MOVEMENT OF GROUND WATER IN COAL-BEARING ROCKS NEAR FISHTRAP LAKE IN PIKE COUNTY, KENTUCKY

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CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric (International System) units, rather than the inch-pound terms used in this report, the following conversion factors may be used:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)

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."

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ABSTRACT

Eight test holes were core-drilled from various altitudes in a typical coal-bearing sequence rocks of Pennsylvanian age in Pike County, eastern Kentucky. Vertical fractures were common in cores from shallow depths, but became less common or absent toward the bottom of two test holes drilled 400 and 291 feet deep. Most fractures readily accepted injected water, and near the bottoms of the two deep holes, coal beds accepted water in the non-fractured rocks.

Rhodamine-WT dye was injected in a 61-foot deep ridge-top well on October 24, 1985 and was detected in varying concentrations in water samples taken from all downgradient piezometers at the study site on November 7, 1985. The presence of dye in downgradient piezometers indicates that ground water in the Eastern Kentucky coal field can move from areas of higher head to areas of lower head. The movement probably occurs in a stair-step fashion through a complex system of near-vertical fractures and laterally through permeable rocks, which probably are the coal beds. This suggests that land uses on ridges could affect the quality of water from wells or springs at lower altitudes on hillsides or in the valley bottoms even though separated by a thick interval of rocks that include beds of low primary permeability.

INTRODUCTION

Knowledge of the movement of ground water in the coal fields is important in protecting the environment from changes caused by surface disturbances - mainly, but not limited to, the surface-mining of coal. Conceptual ground-water flow systems in coal-bearing rocks in the Eastern Kentucky coal field have been presented by numerous authors, including Price and other (1962), Kiesler and others (1983), Quinones and others (1981), Leist and others (1982), and Kipp and others (1983). In adjacent states, Larson and Powell (1986) in Virginia and Wyrick and Borchers (1981) in West Virginia present data pertinent to the ground-water situation in the Eastern Kentucky coal field.

The flow system described by Larson and Powell (1986, p. 40), shown in figure 1 is a simplified concept of ground-water movement, both in Virginia and in eastern Kentucky. Ground water moves primarily within the colluvium-alluvium cover on the hillslopes and valley floor and within the coal beds and weathered bedrock. The principal component of flow in the hillslope areas is downward. Small amounts of water move downward through fractures and intersticial openings in the unweathered bedrock to coal beds. Seeps associated with coal beds are the result of lateral flow within the beds towards the hillslope.

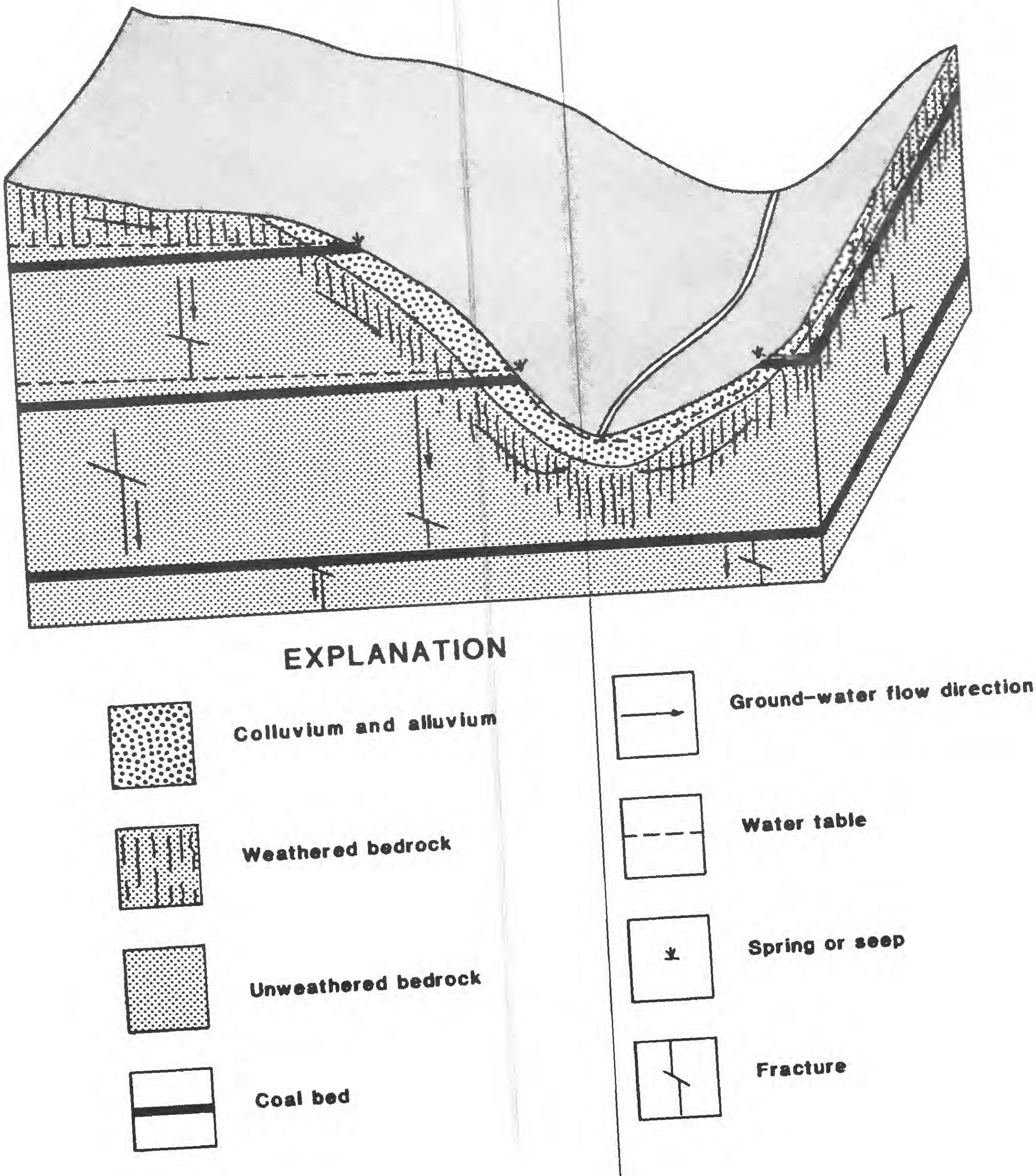


Figure 1.--Conceptual ground-water flow system in the study area. (From Lerson and Powell, 1986).

In the summer of 1985, the U.S. Geological Survey, in cooperation with the U.S. Office of Surface Mining, conducted a study of ground-water movement in a typical coal-bearing sequence of rocks of Pennsylvanian age in eastern Kentucky. The primary purpose of the study was to qualitatively determine the hydraulic connection of vertical fractures and other permeable zones in the rocks. Land-use activities such as mining are frequently permitted on hills and ridges based on the concept of geologic isolation. Generally, this concept is based on the premise that a thick sequence of rocks of low primary permeability will effectively isolate downgradient aquifers from the adverse effects of upgradient land-use activities. Concern about the validity of this concept is expressed by the U.S. Office of Surface Mining (1984, p. 21).

The study area (fig. 2) is adjacent to Fishtrap Lake, a U. S. Army Corps of Engineers reservoir on Levisa Fork of Big Sandy River. The area of this study is small, but the concepts involved are probably applicable to most of the rugged coal-bearing areas of Appalachia.

Purpose and Scope

This report presents the results of a study to determine the hydraulic connection between vertical fractures and permeable zones in a fracture system on a hillside near Fishtrap Lake and to test whether land-use activities, such as strip mining, on hillsides or hilltops are "geologically isolated" from aquifers at lower altitudes. Core holes were drilled to determine the stratigraphy and the depth and occurrence of fractures (figs. 3-6). Hydraulic pressure testing was done at intervals where fractures were observed in cores and at intervals where fracturing was not observed, to detect relative permeability of the intervals.

The test holes were used as piezometers to monitor water levels and water-quality changes. Dye was injected in an upgradient well and sampled in the downgradient piezometers to determine the hydraulic connection between fractures and other permeable zones.

Acknowledgments

The author thanks the Corps of Engineers for permission to use the land near Fishtrap Lake and especially appreciates the assistance and guidance given by personnel of the Corps at their headquarters at Fishtrap Dam. Although not a cooperator, the Kentucky Geological Survey contributed the services of James Dinger and James Kipp who assisted in all field phases of the study. Their help is appreciated.

PHYSIOGRAPHIC AND GEOLOGIC SETTING

The study area (fig. 2) is in Pike County, Kentucky, in the Kanawha section of the Appalachian Plateaus province (Fenneman, 1938). The Kanawha section is a dissected plateau characterized by narrow, crooked valleys and narrow, irregular steep-sided ridges underlain primarily by sandstones,

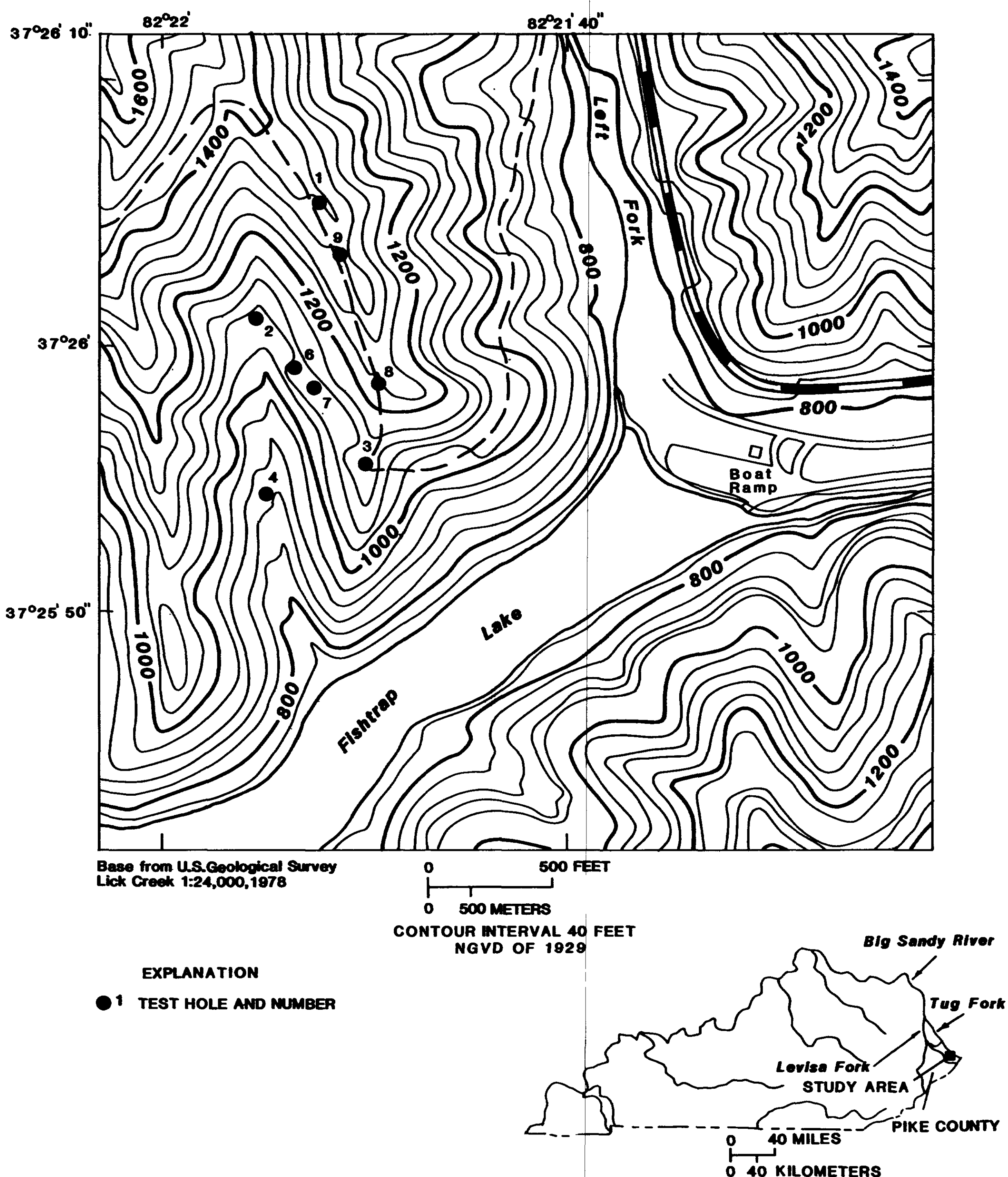
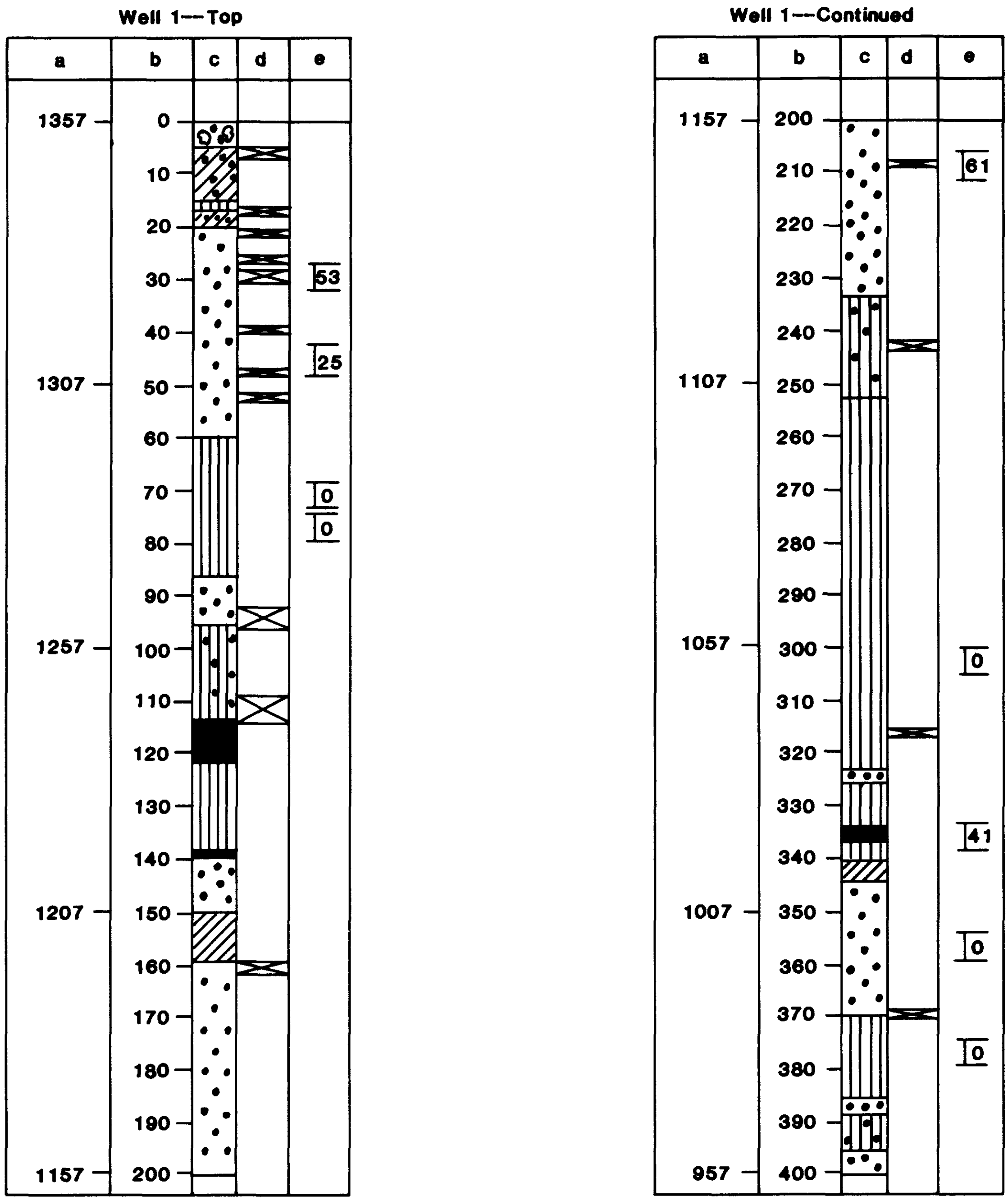


Figure 2.--Study area and test hole locations.



EXPLANATION

for figures 3, 4, 5, and 6

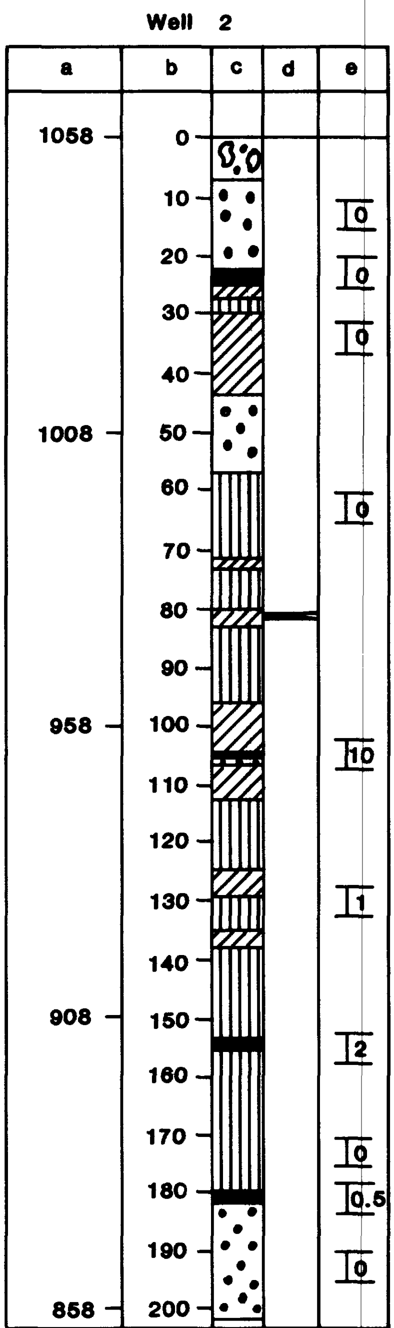
a. APPROXIMATE ALTITUDE, IN FEET ABOVE SEA LEVEL
b. DEPTH BELOW LAND SURFACE, IN FEET
c. LITHOLOGY, AS OBSERVED FROM CORES
d. FRACTURE INTERVAL, AS OBSERVED FROM CORES
e. INFLATABLE PACKER TEST RESULTS-- Bracket shows interval tested and number represents gallons of water injected through the perforated section of the packer stem in 5 minutes at a constant pressure of 50 pounds per square inch.

LITHOLOGY

- SOIL
- SANDSTONE
- SILTSTONE
- SHALE/ CLAYSTONE
- COAL

FRACTURE INTERVAL

Figure 3.--Lithology, fractures, and injection data for well 1.



See page 5 for detailed explanation

Figure 4.--Lithology, fractures, and injection data for well 2.

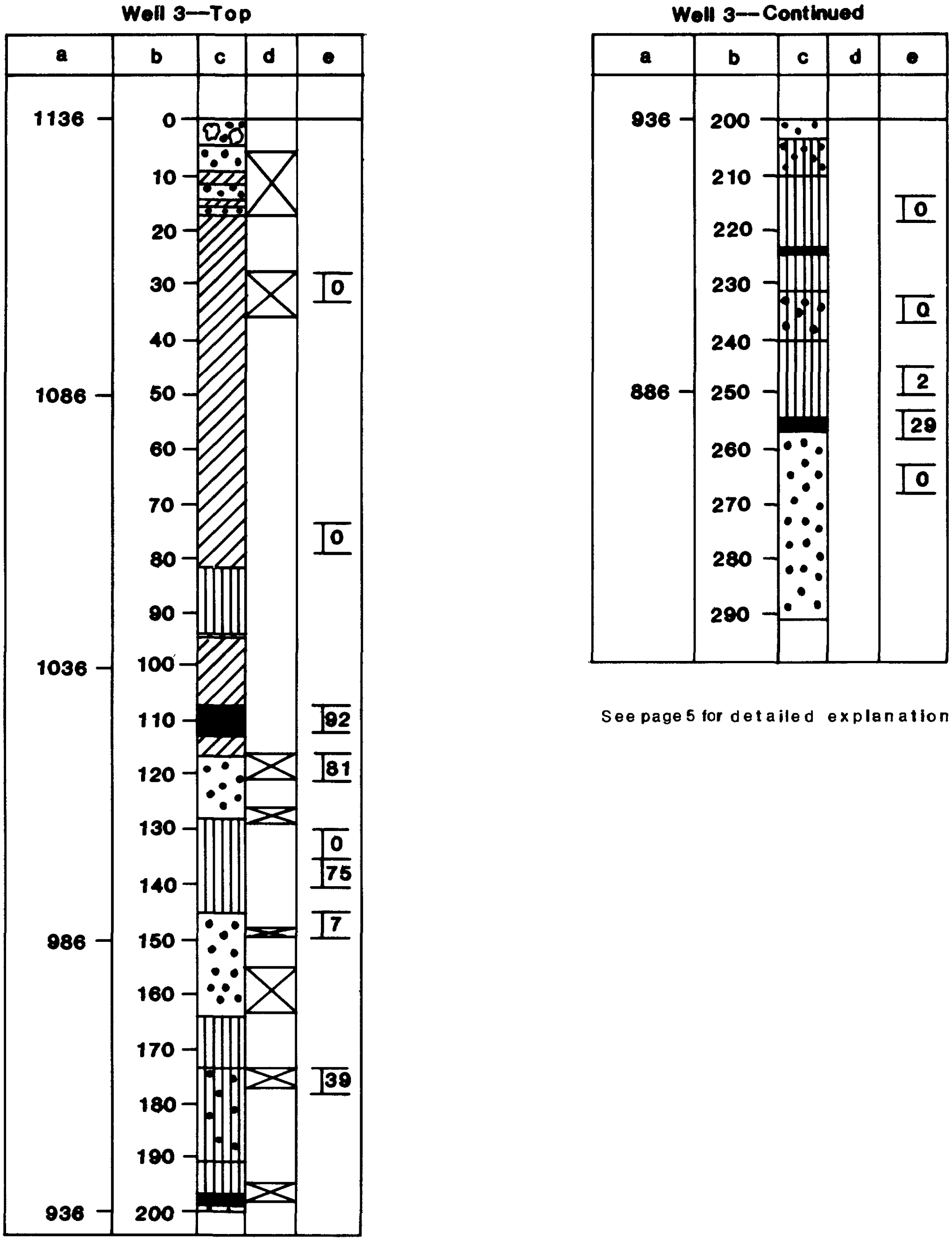


Figure 5.--Lithology, fractures, and injection data for well 3.

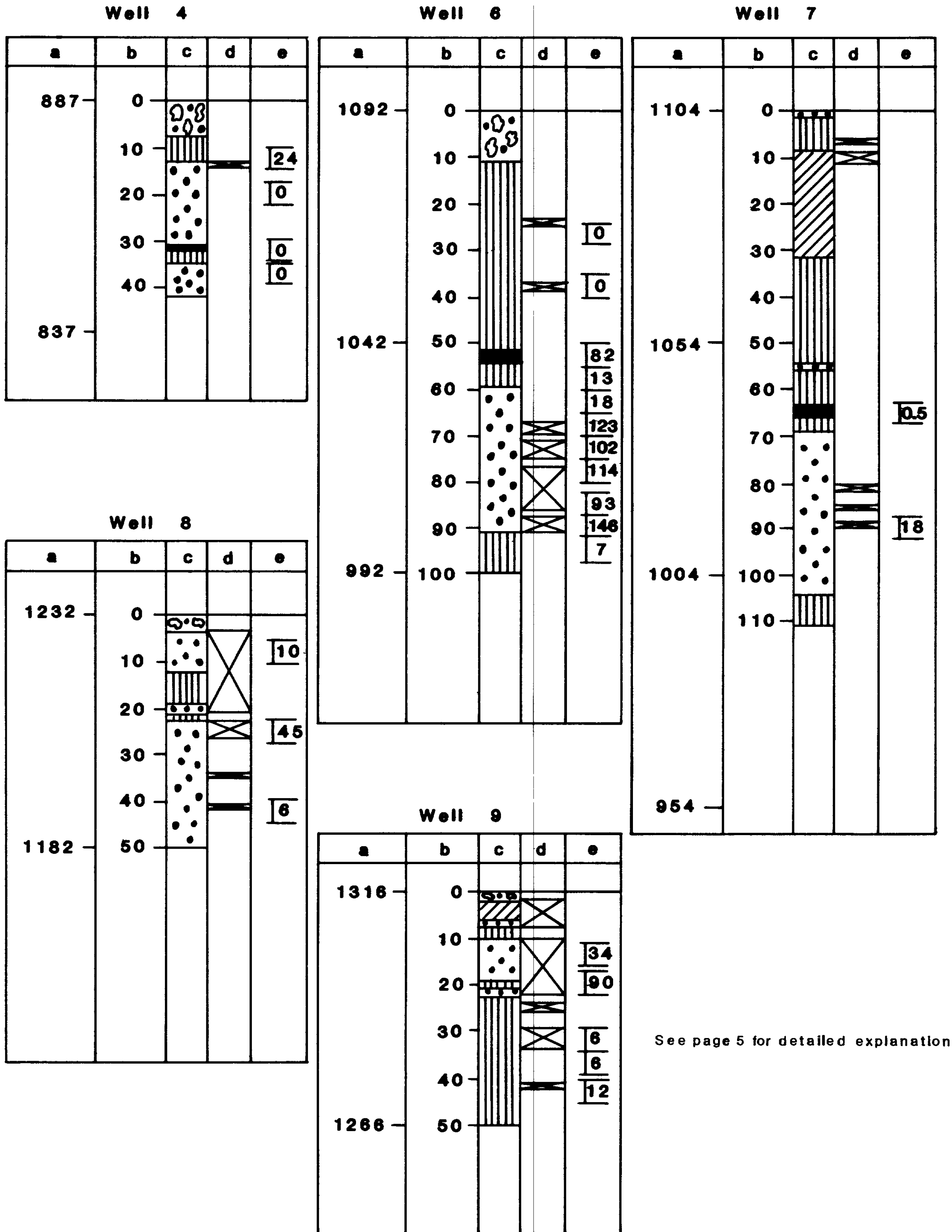


Figure 6.--Lithology, fractures, and injection data for wells 4,6,7,8, and 9.

siltstones, shales, and coals of Pennsylvanian age. Detailed geology of the study area has been mapped on the Lick Creek quadrangle by McKay and Alvord (1969) as part of the Kentucky cooperative geologic mapping program. McKay and Alvord show that rocks at lower altitudes near Fishtrap Lake are near the Hagy coal bed, and those at high altitudes are near the Elkhorn coal beds. All rocks units are part of the Breathitt Formation of Early and Middle Pennsylvanian age.

TEST DRILLING AND PIEZOMETERS

In order to determine the lithology and fractures of the rock units on hillcrests, hillsides, and valleys, eight holes were cored and 1,272 feet of NX(3-in O.D.) core was recovered for inspection. Generalized lithologic logs of the test holes numbered 1 through 4 and 6 through 9 are shown in figures 3-6 (test hole 5 was planned, but not drilled). Lithologic logs of the test holes, water-injection data, well-construction data, and dye-concentration data were published in a report by Davis (1986).

Pressure Testing Permeable Zones

After tabulating the fractured and permeable zones in the test holes, as seen in the cores, pressure injection tests were made in 58 zones, both fractured and unfractured. The tests were made by lowering two inflatable packers, 5 feet apart, into the hole and centering selected 5-foot intervals between the packers at various zones. The packers were inflated to restrict water entry from above or below the packers. Water was injected, or attempted to be injected, into the 5-foot test zones under constant pressure of 50 pounds per square inch for 5 minutes. Water entry into the various zones for the 5-minute periods is shown in figures 3-7.

Two deep test holes, 1 and 3, show a fracture and injection acceptance pattern that is considered typical of the Eastern Kentucky coal field area. Fractures are common at shallow depth, but become less common or absent at deeper depths. Sandstones and coal beds accepted the most injection water; however, a shale bed with a 0.6-foot sandy zone in test hole 3 accepted 75 gallons of water between 135-140 feet even though fractures were not observed in the cores. Coal beds near the bottom of the holes accepted 41 gallons of water in test hole 1 and 29 gallons in test hole 3. Because the coal beds accepted water better than other deep lithologies, the coal beds, rather than fractures, probably are the predominant zones for the storage and movement of deep ground water in the coal field.

Test hole 2 penetrated only one logged fracture zone: the coal beds in this test hole accepted the most injected water. Although test holes 6 and 7 were drilled to about the same depths from similar altitudes, hole 6 penetrated many more fracture zones and accepted much more injected water than hole 7. Test hole 4 penetrated few fracture zones and accepted little injected water; however, holes 8 and 9 were well-fractured, and all zones tested accepted injected water.

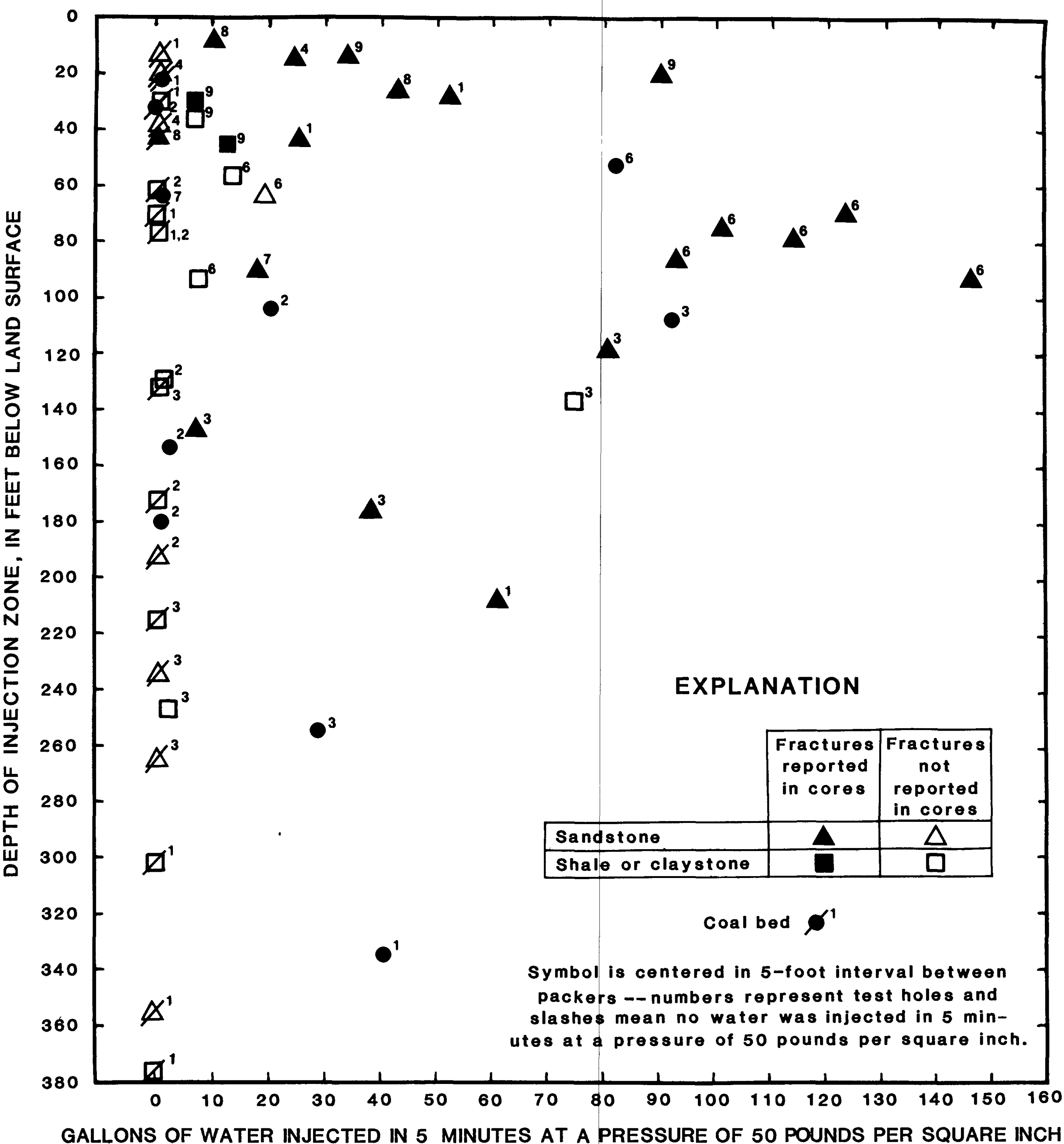


Figure 7.--Gallons of water injected at selected depths in the test holes.

Figure 7 is a graph showing the amount of water injected in the 5-foot zones plotted against depth of injection. There is no trend of decreasing injection of water with greater depth; however, no fractures were tested below a depth of 210 feet. Two coal beds at depth greater than 200 feet accepted water at about the same rate as in shallow coal beds.

Preparation of Piezometers for Flow-Tracing Test

Part of the project was to trace the movement of ground water in typical coal-bearing rocks of Pennsylvanian age. After each test hole was drilled and different zones were pressure-tested by injection of water, one to three piezometers (a type of observation well finished to permit the measurement of the water level in a particular zone) were completed to monitor discrete zones in the hole. At piezometers with multiple monitoring zones, porous plastic tubes were placed at the monitored zone on the end of individual 1/2-inch polyvinylchloride (PVC) pipes. Grout or bentonite was placed below the porous tube. After backfilling the test zone with clean sand, the top of the zone was sealed with grout or bentonite. Table 1 lists the depth of piezometers and the zones monitored. No tube was set in the open hole part of the open-hole piezometers. Figure 8 shows the construction of a typical piezometer.

In order to determine the ability of the monitored zone in the piezometer to receive or release water, a slug test was done on each piezometer. In a slug test the static water level is measured, then a "slug" of water is added to the piezometer, raising the water level in the piezometer to some arbitrary point above the static level. The water level is measured at the end of the water injection and at variable time intervals as the water level declines toward its original static level. Figures 9-12 contain graphs showing the decline of water levels in the piezometers. A steep slope indicates relatively high transmissivity of the receiving zone; a flatter slope indicates lower transmissivity. All piezometers accepted water and water levels declined toward the original static level; however, measurements in all piezometers stopped before the water levels declined to their original static levels. All data are considered to be relative to each other and not quantitative because the porous tubes at the end of the piezometers impeded water movement from the piezometers, and the columns of construction-quality sand in the backfilled monitoring zones were of different lengths.

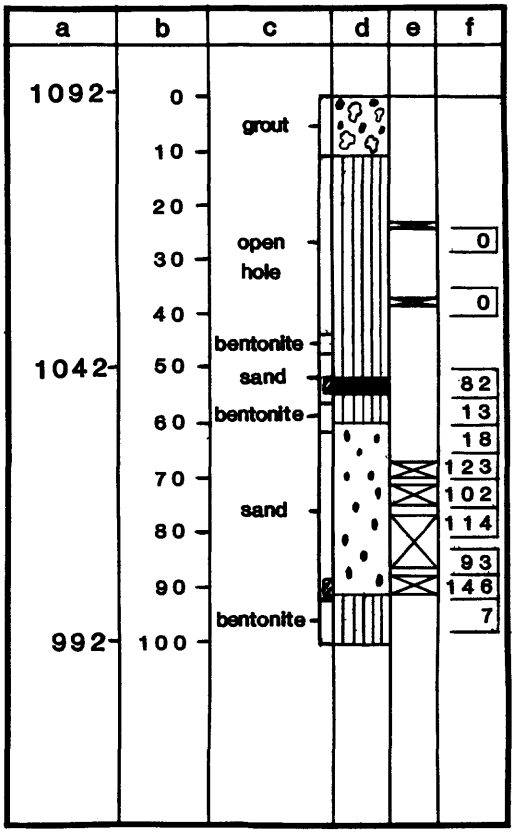
Dye Trace Testing

On October 24, 1985 a liter of 20 percent solution of rhodamine-WT dye was injected into well 1 OH to trace the movement of water at the site. The dye was flushed from the well by adding 200 gallons of water to the well after injecting the dye. On the same day, prior to injecting the dye, the water levels and fluorescent dye concentrations in water from all piezometers downgradient from the injection well were measured for background fluorescent dye values. The background values before dye injection ranged from less than 0.1 to 0.12 ug/L (micrograms per liter).

Table 1.--Physical characteristics of observation wells

[Well type: OH-open hole; P-piezometer; S-shallow, D-deep. Dash (-) = no piezometer]

Well number and type	Bottom of piezometer	Interval monitored
	in feet below surface	
1 OH	-	5.0-61.0
1 PS	209.5	190.5-216
1 PD	333.5	330-339
2 OH	-	11-28
2 P	183	179-184
3 OH	-	3-42
3 PS	125	104-127.9
3 PD	257	253.3-259.2
4 OH	-	3-18
4 P	32.7	28.9-33.5
6 OH	-	3-44
6 PS	55	48-56
6 PD	91	62-92
7 P	110	20-110.8
8 P	50.5	9-50.5
9 P	50	9-50.5



EXPLANATION

a - APPROXIMATE ALTITUDE, IN FEET ABOVE SEA LEVEL
b - DEPTH BELOW LAND SURFACE, IN FEET
c - BACKFILL MATERIAL IN WELL BORE AND PIEZOMETER SETTING
d - LITHOLOGY, AS OBSERVED FROM CORES
e - FRACTURE INTERVAL, AS OBSERVED FROM CORES
f - INFLATABLE PACKER TEST RESULTS-- Bracket shows interval tested and number represents gallons of water injected through the perforated section of the packer stem in 5 minutes at a constant pressure of 50 pounds per square inch.

LITHOLOGY

SOIL

SANDSTONE

SILTSTONE

SHALE/ CLAYSTONE

COAL

FRACTURE INTERVAL

POROUS PIEZOMETER SETTING

Figure 8.--Construction of a typical piezometer.

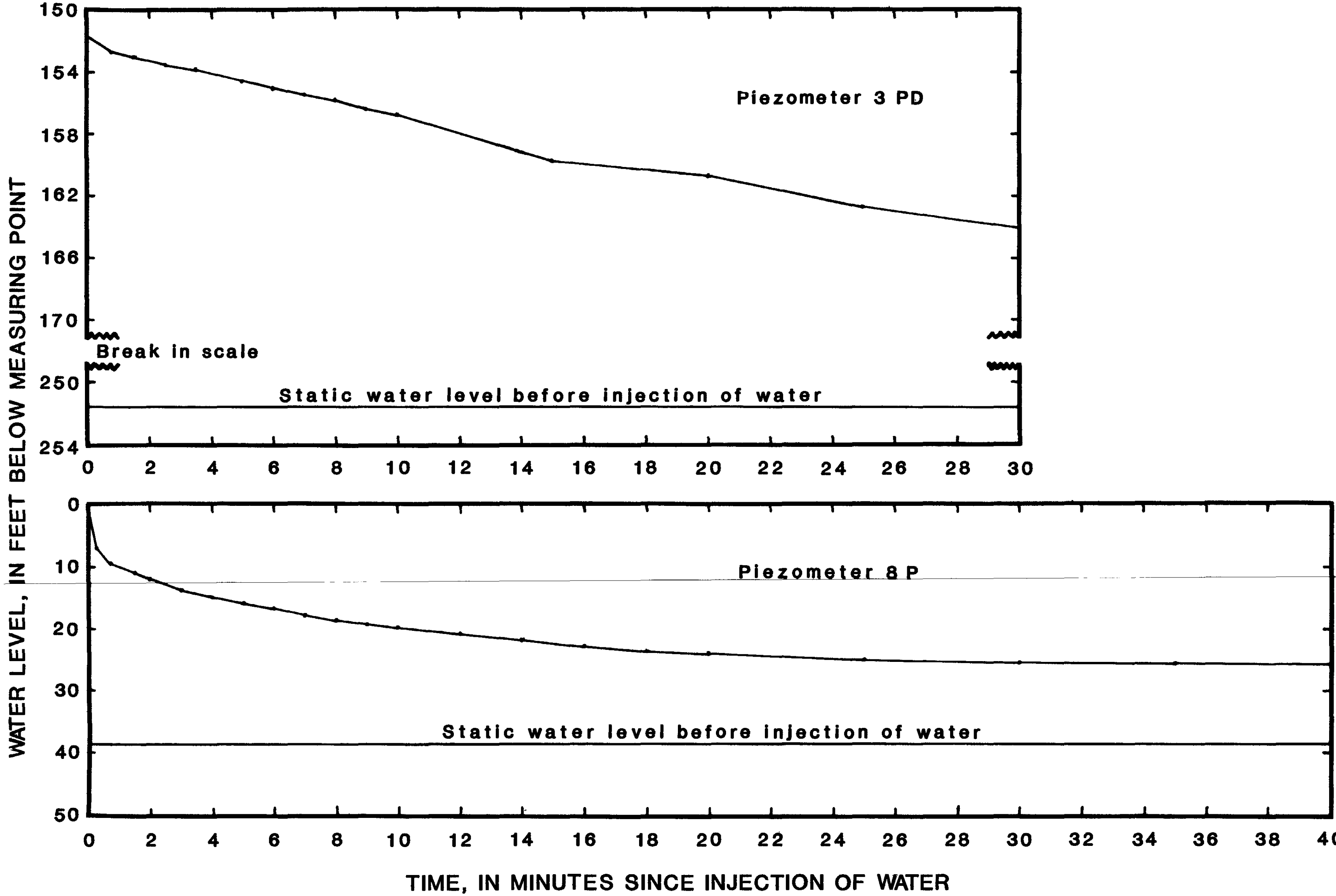


Figure 9.--Decline in water level after injection of a slug of water in piezometers 3 PD and 8 P.

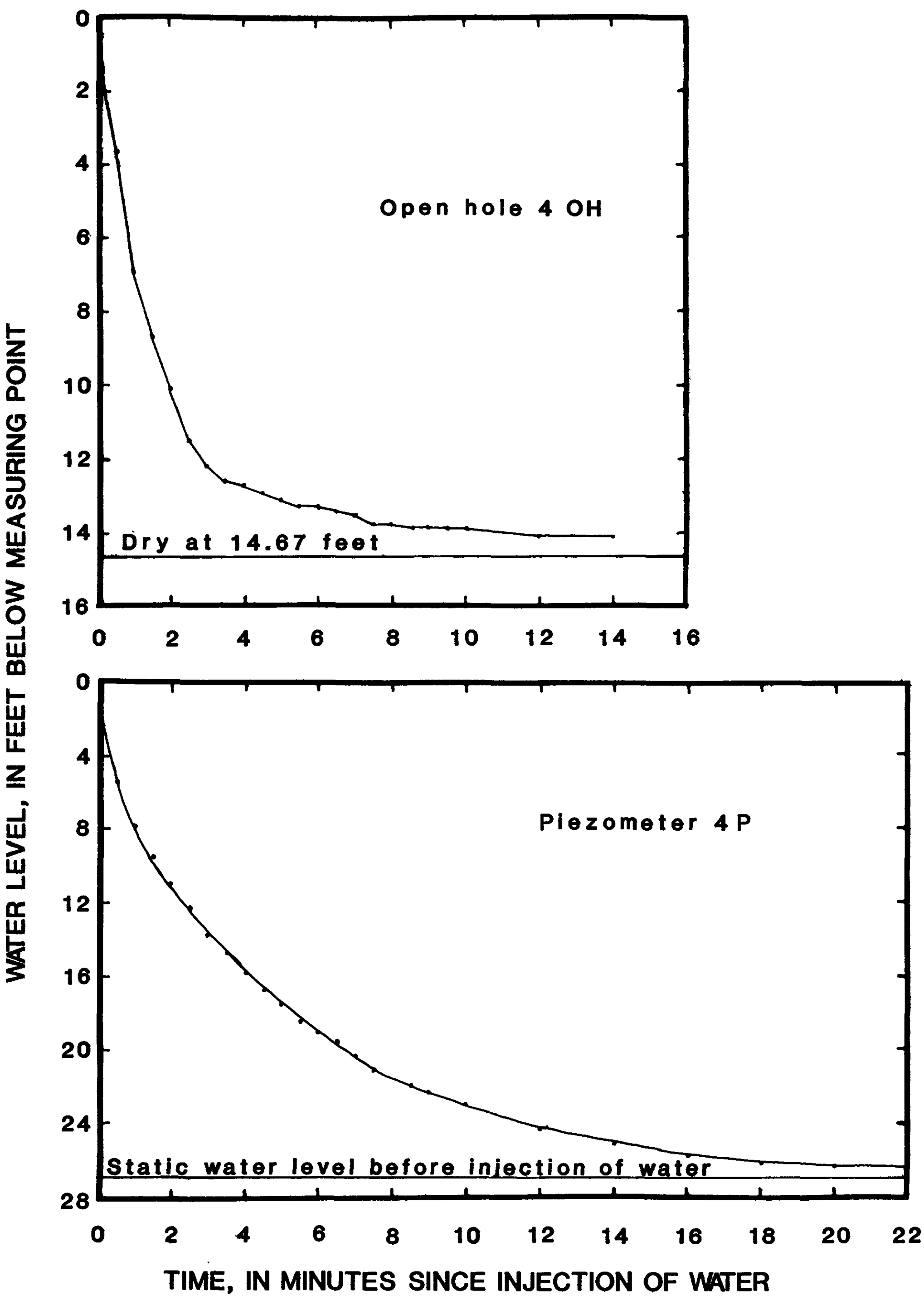


Figure 10.--Decline in water level after injection of a slug of water in open hole 4 OH and piezometer 4 P.

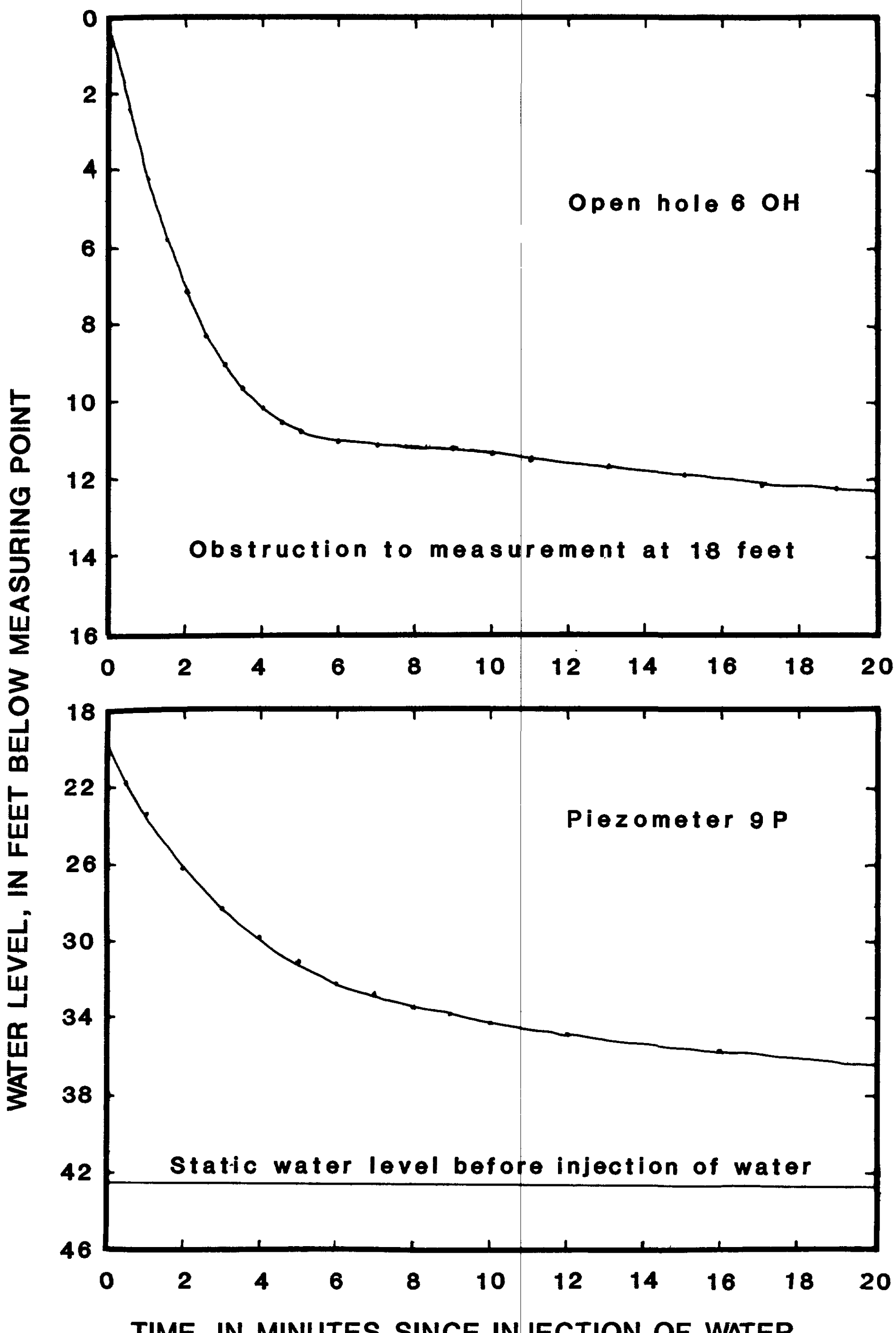


Figure 11.--Decline in water level after injection of a slug of water in open hole 6 OH and piezometer 9 P.

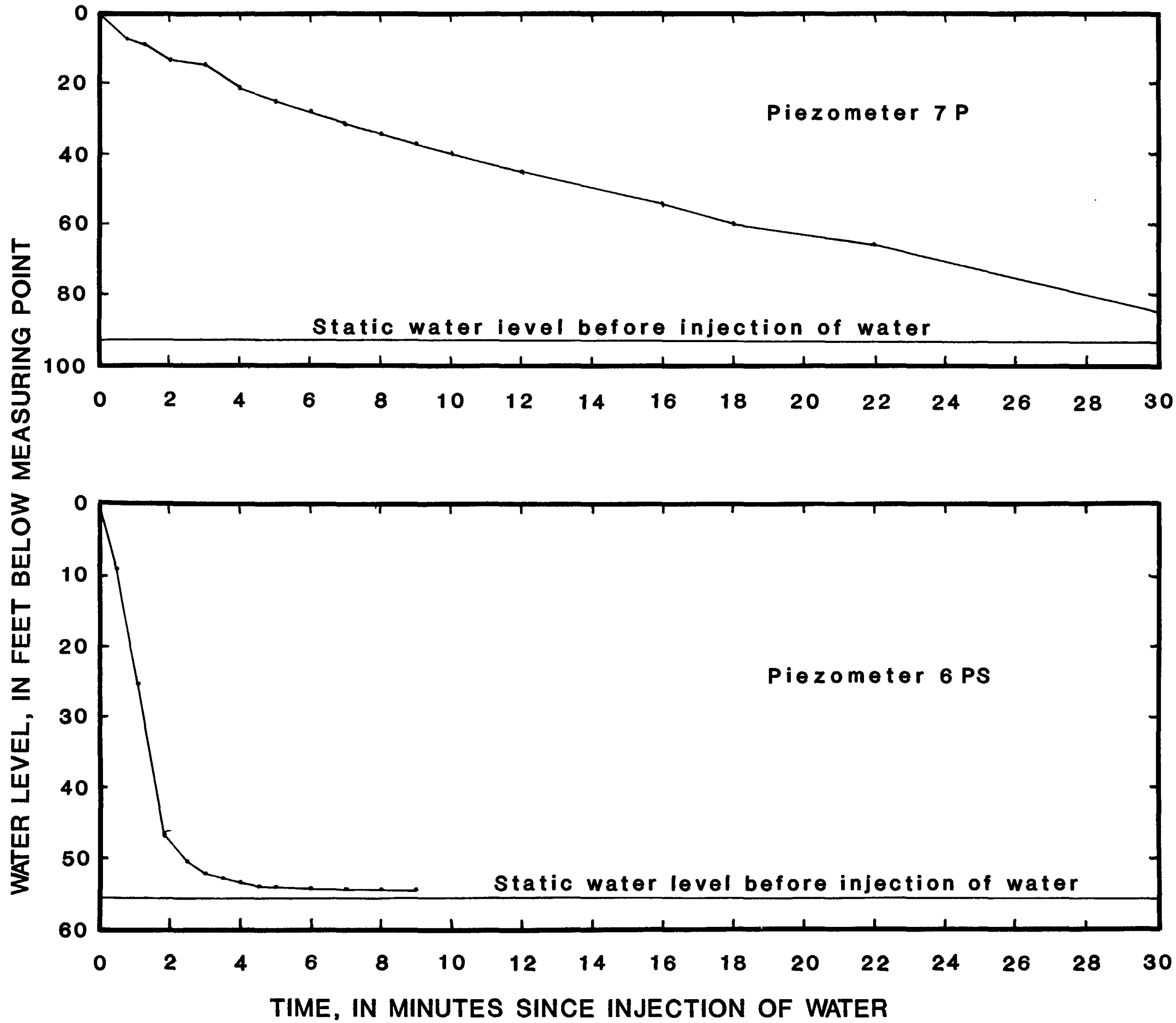


Figure 12.--Decline in water level after injection of a slug of water in piezometers 7 P and 6 PS.

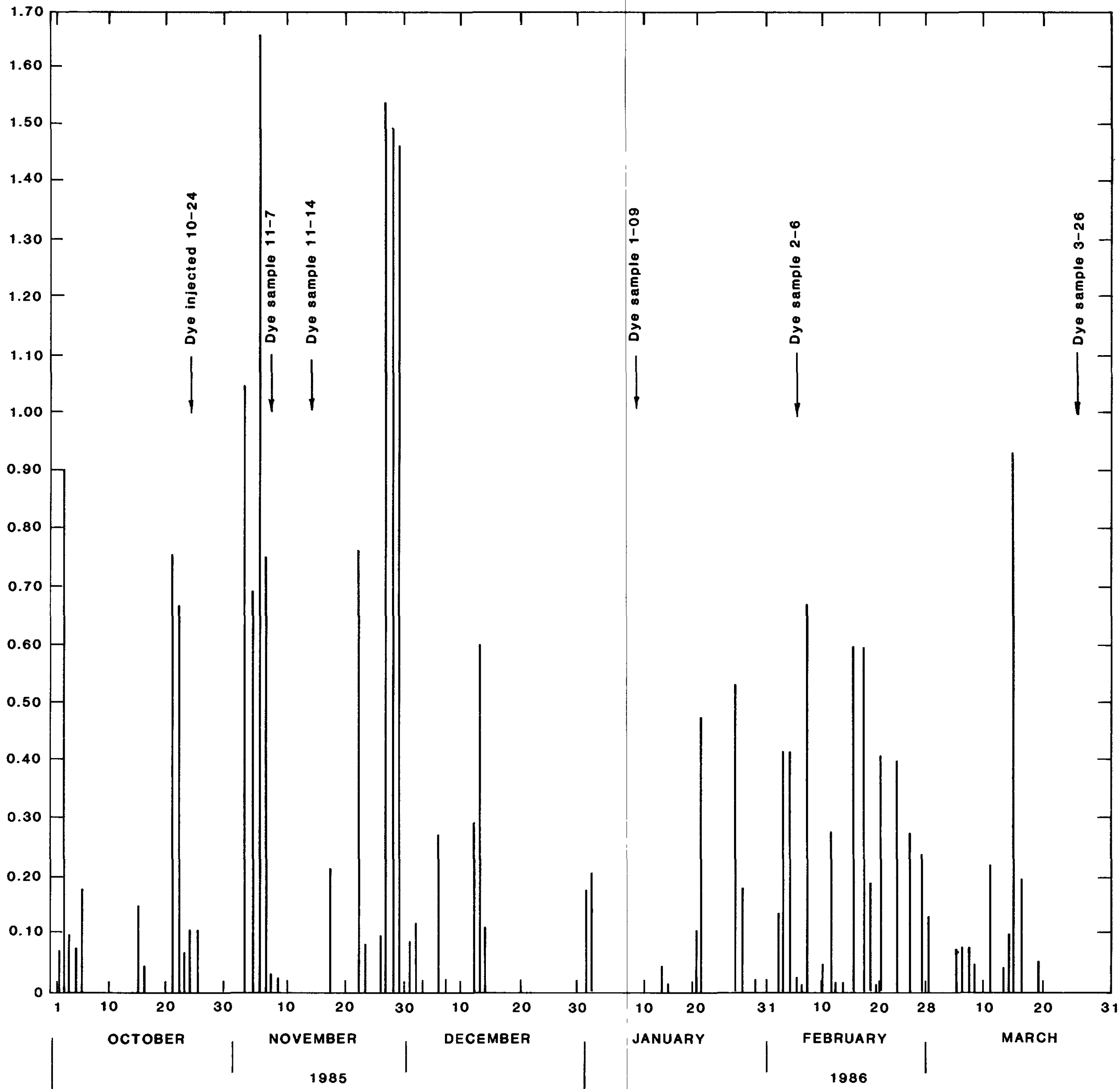


Figure 13.--Precipitation data at Fishtrap Dam.

Table 2.--Water levels and dye concentrations in observation wells

[Well type: OH-open hole; P-piezometer; S-shallow, D-deep. M.P.= Measuring point, top of exterior casing. NW = No water. Dashes (--) = No measurements]

Well number and type	Well depth, in feet below land surface	1985 9-11	1985 9-25	1985 10-9	1985 10-24	1985 11-7	1985 11-14	1986 1-9	1986 2-6	1986 3-26
		Depth to water, in feet below M.P. / Dye concentration, in micrograms per liter								
1 OH	61.0	57	57	57	57.2	51.5	--	57.3	--	50.6
		--	--	--	<.1	875	890	495	--	300
1 PS	209.5	208	208.9	205.3	191.4	197.3	--	NW	NW	NW
		--	--	--	<.1	1.20	1.15	--	--	--
1 PD	333.5	217	218.5	219.8	190.2	199.4	--	213.6	213.4	214.5
		--	--	--	.12	.55	.90	1.13	1.12	1.20
2 OH	25	9.7	11.3	12.5	9.2	7.9	--	8.5	8.7	7.3
		--	--	--	<.1	3.55	.72	.15	.10	.05
2 P	183	--	175.3	175.4	175.3	174.8	--	174.8	174.1	174
		--	--	--	<.1	1.81	10.8	15	14.8	15.4
3 OH	42	NW	NW	NW	NW	NW	NW	40.6	34.5	35.8
		--	--	--	--	--	--	0	0	.09
3 PS	125	121	121.2	121.3	121.5	120.8	--	121.1	121.2	120.6
		--	--	--	<.1	.54	.40	.21	.28	.23
3 PD	257	251	252	251.6	243.9	244.8	--	245.7	246	245.3
		--	--	--	.11	1.68	.43	.15	.15	.13
4 OH	18	NW	NW	NW	12.9	11.1	--	11.8	10.9	11.2
		--	--	--	--	.90	.10	0	0	0
4 P	32.7	26.3	26.8	26.8	27.1	26.8	--	26	26	25
		--	--	--	<.1	1.78	8.30	6.60	6.90	6.80
6 OH	44	NW	NW	NW	NW	13.5	NW	17	13.8	12.6
		--	--	--	--	.75	--	0	0	0
6 PS	55	55	55.3	55.3	55.3	55.3	--	54.8	54.8	54.4
		--	--	--	<.1	7.07	4.80	.45	.18	.40
6 PD	91	84.5	84.9	85	84.9	84.8	--	84.6	84.1	83.8
		--	--	--	<.1	2.97	14.8	28	9.90	23
7 P	110	89.5	91.2	92.8	93.3	94.3	--	93.1	90.5	90.9
		--	--	--	<.1	.42	.92	.12	.01	.03
8 P	50.5	--	37.8	38.5	38.6	37.8	--	34.2	27.8	27.7
		--	--	--	<.1	.77	.10	0	.02	.02
9 P	50	42.0	45.2	42.6	41.7	34.3	--	42.9	31.6	41.4
		--	--	--	<.1	.20	.05	0	.03	.03

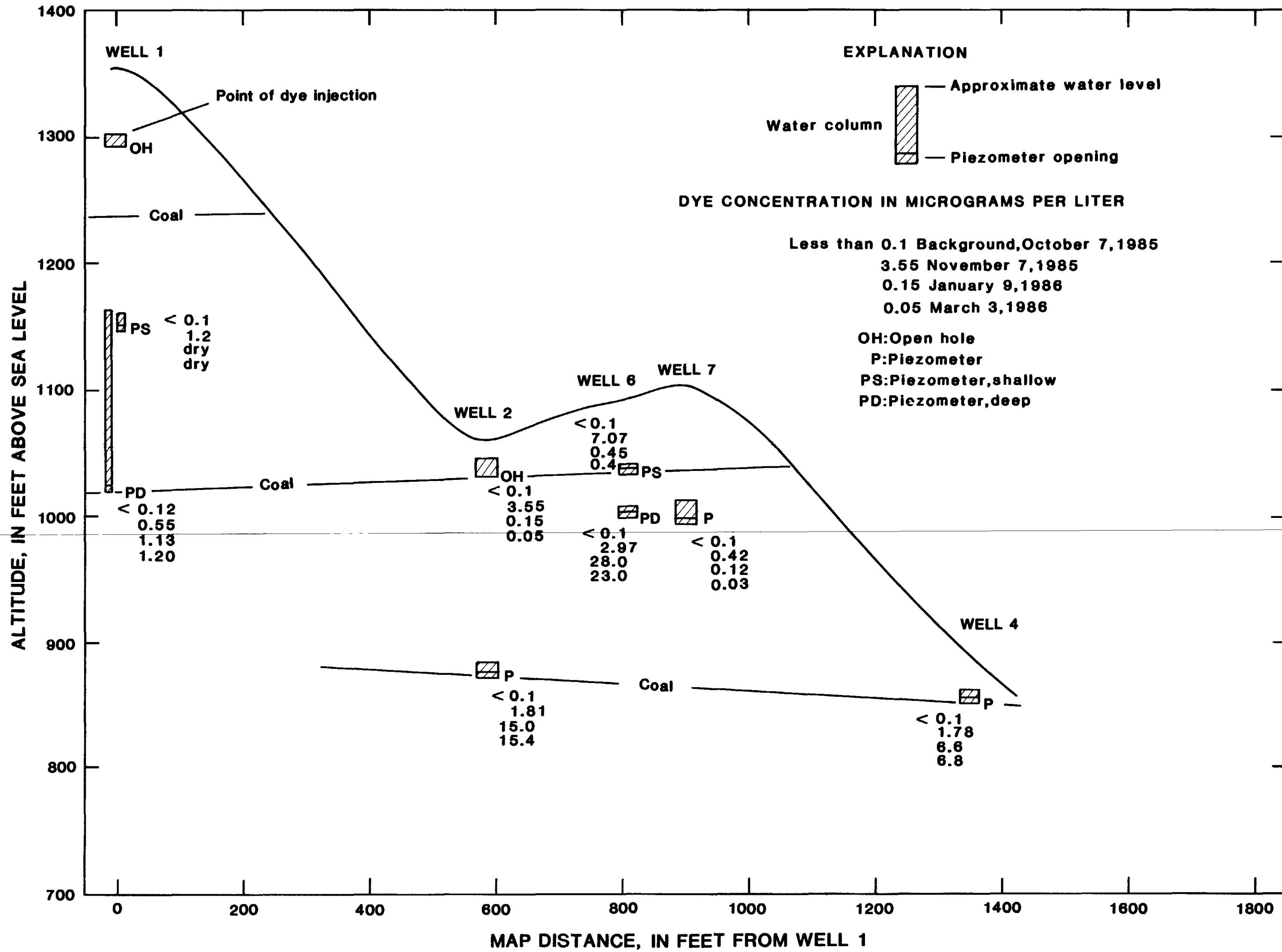


Figure 14.--Concentration of dye in wells 1, 2, 6, 7, and 4.

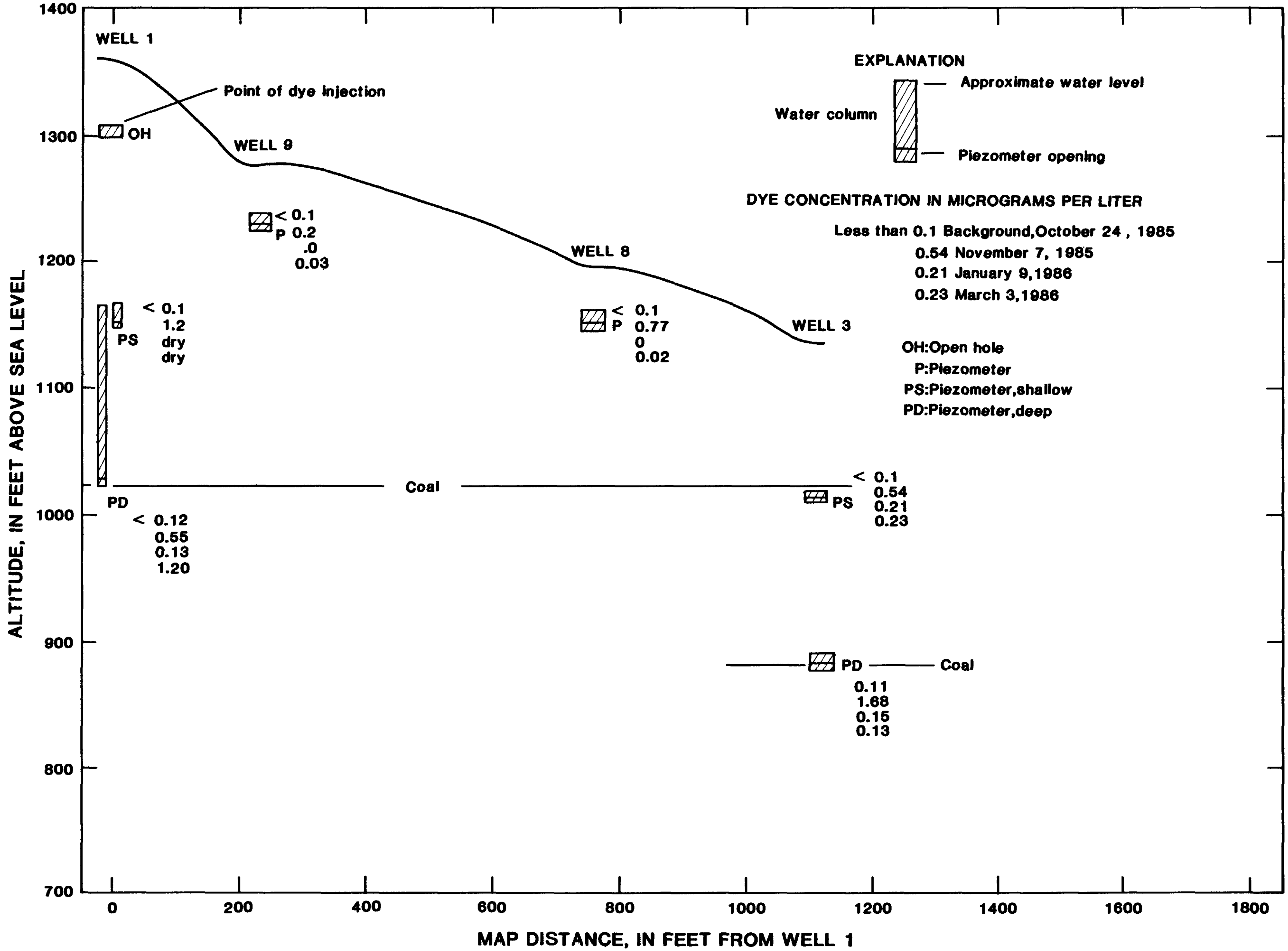


Figure 15.--Concentration of dye in wells 1, 9, 8, and 3.

The dye was expected to move slowly to the downgradient wells, but about 4 inches of rain fell in early November (fig. 13) and probably caused the dye to move faster than expected. When sampled on November 7, 1985, all piezometers contained water with dye concentrations higher than background concentration (table 2). Heavy rain fell periodically throughout the time of study and probably helped to move the dye through the system.

By November 14, 1985, piezometers south-southwest of the injection well, namely 2 P, 4 P, and 6 PD, had increased in dye concentration; however, almost all of the other observation wells showed a decrease in dye concentration.

The concentration of dye in the piezometers at background levels and at three different times of measurement is shown in figures 14 and 15. The figures show that most of the shallow open holes and piezometers (2 OH, 6 PS, 7 P, 9 P, 8 P, and 3 PS) tended to peak early in dye concentration and then diminish. The deeper piezometers (2 P, 6 PD, and 4 P), peaked later than the shallow ones, but peaked at a higher dye concentration level. The highest dye concentration was 28 ug/L from piezometer 6 PD. Figures 6 and 7 show that the test hole 6 penetrates many fractured zones that accepted water readily. Piezometer 2 P had the second highest dye concentration of 15.4 ug/L. This high level of dye concentration came from 183 feet below land surface and about 400 feet lower in altitude than the injection of the dye. Piezometer 3 PD had a dye concentration of 1.68 ug/L two weeks after injection and it is 257 feet below land surface, 400 feet below the injection, and 1,100 feet laterally from the injection well. The coal bed at about 900 feet altitude seems to be a main zone of deep ground-water movement in the study area.

METHOD OF SAMPLING

All samples of water were collected in modified disposable, 10-milliliter capacity, thin plastic pipettes which had the pointed end fused by flame. The pipettes had two holes drilled in their walls near the lip at the open end. Twine was inserted through the holes and was tied to the probe of an electrical water-level indicator. Water-level measurements and sampling of water were done concurrently. New pipettes and twine were used for each sample and the probe and lower several feet of the cable of the water-level indicator were rinsed with distilled water after each use. All measurements of fluorescent dye concentrations were made by standard methods on a fluorometer in the office the day after collection to permit the temperature of all samples to equalize.

MOVEMENT OF GROUND WATER

The occurrence of dye in all of the piezometers at above-background concentrations indicates that ground water in the Eastern Kentucky coal field can move from areas of higher head to areas of lower head through an intricate system of near-vertical, hydraulically-connected fractures, and can move laterally through permeable zones, which probably are the coal beds.

Larsen and Powell (1986, p.40) state: "Flow in the ridgetop and hillslope areas is primarily downward through weathered bedrock. Small amounts of ground water move downward through fractures and interstitial openings in the unweathered bedrock to coal beds". From data collected during this study, it appears that fractures as deep as 210 feet can accept relatively moderate amounts of water, and the concentrations of dye found in the deeper wells indicate hydraulic connections with the surface. Therefore, it seems that in this area of study, more ground water enters and moves through the deeper rocks than envisioned by Larson and Powell (1986). The concept of "geologic isolation" at this site would be invalid and its validity in other similar areas of fractured rock would be questionable.

The movement of the dye could represent the movement of contaminants or acid-mine drainage from a coal seam on a hilltop or hillside to wells or springs lower on the hillside or near the valley bottoms. The movement of dye demonstrates that land-use effects on ridges may not be as isolated from wells or springs lower on the hillside or in the valley bottoms as would be suspected because of the intervening lithology of low-permeability rocks.

SUGGESTED FURTHER STUDIES

The speed of movement of the dye through fractures and possibly coal seams was unanticipated and the velocity of the movement has not been quantified; therefore, a second dye injection with more detailed and rigorous monitoring would be extremely helpful. Two aspects of the dye movement are uncertain at the present time: one is the effect of 4 inches of rain in early November immediately after the dye injection and before the first monitoring of the dye movement; the other is the possibility that alignment of fractures moves the dye preferentially faster in one direction than in other directions. The uncertainty about speed of movement could be resolved by a second injection of dye, followed by early monitoring of the observation wells. The preferential movement of dye could be partially resolved by measuring the time differential that the injected dye takes to reach observation wells and by careful surface mapping of the orientation of fractures in the dye-movement zone. However, prior to another dye injection, all observation wells need to be bailed or flushed to remove or markedly lower vestigial remnants of the first dye injection. This is needed for the second dye injection to be clearly recognized above current background levels of dye concentration.

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