concentrations of the spring ranged from about 7,000 to about 14,000 milligrams per liter before reclamation, was 8,250 milligrams per liter during reclamation, and decreased 50 percent to about 4,000 milligrams per liter after reclamation. Values of pH ranged from 2.5 to 3.0, with the larger values occurring after reclamation.

Ground water in the mine area had dissolved-solids concentrations that ranged from 435 to 10,000 milligrams per liter and pH values that ranged from about 2.3 to 7.7. Recharge to the coal refuse was from lakes S-703 and S-704 and precipitation; however, after reclamation, the lakes became the primary source of recharge.

An aquifer test indicated a transmissivity value of about 183 feet squared per day. Storage coefficients ranged from 0.008 to 0.05. Values of specific capacity for monitoring wells in the mine area ranged from 0.22 to 125 gallons per minute per foot of drawdown.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the Missouri Department of Natural Resources, Land Reclamation Commission, made a study of a coal mining area in southwestern Bates County, Missouri. Coal was actively mined from the Tiger Mine area from mid 1931 to early 1934. The coal was excavated in furrow-type trenches (Vaill and Barks, 1980) and the overburden was dumped on the original land surface. Coal refuse was used to fill final-cut pits at the mine site and the remaining coal refuse was dumped on top of the excavated overburden.

Before surface mining began, an underground mine was operated on the south side of the area, but no data are available for the extent of underground mining. The mine shaft has been filled. After surface-mining operations ceased, a coal-processing plant at the site continued operation, and the mine area was used as a coal-refuse (gob and slurry) disposal site until 1957.

About 275 acres of land was disturbed by surface coal mining and the subsequent disposal of coal refuse. Two streams draining the area had degraded water quality caused by rainfall runoff over exposed coal refuse and spoil (overburden). An acidic spring and associated seeps also contributed to degradation of surface-water quality. Ground-water quality was degraded by water leaching through the coal refuse, resulting in small pH values and large dissolved-solids concentrations.

An area of continual burning occurred in the coal refuse west of the spring discharge point. This burning area was reported by residents of the area to have begun many years ago and continued to 1985. Construction workers covered the smouldering coal refuse with a clay layer during 1985, and apparently have extinguished the fires.

The Missouri Department of Natural Resources reclaimed the mine area during 1984 and 1985. The work plan included leveling and contouring all coal refuse and spoil piles and covering exposed coal refuse with a clay layer; the clay was obtained from an area adjacent to the southern border of the mine area. The reclaimed area was reforested with native vegatation, and wildlife was encouraged by constructing special habitats. Construction of a slurry-bentonite mixture cut-off wall that would divert ground-water movement from source areas west of the mine area around the coal refuse also was proposed, but was not constructed.

Purpose and Scope

The purpose of this report is to describe the geology and determine movement and quality of surface and ground water in the area. A significant part of the study was to identify recharge sources for the acidic spring.

The scope of the study included: (1) Evaluating existing literature and data on the occurrence and quality of water in and near the site; (2) describing the geologic and hydrologic systems; (3) collecting water-level and water-quality data; and (4) monitoring the discharge from the acidic spring after reclamation.

Description of Study Area

The study area includes about 275 acres of reclaimed land in southwestern Bates County, Missouri (fig. 1) and is part of the Osage Plains physiographic section (Fenneman, 1938). The area is characterized by flat to moderately sloping terrain with some hills and knobs. Land surface, before reclamation, was a series of furrow-type hills and mounds of coal spoil and overburden. After reclamation, land surface was recontoured to flat and moderately sloping terrain. Agriculture is the primary economy of the study area, replacing coal mining, which is now (1986) minimal.

Previous Investigations

Robertson (1971) evaluated and mapped the coal reserves of Missouri. Gentile (1976) described the geology of Bates County, Missouri, in detail and briefly described the occurrence and quality of ground water. Vaill and Barks (1980) described the general physical environment and hydrologic characteristics of coal-mining areas in Missouri. Peabody Coal Company (1982) prepared an environmental assessment of the Tiger Mine area and supplied geologic, ground-water-level, and water-quality data for surface and ground water. Kleeschulte and others (1985) made an appraisal of the ground-water resources of Barton, Vernon, and Bates Counties, Missouri, which included a description of the various aquifers and water-level and water-quality data.

GEOLOGY

Clay, shale, limestone, sandstone, and coal of Pennsylvanian age formed the subsurface strata in the study area before surface mining began. Robertson (1971) described a generalized section of the principal coal-bearing units (fig. 2). The Mulky coal bed was mined (Gregory Easson, Missouri Division of Geology and Land Survey, oral commun., 1985), and is the uppermost coal bed in western Missouri. Depth of this coal bed, as mapped by Robertson (1971), ranged from about 30 to about 100 feet (ft) below land surface in southwestern Bates County, and was about 50 ft deep in the mine area.

Peabody Coal Company drilled seven monitoring wells (monitoring wells 1-7) and four test boreholes (B1-B4) and the Missouri Department of Natural Resources, Division of Geology and Land Survey, drilled three monitoring wells (monitoring wells 8-10) in and near the mine area to evaluate the geologic and hydrologic conditions (fig. 3). The U.S. Geological Survey drilled five monitoring wells in and near the mine area (monitoring wells 11-15). Boreholes B1-B4 were plugged after logging of the samples. Construction and geologic data for the wells and boreholes are presented in table 5 (Supplemental Data section at the back of this report).

Surficial Material

The soil near the mine area is classified as the Cherokee Prairie soil association and includes the Hartwell series (D.A. Howard, U.S. Soil Conservation Service, written commun., 1985). This soil is deep and poorly drained, and formed from weathered loess and shale on ridge tops.

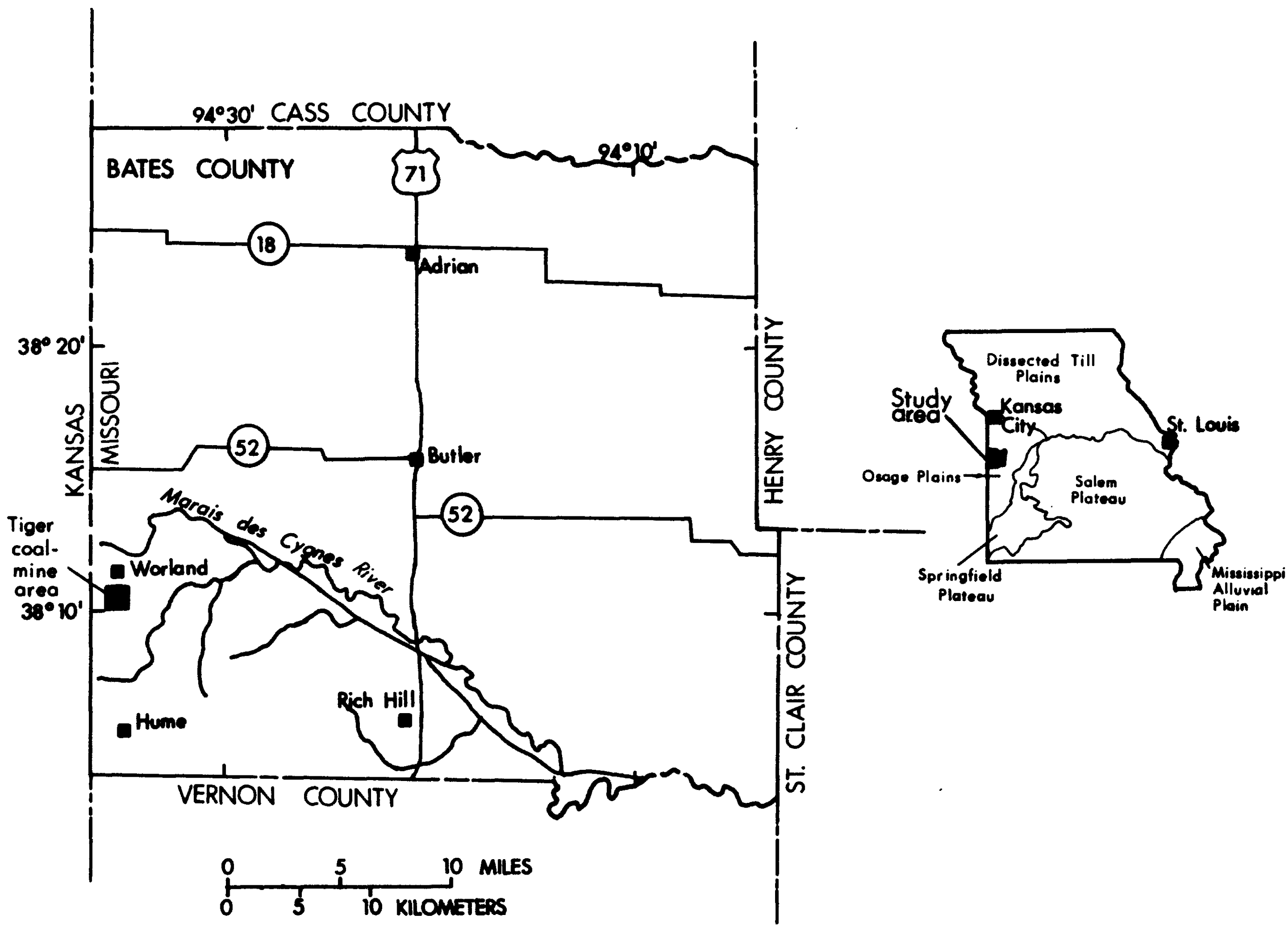
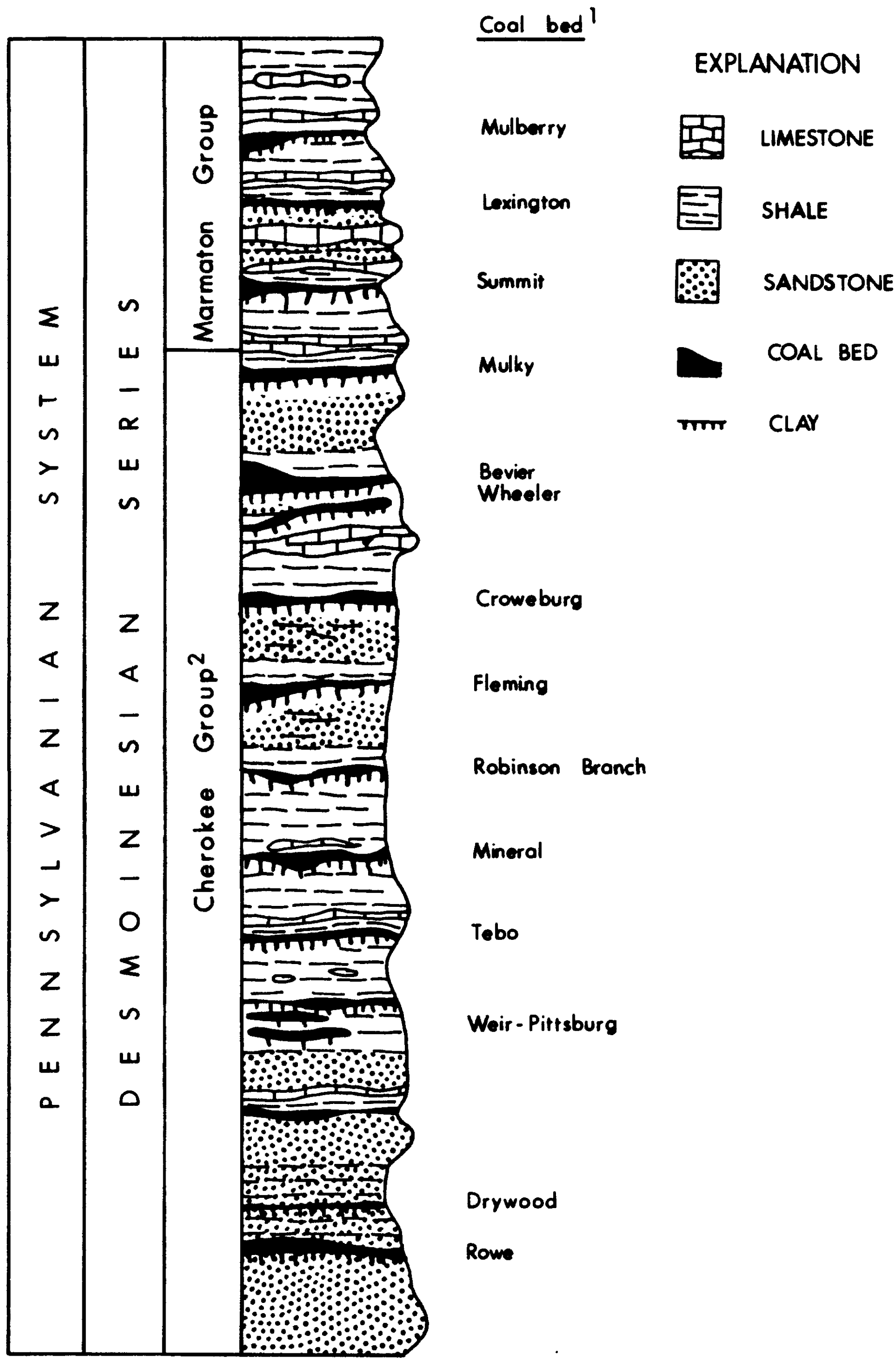


Figure 1.--Location of study area and physiographic sections in Missouri (physiography from Fenneman, 1938).



[1] Unit follows usage of the Missouri Division of Geology and Land Survey

[2] Designated Cherokee Shale by the U. S. Geological Survey

Figure 2.--Stratigraphy of the principal coal-bearing rocks (modified from Robertson, 1971).

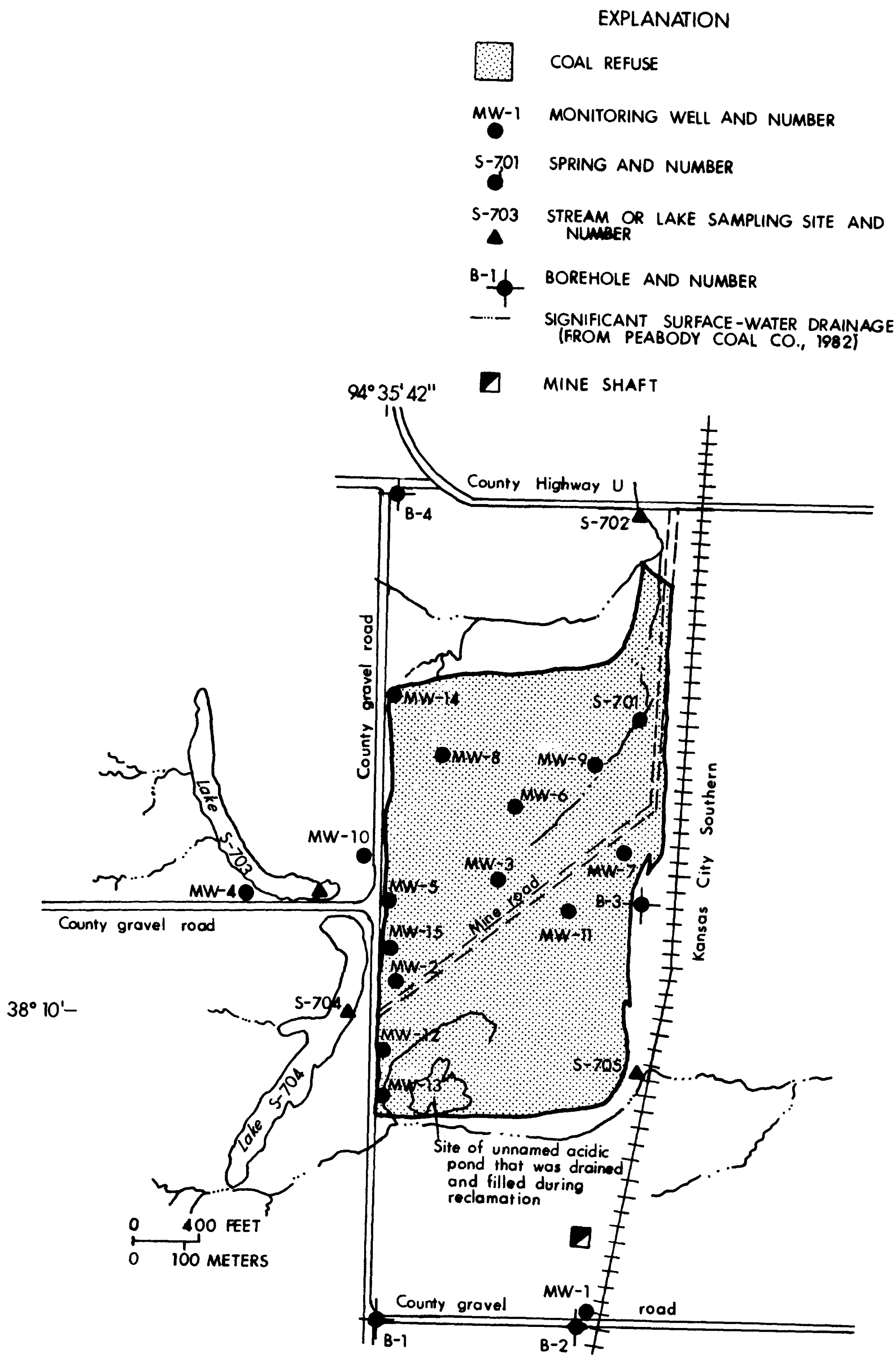


Figure 3.--Location of coal refuse, monitoring wells, surface-water features, and boreholes.

The soil type in western Missouri near rivers and streams formed in alluvium is from the Hepler series, which is described as a deep and poorly drained soil that has a silt-loam surface overlying a silty clay-loam subsoil (Allgood and Persinger, 1979). Before reclamation, the surficial material in the mine area generally consisted of broken coal fragments, refuse, and spoil. The coal refuse and spoil commonly was in furrow-type rows, except in eroded areas where they consisted of fine- to coarse-grained fluvial material.

Coal Refuse

The location and thickness of the coal refuse (fig. 4) indicate that the waste was deposited in the final-cut pit on the northwest side of the mine road and the remainder was piled on the land surface. The coal refuse is thickest, 51 ft, at monitoring well 3, where the gob and slurry pit was located, and thins in an eliptical pattern from monitoring well 3.

Coal refuse primarily is composed of broken coal fragments and chips that range from fine-grained to boulder size. In parts of the mine area where burning occurred, the refuse appeared as cinders. Fine-grained clay sometimes was intermixed with the coal refuse. A lithologic description of the coal refuse is in table 5.

Hydrologic section A-A' (fig. 5) shows the coal refuse surrounded by clay. The potentiometric surface shown on the section was plotted from measurements made September 6, 1985 (table 1). The clay underlying the coal refuse is overlain, at least locally, by overburden that was placed in the pit before emplacement of the coal refuse. Because the overburden could not be differentiated from the undisturbed clay after the overburden became compacted, the surface mapped as the top of the clay unit in figure 6 represents a combination of the top of the compacted overburden and the top of the undisturbed clay. Undisturbed rock of Pennsylvanian age underlies the mine area and dips in a southerly direction. An abrupt change in dip of strata in the mine area may be caused by faulting or may be structurally related to the Schell City-Rich Hill anticline (McCracken, 1971). Data from Peabody Coal Company (1982) indicate that several limestone and shale units are present at borehole 3 (fig. 3).

Geophysical (natural gamma) logs were recorded on monitoring wells 5, 12, 13, 14, and 15 by the Missouri Department of Natural Resources, Division of Geology and Land Survey, and are shown on the geophysical-correlation section B-B' (fig. 7). Natural-gamma logging primarily is used for the identification of lithologic and stratigraphic units (Keys and MacCary, 1971). The natural-gamma activity is much greater for clay and shale than for sand or carbonate material. Generally, coal refuse covers the land surface along the shoulder of the county gravel road. Directly underlying the coal refuse is a yellowish-brown clay, which appears to be weathered spoil. Underlying the weathered spoil is a thick sequence of bluish-gray clay mixed with rock fragments. The bluish-gray clay may be undisturbed material or excavated spoil that has recompacted; however, during the drilling of these wells, the clay appeared to be relatively firm. Geologic data at monitoring well 5, reported by Peabody Coal Company (1982), indicate this bluish-gray clay is missing and coal refuse is present. A limestone unit underlies the bluish-gray clay.

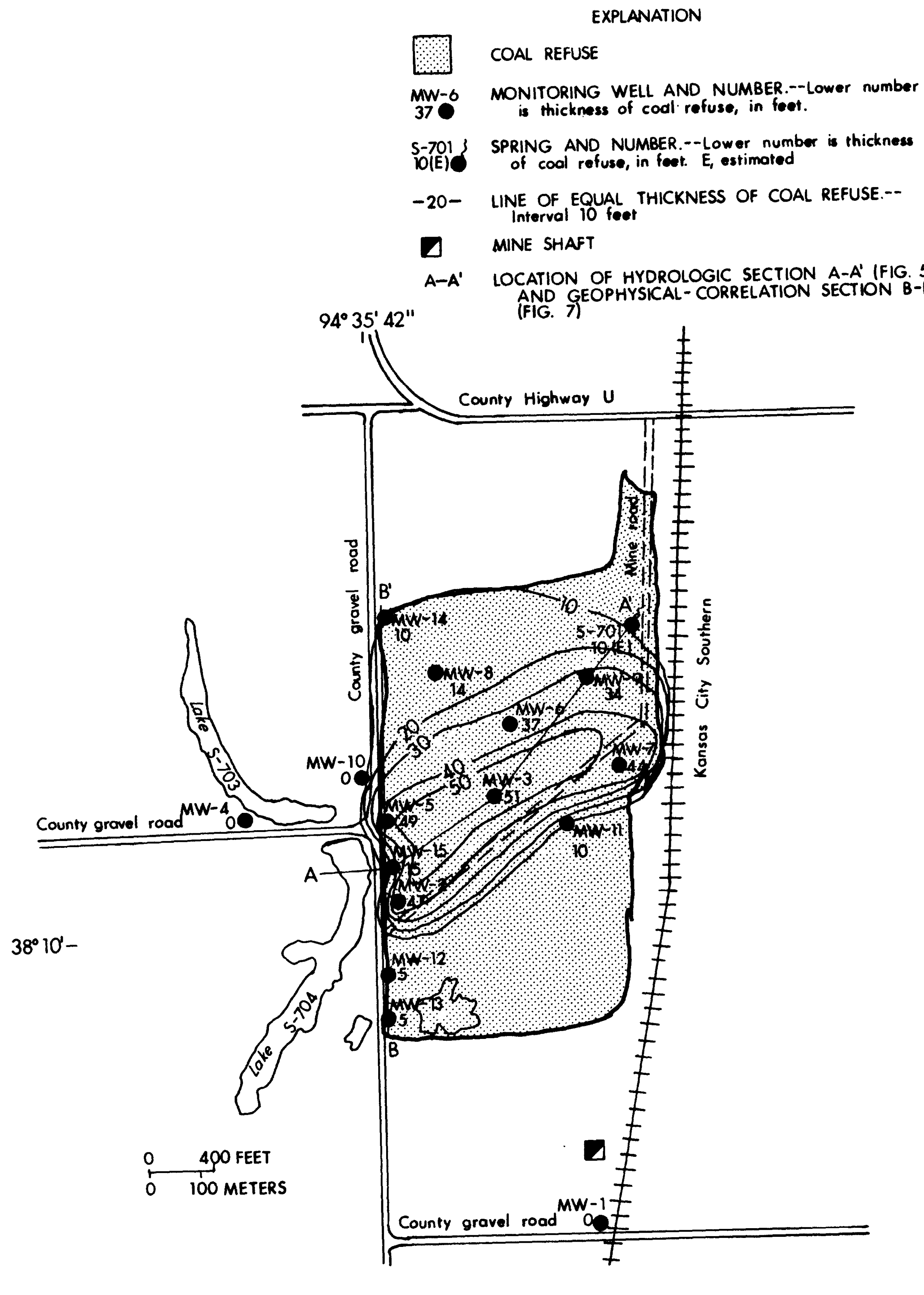


Figure 4.--Thickness of coal refuse and location of hydrologic section A-A' and geophysical-correlation section B-B'.

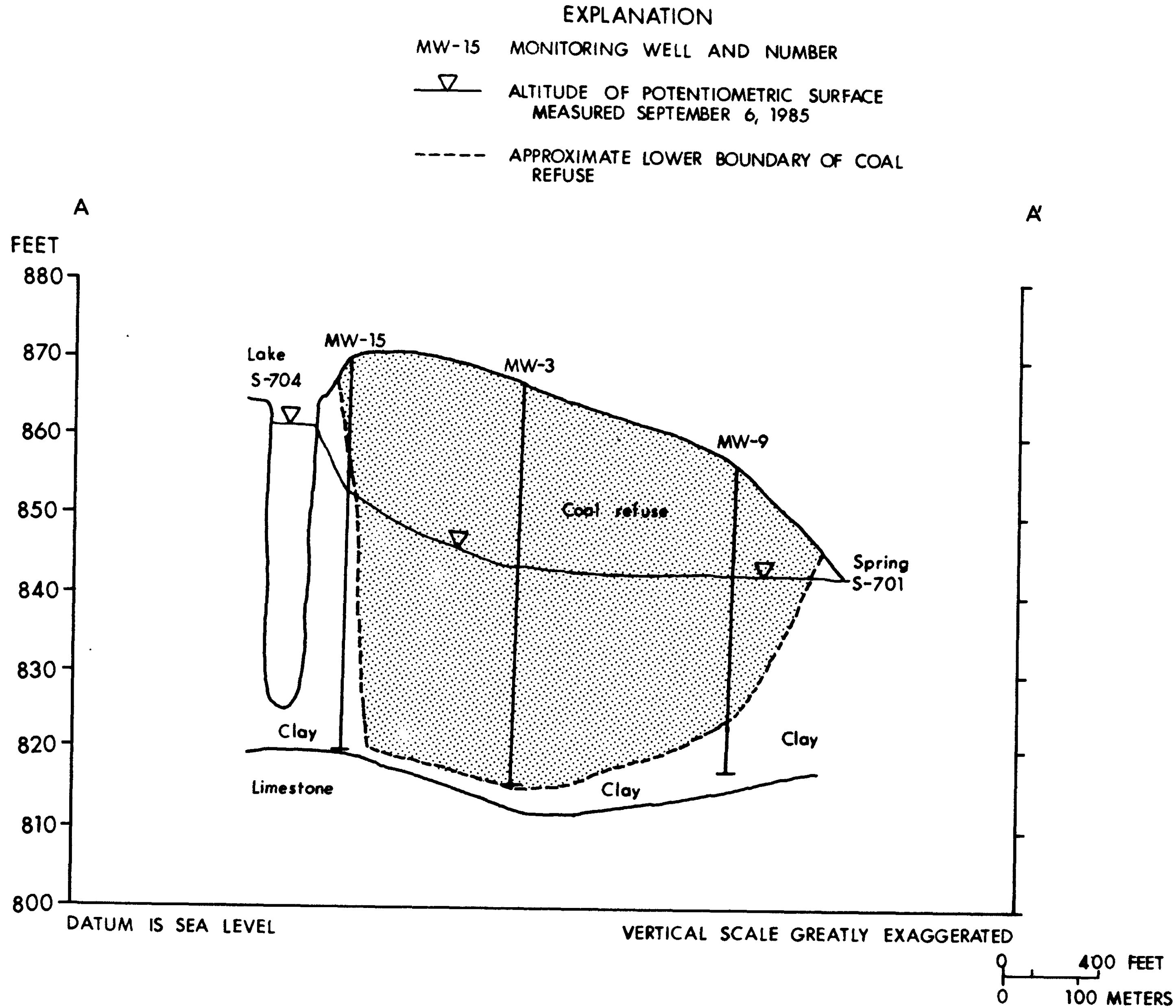


Figure 5.--Hydrologic section A-A'.

Table 1.--Altitude of water levels

[MW, monitoring well; ---, no data; (R), reported data]

Sampling-site location or monitoring well and number (fig. 3)	Water levels, in feet above sea level						Maximum change of water levels from December 18, 1984 or April 17, 1985 to January 14, 1986
	December 18, 1984	April 17, 1985	June 14, 1985	August 29, 1985	September 6, 1985	January 14, 1986	
Lake S-703	---	861.64	---	---	---	---	---
Lake S-704	859.65	861.78	861.95	861.62	861.31	861.62	2.30
Spring S-701[a]	844.81	844.81	844.81	844.81	844.81	844.81	---
MW-1	856.53	858.75	859.52	857.20	856.49	857.10	3.03
MW-2	851.26	853.79	854.27	852.65	853.12	854.35	3.09
MW-3	845.07	845.46	844.53	844.23	844.23	845.21	1.23
MW-4	858.06	861.24	862.36	861.12	860.86	861.60	4.30
MW-5	847.43	851.36	853.26	850.53	850.06	851.59	5.83
MW-6	846.75	849.31	849.39	847.94	847.99	849.21	2.64
MW-7	859.95	863.05	862.17	861.02	860.89	859.20	3.85
MW-8	849.46	847.55	848.40	848.12	848.03	848.23	1.91
MW-9	842.54	845.36	844.38	843.98	843.96	844.25	2.82
MW-10	---	853.18	855.43	850.63	850.53	852.94	4.90
MW-11	---	858.96	859.55	858.36	858.35	857.51	2.04
MW-12	---	856.48	856.86	856.04	855.64	857.12	1.48
MW-13	---	857.00	857.40	856.26	855.93	857.60	1.67
MW-14	---	844.67	844.87	844.59	844.31	844.32	.56
MW-15	---	855.01	855.24	854.57	853.45	854.92	1.79
Mine shaft	---	---	---	---	854(R)	---	---

[a]Altitude of spring orifice from level survey April, 1985.

EXPLANATION

COAL REFUSE

MW-11
821 ● MONITORING WELL AND NUMBER.--Lower number is altitude of the top of clay unit underlying coal refuse, in feet above sea level

S-701
844(E) SPRING AND NUMBER.--Lower number is altitude of the top of clay unit underlying coal refuse, in feet above sea level E, estimated

—820— STRUCTURE CONTOUR.--Shows altitude of the top of clay unit underlying coal refuse. Dashed where approximately located. Contour interval 10 feet. Datum is sea level

MINE SHAFT

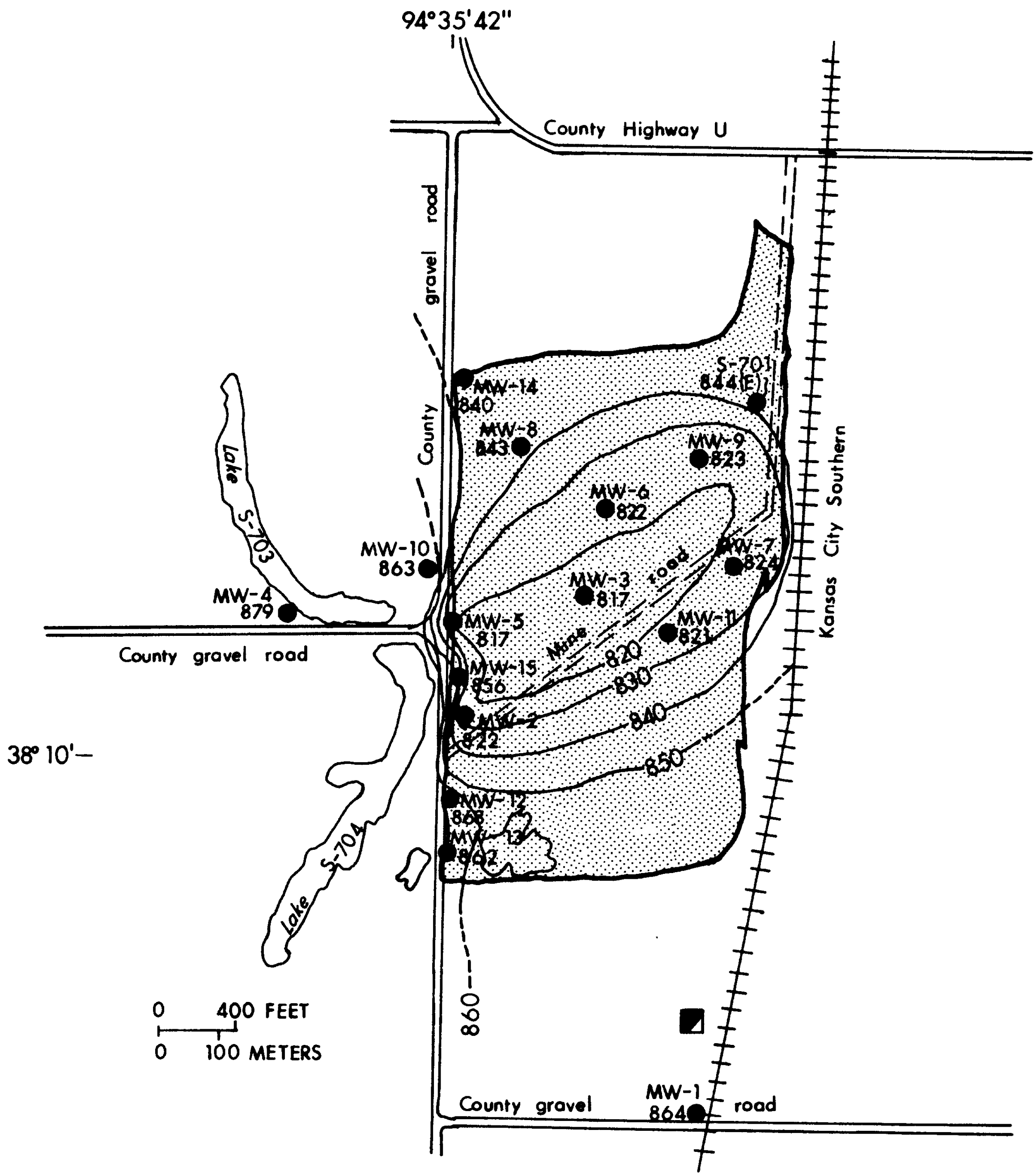


Figure 6.--Altitude of the top of the clay unit underlying the coal refuse.

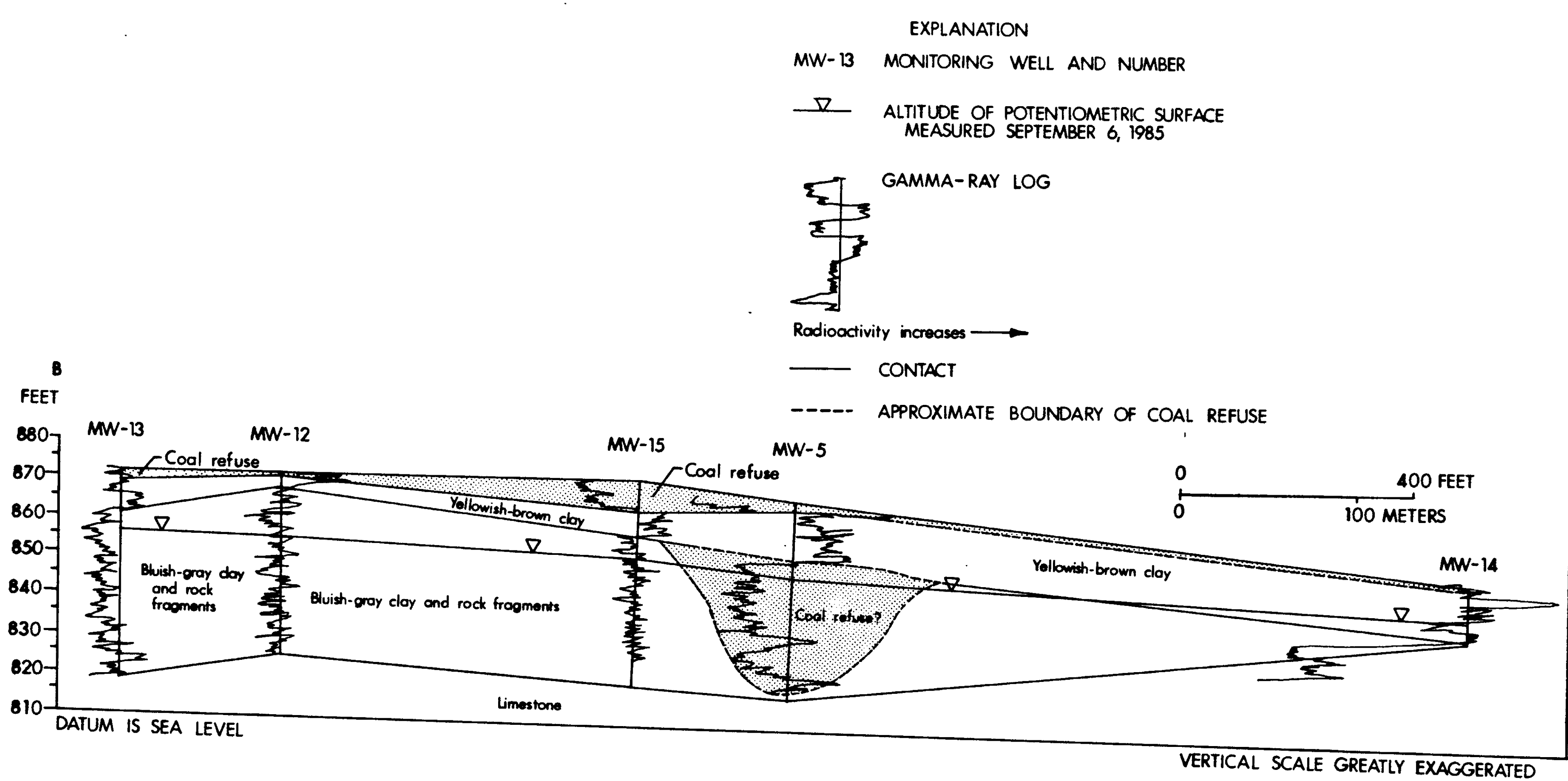


Figure 7.--Geophysical-correlation section B-B'.

HYDROLOGY

Surface- and ground-water interaction occurs in the study area. Surface impoundments provide recharge to the ground-water system and to area streams. Ground water discharges at the spring and seeps into the surface-water system. Precipitation provides a source of water to both systems.

Precipitation and Evapotranspiration

Total precipitation measured at Butler during water year 1985 (October 1, 1984, to September 30, 1985) was about 60 in. (National Oceanic and Atmospheric Administration, 1984-86), which was about 21 in. greater than normal. Average annual evapotranspiration using the pan-evaporation method was estimated by Schroeder (1982) to be about 60 in. in western Missouri. Evaporation from the water table occurs during the hot summer months, but no data were available to determine the extent of change in the altitude of the water table because of evaporation. Effects of transpiration of water from the water table to vegetation were considered to be negligible during the study because the land surface was barren because of the recontouring of the land surface and covering with a clay layer. The covering of the original land surface with a clay layer has decreased the quantity of evapotranspiration and infiltration from precipitation.

Surface Water

Surface impoundments, consisting of several large lakes and numerous small ponds, and intermittent streams are present in and near the mine area (fig. 3). Lakes S-703 and S-704 are large impoundments west of the study area. The altitude of the water surface of these lakes fluctuate seasonally; data from Peabody Coal Company (1982) indicate the altitude of the water surface of lake S-703 fluctuated 2.66 ft during 1982 and that of lake S-704 fluctuated 1.46 ft during the same time. Data also indicate water levels in lake S-703 ranged from about 0.2 to about 2.0 ft lower than in lake S-704. Data collected by the U.S. Geological Survey from December 1984 to January 1986 (table 1) indicate the altitude of lake S-704 had a maximum change of 2.30 ft. Water was withdrawn from lake S-704 during 1985 for dust control during reclamation. The total drainage area for lake S-703 was estimated from the U.S. Geological Survey 7.5-minute quadrangle map (1938) to be less than 0.25 mi^2 and the drainage area for lake S-704 was about 1 mi^2. A large, unnamed acidic pond was located southeast of a mine road and east of monitoring wells 12 and 13, but was drained and filled with material during reclamation. Before reclamation acidic water from the pond was neutralized with lime and pumped from the pond into the surface-water system.

Stream-sampling site S-705 is located southeast of the mine area on an unnamed stream that originally was a diversion ditch used to drain the south side of the mine area. Another unnamed stream on the northeastern border of the mine area drains runoff from the northern part of the mine area; the acidic spring S-701 and seeps drain into this stream. This unnamed stream flows north and drains into the Marais des Cygnes River about 0.5 mi northeast of Worland (fig. 1). The U.S. Geological Survey intermittently has collected water-quality data from this unnamed stream site S-702 where the stream flows under County Highway U southeast of Worland.

Ground Water

Potentiometric-surface maps of water in Pennsylvanian clay and coal refuse were prepared using reported data (Peabody Coal Company, 1982) and data collected by the U.S. Geological Survey during 1984-86. Ground-water flow is toward the north and northeast with localized variations within the mine area as shown in figures 8 and 9. Recharge to the ground-water system occurs from lakes S-703 and S-704 west of the mine area and from precipitation. An isolated recharge area southeast of the mine road corresponds to the topographically highest point within the mine area. Ground-water-level data collected during the study (table 1) indicated the minimum change in water levels was 0.56 ft at monitoring well 14 and the maximum change was 5.83 ft at monitoring well 5. The general pattern of ground-water flow is similar on all the potentiometric-surface maps. The ground-water trough northwest of the mine road from monitoring well 15 northeast to the spring formed as a result of the thick, permeable coal refuse providing an easy path for ground-water flow. The hydraulic gradient rapidly decreases as ground water flows northeast from lake S-704 and becomes slight as water flows through the thickest part of the coal refuse and discharges at spring S-701.

Discharge from the spring S-701 on the northeast edge of the mine area was intermittently measured throughout the study by the U.S. Geological Survey using a flume or a current-velocity meter or both (table 2). In March 1986, an automatic-digital recorder and weir were installed about 100 ft downstream from the spring orifice to record the gage height and discharge for the spring.

No verifiable discharge data are available before reclamation began in December 1984; therefore, all data presented are affected by various phases of reclamation. The maximum discharge, 0.58 ft^3/s, was measured in February 1985; the minimum discharge, 0.09 ft^3/s, was measured in September 1985 and March 1986.

Spring discharge was plotted with daily precipitation at Butler (National Oceanic and Atmospheric Administration, 1984-1986) (fig. 10). Covering the leveled coal refuse with a clay layer was completed during the spring of 1985. Continuous gage-height data from March to September, 1986 after the clay layer was installed indicate precipitation no longer directly affected spring discharge and flow ranged from 0.09 to 0.14 ft^3/s with no significant peaks.

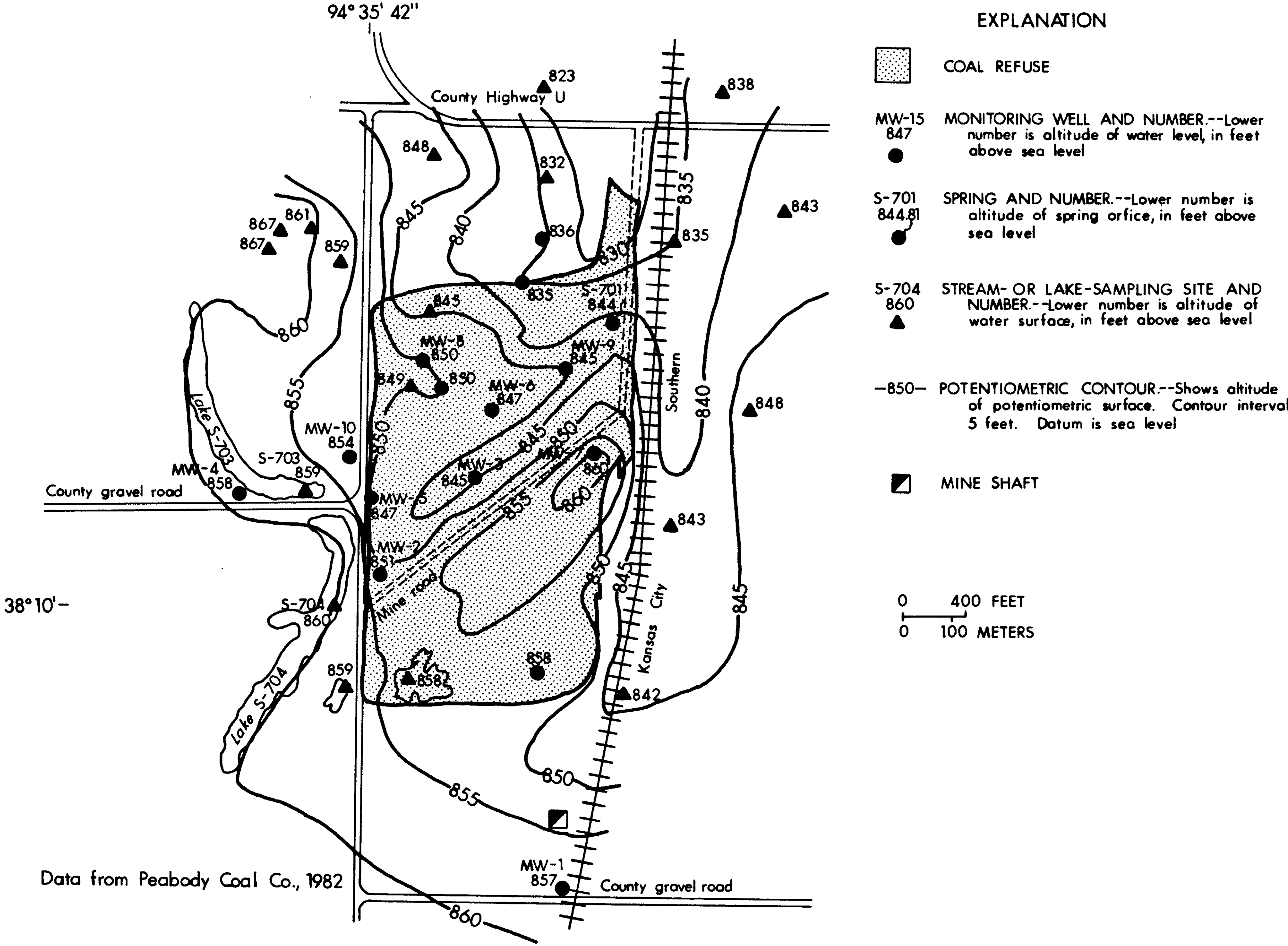
Description and Results of Aquifer Test

A 24-hour pumping and 38-hour-recovery aquifer test was performed at monitoring well 15. Four observation wells were installed at about equal distances around the pumped well (fig. 11), and the existing monitoring wells 2, 5, and 12 also were used as observation wells during the aquifer test. The geologic and well-construction data given in table 5 and the drawdown and recovery (residual drawdown) data for the pumped and observation wells are given in table 6 (Supplemental Data section at the back of this report). Monitoring wells 5 and 12 had no appreciable drawdown during the aquifer test, therefore; no test data are presented for these wells. Graphs of drawdown and residual drawdown are shown in figure 12. Values of transmissivity and storage coefficient were calculated using Theis equations (Lohman, 1972).

Table 2.--Hydrologic data for spring S-701

[ft³/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; ---, no data]

Date of measurement	Discharge (ft^3/s)	pH (units)	Specific conductance (µS/cm)	Water temperature (°C)
2-22-85	0.32	---	---	---
2-25-85	.58	---	---	---
4-17-85	.12	---	7,400	18.0
6-07-85	.21	2.5	6,800	---
6-14-85	.28	2.8	5,890	18.0
6-14-85	.22	2.8	5,890	18.0
6-18-85	.21	---	---	---
6-20-85	.21	---	---	---
6-25-85	.22	---	---	---
7-17-85	.14	---	---	---
7-31-85	.12	---	---	---
9-04-85	.11	---	---	---
9-11-85	.11	---	---	---
9-18-85	.09	---	---	---
1-14-86	.16	3.0	3,840	17.0
3-26-86	.09	3.4	3,550	19.8
6-04-86	.14	3.5	3,600	19.5
7-08-86	.11	---	---	21.0
9-17-86	.14	---	---	---


94° 35' 42"
38° 10'
County Highway U
County gravel road
County gravel road
Southern
Kansas City
Mine road
Lake S-703
Lake S-704
MW-1
857
MW-2
851
MW-3
845
MW-4
858
MW-5
847
MW-6
847
MW-8
850
MW-9
845
MW-10
854
S-701
844
S-703
859
S-704
860
823
832
836
835
838
843
848
867
861
859
849
842
858
EXPLANATION
COAL REFUSE
MW-15
847
MONITORING WELL AND NUMBER.--Lower number is altitude of water level, in feet above sea level
S-701
844.81
SPRING AND NUMBER.--Lower number is altitude of spring orfice, in feet above sea level
S-704
860
STREAM- OR LAKE-SAMPLING SITE AND NUMBER.--Lower number is altitude of water surface, in feet above sea level
—850— POTENTIOMETRIC CONTOUR.--Shows altitude of potentiometric surface. Contour interval 5 feet. Datum is sea level
MINE SHAFT
0 400 FEET
0 100 METERS
Data from Peabody Coal Co., 1982

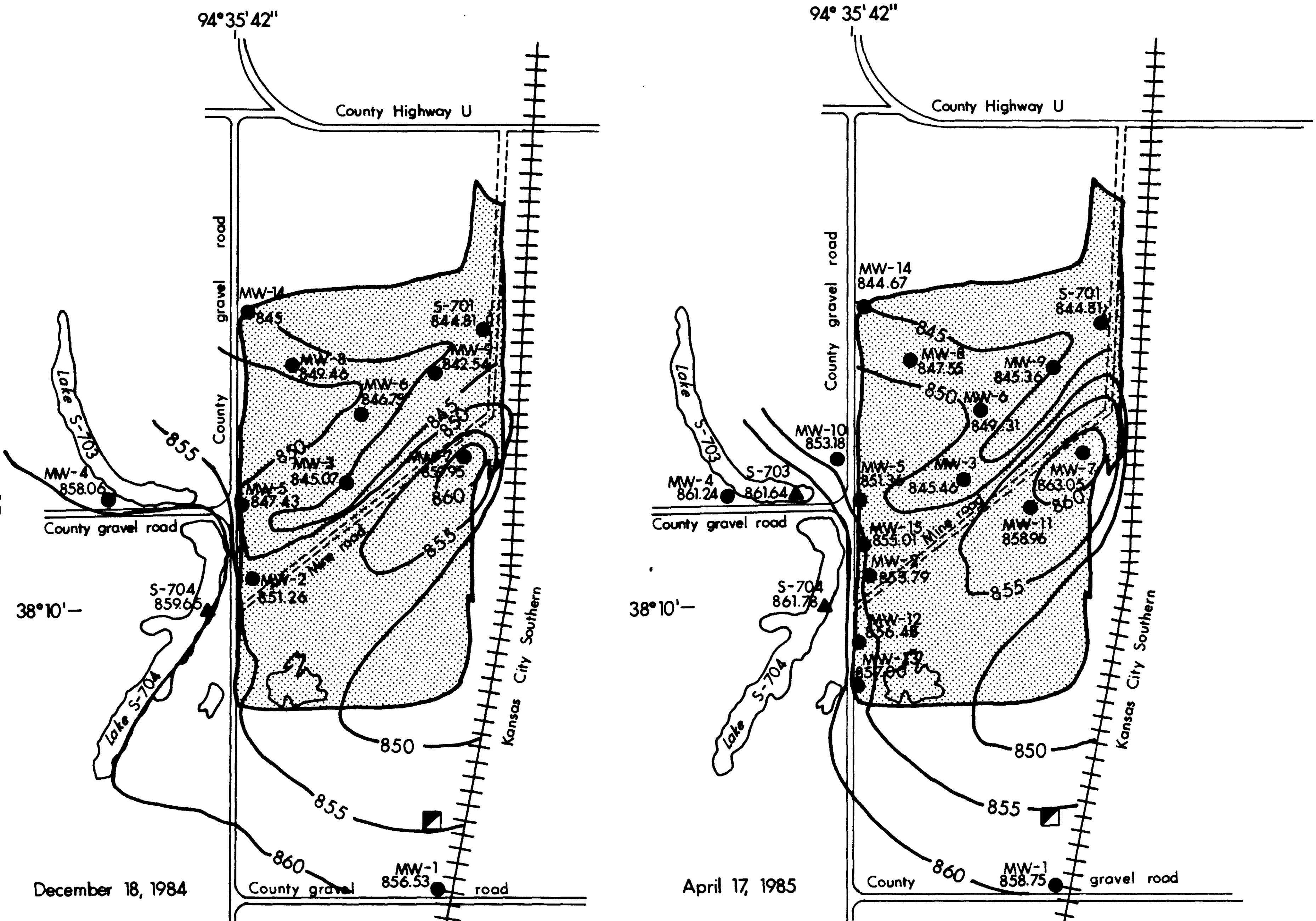
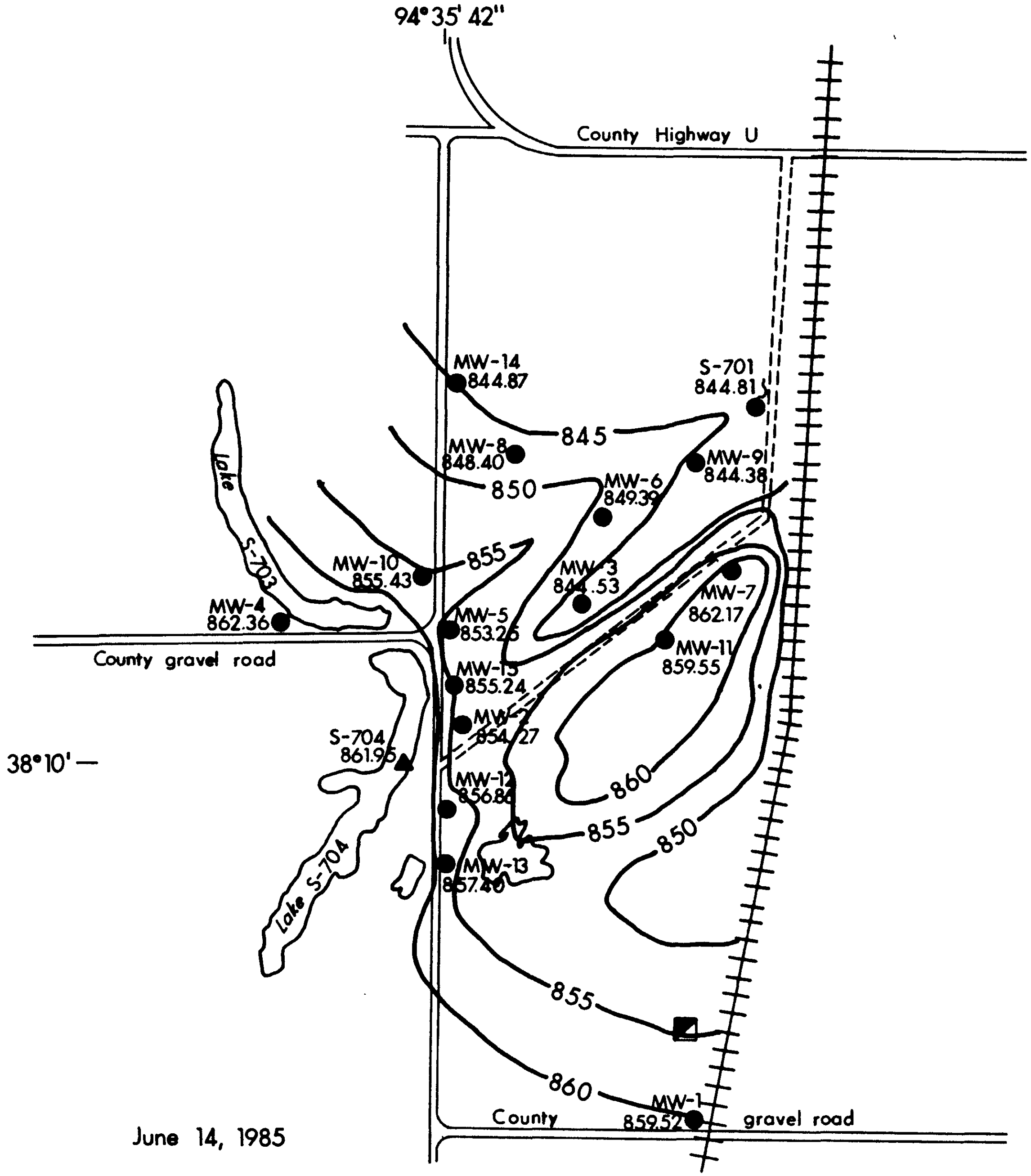


Figure 8.--Potentiometric surface of water in Pennsylvanian clay and coal refuse and altitude of surface water in lakes and streams, 1982, December 1984, and April 1985.

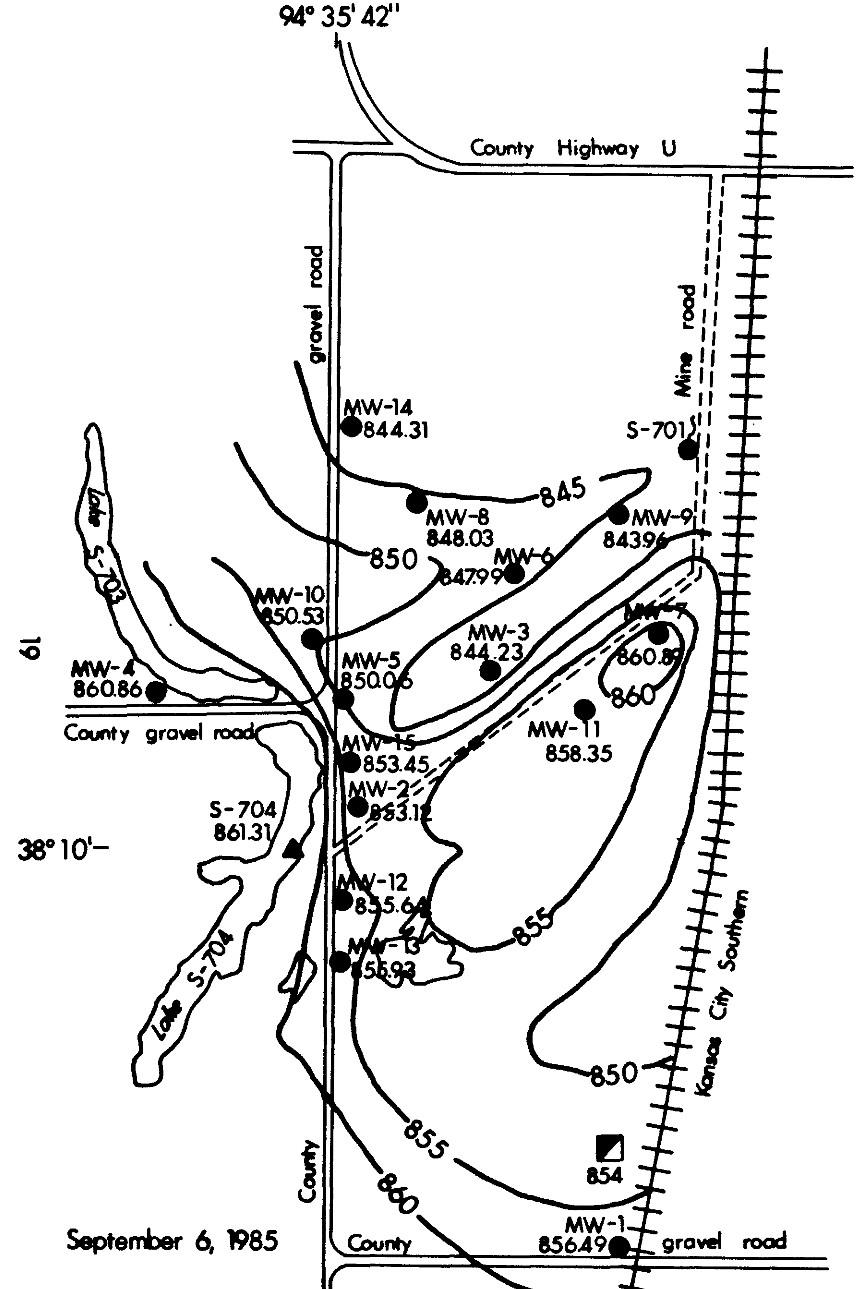


June 14, 1985

EXPLANATION

MW-9 844.38	MONITORING WELL AND NUMBER.--Lower number is altitude of water level, in feet above sea level
S-701 844.81	SPRING AND NUMBER.--Lower number is altitude of spring orfice, in feet above sea level
S-704 861.95	STREAM- OR LAKE-SAMPLING SITE AND NUMBER.--Lower number is altitude of water surface, in feet above sea level
—850—	POTENTIOMETRIC CONTOUR.--Shows altitude of potentiometric surface, in feet above sea level. Contour interval 5 feet
854	MINE SHAFT.--Number is reported altitude of water level, in feet above sea level

0 400 FEET
0 100 METERS



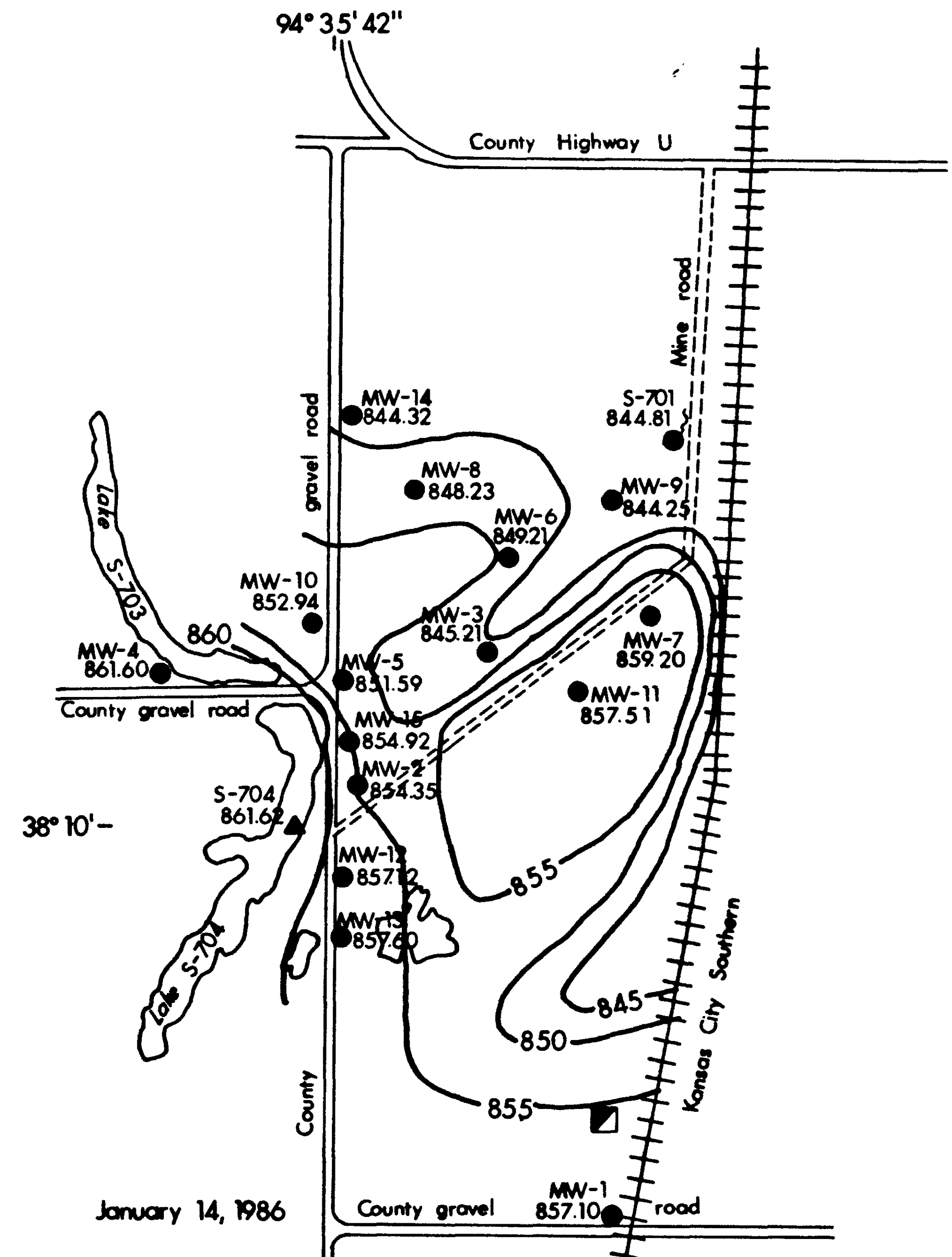


Figure 9.--Potentiometric surface of water in Pennsylvanian clay and coal refuse and altitude water in lakes and streams, June 1985, September 1985, and January 1986.

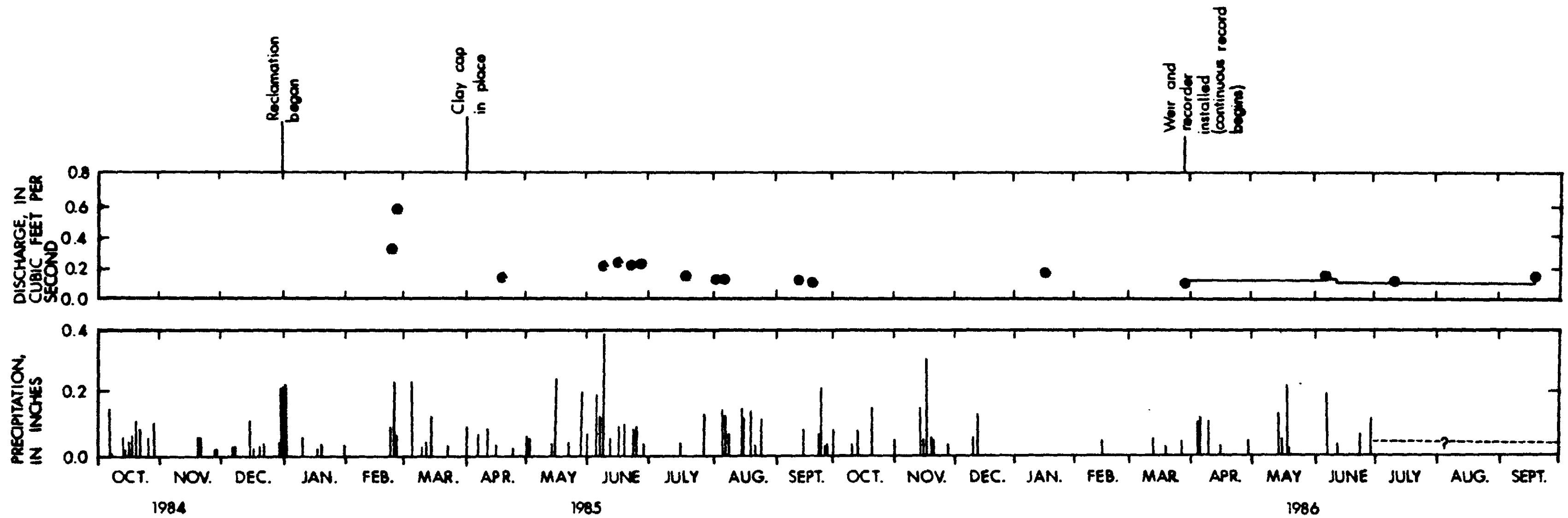


Figure 10.--Discharge from spring S-701 and daily precipitation at Butler, October 1984-September 1986.

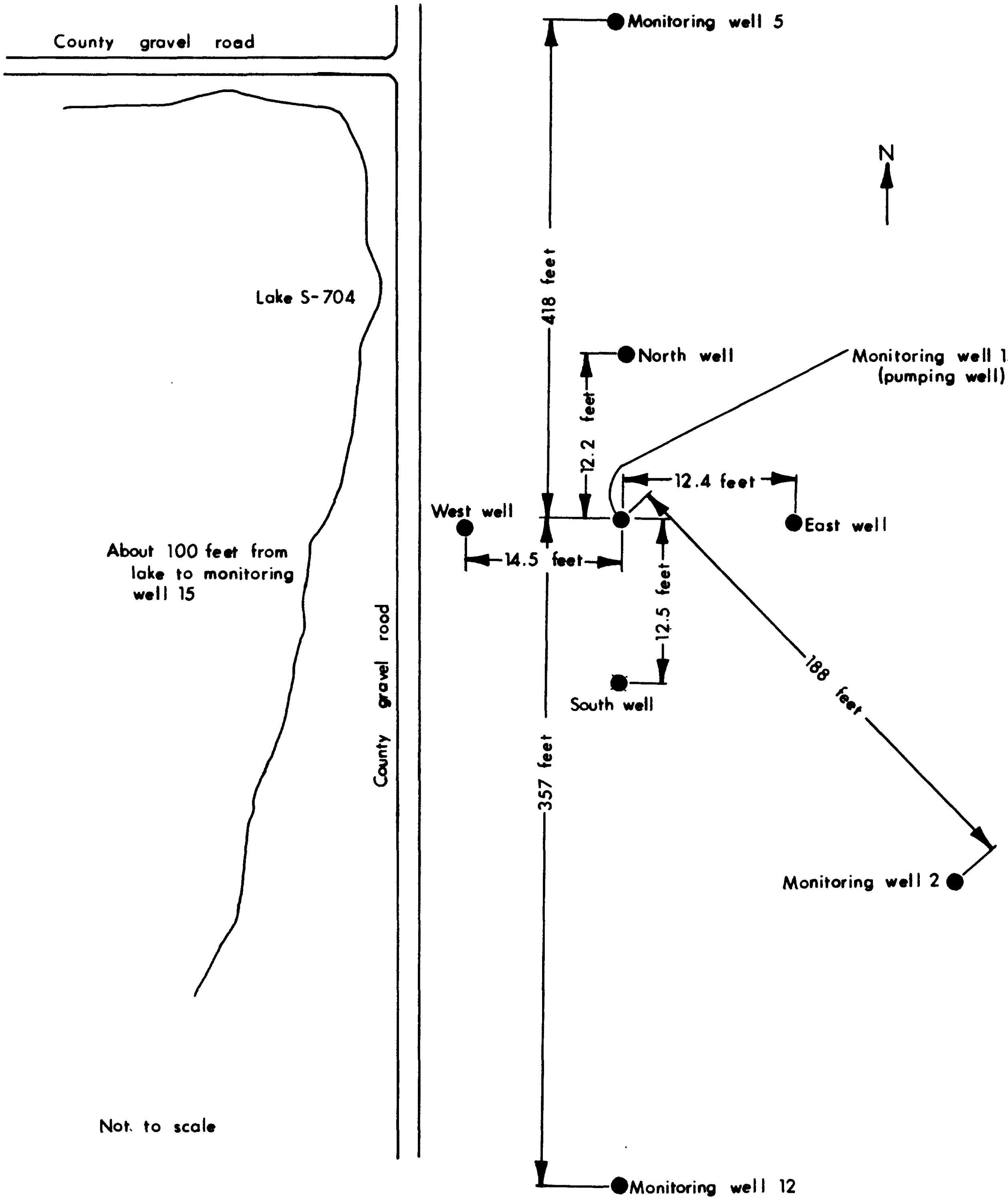


Figure 11.--Location of pumping and observation wells for aquifer-test analysis.

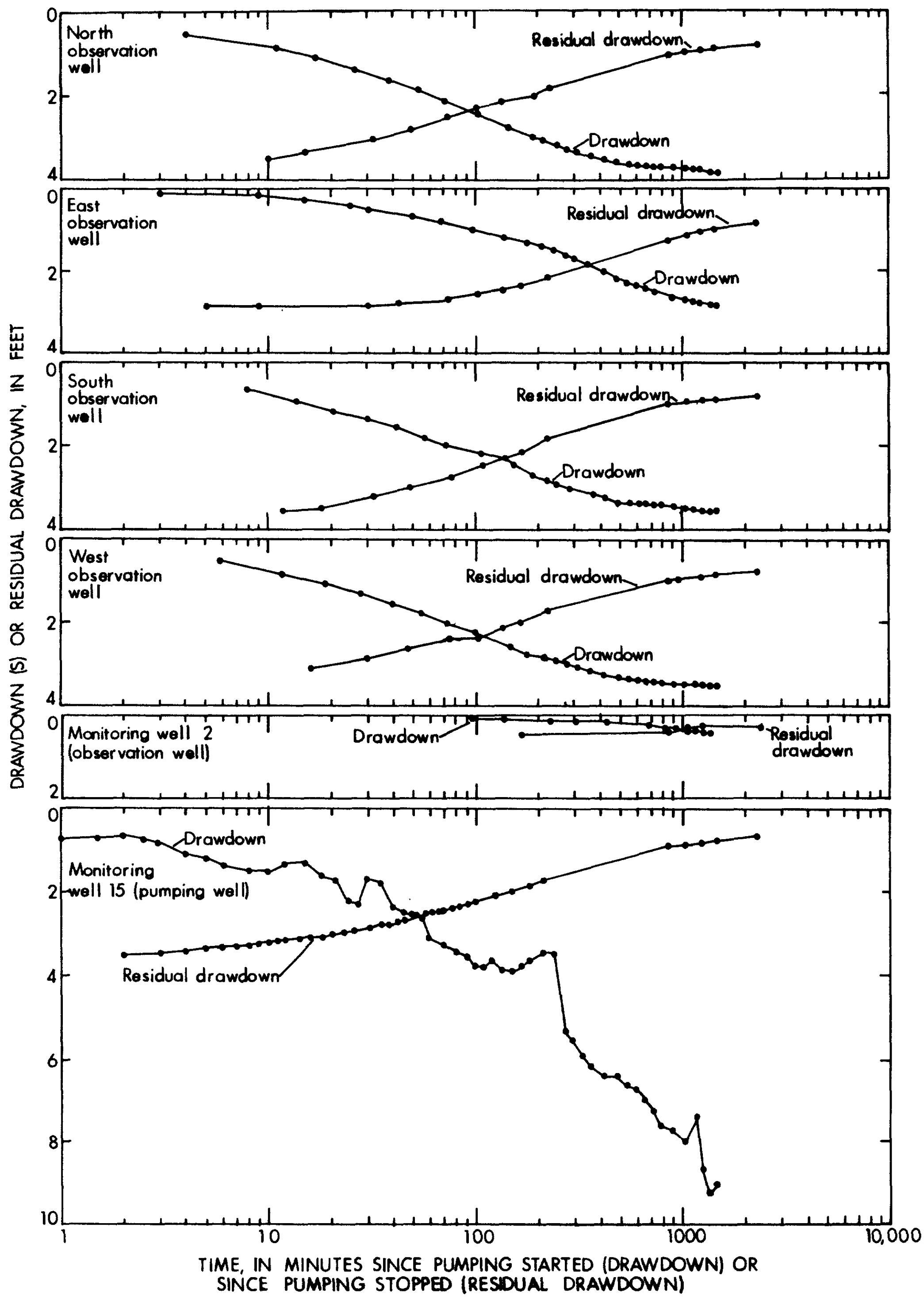


Figure 12.--Time versus drawdown and residual drawdown for aquifer test.

During the drilling of monitoring well 15 and the three shallow observation wells to the north, south, and west, (fig. 11) the aquifer appeared to be under confined conditions. The discharge from the pumped well was intermittently measured throughout the aquifer test and was considered constant at about 9.0 gal/min. Water levels were measured using steel tapes. Values of specific conductance, pH, and water temperature were measured at the pumped well before and after the aquifer test and are as follows:

Time of measurement	Specific conductance, in microsiemens per centimeter at 25 °Celsius	pH, in units	Water temperature, in degrees Celsius
Start of test-------	985	6.9	16.0
End of test---------	800	7.0	14.0

Drawdown data and calculations of r^2/t were plotted for all the observation wells (fig. 13) on log-log graph paper. The plotted data were matched to the Theis-type curve and values of drawdown (s) and r^2/t were chosen that corresponded to W(u)=1.0 and u=0.1 on the type curve. The values from the matched points were used in the Theis equations to calculate transmissivity and the storage coefficients:

$$T = [QW(u)]/4\pi s \text{ and} \quad (1)$$

$$S = [4Tu]/(r^2/t) \quad (2)$$

where T = transmissivity, in feet squared per day;
Q = pumping rate, in cubic feet per day;
W(u) = well function of u;
π = 3.141;
s = drawdown, in feet;
S = storage coefficient;
u = variable of intergration;
r = distance from the pumping well to the observation well, in feet; and
t = time since start of pumping, in days.

Assuming that W(u)=1.0, s=0.75 ft, u=0.1, and $r^2/t=9.2\times10^3$ ft^2/d; and Q=1,730 ft^3/d, the transmissivity was calculated to be 183 ft^2/d and the storage coefficient was calculated to be 0.008. These values of transmissivity and storage coefficient were calculated for the north, south, and west observation wells, and for monitoring well 2. The data for the east observation well plotted to the left of the other curves (fig. 13) and the storage coefficient for this well was calculated to be about 0.05. Comparison of these storage coefficients indicates confined conditions exist around the pumped well, but the east observation well probably is near an area of unconfined conditions.

Generally, Pennsylvanian clay can yield from 1 to 40 gal/min of water and specific capacity of wells can range from about 0.1 to about 3 (gal/min)/ft of drawdown (Kleeschulte and others, 1985). Short-duration specific-capacity tests were performed during water-quality sampling on all monitoring wells within the mine area, except monitoring wells 8, 9, and 10 (table 3). Specific capacity of

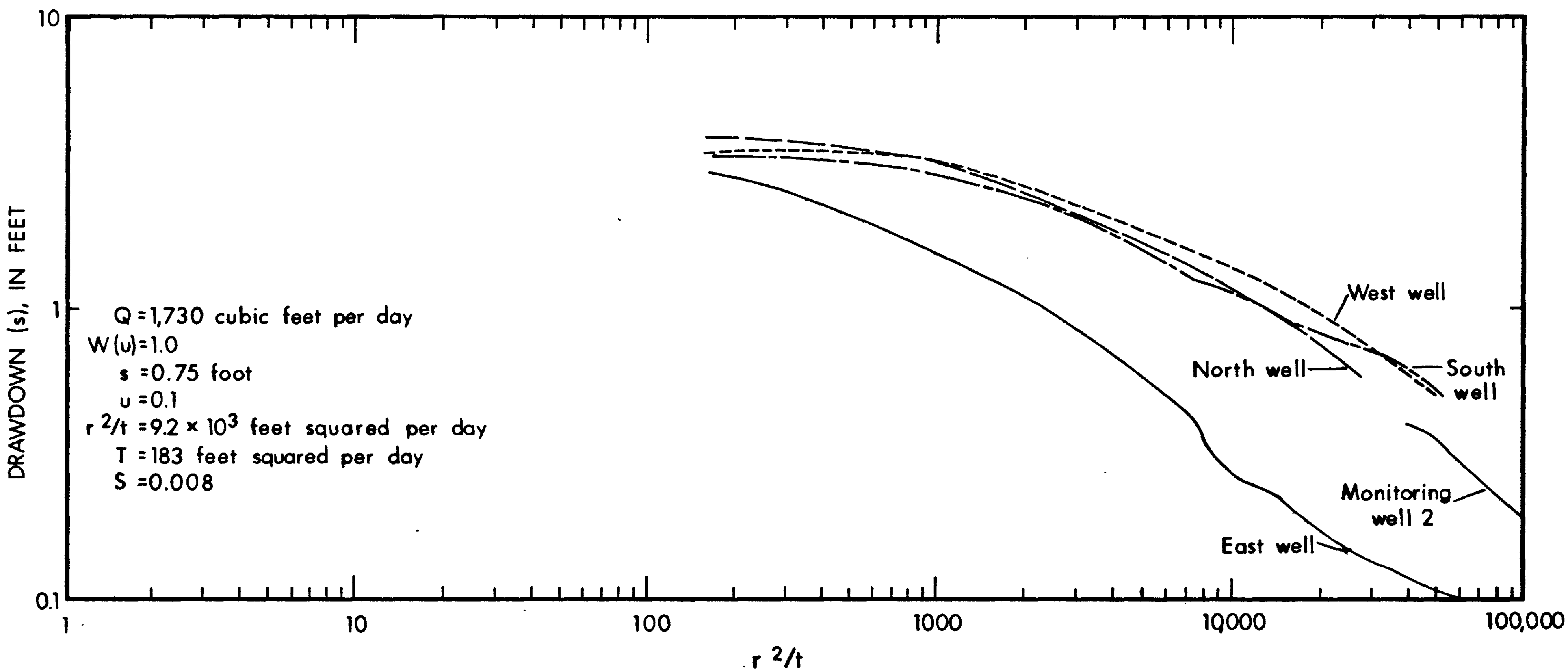


Figure 13.--Drawdown (s) versus r^2/t for observation wells.

Table 3.--Results of short-term aquifer tests during water-quality sampling of wells

[gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot; ft, feet; min, minutes; --, no data]

Monitoring well and number (fig. 3)	Yield of well[a] (gal/min)	Specific capacity [(gal/min)/ft]	Total drawdown (ft)	Initial depth to water below land surface (ft)	Depth of well below land surface (ft)	Time of pumping (min)	Remarks
MW-1	7.5	0.28	26.0	6.73	33.0	9.0	Well pumped dry; recovery was slow.
MW-2	7.5	.32	23.3	20.42	47.0	60.0	Mud pumped at start but developed into a production well.
MW-3	7.5	125.0	.06	27.55	41.0	60.0	Pump did not function when originally set at bottom of well in gob and slurry. Pump was cleaned and set at 5.0 ft below water surface and produced clear water.
MW-4	7.5	.22	33.5	18.56	52.0	10.0	Well pumped dry; recovery was slow.
MW-5	7.5	.95	7.9	14.88	50.0	10.0	Well originally pumped dry; complete recovery in 10 min; well was pumped again and sampled.
MW-6	7.5	.54	14.0	19.09	37.0	30.0	Well pumped dry; recovery fair.
MW-7	7.5	1.50	5.0	10.81	44.1	60.0	---
MW-8	---	---	---	---	33.5	---	Well not sampled.
MW-9	---	---	---	---	40.0	---	Well hand bailed.
MW-10	---	---	---	---	35.0	---	Well hand bailed.
MW-11	7.5	0.29	26.0	11.88	48.0	30.0	Water heard flowing into well.
MW-12	7.5	6.80	1.11	20.17	50.0	60.0	Production well.
MW-13	7.5	22.7	0.33	14.74	57.0	60.0	Production well.
MW-14	7.5	.41	18.21	7.32	27.0	18.0	Well pumped dry after 18 min, allowed to recover to 10.5 ft, pumped 2.5 min and sample collected from well.
MW-15	7.5	2.64	2.84	18.16	50.0	60.0	Clear water production well.

[a]Pumping rate was constant at about 7.5 gallons per minute for the submersible pump. Screen on the pump was about 2.5 feet above the base of the pump.

monitoring wells tested ranged from 0.22 (gal/min)/ft at monitoring well 4, which is completed in Pennsylvanian clay, to 125 (gal/min)/ft at monitoring well 3, which is completed in the thickest part of coal refuse. The specific capacities of monitoring wells 3, 12, 13, and 15 were larger than those normally estimated for wells completed in clay material. This may be attributed to secondary permeability caused by the material being disturbed or from solution activity by acidic water (Tobin and Wild, 1986).

Recharge to Spring S-701

A significant part of this study was to identify recharge sources for the acidic spring. Water-level and water-quality data indicated water primarily infiltrated from lake S-704 into the ground-water system, migrated northeast through the coal refuse, and discharged at the spring on the northeast side of the mine area. A secondary source of recharge was from precipitation directly infiltrating the coal refuse.

An estimate of the quantity of ground water flowing from lake S-704, through the coal refuse, and discharging from the spring was made using the following equation for a section of aquifer material 500 ft wide having a saturated thickness of 35 ft (fig. 14)

$$Q = [KAh]/l \qquad (3)$$

where Q = flow, in cubic feet per day;
K = hydraulic conductivity, in feet per day;
A = area of section of aquifer material, in square feet;
h = change in hydraulic head, in feet; and
l = length of flow path, in feet.

The hydraulic conductivity (K) was calculated using the equation:

$$K = T/b \qquad (4)$$

where T = transmissivity calculated from the aquifer test = 183 ft^2/d; and
b = saturated thickness of the aquifer measured at monitoring well 15 = 35 ft.

The hydraulic conductivity was calculated to be:

$$K = (183\ ft^2/d)/35\ ft = 5.2\ ft/d.$$

The area (A) for the section of aquifer material is the saturated thickness of the aquifer at monitoring well 15, which is 35 feet times the width of the block of aquifer material, which is 500 feet or,

$$A = 35\ ft \times 500\ ft = 17{,}500\ ft^2.$$

The change in hydraulic head (h) is the difference between the altitude of the water level in lake S-704 and in monitoring well 15, which is:

$$h = 861.62\ ft - 854.57\ ft = 7.05\ ft.$$

The distance between lake S-704 and monitoring well 15 measured at the site is:

$$l = 100\ ft.$$

Inserting all the values into the Darcy equation yields:

$$Q = [(5.2\ ft/d) \times (17{,}500\ ft^2/d) \times (7.05\ ft)]/100\ ft;$$

or about 6,400 ft^3/d (0.07 ft^3/s).

Therefore, using the calculated and measured parameters of the aquifer and water in the aquifer, about 0.07 ft^3/s of water flows into the mine site through a section of aquifer material 500 ft wide by 35 feet high at the location of monitoring well 15.

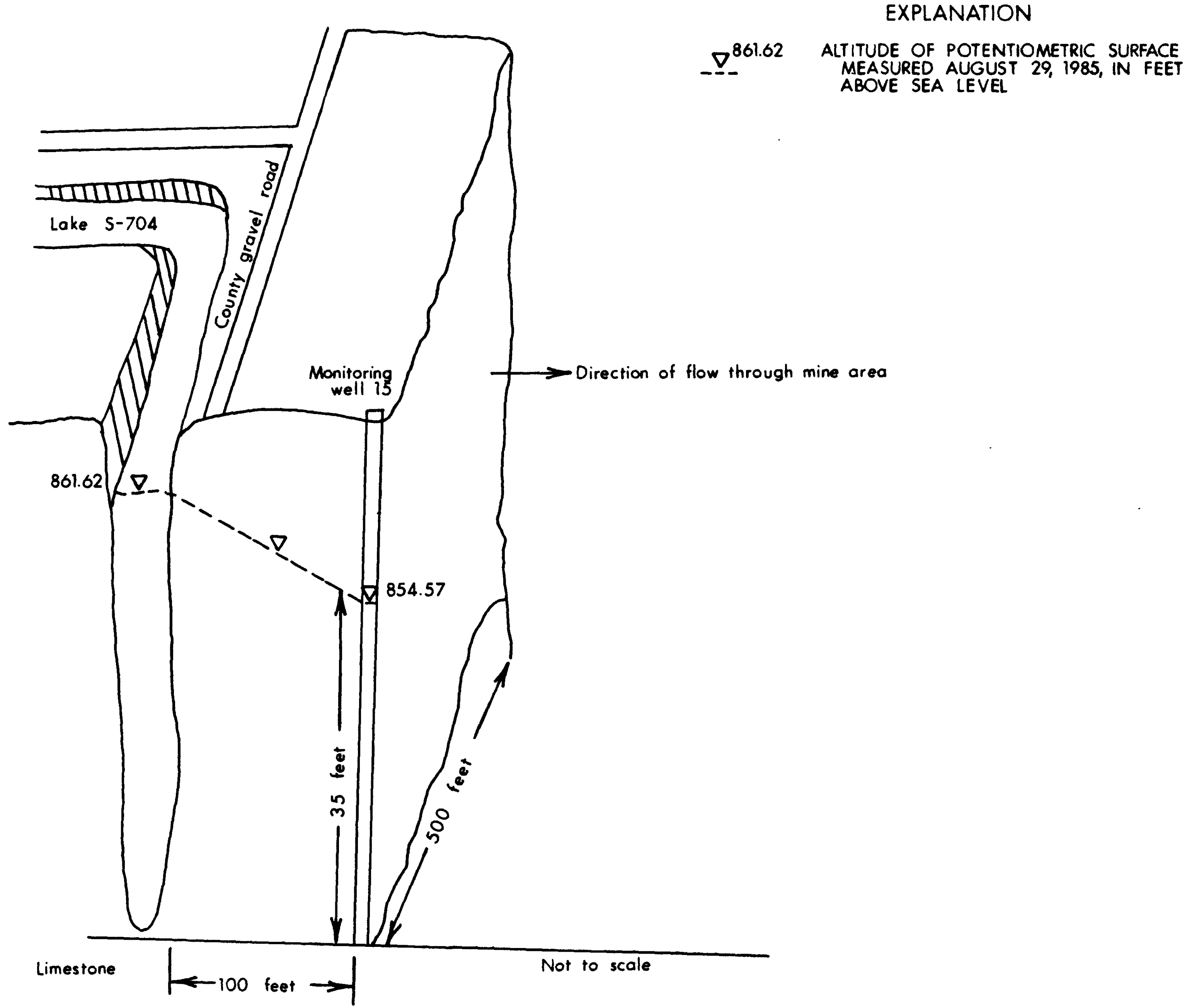


Figure. 14.--Ground-water flow from lake S-704 to monitoring well 15 through a section of aquifer material.

Recharge from precipitation infiltrating the coal refuse contributed to the discharge of spring S-701. Average annual precipitation in the area of the mine is about 39 in.; however, during water year 1985, precipitation was about 60 in. Sharp (1984) presented a recharge rate for a spoil pile in north-central Missouri of about 0.20 in. per year and recharge rates for glacial drift ranging from 1.2 to 5.2 in. per year. Recharge to the coal waste was estimated to be more than 10 in. per year before reclamation; however, this value decreased after installation of the clay layer. No estimates of recharge from precipitation can be made from springflow data until the ground-water system attains equilibrium. Potentiometric data indicate that the recharge area near monitoring well 7 currently (1986) is in a transient condition and water moving from this area toward the spring probably is being removed from storage in the aquifer.

Water Quality

The U.S. Geological Survey collected 19 surface- and ground-water samples for water-quality analysis in June 1985 (table 4). These water samples were analyzed for common ions and selected metals. Water-quality samples collected at lakes S-703 and S-704 indicated water in the lakes generally was fresh. Dissolved-solids concentration in lake S-703 was 642 mg/L (milligrams per liter) and water was a calcium magnesium sulfate type (fig. 15). Concentration of dissolved solids in lake S-704 was 98 mg/L and water was a calcium bicarbonate type. The small concentrations of dissolved solids and other constituents indicate that the quality of water in these lakes primarily is affected by precipitation and does not reflect concentrations of constituents normally present in water from Pennsylvanian clay as reported by Darr (1978).

Flow from the spring and seeps merge with rainfall runoff from the mine area forming a mixed sample at stream-sampling site S-702 at County Highway U. The mixing of these different waters yielded a calcium magnesium sulfate type water that had a dissolved-solids concentration of 5,190 mg/L (fig. 15).

The water sample collected from the unnamed stream S-705, which drains the south side of the mine area, had a dissolved-solids concentration of 592 mg/L (fig. 15). Water was a calcium magnesium sulfate type. This stream drains the overflow from lake S-704 and the mine area; therefore, its chemical characteristics are not representative of either source.

The dissolved-solids concentrations of water discharging from the spring S-701 ranged from about 7,000 to about 14,000 mg/L prior to reclamation and decreased 50 percent to about 4,000 mg/L after reclamation (fig. 16). Values of pH ranged from 2.5 to 3.0 (table 2), with the larger values occurring after reclamation.

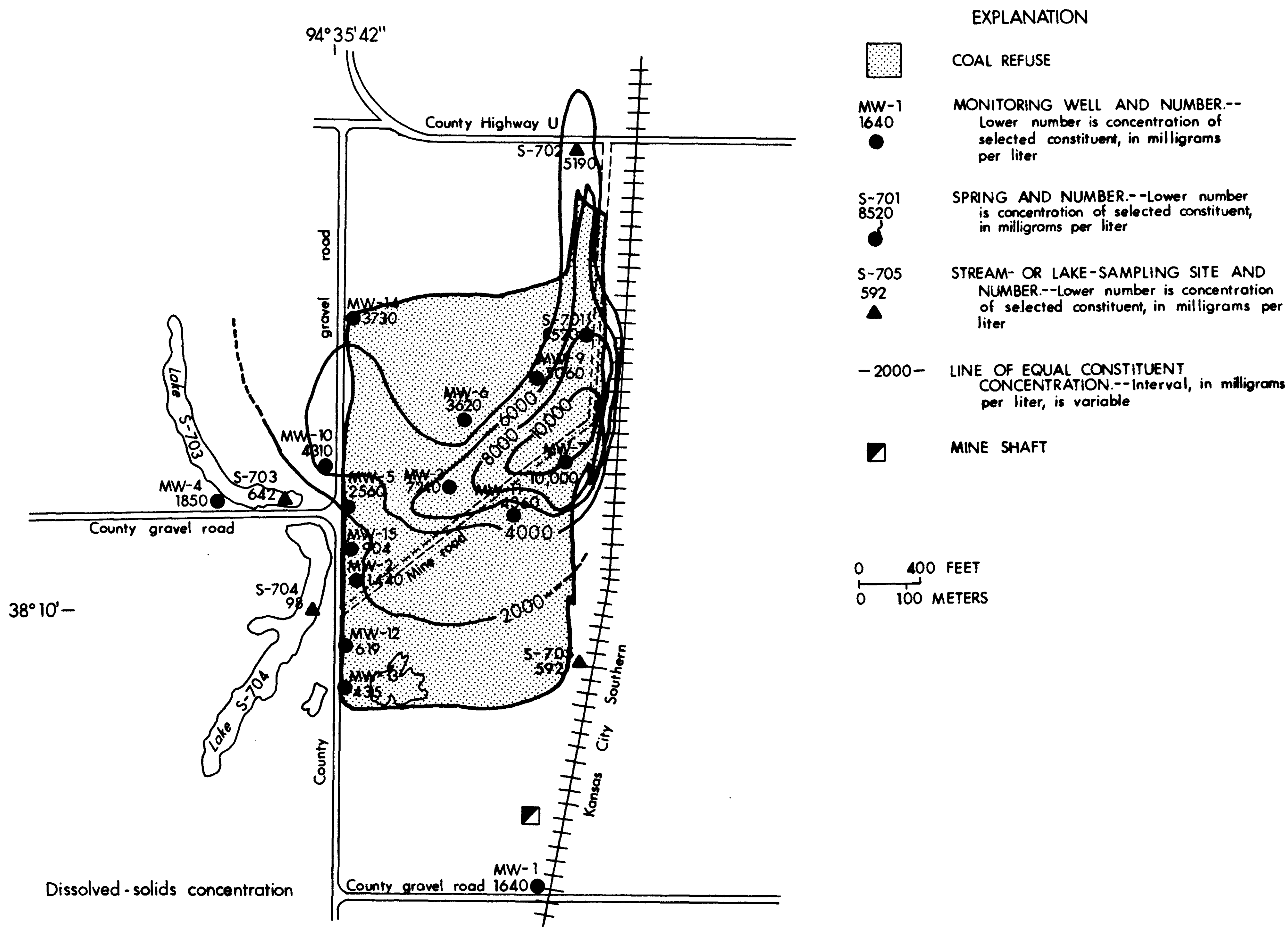
Dissolved-solids concentrations of ground-water samples ranged from 435 to 10,000 mg/L (fig. 15). The largest dissolved-solids concentrations were in water from monitoring wells 3, 7, 9, 10, and 11, which were all completed in the coal refuse. The maximum dissolved-solids concentration was 10,000 mg/L in water from monitoring well 7. Water-quality samples collected and analyzed by the Peabody Coal Company (1982) and samples collected by the Missouri Department of Natural Resources, Land Reclamation Commission, from monitoring wells 3 and 7 consistently had the largest dissolved-solids concentration. The smallest pH value reported in the mine area was 2.23 in water from monitoring well 3.

Table 4.--Analyses of surface- and ground-water samples collected June 11-13, 1985

[Units are in milligrams per liter, except as indicated: µS/cm, microsiemens per centimeter at 25 °C; °C, degrees Celsius; MW, monitoring well; <, less than; ---, no data]

Sampling site[a] (fig. 3)	Specific conductance (µS/cm)	pH (units)	Acidity (as H)	Calcium, dissolved (as Ca)	Magnesium, dissolved (as Mg)	Sodium, dissolved (as Na)	Potassium, dissolved (as K)	Alkalinity, field total (as $CaCO_3$)	Sulfate, dissolved (as SO_4)	Chloride, dissolved (as Cl)	Fluoride, dissolved (as F)	Silica, dissolved (as SiO_2)	Dissolved solids, residue at 180 °C	Iron, total (as Fe)	Manganese, total (as Mn)
Lake S-703	855	7.6	<0.1	90	56	17	3.1	91	370	2.6	0.4	1.6	642	0.24	0.05
Lake S-704	122	7.6	.1	16	3.3	2.7	2.7	41	21	2.2	.1	7.2	98	1.8	.07
Stream S-702 at County Highway U	4,100	3.1	42	360	130	42	9.0	---	3,600	3.3	<.1	51	5,190	500	6.2
Stream S-705	759	6.5	0.5	82	37	8.9	3.6	21	380	3.0	.2	9.8	592	20	2.1
Spring S-701	5,890	2.8	73	420	210	58	16	---	5,300	1.2	<.1	85	8,520	870	3.8
MW-1	1,950	7.0	0.4	300	82	78	4.6	241	860	41	.2	12	1,640	82	1.4
MW-2	1,770	7.1	<.1	220	120	37	3.6	332	740	5.2	.4	10	1,440	110	5.1
MW-3	6,600	2.3	79	240	90	32	9.4	---	3,900	1.6	<.1	22	7,240	800	7.5
MW-4	2,100	7.7	.1	210	110	150	13	150	1,100	9.5	<.1	15	1,850	.35	.06
MW-5	2,610	6.9	.8	370	220	30	5.6	344	1,500	4.3	.2	7.0	2,560	15	.64
MW-6	3,730	6.5	.1	130	98	180	4.2	467	2,100	4.9	.2	8.6	3,620	39	6.6
MW-7	6,400	4.2	88	130	100	20	40	---	6,300	.4	<.1	23	10,000	1,800	18
MW-9	4,150	4.2	16	570	210	68	7.2	---	3,100	1.9	<.1	31	5,060	400	16
MW-10	4,000	6.8	<.1	560	340	130	3.3	470	2,600	6.5	.2	9.4	4,310	350	13
MW-11	4,190	6.6	<.1	580	320	160	3.8	539	2,500	6.3	.3	25	4,360	39	13
MW-12	908	7.0	.4	120	43	13	2.9	235	230	3.9	.2	7.8	619	.81	1.4
MW-13	650	6.4	.3	96	25	5.1	4.6	135	170	2.7	.2	7.5	435	.15	.04
MW-14	3,150	5.2	1.2	340	180	170	5.2	68	2,100	10	.2	27	3,730	360	5.2
MW-15	1,220	5.3	.8	150	65	6.4	3.4	162	480	3.2	.3	7.9	904	29	3.4

[a]Monitoring well 8 was not sampled bacause of an obstruction in the well.



Dissolved-solids concentration

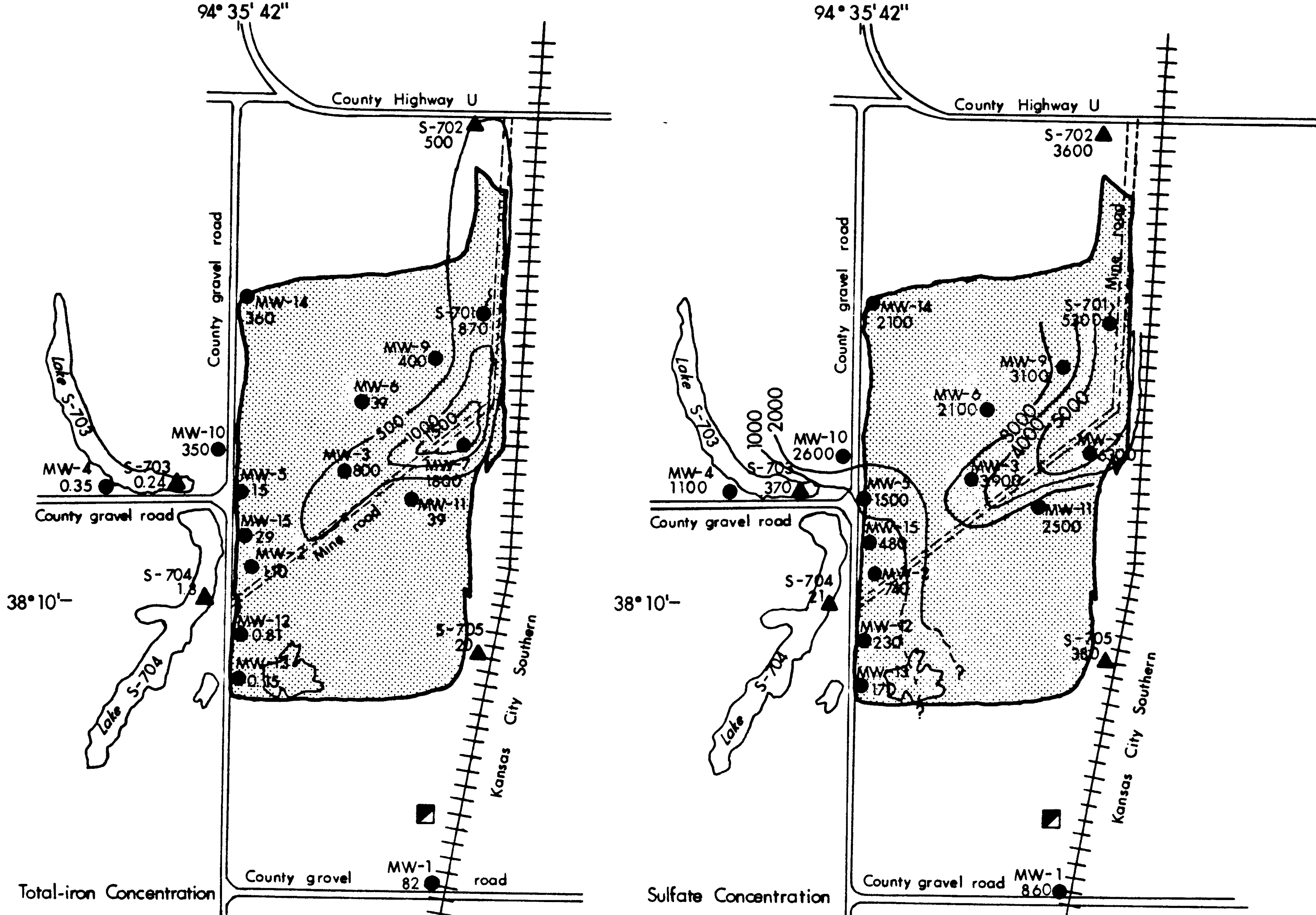


Figure 15.--Dissolved-solids, total-iron, and sulfate concentrations in surface and ground water, June 1985.

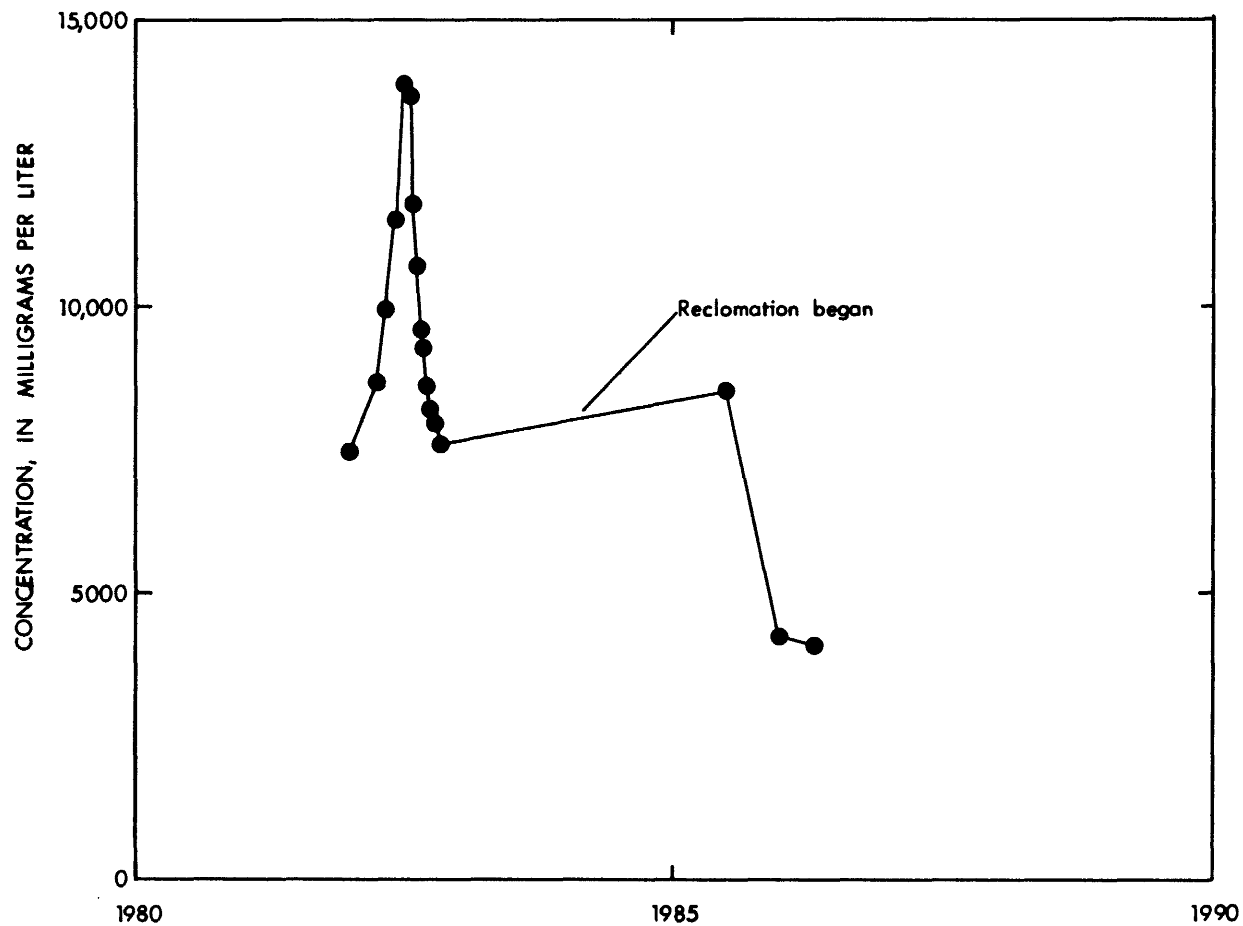


Figure 16.--Dissolved-solids concentrations in water from spring S-701.

Total-iron concentrations (fig. 15) in ground-water samples ranged from 0.15 mg/L at monitoring well 13 to 1,800 mg/L at monitoring well 7. Dissolved-sulfate concentrations (fig. 15) in ground-water samples ranged from 170 mg/L at monitoring well 13 to 6,300 mg/L at monitoring well 7.

Because of the unusual water-quality characteristics in the mine area, typical relations between water-quality properties and constituents are not applicable to the analyses shown in table 3. Hem (1985) reported that specific conductance can be related to a dissolved-solids concentration by the general equation:

$$KA=S \tag{5}$$

where

K = specific conductance, in microsiemens per centimeter at 25 °C;
A = a variable; and
S = dissolved-solids concentration in mg/L.

The variable A, in most natural water, can range from 0.54 to 0.96, with the larger value associated with a large sulfate concentration. Dissolved-solids concentrations, determined using equation 5, in water from surface-water sampling sites S-701 and S-702, and monitoring wells 3, 7, 9, 10, 11, and 14 were all less than the measured dissolved-solids concentrations. Therefore, the general correlation equation described by Hem (1985) does not apply.

Water that was in contact with the coal refuse had dissolved-sulfate concentrations ranging from 2,100 to 6,300 mg/L, which probably contributed to the nonapplicability of equation 5. Hem (1985) also reported that dissolved silica (SiO_2) in water usually does not react as an ionic species and may not affect specific conductance, but is included in the dissolved-solids concentration. Except for monitoring well 10, the concentration of SiO_2 commonly was 20 to 30 mg/L but was 85 mg/L at spring-sampling site S-701.

The anion-cation mass balance for water samples collected from the thickest part of the coal refuse and the spring exceeded the allowable tolerance limit of 5 percent. The most probable reason for this was that the dissolved-aluminum concentration was not analyzed in the samples collected by the U.S. Geological Survey; however, data from Peabody Coal Company (1982) indicated the dissolved-aluminum concentration in water from spring S-701 can be as much as 500 mg/L, which probably was the cause of the excessive percentage difference in the anion-cation mass balance.

SUMMARY

The uppermost coal seam in western Missouri is the Mulky coal bed that ranges from about 30 to about 100 ft below land surface and was about 50 ft below land surface in the mine area. Pennsylvanian clay, shale, limestone, sandstone, and coal form the subsurface strata in the mine area, except at the mine site. Surficial soils in the area are from the Hartwell series that formed from loess and shale. The surficial material in the mine area consisted of coal refuse and fragments before reclamation. The coal refuse was as much as 51 ft thick. Clay material underlies the coal refuse and may be undisturbed or excavated spoil (overburden). Undisturbed Pennsylvanian strata underlies the entire area and dips in a southerly direction. Hydrologic and geophysical correlation sections drawn through the study area indicate the coal refuse generally is surrounded by clay.

Surface impoundments consisting of several large lakes and numerous small ponds, and intermittent streams are in the area. Water levels in the large lakes fluctuated from about 1.50 to 2.50 ft during 1982. The drainage areas of the two largest lakes to the west of the mine area range from about 0.25 mi^2 to about 1 mi^2. Several unnamed tributaries drain the area.

Water moving through the Pennsylvanian clay and coal refuse generally flows northeast through the mine area. Potentiometric-surface maps indicated ground-water levels fluctuated a minimum of 0.56 ft and a maximum of 5.83 ft during the study. Flow patterns indicated primary recharge to the mine area was from lakes to the west and secondary recharge was from precipitation. The hydraulic gradient rapidly decreased as ground water flowed northeast from the lakes and became slight in the coal refuse.

Discharge from the acidic spring, on the northeast boundary of the mine area at the base of the coal refuse, ranged from about 0.09 to 0.58 ft^3/s. Maximum discharge was measured at the spring in February 1985; however, after recontouring and installation of a clay layer on the coal refuse, springflow gradually decreased. Beginning in March 1986, stage was continuously recorded using an automatic recorder, and discharge ranged from 0.09 to 0.14 ft^3/s, with no major peaks recorded.

An aquifer test indicated a transmissivity value of 183 ft^2/d. The storage coefficient ranged from 0.008 to 0.05. This range indicates confined and unconfined conditions may exist near the test site. Wells had specific capacity values that ranged from 0.22 (gal/min)/ft of drawdown for a well completed in the clay to 125 (gal/min)/ft of drawdown for a well completed in the coal refuse.

An estimate of the quantity of water recharging the mine area from lake S-704 was made by applying the aquifer properties, calculated from the aquifer test, to a section of saturated aquifer material 500 ft wide and 35 ft thick. About 0.07 ft^3/s of water flowed through the section of saturated aquifer material from lake S-704 into a ground-water trough in the coal-refuse material and moved toward the spring. The base flow of the spring was about 0.10 ft^3/s.

Water in lakes S-703 and S-704 generally was fresh with dissolved-solids concentrations of 642 mg/L in lake S-703 and 98 mg/L in lake S-704. Water in lake S-703 was a calcium magnesium sulfate type and in lake S-704 water was a calcium bicarbonate type. Water quality in the lakes primarily was affected by precipitation and did not reflect concentrations of constituents normally present in water from Pennsylvanian clay. Streams draining these lakes had variable water quality because of the mixing of surface water, ground water, and precipitation. Dissolved-solids concentrations in the streams ranged from about 600 to about 5,200 mg/L. Quality of ground water was variable with dissolved-solids concentrations ranging from 435 to 10,000 mg/L. The smallest dissolved-solids concentration was in water from monitoring well 13 near lake S-704. The largest dissolved-solids concentration was in water from monitoring well completed in the coal refuse. The smallest pH value measured during the study was about 2.3 at monitoring well 3. Total-iron concentrations ranged from 0.15 to 1,800 mg/l. Dissolved-sulfate concentrations ranged from 170 to 6,300 mg/L. Dissolved-solids concentrations in water from spring S-701 ranged from about 7,000 to about 14,000 mg/L before reclamation, were 8,520 mg/L during reclamation, and decreased 50 percent to about 4,000 mg/L after reclamation. The total-iron concentration was 870 mg/L, and the dissolved-sulfate concentration was 5,300 mg/L in June 1985. The smallest pH value measured at the spring was 2.5 and the largest value was 3.0.

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SUPPLEMENTAL DATA

Table 5.--Well-drilling and construction data

[Peabody Coal Company borehole 1 located in center of county gravel road 0.5 mile south of Tiger Mine office at the intersection of two county gravel roads; altitude of land surface from topographic map is 883 feet; date drilled, May 10, 1982; borehole has been plugged]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company borehole 1		
Surface clay	8.9	0.0- 8.9
Limestone	1.3	8.9-10.2
Shale, gray	37.9	10.2-48.1

Note: Cave-in at 48.1 feet

[Peabody Coal Company borehole 2 located in road about 10 feet south of monitoring well 1 at intersection of county gravel road and Kansas City Southern Railroad line; altitude of land surface from topographic map is 863 feet; date drilled, May 11, 1982; borehole has been plugged]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company borehole 2		
Surface clay	16.8	0.0-16.8
Shale, gray	13.5	16.8-30.3
Shale, dark	.4	30.3-30.7
Coal	2.2	30.7-32.9
Fireclay	1.1	32.9-34.0

Table 5.--Well-drilling and construction data--Continued

[Peabody Coal Company borehole 3 located about 100 feet southeast of monitoring well 7; altitude of land surface from topographic map is 865 feet; date drilled, May 20, 1982; borehole has been plugged]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company borehole 3		
Clay	19.1	0.0- 19.1
Shale	.5	19.1- 19.6
Coal	2.6	19.6- 22.2
Fireclay	9.1	22.2- 31.3
Limestone	21.3	31.3- 52.6
Shale, gray, dark	15.2	52.6- 67.8
Limestone	4.8	67.8- 72.6
Shale, dark	7.6	72.6- 80.2
Shale, gray	2.3	80.2- 82.5
Sandstone	5.1	82.5- 87.6
Shale, gray	12.4	87.6-100.0

[Peabody Coal Company borehole 4 located in gravel road 0.5 mile north of Tiger Mine office at intersection of gravel road; altitude of land surface from topographic map is 854 feet; date drilled, May 13, 1982; borehole has been plugged]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company borehole 4		
Surface clay	13.7	0.0- 13.7
Limestone	11.0	13.7- 24.7
Shale, dark	13.1	24.7- 37.8
Limestone	3.0	37.8- 40.8
Shale, dark	10.3	40.8- 51.1
Sandstone	6.0	51.1- 57.1
Shale, gray	18.5	57.1- 75.6
Sandstone	4.3	75.6- 79.9
Shale, gray	20.1	79.9-100.0

Table 5.--Well-drilling and construction data--Continued

[Peabody Coal Company monitoring well 1 located south side of mine site near intersection of county gravel road and Kansas City Southern Railraod line; altitude of top of steel casing by level measurement is 866.30 feet; date drilled, May 18, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 1		
Shale, clay	16.8	0.0-16.8
Shale, gray	13.5	16.8-30.3
Shale, dark	.4	30.3-30.7
Coal	2.3	30.7-33.0

Note: Eight-inch hole, 6-inch casing, 25 feet of perforated casing and 8 feet of solid casing, gravel pack to solid casing, cement grout with one bag

[Peabody Coal Company monitoring well 2 located northwest side of mine road about 100 feet from mine office; altitude of top of plastic casing by level measurement is 874.44 feet; date drilled, May 18, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 2		
Coal spoil	47.0	0.0-47.0

Note: Fireclay at total depth. Eight-inch hole, 6-inch casing, 40 feet of perforated casing, and 7 feet of solid casing (extended during reclamation), gravel pack to solid casing, cement grout with two bags

[Peabody Coal Company monitoring well 3 located about 300 feet northwest of the mine road; altitude of top of plastic casing by level measurement is 871.94 feet; date drilled, May 19, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 3		
Slurry pit	51.0	0.0-51.0

Note: Fireclay at total depth. Ten feet caved in and only 41 feet were cased. Eight-inch hole, 6-inch casing, 34 feet of perforated casing with 7 feet of solid casing, gravel pack to solid casing, cement grout with two bags

Table 5.--Well-drilling and construction data--Continued

[Peabody Coal Company monitoring well 4 located west of mine site on north shoulder of east-west county gravel road; altitude of top of steel casing by level measurement is 880.94 feet; date drilled, May 17, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 4		
Surface clay	16.0	0.0-16.0
Shale, gray	31.8	16.0-47.8
Coal	3.2	47.8-52.0

Note: Eight-inch hole, 6-inch casing, 35 feet of perforated casing, 16.5 feet of solid casing, gravel packed to solid casing, cement grout with three bags

[Peabody Coal Company monitoring well 5 located east of the intersection of the north-south and east-west gravel roads about 700 feet north of Tiger Mine office; altitude of top of plastic casing by level measurement is 868.06 feet; date drilled, August 19, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 5		
Coal refuse	48.8	0.0-48.8
Fireclay	1.2	48.8-50.0

Note: Eight-inch hole, 6-inch casing, 40.0 feet of perforated casing, 8.8 feet of solid casing, cement grout with three bags

[Peabody Coal Company monitoring well 6 located about 700 feet north of mine road and 800 feet east of the north-south gravel road; altitude of top of plastic casing by level measurement is 868.61 feet; date drilled, August 26, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 6		
Coal refuse	36.5	0.0-36.5
Fireclay	.5	36.5-37.0

Note: Eight-inch hole, 6-inch casing, 32.5 feet of perforated casing, 4 to 5 feet of solid casing, cement grout with two bags

Table 5.--Well-drilling and construction data--Continued

[Peabody Coal Company monitoring well 7 located about 250 feet south of mine road and 400 feet west of Kansas City Southern Railroad line; altitude of top of plastic casing by level measurement is 872.90 feet; date drilled, August 25, 1982]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 7		
Coal gob	5.8	0.0- 5.8
Coal spoil	38.1	5.8-43.9
Fireclay	.2	43.9-44.1

Note: Eight-inch hole, 6-inch casing, 40.9 feet of perforated casing, 3.9 feet of solid casing, cement grout with one bag

[Peabody Coal Company monitoring well 8 located about 400 feet east of north-south gravel road and 300 feet north of mine road; altitude of top of casing of stand pipe by level measurement is 866.35 feet; date drilled, November 17, 1983, contracted by Missouri Department of Natural Resources]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 8		
Coal fragments, loose, dry	3.5	0.0- 3.5
No sample	5.0	3.5- 8.5
Coal fragments, gravel-size fragments at 12.5 feet	5.0	8.5-13.5
Clay and silt; yellow, brown, soft, wet; possibly disturbed soil remnant from strip mining from 13.5 to 15.0 feet	10.0	13.5-23.5
Clay and silt; dark-gray, slightly firm; with gravel-size sandstone fragments, few gravel fragments at 24 feet	5.0	23.5-28.5
Clay, shale, and sandy shale fragments	5.0	28.5-33.5

Note: Bedrock at 33.5 feet, possibly shale based on auger interpretation; original ground line probably at 27 feet. Water at 8.5 feet during drilling, at 7.6 feet at completion. Eighteen and one-half feet of 4-inch steel-pipe casing, screen at 18.5 to 23.5 feet, open hole to 33.5 feet, gravel pack with one-fourth limestone, bentonite pellet grout at 8 to 10 feet covered by clay pack with surficial cement grout

Table 5.--Well-drilling and construction data--Continued

[Peabody Coal Company monitoring well 9 located about 500 feet north of mine road and 300 feet southeast of spring; altitude of top of steel-casing pipe by level measurement is 859.53 feet; date drilled, November 17, 1983, contracted by Missouri Department of Natural Resources]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 9		
Coal fragments, loose, dry, gravel-sized or larger	8.5	0.0- 8.5
Coal fragments with clay matrix	10.0	8.5-18.5
Coal fragments	5.0	18.5-23.5
Coal fragments, large	5.0	23.5-28.5
Loose material becoming firmer with depth	5.0	28.5-33.5
Shale, weathered, slightly firm mixed with yellow-brown clay	1.5	33.5-35.0
No sample	3.5	35.0-38.5
Shale, silty, weathered, firm, yellow, brown	1.5	38.5-40.0

Note: Water table at 13.0 feet. Hole completed with auger at 38.5 feet. Twenty-three and one-half feet of 4-inch steel casing, screen at 23.5 to 28.5 feet, 4-inch steel casing to 38.5 feet; hole caved and no gravel pack

Table 5.--Well-drilling and construction data--Continued

[Peabody Coal Company monitoring well 10 located on west shoulder of north-south gravel road about 1,000 feet north of mine road; altitude of top of steel-casing pipe by level measurement is 865.18 feet; date drilled, November 17, 1983, contracted by Missouri Department of Natural Resources]

Material	Thickness (feet)	Depth (feet)
Peabody Coal Company monitoring well 10		
Silt and loam; brown, moist	3.5	0.0- 3.5
Shale, weathered, gray, dry	1.5	3.5- 5.0
Shale; clay, silty	3.5	5.0- 8.5
Shale, weathered, mixed with silty clay	5.0	8.5-13.5
Shale, sandy, brown, dry disturbed material	5.0	13.5-18.5
Silt; shale; and silty clay; firm, moist, disturbed material	5.0	18.5-23.5
Shale, weathered, yellow, brown, soft; some intervals sandy, moist, slightly firm	1.5	23.5-25.0
No sample	3.5	25.0-28.5
Clay, brown, firm, moist; undisturbed soil is natural ground material overlain by coal refuse; original land surface about 830 feet above sea level; area reportedly has not been strip mined; coal from unmined bed 30 to 32 feet	5.0	28.5-33.5
Shale, gray, firm, resistant	1.5	33.5-35.0

Note: Twenty eight and one-half feet of 4-inch steel-casing screen at 28.5 to 33.5 feet, gravel pack to 10 feet below land surface; hole finished with bentonite pellets, clay, and cement grout

Table 5.--Well-drilling and construction data--Continued

[U.S. Geological Survey monitoring well 11 located about 50 feet south of mine road between monitoring wells 3 and 7; altitude of top of casing by level measurement is 871.16 feet; date drilled, February 15, 1985, T.O. Mesko and D.C. Hall, U.S. Geological Survey]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey monitoring well 11		
Coal fragments, clayey, compact, earthy-globules; coarse coal fragments at least 30 to 50 percent clay, black	5.0	0.0- 5.0
Coal fragments, some shale, coarse to medium to fine; small quantity of clay, black to dark brown	5.0	5.0-10.0
Silt; clay, yellow, brown; coal fragments, medium to fine, possible spoil	5.0	10.0-15.0
Silt; clay, yellow-brown, sticky, possibly spoil	5.0	15.0-20.0
No sample	5.0	20.0-25.0
Clay and silt; yellow-brown, with coal fragments	10.0	25.0-35.0
Clay, unconsolidated, yellow, brown, coal fragments, 0.5 inch	5.0	35.0-40.0
Clay, 95 percent, yellow, brown soft; few coal fragments	5.0	40.0-45.0
Clay, fine, yellow, brown; some coal fragments, probably cave-in material; completed on solid, hard rock, probably shale or limestone	3.0	45.0-48.0

Note: Hole was dry-drilled; began using water to circulate cuttings out of hole at 20 feet; water started circulating at 30 feet; pumped about 200 gallons of water into well during drilling. Upon completion of drilling, forced air to evacuate finished hole. Fifty-two feet of 4-inch plastic casing, capped top and bottom, lower 30 feet perforated by drilling, gravel pack with bentonite seal

Table 5.--Well-drilling and construction data--Continued

[U.S. Geological Survey monitoring well 12 located about 50 feet south of Tiger Mine office on east shoulder of road; altitude of top of casing by level measurement is 872.28 feet; date drilled, February 6, 1985, T.O. Mesko and D.C. Hall, U.S. Geological Survey]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey monitoring well 12		
Coal fragments, brownish-yellow, gray; clay, argillaceous, blue, dry	5.0	0.0- 5.0
Clay, brownish-gray; limestone pebbles; few coal fragments, dry	5.0	5.0-10.0
Clay, bluish-gray, fine-grained, dry, powdered	5.0	10.0-15.0
Clay, bluish-gray, argillaceous, some mica, clay balls, slightly moist	5.0	15.0-20.0
Clay, bluish-gray; shale fragments, limestone fragments from 20 to 25 feet	10.0	20.0-25.0
Shale, bluish-gray; coal fragments; limestone at 35 to 36 feet	5.0	30.0-35.0
Limestone; clay; brown chert; few coal fragments	5.0	35.0-40.0
Coal; brown chert; limestone	5.0	40.0-45.0
Limestone	5.0	45.0-50.0

Note: Saturated zone at 17 feet; started circulating water at 20 feet. Fifty-two feet of 4-inch plastic casing, capped top and bottom, lower 30 feet perforated by drilling, gravel pack and bentonite seal at top (one bag)

Table 5.--Well-drilling and construction data--Continued

[U.S. Geological Survey monitoring well 13 located about 200 feet south of Tiger Mine office and 100 feet south of monitoring well 12 on east shoulder of road; altitude of top of casing by level measurement is 872.10 feet; date drilled, February 6, 1985, T.O. Mesko and D.C. Hall, U.S. Geological Survey]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey monitoring well 13		
Clay, bluish-gray, fine; some coal fragments	5.0	0.0- 5.0
Clay, bluish-gray; few fragments	5.0	5.0-10.0
Clay, bluish-gray, tan, few rock fragments	5.0	10.0-15.0
Clay, bluish-gray, fine, dry, powdery	5.0	15.0-20.0
Clay, bluish-gray, numerous rock fragments	10.0	20.0-30.0
Clay, bluish-gray; some rock fragments and limestone	5.0	30.0-35.0
Limestone fragments, dark gray; some chert	5.0	35.0-40.0
Limestone and chert fragments; balled clay (mostly clay with considerable rock fragments)	5.0	40.0-45.0
Clay, dark gray; considerable chert fragments	5.0	45.0-50.0
Clay, gray; limestone fragments, brownish-gray; some coal fragments	5.0	50.0-55.0
Limestone	2.0	55.0-57.0

Note: Saturated zone after 15 feet; started circulating water at 20 feet. Fifty-nine feet of 4-inch plastic casing, capped top and bottom, lower 30 feet perforated by drilling, gravel pack with bentonite seal (one bag)

Table 5.--Well-drilling and construction data--Continued

[U.S. Geological Survey monitoring well 14 located at north boundary of Peabody Coal Company property on east side of road on field road at corner of field; altitude of top of casing by level measurement is 852.82 feet; date drilled, February 7, 1985, T.O. Mesko and D.C. Hall, U.S. Geological Survey]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey monitoring well 14		
Black soil or tailings, moist	5.0	0.0-5.0
Clay, grayish-brown, yellow, balled	5.0	5.0-10.0
Clay, yellowish-gray; silt, black	5.0	10.0-15.0
Sand; gravel; clay, yellow, balled; coal fragments,	5.0	15.0-20.0
Limestone	2.0	20.0-22.0
Clay, gray, balled; clay, brownish-black, argillaceous	.5	22.0-22.5
Limestone	4.5	22.5-27.0

Note: Twenty-nine feet of 4-inch plastic casing, perforated lower 15 feet, gravel pack with bentonite seal

[U.S. Geological Survey monitoring well 15 located 150 feet north of Tiger Mine office on east shoulder of road; altitude of top of casing by level measurement is 873.21 feet; date drilled, February 7, 1985, T.O. Mesko and D.C. Hall, U.S. Geological Survey]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey monitoring well 15		
Tailings, black	10.0	0.0-10.0
Clay, brownish-yellow; silt	5.0	10.0-15.0
Clay, brownish-yellow; silt; chert fragments	5.0	15.0-20.0
Limestone; clay, grayish-brown	5.0	20.0-25.0
Limestone	5.0	25.0-30.0
Limestone; clay, yellow, brown, gray	5.0	30.0-35.0

Table 5.--Well-drilling and construction data--Continued

Material	Thickness (feet)	Depth (feet)
Limestone; chert	5.0	35.0-40.0
Shale, with mica and limestone	5.0	40.0-45.0
Shale, hard or limestone	5.0	45.0-50.0

Note: Fifty-two feet of 4-inch plastic casing, lower 30 feet perforated by drilling, gravel pack with bentonite seal

[U.S. Geological Survey north observation well located 12.2 feet north of monitoring well 15; altitude of top of plastic casing by level measurement is 871.65 feet; date drilled, August 29, 1985]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey north observation well		
Coal fragments	5.0	0.0- 5.0
Clay, light-gray, yellow, semi-moist	5.0	5.0-10.0
Clay, light-gray, semi-moist	5.0	10.0-15.0
Clay, light-gray, balled, semi-moist; clay, dark, possible organic material	5.0	15.0-20.0
Clay light-gray	5.0	20.0-25.0
Clay, light-gray, saturated with water	5.0	25.0-30.0

Note: Hole cased with thirty feet of 2-inch plastic pipe, gravel pack

Table 5.--Well-drilling and construction data--Continued

[U.S. Geological Survey west observation well located 14.5 feet west of monitoring well 15; altitude of top of plastic casing by level measurement is 871.63 feet; date drilled, August 29, 1985]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey west observation well		
Coal fragments; clay	5.0	0.0- 5.0
Coal fragments; cinders	10.0	5.0-15.0
Clay, light-gray, balled, semi-moist	5.0	15.0-20.0
Clay, light-gray, completely saturated with water	5.0	20.0-25.0

Note: Twenty-five feet of 2-inch plastic casing, gravel pack

[U.S. Geological Survey south observation well located 12.5 feet south of monitoring well 15; altitude of top of plastic casing by level measurement is 873.15 feet; date drilled, August 29, 1985]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey south observation well		
Coal fragments; clay	5.0	0.0- 5.0
Coal fragments	5.0	5.0-10.0
Coal fragments, semi-moist	5.0	10.0-15.0
Coal fragments, clayey, sticky	5.0	15.0-20.0
Clay, light-gray	5.0	20.0-25.0

Note: Twenty-five feet of 2-inch plastic casing, gravel pack

[U.S. Geological Survey east observation well located 12.4 feet east of monitoring well 15; altitude of top of plastic casing by level measurement is 871.31 feet; date drilled, August 29, 1985]

Material	Thickness (feet)	Depth (feet)
U.S. Geological Survey east observation well		
Coal fragments	15.0	0.0-15.0
Clay, light-gray, wet	10.0	15.0-25.0

Note: Twenty-five feet of 2-inch plastic casing, gravel pack

Table 6.--Aquifer-test data

Pumping phase of test					
Date measured	Time since pump started, in minutes[a]	Drawdown of water level, in feet	Date measured	Time since pump started, in minutes[a]	Drawdown of water level, in feet
Monitoring well 15 (Pumped well)					
9-3-85	0.0	0.00	9-3-85	90	3.48
9-3-85	.5	.73	9-3-85	100	3.75
9-3-85	1	.70	9-3-85	110	3.76
9-3-85	1.5	.60	9-3-85	120	3.61
9-3-85	2	.74	9-3-85	135	3.83
9-3-85	2.5	.73	9-3-85	150	3.86
9-3-85	3	.81	9-3-85	165	3.77
9-3-85	4	1.10	9-3-85	180	3.61
9-3-85	5	1.20	9-3-85	210	3.43
9-3-85	6	1.41	9-3-85	240	3.45
9-3-85	8	1.51	9-3-85	270	5.30
9-3-85	10	1.56	9-3-85	300	5.48
9-3-85	14	1.32	9-3-85	330	5.89
9-3-85	15	1.29	9-3-85	360	6.09
9-3-85	18	1.82	9-4-85	420	6.35
9-3-85	21	1.70	9-4-85	480	6.36
9-3-85	24	2.20	9-4-85	540	6.61
9-3-85	27	2.27	9-4-85	600	6.68
9-3-85	30	1.70	9-4-85	660	6.99
9-3-85	35	1.76	9-4-85	720	7.26
9-3-85	40	2.34	9-4-85	780	6.57
9-3-85	45	2.53	9-4-85	900	7.66
9-3-85	50	2.47	9-4-85	1,020	8.06
9-3-85	55	2.59	9-4-85	1,150	7.41
9-3-85	60	3.06	9-4-85	1,260	8.66
9-3-85	70	3.22	9-4-85	1,390	9.26
9-3-85	80	3.44	9-4-85	1,440	9.06

Table 6.--Aquifer-test data--Continued

Recovery phase of test					
Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet	Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet
		Monitoring well 15 (pumped well)			
9-4-85	0	9.06	9-4-85	38	2.75
9-4-85	2	3.51	9-4-85	41	2.71
9-4-85	3	3.45	9-4-85	45	2.67
9-4-85	4	3.40	9-4-85	52	2.60
9-4-85	5	3.37	9-4-85	56	2.55
9-4-85	6	3.35	9-4-85	60	2.52
9-4-85	7	3.33	9-4-85	65	2.48
9-4-85	8	3.26	9-4-85	70	2.44
9-4-85	9	3.24	9-4-85	79	2.40
9-4-85	10	3.23	9-4-85	80	2.37
9-4-85	12	3.14	9-4-85	90	2.30
9-4-85	14	3.11	9-4-85	100	2.25
9-4-85	16	3.07	9-4-85	125	2.14
9-4-85	18	3.03	9-4-85	150	2.01
9-4-85	20	2.99	9-4-85	180	1.84
9-4-85	23	2.94	9-4-85	210	1.73
9-4-85	26	2.90	9-5-85	860	.95
			9-5-85	1,040	.86

Table 6.--Aquifer-test data--Continued

Pumping phase of test

Date measured	Time since pump started, in minutes[a]	[c]r^2/t	Drawdown of water level, in feet	Date measured	Time since pump started, in minutes[a]	[c]r^2/t	Drawdown of water level, in feet
			North Observation Well				
9-3-85	4	$5.36x10^4$	.54	9-4-85	360	$5.95x10^2$	3.44
9-3-85	11	$1.95x10^4$	.83	9-4-85	420	$5.10x10^2$	3.49
9-3-85	17	$1.26x10^4$	1.06	9-4-85	480	$4.46x10^2$	3.57
9-3-85	26	$8.24x10^3$	1.34	9-4-85	545	$3.93x10^2$	3.64
9-3-85	38	$5.64x10^3$	1.61	9-4-85	505	$3.54x10^2$	3.67
9-3-85	53	$4.04x10^3$	1.87	9-4-85	568	$3.21x10^2$	3.71
9-3-85	71	$3.02x10^3$	2.10	9-4-85	725	$2.96x10^2$	3.69
9-3-85	101	$2.12x10^3$	2.41	9-4-85	791	$2.71x10^2$	3.70
9-3-85	145	$1.48x10^3$	2.74	9-4-85	903	$2.37x10^2$	3.77
9-3-85	190	$1.13x10^3$	2.96	9-4-85	1,024	$2.09x10^2$	3.79
9-3-85	215	$9.97x10^2$	3.04	9-4-85	1,140	$1.88x10^2$	3.78
9-3-85	250	$8.57x10^2$	3.17	9-4-85	1,201	$1.78x10^2$	3.80
9-3-85	280	$7.65x10^2$	3.26	9-4-85	1,375	$1.56x10^2$	3.86
9-3-85	310	$6.91x10^2$	3.33	9-4-85	1,436	$1.49x10^2$	3.81

Recovery phase of test

Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet	Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet
		North observation well			
9-4-85	0	3.81	9-4-85	195	2.01
9-4-85	10	3.51	9-4-85	230	1.74
9-4-85	15	3.31	9-5-85	860	1.01
9-4-85	32	3.00	9-5-85	1,060	.95
9-4-85	48	2.79	9-5-85	1,245	.88
9-4-85	75	2.50	9-5-85	1,420	.84
9-4-85	110	2.31	9-6-85	2,300	.80
9-4-85	135	2.16			

Table 6.--Aquifer-test data--Continued

Pumping phase of test

Date measured	Time since pump started, in minutes[a]	[d]r^2/t	Drawdown of water level, in feet	Date measured	Time since pump started, in minutes[a]	[d]r^2/t	Drawdown of water level, in feet
West observation well							
9-3-85	6	$5.05x10^4$	0.49	9-3-85	360	$8.41x10^2$	3.13
9-3-85	12	$2.52x10^4$	.85	9-4-85	415	$7.30x10^2$	3.23
9-3-85	19	$1.59x10^4$	1.04	9-4-85	485	$6.24x10^2$	3.27
9-3-85	28	$1.08x10^4$	1.29	9-4-85	547	$5.53x10^2$	3.34
9-3-85	40	$7.57x10^3$	1.54	9-4-85	610	$4.95x10^2$	3.38
9-3-85	55	$5.50x10^3$	1.76	9-4-85	670	$4.52x10^2$	3.41
9-3-85	71	$4.26x10^3$	1.98	9-4-85	725	$4.18x10^2$	3.42
9-3-85	103	$2.94x10^3$	2.22	9-4-85	793	$3.82x10^2$	3.43
9-3-85	150	$2.02x10^3$	2.55	9-4-85	905	$3.35x10^2$	3.47
9-3-85	183	$1.65x10^3$	2.75	9-4-85	1,027	$2.95x10^2$	3.49
9-3-85	215	$1.41x10^3$	2.79	9-4-85	1,140	$2.66x10^2$	3.49
9-3-85	245	$1.24x10^3$	2.92	9-4-85	1,265	$2.39x10^2$	3.53
9-3-85	280	$1.08x10^3$	3.00	9-4-85	1,375	$2.20x10^2$	3.56
9-3-85	310	$9.77x10^2$	3.05	9-4-85	1,438	$2.10x10^2$	3.56

Recovery phase of test

Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet	Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet
West observation well					
9-4-85	0	3.56	9-4-85	165	1.93
9-4-85	16	3.03	9-4-85	225	1.71
9-4-85	30	2.82	9-4-85	865	.99
9-4-85	47	2.65	9-4-85	943	.93
9-4-85	76	2.38	9-4-85	1,242	.87
9-4-85	106	2.19	9-4-85	1,416	.84
9-4-85	136	2.07	9-4-85	2,313	.80

Table 6.--Aquifer-test data--Continued

Pumping phase of test

Date measured	Time since pump started, in minutes[a]	$^{e}r^2/t$	Drawdown of water level, in feet	Date measured	Time since pump started, in minutes[a]	$^{e}r^2/t$	Drawdown of water level, in feet
			South observation well				
9-3-85	8	$2.81x10^4$	0.58	9-4-85	375	$6.00x10^2$	3.18
9-3-85	14	$1.61x10^4$	.91	9-4-85	420	$5.36x10^2$	3.25
9-3-85	21	$1.07x10^4$	1.13	9-4-85	495	$4.55x10^2$	3.36
9-3-85	30	$7.50x10^3$	1.33	9-4-85	555	$4.05x10^2$	3.33
9-3-85	42	$5.36x10^3$	1.53	9-4-85	615	$3.65x10^2$	3.35
9-3-85	57	$3.95x10^3$	1.79	9-4-85	675	$3.33x10^2$	3.36
9-3-85	72	$3.13x10^3$	1.96	9-4-85	730	$3.08x10^2$	3.36
9-3-85	108	$2.08x10^3$	2.16	9-4-85	796	$2.83x10^2$	3.40
9-3-85	155	$1.45x10^3$	2.42	9-4-85	907	$2.48x10^2$	3.42
9-3-85	190	$1.18x10^3$	2.68	9-4-85	1,029	$2.19x10^2$	3.46
9-3-85	220	$1.02x10^3$	2.81	9-4-85	1,140	$1.97x10^2$	3.48
9-3-85	250	$9.00x10^2$	2.90	9-4-85	1,265	$1.78x10^2$	3.52
9-3-85	280	$8.03x10^2$	3.00	9-4-85	1,380	$1.63x10^2$	3.54
9-3-85	315	$7.14x10^2$	4.05	9-4-85	1,439	$1.56x10^2$	3.51

Recovery phase of test

Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet	Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet
		South observation well			
9-4-85	0	3.51	9-4-85	168	2.14
9-4-85	12	3.48	9-4-85	225	1.81
9-4-85	18	3.47	9-5-85	865	1.03
9-4-85	33	3.13	9-5-85	1,065	.97
9-4-85	49	2.93	9-5-85	1,243	.93
9-4-85	77	2.69	9-5-85	1,416	.90
9-4-85	110	2.45	9-5-85	2,315	.85
9-4-85	140	2.29			

Table 6.--Aquifer-test data--Continued

Pumping phase of test

Date measured	Time since pump started, in minutes[a]	[f]r^2/t	Drawdown of water level, in feet	Date measured	Time since pump started, in minutes[a]	[f]r^2/t	Drawdown of water level, in feet
			East observation well				
9-3-85	3	7.38×10^4	.06	9-3-85	355	6.24×10^2	1.83
9-3-85	9	2.40×10^4	.15	9-4-85	415	5.34×10^2	2.01
9-3-85	15	1.48×10^4	.23	9-4-85	480	4.61×10^2	2.19
9-3-85	25	3.80×10^3	.35	9-4-85	540	4.10×10^2	2.31
9-3-85	31	7.14×10^3	.46	9-4-85	600	3.69×10^2	2.37
9-3-85	51	4.34×10^3	.61	9-4-85	665	3.33×10^2	2.42
9-3-85	69	3.20×10^3	.76	9-4-85	720	3.07×10^2	2.48
9-3-85	99	2.23×10^3	.97	9-4-85	780	2.84×10^2	2.52
9-3-85	140	1.58×10^3	1.17	9-4-85	900	2.46×10^2	2.62
9-3-85	185	1.20×10^3	1.31	9-4-85	1,022	2.17×10^2	2.69
9-3-85	210	1.05×10^3	1.41	9-4-85	1,140	1.94×10^2	2.71
9-3-85	245	9.04×10^2	1.51	9-4-85	1,195	1.85×10^2	2.77
9-3-85	280	7.91×10^2	1.61	9-4-85	1,375	1.51×10^2	2.85
9-3-85	305	7.25×10^2	1.73	9-4-85	1,435	1.54×10^2	2.85

Recovery phase of test

Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet	Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet
		East observation well			
9-4-85	0	2.85	9-4-85	165	2.35
9-4-85	5	2.84	9-4-85	225	2.16
9-4-85	9	2.84	9-5-85	860	1.26
9-4-85	30	2.78	9-5-85	1,060	1.11
9-4-85	43	2.76	9-5-85	1,240	1.03
9-4-85	73	2.63	9-5-85	1,415	.96
9-4-85	105	2.51	9-6-85	2,300	.84
9-4-85	135	2.44			

Table 6.--Aquifer-test data--Continued

Pumping phase of test

Date measured	Time since pump started, in minutes[a]	$^{g}r^2/t$	Drawdown of water level, in feet	Date measured	Time since pump started, in minutes[a]	$^{g}r^2/t$	Drawdown of water level, in feet
Monitoring well 2							
9-3-85	95	$5.36x10^5$	0.04	9-3-85	807	$6.31x10^4$	0.28
9-3-85	134	$3.80x10^5$	0.04	9-3-85	910	$5.59x10^4$	0.33
9-3-85	225	$2.20x10^5$	0.07	9-3-85	1,032	$4.93x10^4$	0.36
9-3-85	300	$1.70x10^5$	0.10	9-3-85	1,152	$4.42x10^4$	0.39
9-3-85	430	$1.18x10^5$	0.13	9-3-85	1,268	$4.01x10^4$	0.39
9-3-85	680	$7.48x10^4$	0.24	9-3-85	1,323	$3.85x10^4$	0.41

Recovery phase of test

Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet	Date measured	Time since pump stopped, in minutes[b]	Residual drawdown of water level, in feet
Monitoring well 2					
9-4-85	0	0.42	9-5-85	1,245	.31
9-4-85	168	.43	9-5-85	1,420	.31
9-5-85	870	.39	9-5-85	2,310	.30
9-5-85	1,065	.35			

[a]Pumping of monitoring well 15 was started at 1800 hours on September 3, 1985.
[b]Pump was shut down at 1815 hours on September 4, 1985.
[c]r, 12.2 feet, distance from pumped well; t, time since pump started, in days.
[d]r, 14.5 feet, distance from pumped well; t, time since pump started, in days.
[e]r, 12.5 feet, distance from pumped well; t, time since pump started, in days.
[f]r, 12.4 feet, distance from pumped well; t, time since pump started, in days.
[g]r, 188 feet, distance from pumped well; t, time since pump started, in days.