GROUND-WATER HYDROLOGY OF MARSHALL COUNTY, WEST VIRGINIA, WITH EMPHASIS ON THE EFFECTS OF LONGWALL COAL MINING

By Robert A. Shultz

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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

The following factors may be used to convert the inch-pound units published herein to metric units.

Multiply inch-pound units	by	To obtain metric units
	Length	
inch (in)	25.4	millimeter (mm)
	0.0254	meter (m)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
	Volume	
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
million gallons (Mgal)	3785	cubic meter (m^3)
	0.003785	cubic hectometer (hm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	0.0000063090	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Temperature	
degree Fahrenheit (°F)	°C=5/9X(°F-32)	degree Celsius (°C)
	Specific Capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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."

GLOSSARY

Selected Hydrologic and Mining Terms Defined to Help the Reader Understand the Report

Hydrology and underground mining have their own terminology, and an understanding of certain terms is essential when reading this report. The definitions of these terms have been simplified and shortened. If a more detailed definition is required, refer to Meinzer (1923), Langbein and Iseri (1960), Lohman and others (1970, 1972), Lee and Abel (1983), and Bates and Jackson (1984).

ALLUVIUM--Unconsolidated deposits made by streams on river beds, flood plains, and alluvial fans.

ANGLE OF DRAW--The angle formed by the vertical and a line drawn from the edge of the underground workings (ribside) to the point of zero subsidence on the ground surface.

ANTICLINE--An upward fold in the rocks.

AQUIFER--A rock formation that contains sufficient saturated permeable material to yield significant amounts of water to wells and springs.

AQUIFER, CONFINED (ARTESIAN)--The water level in a well tapping a confined aquifer will rise above the top of the aquifer because of hydrostatic pressure. Water will flow when hydrostatic pressure exceeds the top of the well casing.

AQUIFER, SEMICONFINED--The distinction between confined and unconfined water is entirely gradational. The term semiconfined is used for the intermediate conditions. The material overlying an aquifer may be semipermeable so that water is only semiconfined.

AQUIFER, UNCONFINED--The water level in a well tapping an unconfined aquifer will not rise above the water table.

BEDDING PLANE--Any plane in sedimentary rock, along which sediment was deposited simultaneously.

BOTTOM--A lowland along a stream; an alluvial plain.

COEFFICIENT OF STORAGE--The volume of water an aquifer releases, or stores per unit surface area of the aquifer, per unit change in head.

COMPRESSION--Forces or stresses that tend to decrease the volume of, or shorten, a substance.

CONFINING BED--A body of impermeable material stratigraphically adjacent to one or more aquifers. In nature, however, its hydraulic conductivity may range from nearly zero to some value significantly lower than that of the aquifer.

DIP OF ROCK STRATA--The angle between the horizontal and the bedding plane; dip is measured in a vertical plane at right angles to the strike of the bedding (see strike of rock strata).

DRAWDOWN IN A WELL--The vertical drop in water level in a well caused by pumping. For example, the difference between static water level and the water level during pumpage.

DRAWDOWN, RESIDUAL--The difference between the static water level before an aquifer test and the recovering water level during the test.

EVAPOTRANSPIRATION--Water lost through evaporation from the soil and surface water bodies plus transpiration from plants.

FAULT--A fracture in the Earth's crust accompanied by displacement of one side of the fracture with respect to the other.

FRACTURE--A break in rock caused by compressional or tensional forces.

GOB OR SPOIL--The refuse or waste rock material displaced by mining.

GRADIENT, HYDRAULIC--The change of pressure head per unit distance from one point to another in an aquifer.

GROUND WATER--Water contained in the zone of saturation.

HEAD--Pressure, expressed as the height of a column of water that can be supported by the pressure.

HYDRAULIC CONDUCTIVITY--The volume of water that will move in unit time (commonly, a day) under a unit hydraulic gradient (such as foot per foot) through a unit area (such as square feet), measured at right angles to the direction of flow.

JOINTS--System of fractures in rocks along which there has been no movement parallel to the fracture surface.

LINEAMENTS--Linear features on aerial photographs or imagery formed by the alignment of stream channels or tonal features in soil, vegetation, or topography.

LOSING STREAM--A stream, or segment of a stream, that is contributing water to an underlying aquifer.

MILLIEQUIVALENTS PER LITER--In an analysis expressed in milliequivalents per liter, unit concentrations of all ions are chemically equivalent. Milligrams per liter values may be converted to milliequivalents per liter by multiplying the concentration in milligrams per liter by the charge of the ion, and dividing by the atomic weight of the ion.

MINING HEIGHT--The thickness of the rock extracted during mining.

OVERBURDEN--Rock and soil overlying a minable coal bed.

PERCHED WATER TABLE--A saturated zone of rock separated from an underlying body of ground water by unsaturated, relatively impermeable rock.

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

POROSITY--The ratio of the volume of interstices to the total volume.

POROSITY, PRIMARY--Interstices that were created at the time the rocks were formed, such as pores.

POROSITY, SECONDARY--The porosity developed in a rock after its deposition, through such processes as solution or fracturing.

POTENTIOMETRIC SURFACE--An imaginary surface that coincides with the static level of water in the aquifer.

RECOVERY OF PUMPED WELL--The period of time after pumping has ceased during which the water level rises (or recovers) to approximately the level (static level) before pumping.

SPECIFIC CAPACITY--The rate of discharge of water from a well divided by the drawdown of the water level within the well.

STRESS RELIEF--The removal of compressional stress on underlying rocks by erosion of overlying rocks.

STRIKE OF ROCK STRATA--The direction of a line formed by the intersection of the bedding and a horizontal plane (see dip of rock strata).

SUBSIDENCE--A sinking of part of the Earth's surface, such as may result from soil compaction, collapse of underground mines, or removal of ground water, oil or gas.

SUBSIDENCE FRACTURE--A crack or joint in the rock formed or widened as a result of subsidence.

SURFACE WATER--Water on the surface of the Earth, including snow and ice.

SYNCLINE--A downward fold in the rocks.

TENSION--Stress that tends to pull a body apart.

TRANSMISSIVITY--The rate at which water of a prevailing viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

TABLE, WATER--That surface in an unconfined water body at which pressure is atmospheric; generally, the top of the saturated zone.

VERTICAL DRAINAGE DISTANCE--Distance from the drainage divide to the bottom of the well.

ZONE OF SATURATION--That part of the Earth's crust beneath the deepest water table in which all voids are filled with water under pressure greater than atmospheric.

GROUND-WATER HYDROLOGY OF MARSHALL COUNTY, WEST VIRGINIA, WITH EMPHASIS ON THE EFFECTS OF LONGWALL COAL MINING

BY R. A. SHULTZ

ABSTRACT

Marshall County, West Virginia, is underlain by two major types of aquifers--unconsolidated alluvial deposits and consolidated bedrock. The unconsolidated alluvial deposits of clay, silt, sand, and gravel are limited in extent to the floodplain of the Ohio River. Alluvial wells commonly yield several hundred gallons of water per minute. The bedrock consists of shale, sandstone, limestone, and coal. Ground water in the bedrock flows from the hilltops to the valleys. Perched bedrock aquifers are common in the hills, and confined aquifers are common in the valleys. The mean reported yield for bedrock wells was 5.2 gallons per minute. Springs are formed where ground water is diverted to the hillside by relatively impermeable beds of unfractured shale or clay. The mean springflow was 0.94 gallons per minute. In 1985, an estimated 13.1 million gallons of ground water were withdrawn each day in the County for industrial, public supply, mining, and domestic self-supply uses. The chemical quality of ground water generally is acceptable for domestic use. Locally, concentrations of manganese, iron, sulfate, total dissolved solids, nitrate, fluoride, and arsenic exceeded public water-supply limits. Ground water in both the alluvium and bedrock typically is calcium bicarbonate in type and hard to very hard.

Subsidence and fracturing of the overburden caused by longwall mining has changed ground-water conditions. Changes include increases in overburden transmissivity, declines in ground-water levels, increases in water-level fluctuations, and decreases in springflow. Pre- and post-mining aquifer tests showed significant increases in estimated transmissivity at two of three sites. The decline in mean water levels at eight observation wells ranged from 1.56 to 41.99 feet below pre-mining levels. These declines were caused by the combined effects of longwall mining and dry weather. Longwall mining can cause increases in water-level fluctuations. For wells greater than or equal to 50 feet deep, the mean annual water-level fluctuation was at least 5.48 feet per year more for wells in longwall-mined areas than for wells in other areas. Mean annual discharge was 0.32 gallons per minute for springs overlying longwall mines versus 0.94 gallons per minute for springs at unmined sites. Mean annual discharge was significantly lower during the post-mining period than during the pre-mining period at three observation springs.

1.0 INTRODUCTION

1.1 Purpose and Scope

DESCRIPTION OF GROUND-WATER HYDROLOGY
AND THE EFFECTS OF LONGWALL MINING

THIS REPORT DESCRIBES THE GROUND-WATER HYDROLOGY OF MARSHALL COUNTY, WEST VIRGINIA, WITH EMPHASIS ON THE EFFECTS OF LONGWALL COAL MINING.

This report describes the ground-water hydrology of Marshall County, West Virginia, with emphasis on the effects of longwall coal mining. Average annual coal production in Marshall County from 1980 through 1985 was 5.1 million tons, of which more than half was mined using longwall techniques (West Virginia Department of Mines Annual Reports, 1980 to 1985). Ground-water data were collected from February 1985 through March 1987. Two hundred and eighteen wells and 59 springs were inventoried (Appendix A). A ground-water monitoring network was established whereby water-levels in 62 wells and discharges of 13 springs were measured at least monthly (Appendix C). Single-well aquifer tests were made at 3 sites. The following geophysical logs were run on selected wells: gamma ray--15 wells, caliper--14 wells, and electric resistivity--2 wells. Two observation wells were drilled in July 1985 ahead of an advancing longwall panel to obtain pre- and post-mining data. Water samples from 56 wells and 16 springs were analyzed for major chemical constituents.

Additional ground-water data obtained during previous studies by the U.S. Geological Survey also are available. Many of the wells were inventoried from 1940 to 1955, and tap the alluvial aquifer along the Ohio River. Water-level records are available for two observation wells in the Ohio River alluvium. The records for one well are from 1950 to 1976 and the records of the other well are from 1977 through 1982. Weekly measurements for the period July 1971 through January 1973 are available for one well drilled into rocks of the Dunkard Group.

1.0 INTRODUCTION (Continued)

1.2 Location, Land Use, and Climate

MARSHALL COUNTY IS IN THE NORTHERN
PANHANDLE OF WEST VIRGINIA

MARSHALL COUNTY IS AT THE BASE OF THE NORTHERN PANHANDLE OF WEST VIRGINIA. TOPOGRAPHY IS CHARACTERIZED BY RIDGES WITH STEEP SLOPES AND NARROW "V"-SHAPED VALLEYS. MOST OF THE LAND IS FOREST OR PASTURE. AVERAGE ANNUAL PRECIPITATION RANGED FROM 38.50 TO 42.25 INCHES DURING THE PERIOD 1951-80.

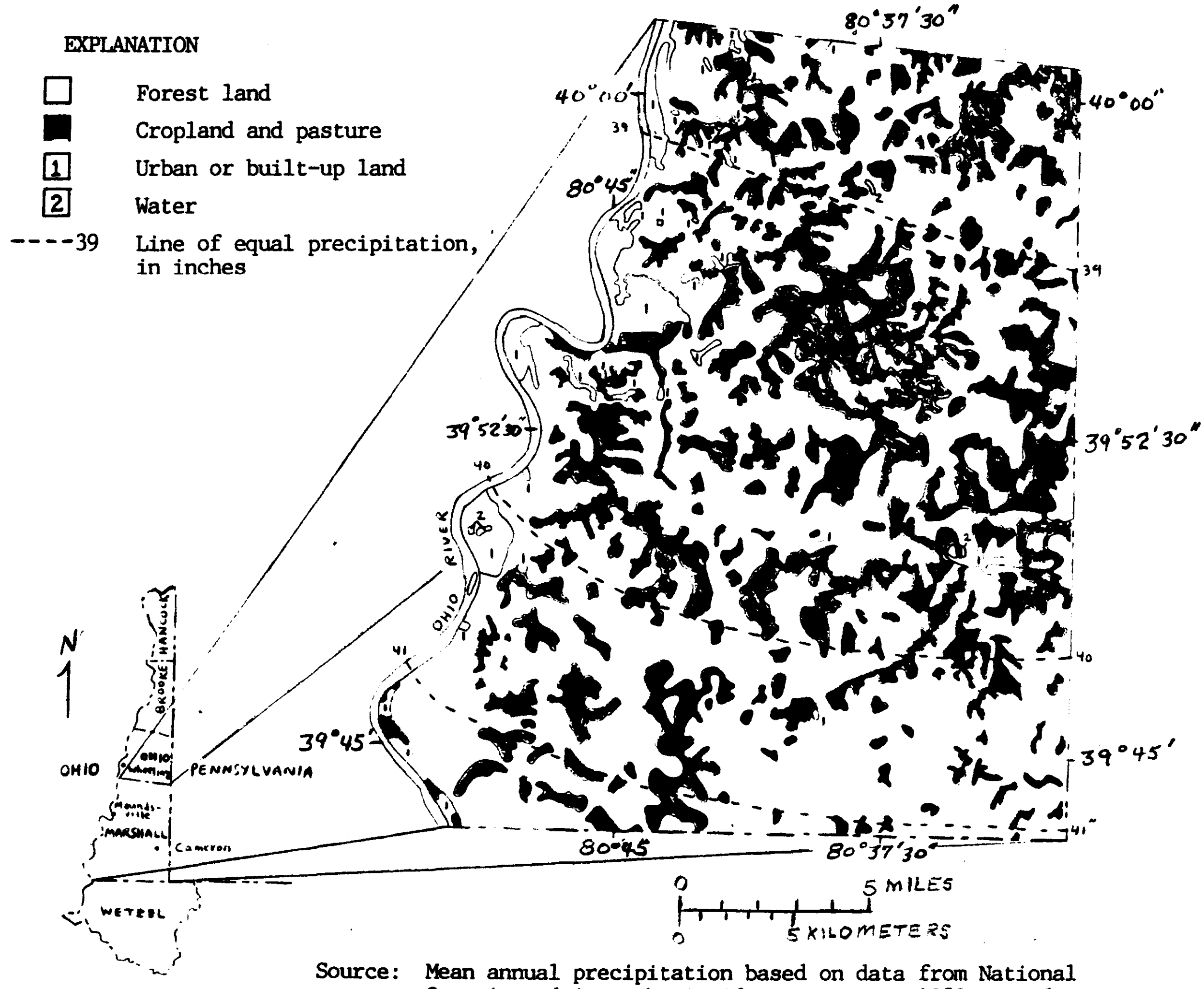
Marshall County encompasses a 315-square-mile area at the base of the Northern Panhandle of West Virginia. It is bordered by Pennsylvania to the east, Ohio to the west, and the West Virginia Counties of Ohio and Wetzel to the north and south, respectively (figure 1.2-A). The population of the County was 41,608 in 1980 (U.S. Department of Commerce, 1981). Most of the population is concentrated on the Ohio River floodplain from Moundsville to the Ohio County line. Moundsville, the largest city and the County Seat, had a population of 12,419 in 1980.

The topography is characterized by long, gently rolling ridges with steep slopes and narrow, "V"-shaped valleys. The highest hilltop is 1,602 feet above sea level and is located about 2.2 miles east of Cameron near the Pennsylvania border. Numerous ridgetops have elevations greater than 1,300 feet above sea level, but only a few exceed 1,500 feet. The lowest elevation is about 623 feet above sea level where the Ohio River flows out of the County. Generally, the average slope is greater than 25 percent or 1,320 feet per mile (Cross and Schemel, 1965b, figure I-92, p. 114). Slopes between 25 and 40 percent are considered rolling to steep, and slopes greater than 40 percent are steep.

McColloch and Lessing in 1980 reported that about 64 percent of the County was forested and 31 percent was agricultural land. Because of steep slopes, cropland is limited to the valleys and the Ohio River floodplain. Most of the agricultural land is pasture (figure 1.2-A).

On the basis of data from the National Oceanic and Atmospheric Administration (1982a, 1982b, 1982c), average annual precipitation ranged from 38.50 inches to 42.25 inches during the period 1951-80 (figure 1.2-A). July typically is the wettest month and February, the driest. Spring and summer are characterized by local thunderstorms with rainfall rates that can exceed several inches per hour. Fall and winter storms typically cover larger areas and are of longer duration, but have lower rainfall rates than spring and summer thunderstorms. Snowfall averages about 30 inches per year.

The County lies in a zone of prevailing westerly winds, which are frequently interrupted by northward and southward surges of relatively warm and cold air, respectively. The average monthly temperature at Wheeling, Ohio County, table 1.2-B, typically is within 1 to 2 degrees of Marshall County temperatures. January is the coldest month and July, the hottest. Minimum temperatures near or below zero degrees Fahrenheit occur two or three times each winter, but usually do not last more than 2 days. Maximum daily temperatures of 90 degrees Fahrenheit or higher occur about 15 to 20 times each year during late spring and summer (National Oceanic and Atmospheric Administration, 1977).



Source: Mean annual precipitation based on data from National Oceanic and Atmospheric Administration, 1982. Land use pattern based on data from U.S. Department of Interior, Geological Survey, 1976, Land Use Series Maps.

Figure 1.2-A.--Location, land use, and mean annual precipitation of study area.

Table 1.2-B.--Monthly minimum, maximum, and mean air temperature normals (temperatures, in degrees Fahrenheit)

Source: Data from National Oceanic and Atmospheric Administration, 1982.

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
MAXIMUM	37.5	39.8	50.4	62.7	73.3	81.5	84.8	83.6	78.1	66.4	53.1	41.8
MINIMUM	20.6	21.5	30.0	39.6	48.5	57.8	62.3	61.7	54.9	43.0	34.4	25.7
MEAN	29.1	30.7	40.2	51.2	60.9	69.7	73.6	72.6	66.5	54.8	43.8	33.8

1.0 INTRODUCTION (Continued)

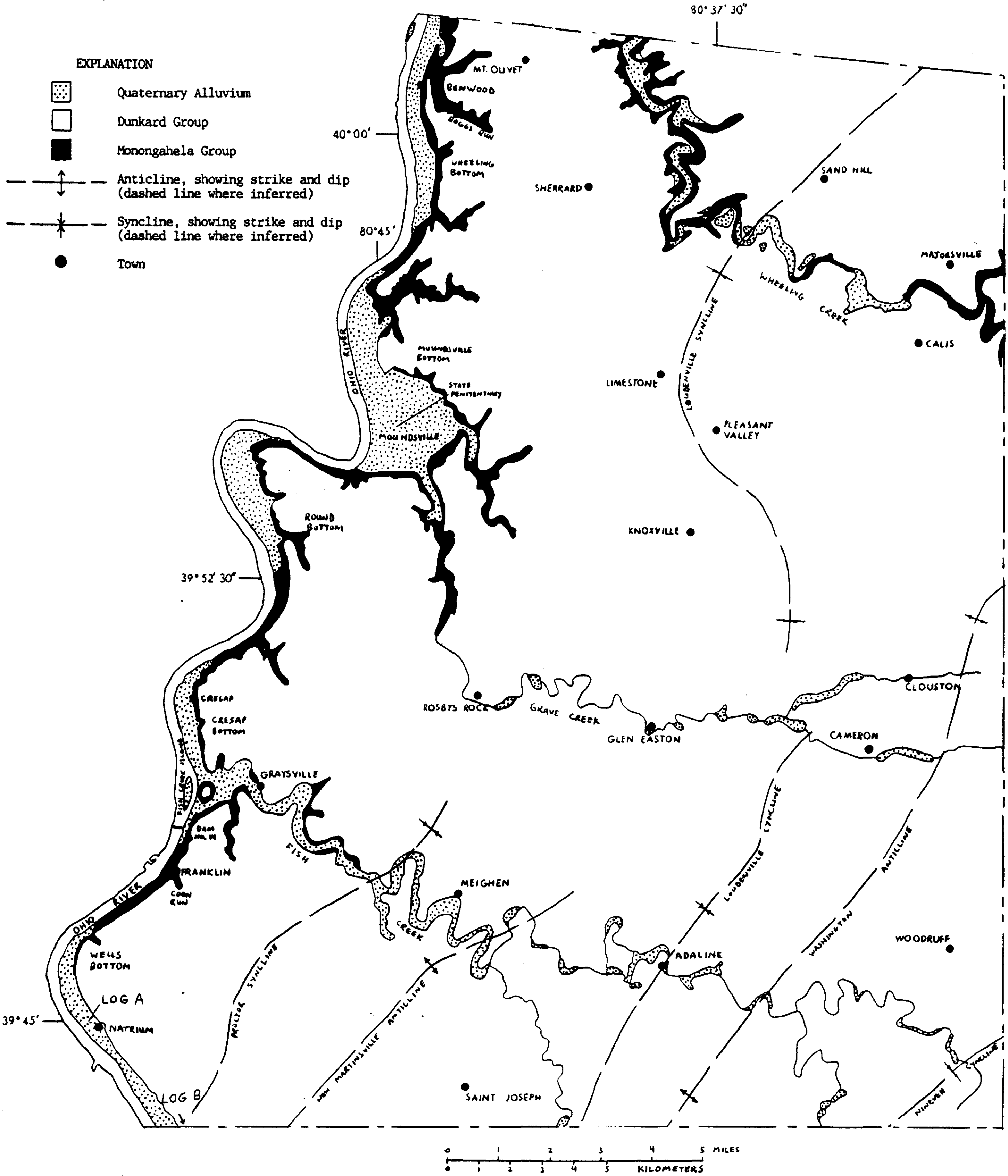
1.3 Geologic Setting

MARSHALL COUNTY IS UNDERLAIN BY GLACIAL OUTWASH OF WISCONSINAN AGE, AND BY BEDROCK OF PERMIAN AND LATE PENNSYLVANIAN AGE

THE GLACIAL OUTWASH WAS DEPOSITED DURING TWO PERIODS OF GLACIATION DURING THE WISCONSINAN STAGE. THE SURFICIAL BEDROCK IS OF PERMIAN AND LATE PENNSYLVANIAN AGE.

Most of the alluvium of the Ohio River valley was deposited as glacial outwash during two periods of glaciation (Simard, 1987). The first glaciation, called the Altonian Substage of early Wisconsinan age, extended to within 8 miles of West Virginia's northern panhandle between about 65,000 and 75,000 years ago. Meltwater transported great quantities of glacial debris down the Ohio River. Outwash deposits of sand and gravel from as far north as Canada filled the Ohio River valley and formed a wide, flat floodplain. Local sand and gravel from tributaries and rock fragments from valley sides also were incorporated in the floodplain as the valley filled. After glacial retreat, the Ohio River cut a meandering channel into the sediment filled valley, leaving the former floodplain as a hillside terrace. The next glaciation, called the Woodfordian substage of late Wisconsinan age, advanced to within 12 miles of West Virginia's northern panhandle about 23,000 years ago. Meltwater reworked the Altonian outwash deposits and added additional deposits to the floodplain. A layer of clay and silt was deposited on the floodplain when the river flow decreased during glacial retreat. The river again incised and abandoned this floodplain as a lower terrace. The Ohio River still flows over a layer of sand and gravel. The present floodplain has been covered by recent deposits of clay and silt.

The surficial bedrock is of Permian and Late Pennsylvanian age, and consists of rocks classified as the Dunkard, Monongahela, and Conemaugh Groups (figure 1.3-A). The stratigraphic nomenclature used in this report follows the usage of the West Virginia Geological and Economic Survey and does not necessarily conform to that used by the U.S. Geological Survey. These rocks were formed from sediment deposited about 250 million years ago (Cross and Schemel, 1956b, p. 43). At that time the Ohio River valley probably was a flat coastal plain. This plain was part of a broad, constantly subsiding block of the earth's crust. The depression has been named the Appalachian geosyncline. It also is called the Dunkard Basin. Marshall County lies in the northern part of the Dunkard Basin. Sediments were laid down in the Dunkard Basin as relatively flat sheets. They were later folded by pressure from rocks pushing against them to the east during the formation of the Appalachian Mountains. These folds, called anticlines and synclines, trend northeast-southwest, virtually perpendicular to the direction of the pressure. These folds are named, from east to west, the Nineveh syncline, Washington anticline, Loudenville syncline, New Martinsville anticline, and Proctor syncline.



Note: The stratigraphic nomenclature used in this report follows the usage of the West Virginia Geological and Economic Survey and does not necessarily conform to that used by the U.S. Geological Survey.

Figure 1.3-A.--Surficial geologic units and structure. (Modified from Cross and Schemel, 1956c).

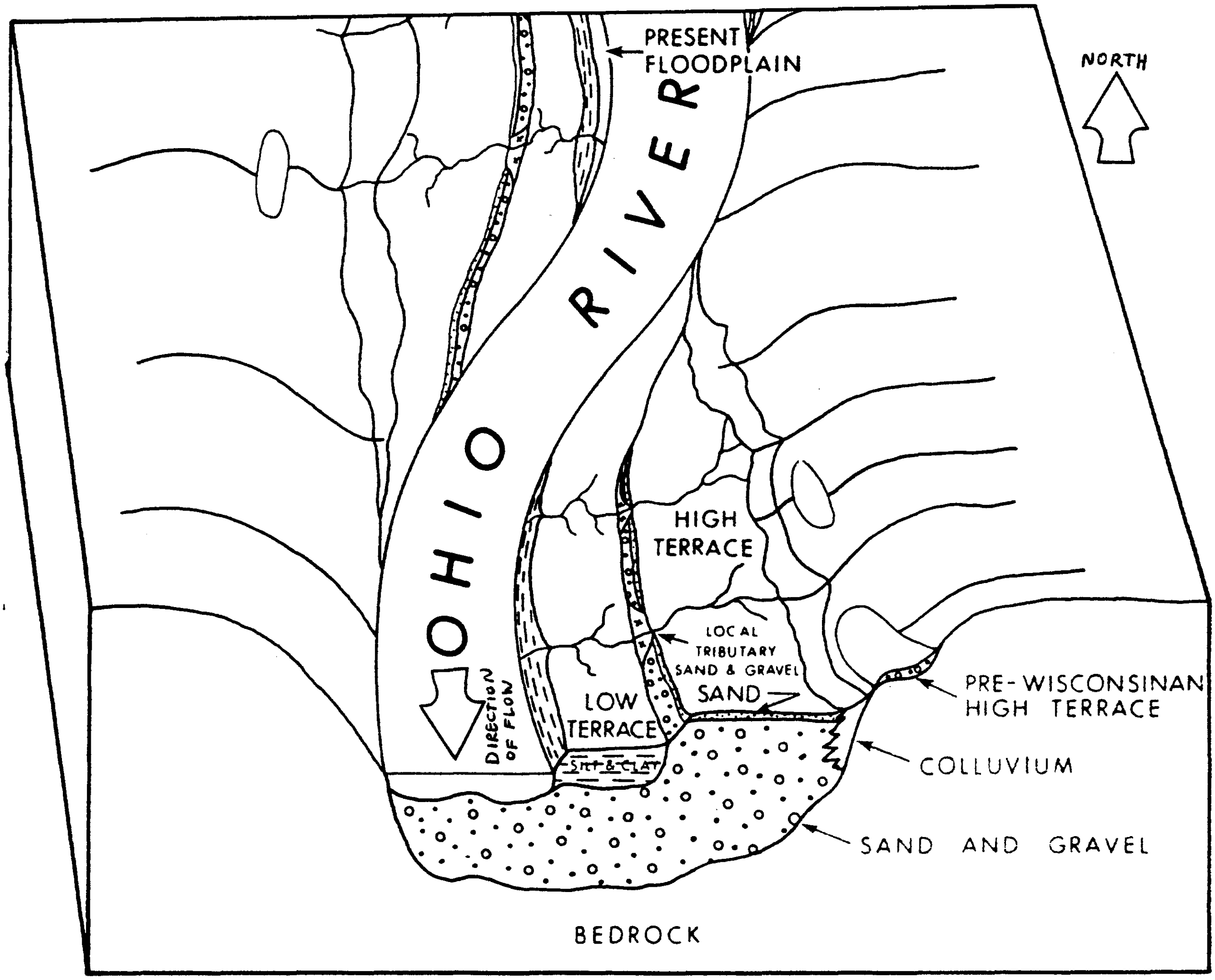


Figure 1.3-B.--Generalized diagram of the Ohio River Valley showing terraces and present floodplain. (Modified from Simard, 1987).

1.0 INTRODUCTION (Continued)

1.3 Geologic Setting (Continued)

1.3.1 Alluvium

ALLUVIAL DEPOSITS OVERLIE THE BEDROCK ALONG THE OHIO RIVER AND THE LOWER REACHES OF TRIBUTARY STREAMS

UNCONSOLIDATED DEPOSITS OF CLAY, SILT, SAND AND GRAVEL OVERLIE THE BEDROCK ALONG THE OHIO RIVER AND ALONG THE LOWER REACHES OF TRIBUTARY STREAMS. THESE DEPOSITS FORM TERRACES AND RANGE IN THICKNESS FROM ZERO TO MORE THAN 100 FEET.

Unconsolidated deposits of variable proportions of clay, silt, sand, and gravel overlie the bedrock along the Ohio River and along the lower reaches of tributary streams. The deposits consist largely of glacial outwash that was deposited as alluvium, but also includes variable amounts of modern alluvium. They form terraces in bottoms and range in thickness from zero to more than 100 feet. In many places the deposits have been covered by fill material, such as slag from steel-processing plants and waste from coal preparation plants. The following descriptions of each bottom are summarized from Carlston and Graeff (1955). The location of each bottom is shown in figure 1.3-A.

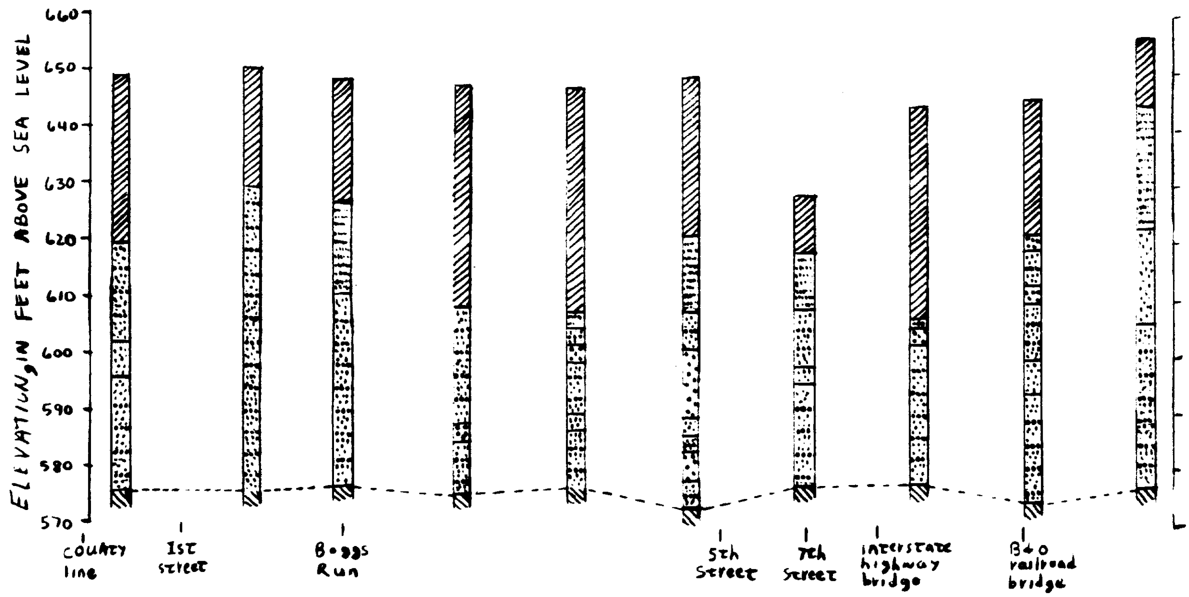
Average thickness of alluvium in Wheeling Bottom is about 70 feet (figure 1.3.1-A). In places, the alluvium is covered with variable amounts of fill material. A layer of clay and silt nearly 25 feet thick underlies the fill material in most areas. Sand with some gravel usually comprises the remainder of the alluvium. The elevation of the bedrock averages about 575 feet above sea level.

Little information is available about the thickness and lithology of the alluvium of Moundsville Bottom. Two wells next to the Ohio River at Moundsville penetrated 70 feet of alluvium without entering bedrock; and wells about 0.4 miles east, at the State Penitentiary, reportedly penetrated 100 feet of gravel without entering bedrock.

The average thickness of alluvium in Round Bottom is at least 70 feet in the north and about 65 feet in the central part of the bottom. No information was available for the remainder of Round Bottom. The lithology of the alluvium in the northern and central parts of Round Bottom was determined through test borings (Ranney Method Water Supplies, Inc., 1952a, 1952b, 1953). The northern part of the bottom has a layer of sandy clay extending from land surface to a depth of about 30 to 40 feet. This layer is underlain by sand and gravel that is locally silty and at least 25 to 30 feet thick. The bedrock contact is not well defined. The central part of Round Bottom has a layer of sandy clay extending from land surface to a depth of about 35 to 45 feet. The bottom 5 to 10 feet of this layer typically is mixed with gravel. This is underlain by a layer of sand and gravel about 20 to 30 feet thick. The bedrock contact is at about 560 to 570 feet above sea level.

The alluvium of Cresap Bottom, between Cresap and Fish Creek Island, is 80 to 100 feet thick. The elevation of the bedrock floor is poorly defined in this area. The thickness of alluvium decreases to 16 feet or less about 1,000 feet north of the U.S. Corps of Engineers Dam Number 14. This decrease results from an increase in the elevation of the bedrock floor. The elevation of the bedrock floor is 584 to 594 feet above sea level in this area. Generally, the thickness of alluvium in the rest of Cresap Bottom to the south is about 12 to 25 feet. The elevation of the bedrock floor is about 570 to 590 feet above sea level. Little information was available on the lithology of the alluvium. The deepest well for which a log was available was located 525 feet north of Fish Creek. The log is as follows, in feet above sea level: 600 to 592.4 - mud, 592.4 to 589.8 - sand, 589.8 to 584.4 - gravel, 584.4 - bedrock.

The alluvium in northern and central Wells Bottom is 51 to 86 feet thick. The elevation of the bedrock floor ranges from about 560 to 580 feet above sea level. The alluvium is primarily sand and clay overlying sand and fine to coarse gravel. Log A (table 1.3.1-B) is representative of the lithology of the alluvium in the northern and central parts of the Bottom. Log B is representative of the alluvium in the southern end of the Bottom.



EXPLANATION

Fill, slag
Silty clay and clayey silt
Sand
Sand with some gravel
Gravel
Bedrock
Alluvium-bedrock contact

0 1000 2000 FEET

0 200 400 METERS

Vertical scale greatly exaggerated

Figure 1.3.1-A.--Cores from Wheeling Bottom. (Modified from Carlston and Graeff, 1955, p. 56).

Table 1.3.1-B.--Lithologic logs of wells penetrating the alluvium in Wells Bottom (Modified from Carlston and Graeff, 1955, p. 64)

Log A

Land-surface elevation 650 feet above sea level

Lithology	Depth (feet)
sand, yellow clay	0-7
clay-bound, mixed gravel	7-16
coarse gravel and cobbles	16-20
very coarse gravel and cobbles	20-27
coarse sand, pea gravel, and scattered medium and coarse gravel	27-33
fine and medium sand, pea gravel, scattered medium gravel	33-35
medium and coarse sand, pea gravel, and scattered medium and coarse gravel	35-45
coarse sand, pea gravel, and scattered medium gravel	45-50
coarse sand, pea gravel, medium gravel, and scattered coarse gravel	50-55
fine to coarse sand, with pea gravel and scattered medium gravel (heaved strongly at 63 feet)	55-65
medium and coarse sand, pea gravel, and medium gravel	65-70
coarse sand, pea gravel, medium gravel, and occasional boulders	70-86.8
blue-green shale (bedrock)	86.8-

Log B

Land-surface elevation approximately 640 feet above sea level

Lithology	Depth (feet)
material concealed and disturbed, mostly coarse gravel	0-16.0
very coarse gravel, pebbles averaging 1.5 inches	16.0-18.5
fine gravel, pebbles 0.25 inch, streaks of fine sand cemented with limonite	18.5-21-5
medium sand	22.5-22.5
sandy yellow clay	22.5-22.9
gravel and medium sand, crossbedded, coal boulders up to 7 inches in diameter	22.9-28.8
concealed	28.8-36.8
gravel, pebbles up to 1 inch; medium sand, slightly crossbedded	36.8-43.8
medium sand, cross-bedded, gravel layers, pebbles up to 1 inch	43.8-49.3
yellow clay	49.3-51.1
medium to fine sand	51.1-52.6
medium to fine sand, with a few pebbles	52.6-54.1
yellow clay	54.1-55.1
sand, some clay streaks, pebbles up to 1 inch	55.1-62.3
water level in pit	62.3-

Note: The locations of the logs are shown on figure 1.3-A

1.0 INTRODUCTION (Continued)

1.3 Geologic Setting (Continued)

1.3.2 Bedrock

THE DUNKARD GROUP OF PERMIAN AND PENNSYLVANIAN AGE IS EXPOSED IN MOST OF THE COUNTY

THE DUNKARD GROUP IS EXPOSED IN MOST OF THE COUNTY. THE MONONGAHELA GROUP CROPS OUT ALONG THE OHIO RIVER AND THE LOWER REACHES OF THE OHIO RIVER'S TRIBUTARIES. THE CONEMAUGH GROUP IS COVERED BY ALLUVIUM IN THE EXTREME NORTHWEST CORNER OF THE COUNTY. THE BEDROCK IS COMPRISED OF VARIABLE PROPORTIONS OF SHALE, SANDSTONE, LIMESTONE, AND COAL.

The Dunkard Group of Permian and Pennsylvanian age is the youngest bedrock unit and is exposed throughout most of the County. It extends downward from the top of the Proctor Sandstone to the top of the Waynesburg coal of the Monongahela Group. The Dunkard Group attains a maximum thickness of almost 1,150 feet in the southeastern corner of the County. It thins to the north and west, and has been eroded along the Ohio River and the lower reaches of the Ohio River's tributaries, exposing the underlying Monongahela Group.

The Dunkard Group consists of shale interbedded with sandstone, limestone, and coal. Shale is the most common rock type, and commonly contains clay layers a few inches thick. Sandstone beds typically are less than 50 feet thick and are not areally extensive. However, sandstone beds are the major source of ground water in the bedrock. Limestone beds typically are less than 10 feet thick and generally are thicker in the northern half of the County than in the southern half. The Washington coal seam is the thickest and most persistent coal seam in the Dunkard Group. Its average thickness is 1 to 2 feet. Locally, it attains a maximum thickness of about 5 feet. The original minable reserves are estimated to be about 385 million tons (Fedorko, N., West Virginia State Geological and Economic Survey, oral commun., 1987). Other coal seams typically are less than 1 foot in thickness and are not areally extensive.

The Monongahela Group extends downward from the top of the Waynesburg coal to the base of the Pittsburgh coal. The Monongahela Group attains a maximum thickness of 300 to 350 feet in the southeastern corner of the County. Like the Dunkard Group, it thins to the north and west and has been eroded along the Ohio River at Benwood in the northwestern corner of the County.

The Monongahela Group consists of shale interbedded with limestone, sandstone, and coal. Shale is the most common rock type. Limestone is thicker in the Monongahela Group than in the Dunkard Group and, combined with shale, comprises more than 75 percent of the rock. The Benwood Limestone is the thickest and most persistent limestone of the Monongahela Group. At places, it is 60 feet thick and is typically interbedded with limey shales. Sandstone is less common in the Monongahela Group than in the Dunkard Group and typically is thin and not persistent. Three coal seams are more than 4 feet thick--the Waynesburg coal, Sewickley coal, and Pittsburgh coal. The Pittsburgh coal is the only seam commercially mined in the County.

The geologic sections show the lithologic variation of the Dunkard and Monongahela Groups (figures 1.3.2-A to C). Proportions of shale, sandstone, limestone, and coal differ considerably. Hennen (1909, p. 246) described the Waynesburg Sandstone of the Dunkard Group--"Along the hill road leading northwest from Majorsville its horizon is represented by 35 feet of sandy shales with streaks of thin sandstone, but along the road leading north from Wheeling Creek, two miles west of Majorsville, 35 feet of sandstone occurs at this horizon...."

The Conemaugh Group extends from the base of the Pittsburgh coal to the top of the Upper Freeport coal in the underlying Allegheny Formation. It is overlain by the Monongahela and Dunkard Groups except in the extreme northwestern corner of the County along the Ohio River; there it is overlain by alluvium. The Conemaugh Group is not exposed on the surface and, therefore, does not appear on figure 1.3-A. The Conemaugh Group is not a significant source of ground water in the County and will not be described in detail. It ranges in thickness from about 475 to 575 feet and is composed of variable proportions of sandstone, limestone, shale, and coal.

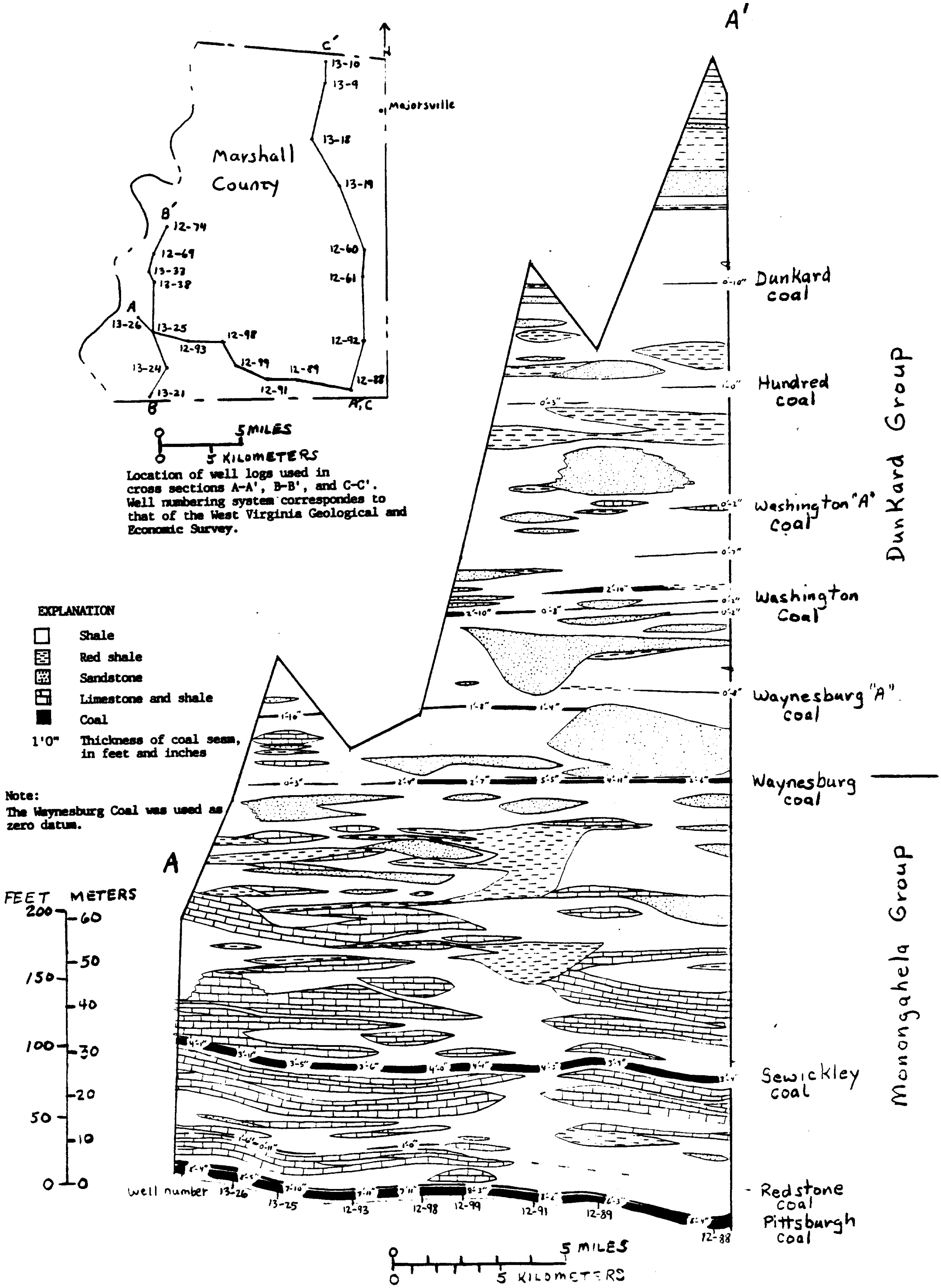


Figure 1.3.2-A.--Geologic section A-A'. (Modified from unpublished geologic sections made by the West Virginia Geological and Economic Survey).

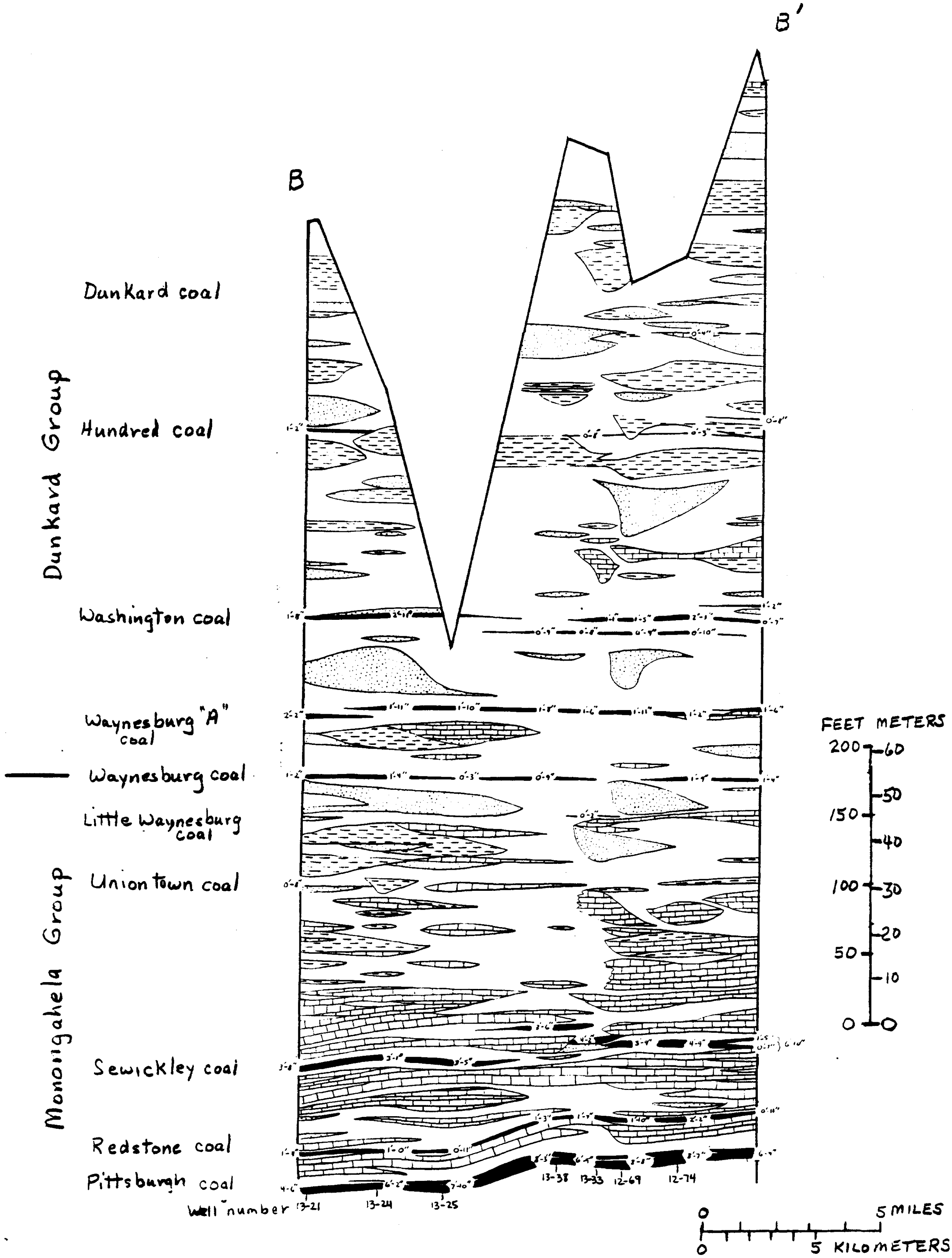


Figure 1.3.2-B.--Geologic section B-B'. (Modified from unpublished geologic sections made by the West Virginia Geological and Economic Survey).

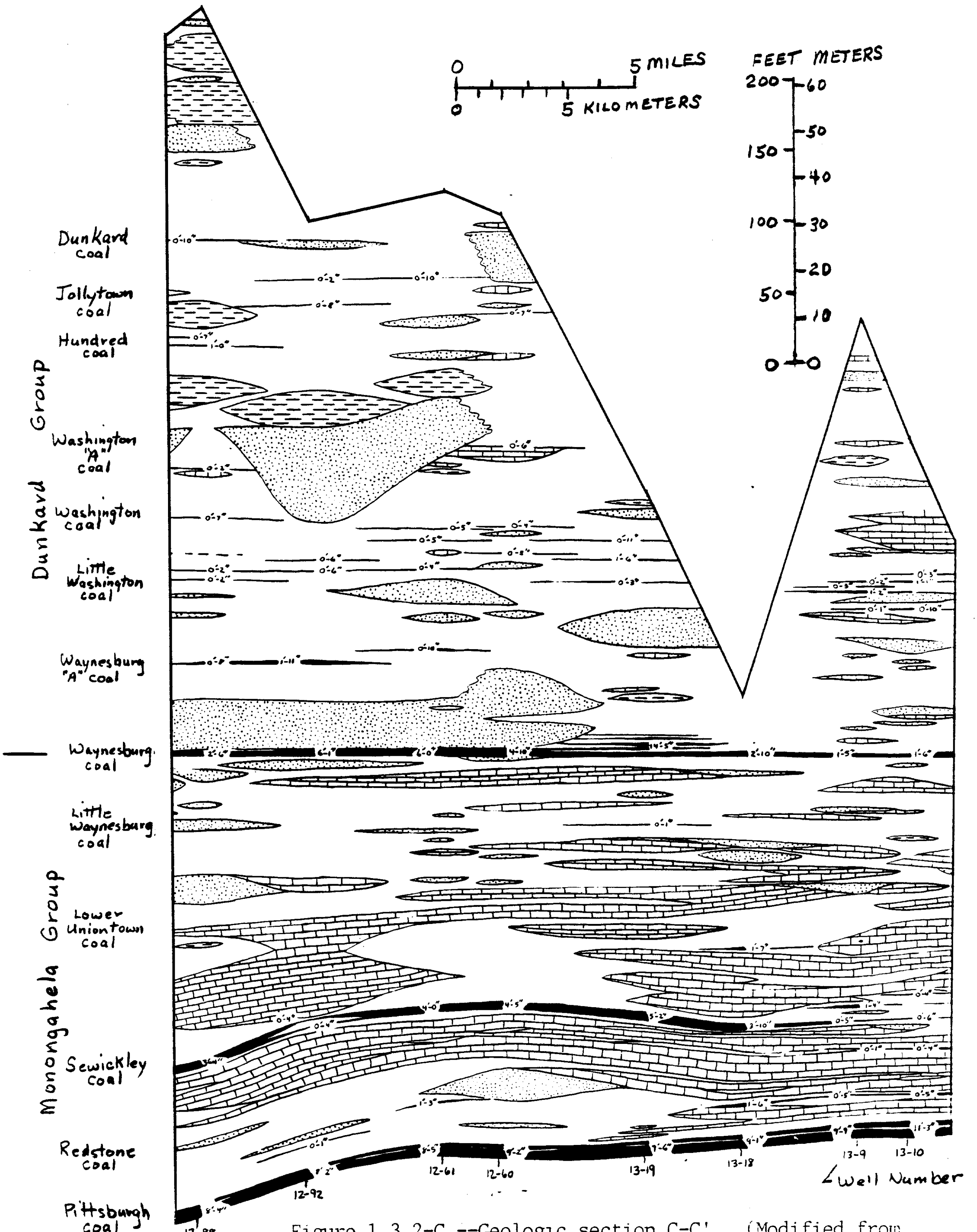


Figure 1.3.2-C.--Geologic section C-C'. (Modified from unpublished geologic sections made by the West Virginia Geological and Economic Survey).

1.0 INTRODUCTION (Continued)

1.4 Acknowledgments

This investigation was conducted in cooperation with the Marshall County Commission. The author wishes to thank the many landowners, Consolidation Coal Company, and officials of local, State, and Federal agencies for their help during all phases of this investigation. Personnel of Consolidation Coal Company and Nick Fedorko of the West Virginia Geological and Economic Survey provided maps of mining activities and coal seams. Dave Barto of the U.S. Environmental Protection Agency provided field assistance in measuring water levels and spring discharges. Special thanks are given to Charles Hoskins, for allowing access on his property to drill observation wells; to Daniel Rogerson, for observing and maintaining precipitation records; and to the Limestone Volunteer Fire Department for providing equipment for hauling water for drilling and aquifer testing.

2.0 GROUND-WATER HYDROLOGY

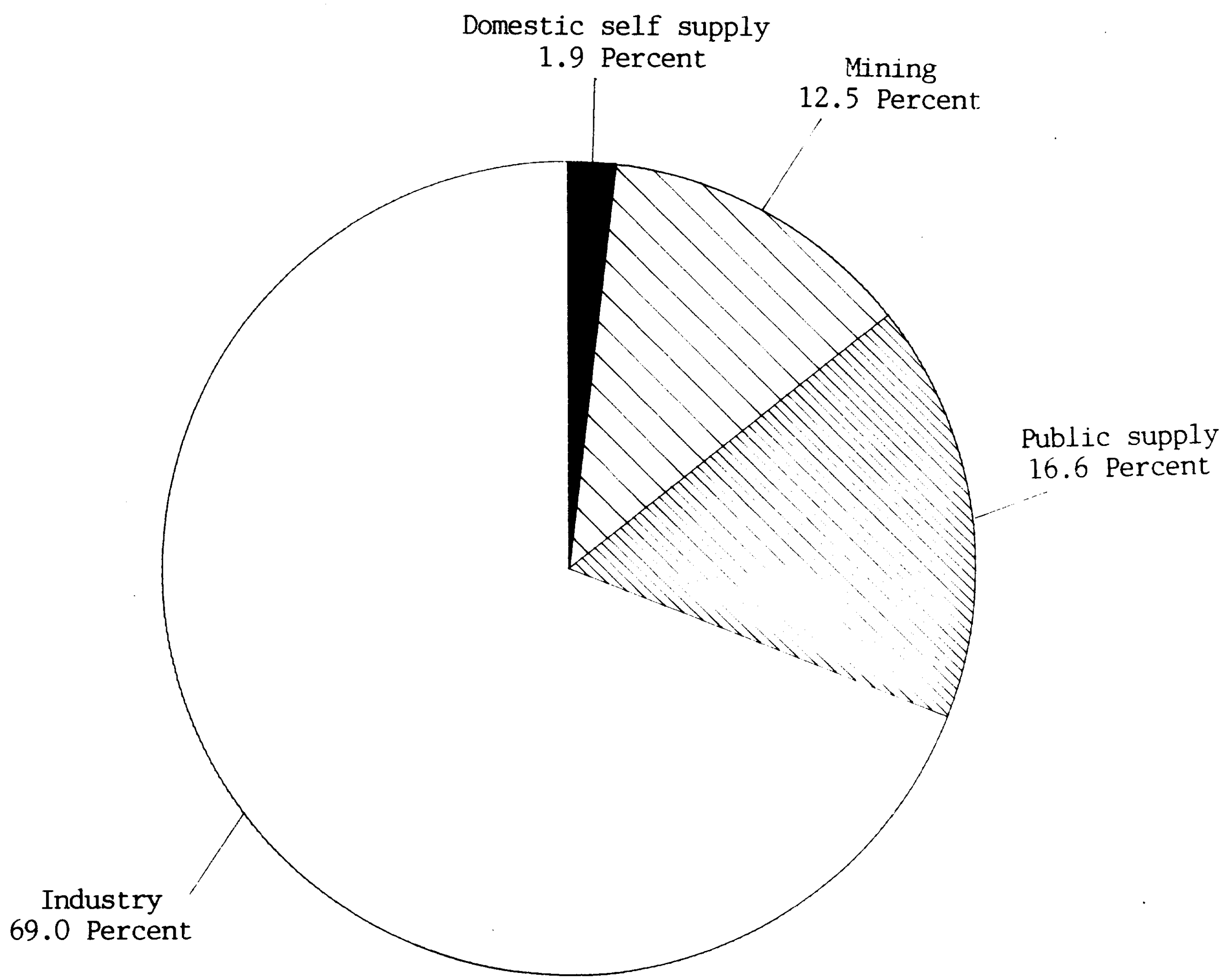
2.1 Water Use

GROUND WATER IS AN IMPORTANT
RESOURCE OF THE COUNTY

AVERAGE WITHDRAWAL OF GROUND WATER WAS APPROXIMATELY 13.1 MILLION GALLONS PER DAY IN 1985. GROUND WATER WAS WITHDRAWN FOR INDUSTRIAL, PUBLIC-SUPPLY, MINING, AND DOMESTIC SELF-SUPPLY USES.

An average of 13.1 million gallons of ground water was withdrawn each day in 1985 (U.S. Geological Survey National Data Storage and Retrieval System--WATSTORE). Ground water was withdrawn for industrial, public-supply, mining, and domestic self-supply uses (figure 2.1-A). About 9.04 Mgal/d was withdrawn for industrial uses. Industrial use includes water used in the manufacturing of steel, chemical and allied products, paper and allied products, and petroleum refining. Most of the ground water was withdrawn from the alluvium along the Ohio River. About 2.17 Mgal/d was withdrawn for public supply. Most of this ground water came from the Ohio River alluvium and supplied about 30,000 people. About 1.63 Mgal/d was withdrawn for mining use. Mining use includes water used in the extraction of minerals, such as coal and ores, crude petroleum, and natural gas. It also includes quarrying, well operation, milling, and other operations normally done at the mine site or as part of a mining activity, but excludes the processing of raw materials, such as ore smelting, petroleum refining, and operation of slurry pipelines.

Approximately 0.25 Mgal/d was withdrawn for domestic self supply. Domestic self-supplied usage was estimated by assuming the average daily water use of individuals not on public-supply systems was 25 gallons per day. Domestic use includes water used for normal household purposes such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, and watering lawns and gardens. Most of the ground water used for domestic self supply was withdrawn from the bedrock.



Source: U.S. Geological Survey National Water Data Storage and Retrieval System (WATSTORE)

Figure 2.1-A.--Percentages of ground-water use in 1985 by categories.

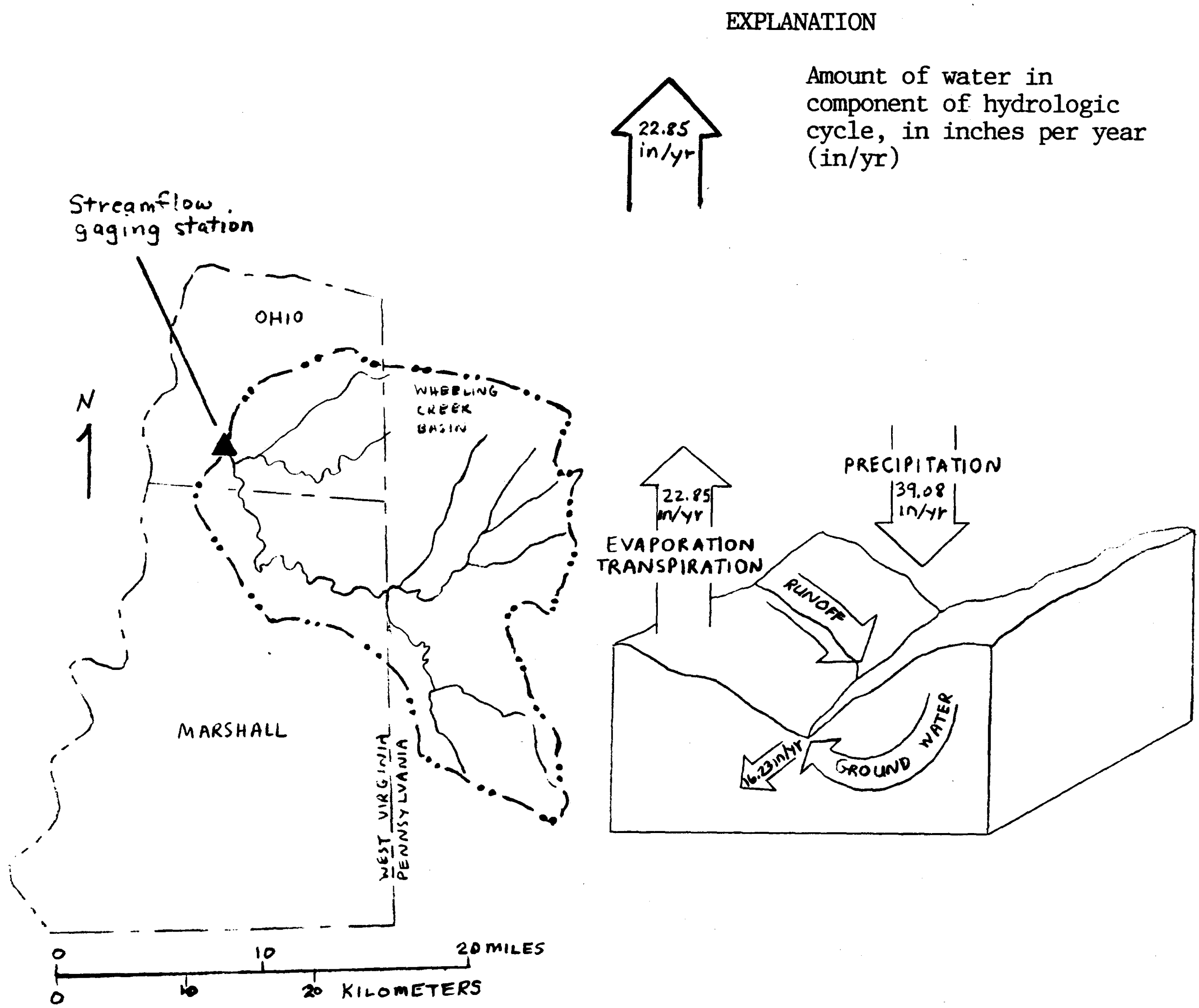
2.2 Source of Ground Water

PRECIPITATION IS THE SOURCE OF MOST GROUND WATER

PRECIPITATION IS THE PRINCIPAL SOURCE OF GROUND WATER. HOWEVER, THE ALLUVIAL AQUIFER ALSO IS RECHARGED FROM ADJACENT BEDROCK AND FROM STREAMS.

Precipitation is the principal source of ground water. Some precipitation is lost through evapotranspiration and overland runoff. Figure 2.2-A shows that about 58 percent of the annual precipitation is lost to evapotranspiration. The remaining 42 percent either moves to the streams as overland runoff or infiltrates the ground and recharges the ground-water system. These values were estimated by subtracting the mean annual runoff, in inches, from the mean annual precipitation, in inches. This does not take into account interbasin transfer of ground water by mine pumpage or any other means. Most recharge occurs during late fall, winter, and early spring, when plants are dormant and evapotranspiration rates are low. A large percentage of precipitation is lost through evapotranspiration during the summer when temperature, solar radiation, and photosynthesis are at a maximum. Consequently, ground-water levels and spring discharges follow a seasonal pattern. They commonly peak in late winter or early spring and decline to their lowest levels in early fall. Water levels and spring discharges begin to rise in the early fall when precipitation effectively recharges the ground-water system because of decreased evapotranspiration rates.

The rate of infiltration from precipitation probably is not uniform, especially in the alluvium. A semiconfining layer of clay and silt of variable thickness commonly lies at the top of the alluvium and slows the rate of infiltration. Bader, Mathes, and Shultz (in press) noted that ground water in areas where surface disposal of coal wastes had occurred contained higher concentrations of dissolved sulfate than ground water in areas where there was no coal waste. This indicates that infiltration can occur through the clay-silt layer. Streams that flow across the floodplain are a source of ground water as water seeps through streambeds into the alluvium. Discharge in Little Grave Creek at Moundsville was estimated to have decreased from 10 ft^3/s (cubic feet per second) in the upstream bedrock to 0.5 ft^3/s downstream on the alluvial floodplain (Friel, E. A., U.S. Geological Survey, oral commun., 1984). The adjacent bedrock is a source of ground water to the alluvium where fractures allow water to pass from the bedrock to the alluvium. The Ohio River also is a source of water to the alluvium when ground-water withdrawals lower the water table below river stage, causing river water to enter the alluvium.



Source: **Precipitation based on period from 1951-80 from data of the National Oceanic and Atmospheric Administration (1982). Streamflow based on period from 1951-80 from data of the U.S. Geological Survey.**

Figure 2.2-A.--Generalized diagram showing approximate amounts of water in various components of the hydrologic cycle in Wheeling Creek Basin upstream from the Elm Grove gage.

2.3 Water in Alluvium

2.3.1 Movement

WATER IN THE ALLUVIUM MOVES
THROUGH INTERGRANULAR SPACES

WATER IN THE ALLUVIUM MOVES THROUGH CONNECTED INTERGRANULAR SPACES. UNDER NATURAL CONDITIONS, GROUND WATER FLOWS FROM BEDROCK BORDERING THE ALLUVIUM, THROUGH THE ALLUVIUM, AND INTO THE OHIO RIVER.

Ground water moves through connected intergranular spaces. Alluvial deposits can be well-sorted to poorly sorted. Well-sorted deposits contain particles of nearly uniform shape and size, whereas poorly sorted deposits consist of particles of varying shapes and sizes. The intergranular spaces in poorly sorted deposits typically are smaller than intergranular spaces in well-sorted deposits. As a result, poorly sorted deposits have lower porosity and typically transmit less water than do well-sorted deposits.

The alluvium is more permeable than the surrounding bedrock. Under natural conditions, ground water flows from the adjacent bedrock (areas of higher hydraulic head), through the alluvium, and into the Ohio River (area of lower hydraulic head). However, the direction of flow can be reversed by pumpage, which can alter head relations in the bedrock and alluvium.

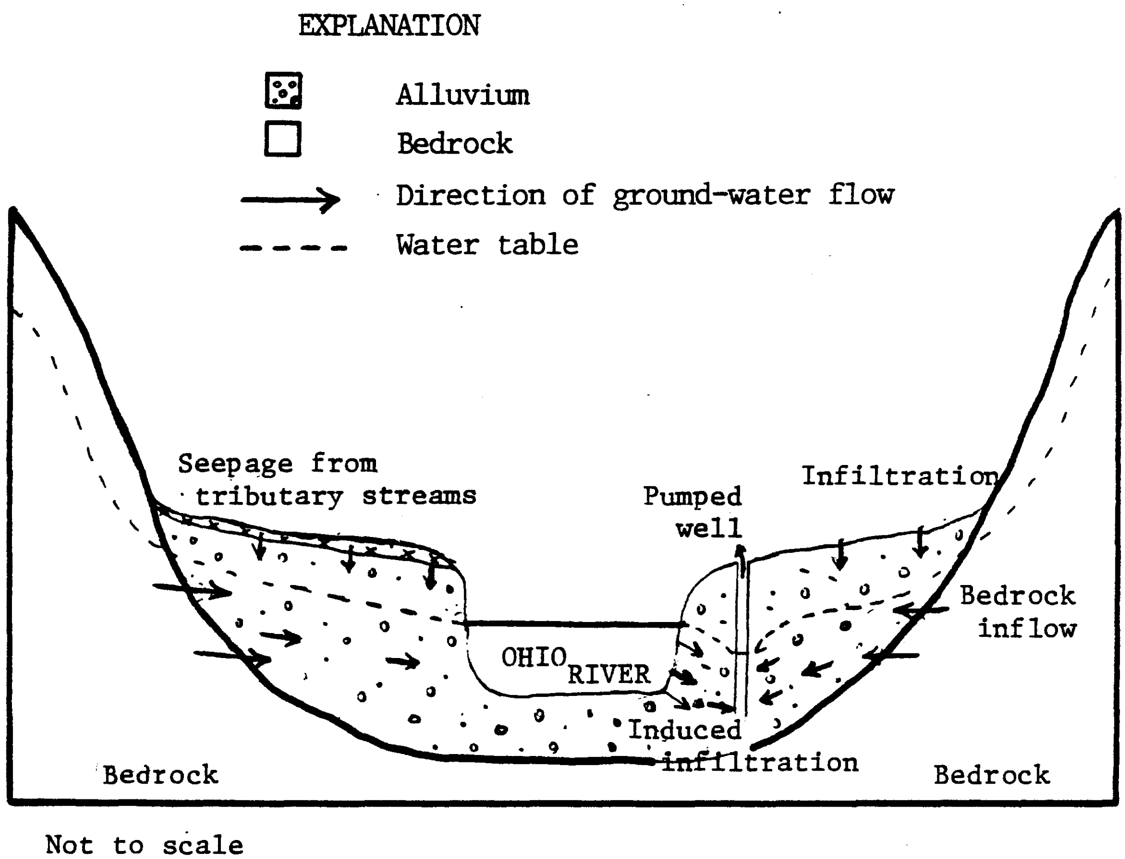


Figure 2.3.1-A.--Generalized diagram showing ground-water movement in the alluvium.

2.0 GROUND-WATER HYDROLOGY (Continued)

2.3 Water in Alluvium (Continued)

2.3.2 Availability

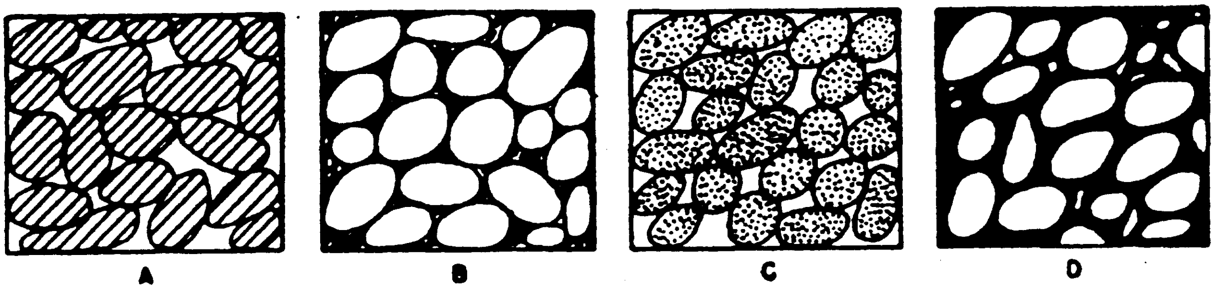
ALLUVIAL DEPOSITS ARE CAPABLE OF YIELDING LARGE QUANTITIES OF WATER

MOST WELLS IN THE ALLUVIUM ARE CAPABLE OF YIELDING SEVERAL HUNDRED GALLONS PER MINUTE. HOWEVER, WELL YIELD CAN DECREASE OVER TIME.

Most wells in the alluvium are capable of yielding several hundred gallons per minute. Radial collectors that induce infiltration from the Ohio River are capable of yielding several thousand gallons per minute. Thick deposits of well-sorted gravel and sand yield the largest quantities of ground water. These deposits can store and transmit sufficient quantities of ground water for public supply.

Estimated transmissivities of the alluvium range from 1,100 to 17,000 ft^2/d (feet squared per day) (Bader, Mathes, and Shultz, in press). Reported transmissivities at Round Bottom ranged from about 27,000 to 54,000 ft^2/d (Ranney Method Water Supplies, Inc., 1952a, 1952b, 1953). Infiltration was induced from the Ohio River during the tests at Round Bottom.

Well yield can deteriorate over time. Possible causes are (1) incrustation or plugging of the screen and of the surrounding deposits; (2) corrosion of the screen, casing, or pump components; (3) interference from nearby wells; and (4) changes in climate. The chemical quality of water affects the development of incrustation. Driscoll (1986) states that "the major forms of incrustation include: (1) incrustation from precipitation of iron and manganese compounds, primarily their hydroxides or hydrated oxides; and (2) plugging caused by slime-producing iron bacteria or other slime-forming organisms (biofouling)." Fine particles can also plug the screen and the surrounding deposits, and can erode the screen itself if they are pumped through the slots. In addition, the pump can be damaged by sand or other fine particles. Corrosion can result in enlargement of the screen slots or the development of new holes, allowing sand and other particles to be pumped into the well. The screen or casing can also be weakened to the point of collapse. Corrosion products can block the screen slots, causing a reduction in yield, and they can be pumped into the well, causing a reduction in water quality. Interference from nearby wells can also reduce the well yield if the wells are too close together. Changes in climate such as a decrease in precipitation can reduce the well yield by decreasing the amount of recharge to the aquifer.



A – Well-sorted deposit with high porosity

B – Poorly sorted deposit with low porosity

C – Well-sorted deposit consisting of porous pebbles, with very high porosity

D – Well-sorted deposit whose porosity has been diminished by the deposition incrustation of mineral matter in the interstices.

Figure 2.3.2-A.--Generalized diagram showing porosity in alluvial deposits. (Modified from Carlston and Graeff, 1955, p. 11).

2.0 GROUND-WATER HYDROLOGY (Continued)

2.4 Water in Bedrock

2.4.1 Movement

GROUND WATER FLOWS FROM
HILLTOPS TO VALLEYS

GROUND WATER FLOWS THROUGH BEDROCK FROM HILLTOPS TO VALLEYS. PERCHED WATER-TABLE AQUIFERS ARE COMMON BENEATH THE HILLS. BEDROCK AQUIFERS IN THE VALLEYS TYPICALLY ARE UNDER CONFINED CONDITIONS.

Ground water in the bedrock aquifers flows from hilltops to valleys in response to gravity. The primary permeability of the bedrock generally is negligible. Most movement of ground water occurs through fractures. Fractured sandstone layers are the major bedrock aquifers in the County because they can store and transmit quantities of water sufficient for domestic use. Fractures are more numerous in hard rocks, such as sandstone, limestone, and coal, than in soft rocks, such as shale and clay. During deformation, hard rocks typically break to form fractures, whereas soft rocks tend to bend. Shale and clay are relatively impermeable and commonly act as confining layers.

Perched water-table aquifers are common beneath the hills and are found where relatively impermeable beds of clay or unfractured shale impede the downward movement of ground water. Some seepage does occur along the edges of and through these impermeable beds, and springs and seeps can develop at outcrops. Site 300, a spring, is located where water that moves laterally through sandstone overlying a clayey shale has reached land surface. Similar conditions for spring formation are present in neighboring Ohio County (Robison, 1964, p. 16). Perched aquifers are the major source of ground water in the rural areas of the County. The water level in a well depends on the pressure head in the aquifers. Head decreases with depth in hilltops and hillsides. Consequently, the water level in a well being drilled on a hilltop or hillside will decline as the hole is deepened (figure 2.4.1-B). The rate of decline is less than the rate of deepening.

Some wells are drilled through several aquifers and confining beds. Where water-bearing strata are overlain by relatively impermeable beds, the strata are said to be confined. Bedrock aquifers underlying valleys typically are under confined conditions. Head increases with depth in valley areas. Theoretically, the water level will rise in a valley well as the hole is deepened, but the available data were insufficient to show any trends.

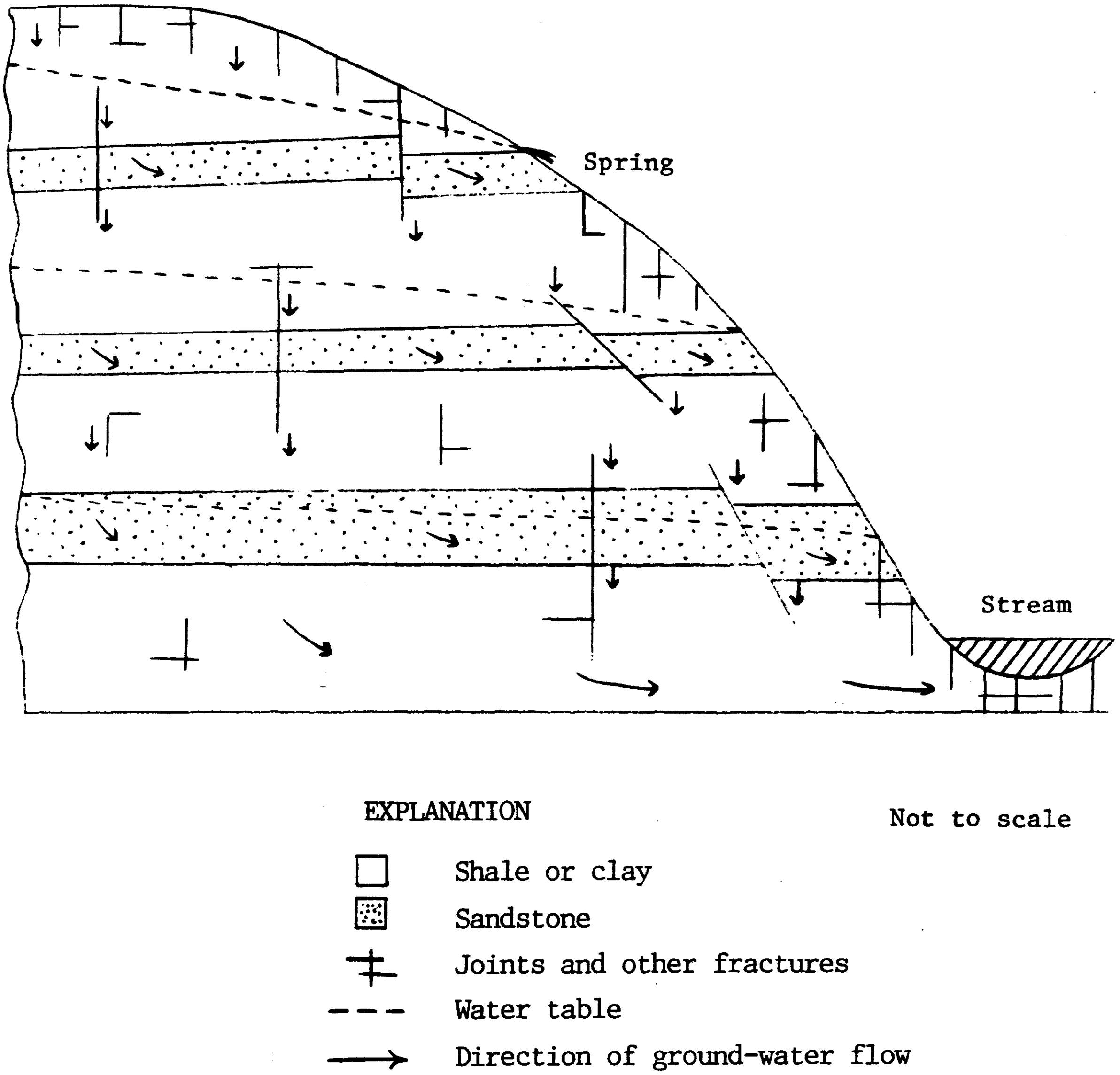
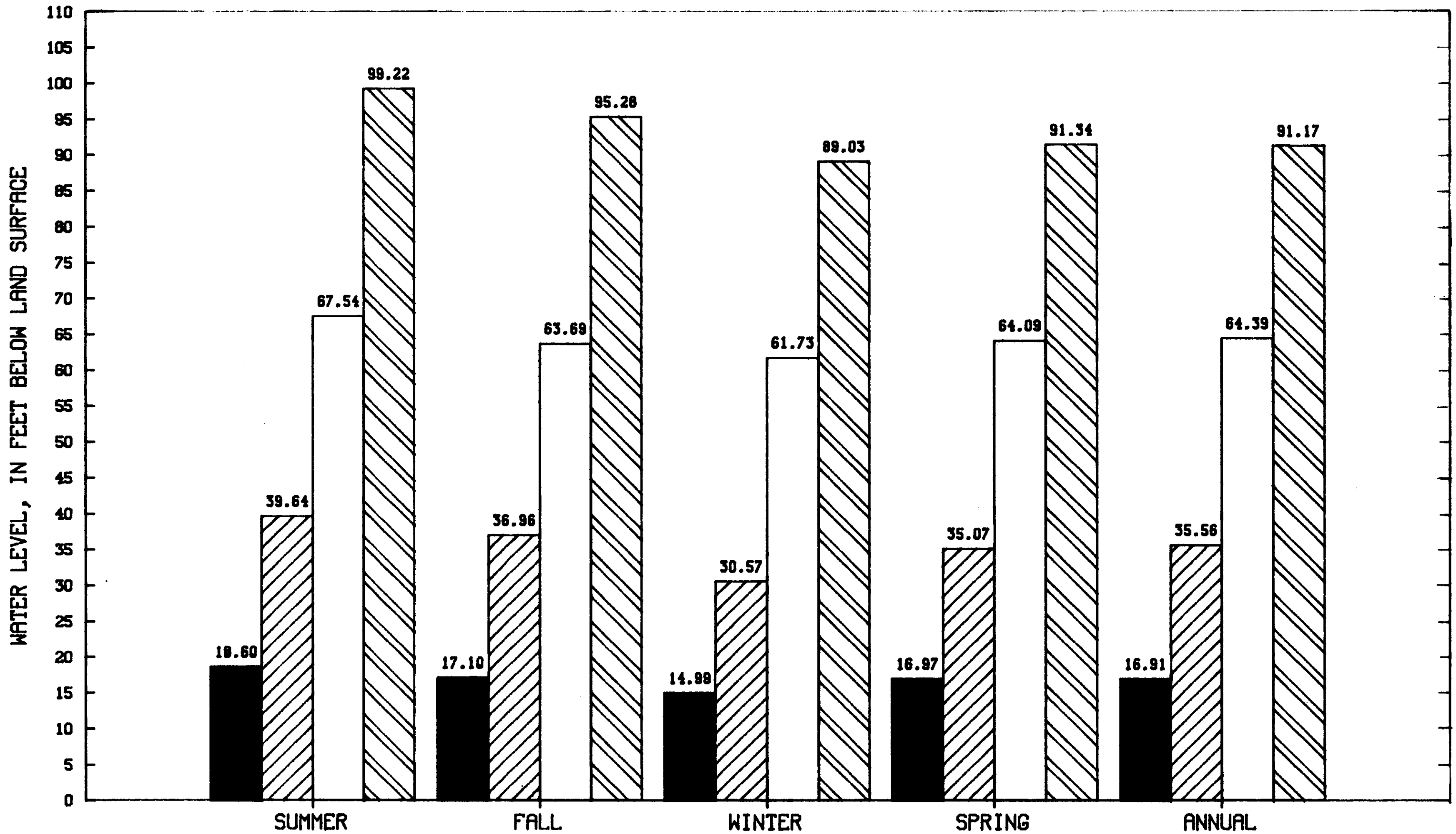


Figure 2.4.1-A.--Generalized diagram showing ground-water movement in the bedrock.



EXPLANATION

- ■ Well depth 0 to 49 feet
- ▨ Well depth 50 to 99 feet
- □ Well depth 100 to 149 feet
- ⧅ Well depth 150 to 199 feet
- 61.73 Number is mean water level, in feet below land surface datum.

Figure 2.4.1-B.--Mean ground-water levels, by well depth and season, for hilltop and upper-hillside sites.

2.0 GROUND-WATER HYDROLOGY (Continued)

2.4 Water in Bedrock (Continued)

2.4.2 Availability

FRACTURED SANDSTONES ARE THE PRIMARY SOURCE OF WATER IN BEDROCK

FRACTURED SANDSTONES ARE THE PRIMARY SOURCE OF WATER IN THE BEDROCK. THE MEAN REPORTED WELL YIELD IS 5.0 GAL/MIN (GALLONS PER MINUTE), AND THE MEAN ANNUAL SPRING DISCHARGE IS 0.94 GAL/MIN.

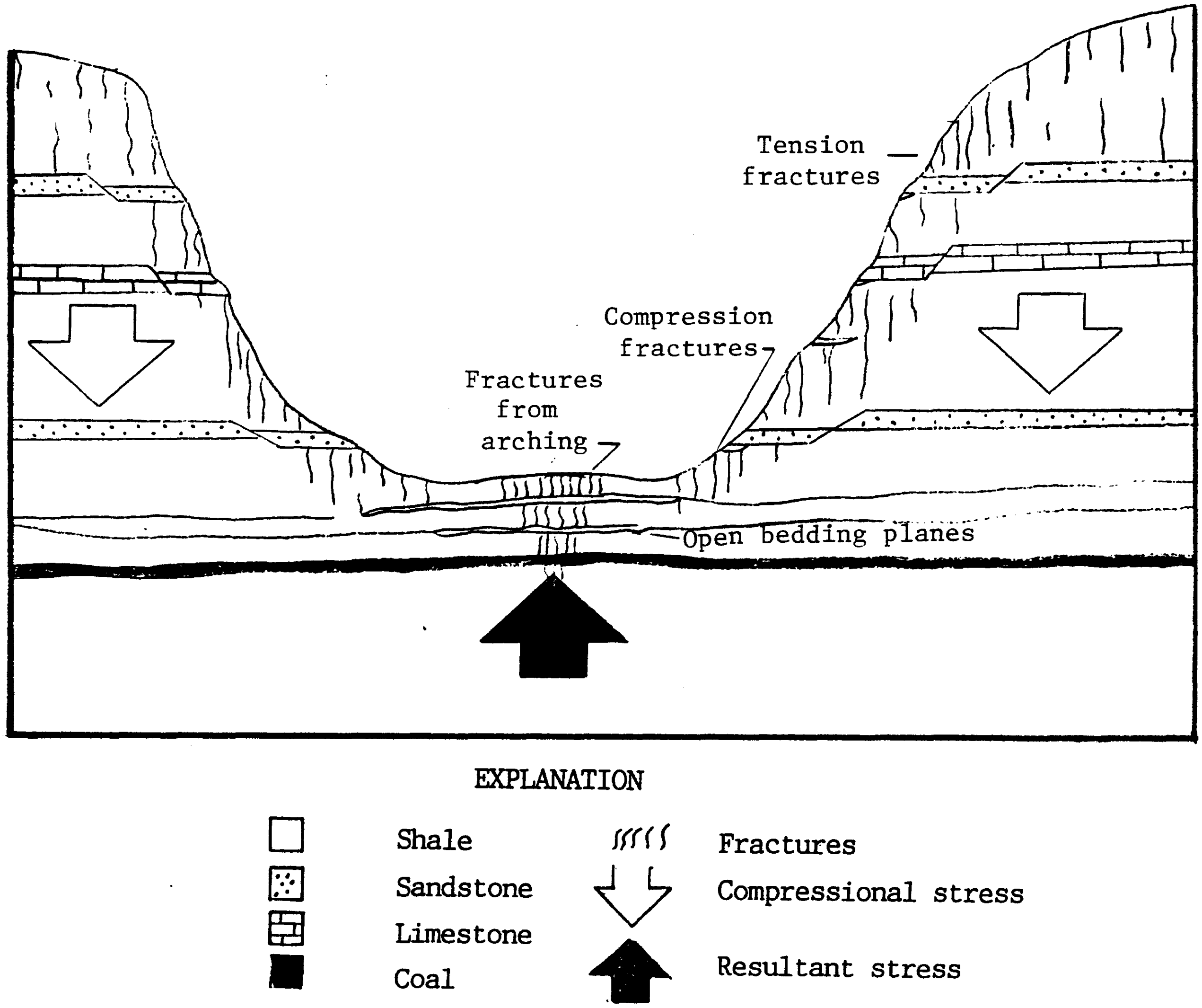
Fractured sandstones are the primary source of water in the bedrock. Fractured shale can yield quantities of water sufficient for domestic use. Well yield depends on the ability of the aquifers to store and transmit water and on well construction. Wells that intersect numerous fractures typically have higher yields than those that intersect few fractures. The number and location of fractures is influenced by lithology, geologic structure, and topography. Land-use activities, such as mining, can cause additional fractures and alter existing fractures.

The mean reported yield at 51 wells unaffected by longwall coal mining was 5.0 gal/min. Reported well yields ranged from 0.04 to 21 gal/min. Well yields were reported by well owners and were not measured during field work. The mean annual discharge for nine springs unaffected by mining was 0.94 gal/min. The minimum and maximum mean annual spring discharges were 0.21 and 1.66 gal/min, respectively.

Valley bedrock wells typically yield more water than hilltop or hillside bedrock wells. Median reported yields for valley, hillside, and hilltop bedrock wells unaffected by longwall mining were 5, 2, and 4 gal/min, respectively. Owners of valley wells also had the fewest problems concerning adequacy of well yield. Insufficient yield for domestic use was reported at 5 percent of 39 valley wells, 11 percent of 36 hillside wells, and 18 percent of 104 hilltop wells. Valley wells typically yield more water than hillside or hilltop wells because (1) rocks in valleys are more likely to be fractured as a result of stress relief (figure 2.4.2-A), and (2) more water is available for recharge. Aquifers that yield water to hilltop and hillside wells are limited in areal extent by the boundaries of the hills.

Numerous fractures are associated with lineaments and anticlines. These fracture features generally are capable of yielding large amounts of ground water. Lineaments are linear features visible on aerial photographs or other remote imagery and represent linear stream channels, aligned depressions, gulleys, or tonal variations in the soil or vegetation. Stream channels, depressions, and gulleys commonly form in fractured rock because the rock is more easily eroded than the surrounding unfractured rock. Tonal variations in soil or vegetation can be related to differential weathering or moisture content along rock fractures. Anticlines generally contain more fractures than synclines. Clark and others (1976) reported that wells drilled into anticlines had higher specific capacities than did wells drilled into synclines.

The depth and diameter of a well also affect the yield. Hilltop wells less than 100 feet deep had a mean well yield of 8.3 gal/min, but deeper wells had a mean well yield of 4.7 gal/min. No decrease in yield with depth was apparent for hillside or valley wells. Increasing the well diameter increases the storage capacity of the well and slightly increases the yield. Doubling the well diameter from 6 to 12 inches produces about a 10 percent increase in yield (Heath, 1982, p. 56).



Stress relief occurs with the removal of compressional stress on underlying rocks by erosion of overlying rocks. The same rock unit that erosion has exposed on the valley floor is buried underneath the hillsides. The compressional stresses on the rock unit under the hillsides lead to upward arching of the valley floor. Horizontal fractures, called bedding-plane separations, occur where the rock layers arch unequally. Arching also causes minor vertical fracturing near the axis of the arch. In addition, vertical tensile fractures form along the valley walls. These fractures allow the valley walls to slump, causing compressional fractures at the base of the valley walls.

Figure 2.4.2-A.--Generalized geologic section showing fracturing caused by stress relief. (Modified from Wyrick and Borchers, 1981).

2.0 . GROUND-WATER HYDROLOGY (Continued)

2.5 Chemical Quality of Water

GROUND-WATER QUALITY DEPENDS ON SEVERAL FACTORS

THE CHEMICAL QUALITY OF GROUND WATER DEPENDS ON THE CHEMICAL COMPOSITION OF PRECIPITATION, THE MINERALOGIC COMPOSITION OF THE ROCKS THAT THE WATER CONTACTS, THE DURATION OF CONTACT, AND THE LAND-USE ACTIVITIES.

The concentration of dissolved minerals in ground water depends on the chemical composition of precipitation, the mineralogic composition of the rocks that the water contacts, the duration of contact, and the land-use activities. The suitability of ground water depends on its chemical characteristics and the intended use of the water.

Chemical analyses of precipitation show the chemistry of the water before it enters the ground. The West Virginia Air Pollution Control Commission supplied analyses from weekly precipitation samples collected in Moundsville from January 1985 through March 1986 (Flesher, V.L., West Virginia Air Pollution Control Commission, written communication, June 30, 1986). The mean specific conductance of precipitation samples was 57 us/cm (microsiemens per centimeter at 25^{o}Celsius), the median pH was 4.0, and the mean concentrations of select dissolved constituents were: sulfate--4.8 mg/L (milligrams per liter), nitrate--3.0 mg/L, chloride--0.88 mg/L, calcium--0.40 mg/L, fluoride--0.20 mg/L, potassium--0.07 mg/L, and magnesium-- 0.05 mg/L.

The chemistry of precipitation changes as it enters the ground and reacts with minerals in the soil and rock. Generally, most of the major ions increase in concentration as water infiltrates the soil and moves along the ground-water flow path. Table 2.5-A describes some chemical characteristics of ground water. The West Virginia State Board of Health (1981) has set maximum concentration limits for some chemical constituents for public water supplies. One or more constituents in ground water from the alluvium and bedrock exceeded the following limits: arsenic--50 ug/L (micrograms per liter), fluoride--2.0 to 2.4 mg/L (milligrams per liter), iron--300 ug/L, manganese--50 ug/L, nitrate--10 mg/L, sulfate--250 mg/L, and total dissolved solids--500 mg/L. The locations of ground-water sampling sites are shown in Appendix B. The water-quality data collected during this investigation are published in the Water Resources Data - West Virginia - Water Year 1986 (in press).

Table 2.5-A.--Selected constituents and properties that affect ground-water quality
(Modified from Heath, 1983, p. 65)

Constituent or Property	Natural sources	Effects on water quality
Alkalinity ($CaCO_3$)	Bicarbonate (HCO_3) and Carbonate (CO_3) ions dissolved from carbonate rocks such as limestone ($CaCo_3$) and dolomite (CaMg $(CO_3)_2$) by water containing carbon dioxide.	The capacity of water to neutralize acids. Bicarbonates of calcium and magnesium decompose in steam boilers and water heaters to form scale and release corrosive carbon dioxide gas. Bicarbonate and carbonate in combination with calcium and magnesium cause carbonate hardness.
Calcium (Ca)	Soils and rocks containing limestone, dolomite, and gypsum ($CaSO_4$).	Principal cause of hardness and contributes to boiler scale and deposits in hot-water heaters. Contributes to well screen clogging in the alluvium.
Chloride (Cl)	Seawater trapped in sediments at time of deposition.	Gives water a salty taste when combined with sodium. May also increase the corrosiveness of the water.
Fluoride (F)	Minerals that contain fluoride commonly occur in sedimentary rocks. Fluorite (CaF_2) occurs in dolomite and limestone. Fluoride also occurs in some brines.	Optimum concentration range determined by the U.S. Public Health Service is 0.7 to 1.2 milligrams per liter (mg/L), depending on the amount of water consumed and on the mean air temperature. Within these concentrations, fluoride reduces tooth decay. At higher concentrations, it may cause mottling of the tooth enamel.
Hardness ($CaCO_3$)	Calcium and magnesium dissolved in water.	Related to the amount of soap needed to produce a lather. Calcium and magnesium combine with soap to produce an insoluble curd, inhibiting the formation of a lather. Hardness is classified as follows (mg/L of $CaCO_3$): 0 to 60 - soft, 61 to 120 - moderately hard, 121 to 180 - hard, more than 180 - very hard.
Iron (Fe)	Present in most soils and rocks. Often occurs in association with manganese. Ground water contains greater concentrations of iron in the valleys than on hillsides or hilltops.	Concentration in excess of 300 microgram per liter (ug/L) often causes reddish-brown stains on laundry, utensils, and plumbing fixtures; and is objectionable in food processing, dyeing, bleaching, ice manufacturing, brewing, and other industrial processes. It may also contribute to well screen clogging in the alluvium.
Magnesium (Mg)	Soils and rocks containing limestone, dolomite, and gypsum.	Causes hardness of water, but to a lesser amount than calcium.
Manganese (Mn)	Present in most soils and rocks. Often occurs with iron, but is not as widely distributed. Ground water generally contains higher concentrations of manganese in valleys than on hillsides or hilltops.	Concentration in excess of 50 ug/L commonly causes dark-brown or black stains, similar to iron.
Nitrate (N)	Decaying organic matter, sewage, fertilizers, and nitrates in the soil.	Concentration greater than 10 mg/L indicates possible contamination by animal wastes, sewage, industrial processes, or fertilizers. May cause methemoglobinemia ("blue baby" disease) in infants. Nitrate promotes the growth of algae and other organisms which produce undesirable tastes and odors.
pH (units)	The negative logarithm of the the hydrogen in concentration in the water.	The pH of water is a measure of its reactivity. pH values are classified as follows: less than 7.0--water is acidic, equal to 7.0-- water is neutral, greater than 7.0--water is basic. Low values of pH, particularly below pH 4.0, indicate a corrosive water that will tend to dissolve metals and other minerals that it contacts. High values of pH, particularly above 8.5, indicate an alkaline water that, on heating, will tend to form scale.
Sodium (Na)	Present in most soils and rocks. Often dissolved in ground water through cation exchange with calcium. Large amounts may be present in sediments containing seawater that was trapped at the time of deposition.	Gives water a salty taste in combination with chloride, and may affect people with cardiac problems, hypertension, and certain other medical conditions. Concentration should be less than 170 mg/L for those on a moderate sodium diet, and less than 20 mg/L for those on a strict diet. Depending on the concentration of calcium and magnesium, sodium concentration above 69 mg/L may be detrimental to some irrigated crops.
Sulfate (SO)	Soils and rocks containing gypsum, pyrite (FeS), and other rocks containing sulfur (S) compounds. Fill material consisting of slag from steel-processing plants, waste from coal-processing plants and mines, or other waste may be sources of sulfate.	May give water a bitter taste when the concentration exceeds 300 to 400 mg/L, and may act as a laxative in concentrations exceeding 600 to 1,000 mg/L. It also forms a hard calcium carbonate scale in steam boilers when combined with calcium. Sulfate reduces to hydrogen sulfide, which has an odor of rotten eggs.
Total Dissolved Solids	Minerals dissolved in water.	Total dissolved solids is a measure of the total amount of minerals dissolved in water. Water containing less than 500 mg/L is preferred for domestic use and for many industrial processes.

2.5.1 Water in Alluvium

THE QUALITY OF GROUND WATER GENERALLY IS ACCEPTABLE FOR DOMESTIC AND INDUSTRIAL USE

GROUND WATER TYPICALLY IS CALCIUM BICARBONATE IN TYPE AND HARD TO VERY HARD. LOCALLY, CONCENTRATIONS OF MANGANESE, IRON, SULFATE, DISSOLVED SOLIDS, NITRITE PLUS NITRATE, AND ARSENIC EXCEEDED STATE PUBLIC SUPPLY LIMITS.

The quality of ground water from the alluvium generally is acceptable for domestic and industrial use. The water typically is a calcium bicarbonate type and hard to very hard. Hardness is at least 150 mg/L as $CaCO_3$ in 24 samples. Table 2.5.1-A gives the mean, median, minimum, and maximum concentrations and the number of samples for select dissolved constituents. Locally, concentrations of manganese, iron, sulfate, dissolved solids, nitrite plus nitrate, and arsenic exceeded the limits for public-water supplies set by the West Virginia State Board of Health (1981). The number of samples that exceeded the limits for each constituent were as follows: manganese--7 of 15 samples, iron--6 of 23 samples, sulfate--3 of 24 samples, total dissolved solids--5 of 21 samples, nitrite plus nitrate--2 of 15 samples, and arsenic--1 of 9 samples. The following constituents did not exceed the limits in any samples: barium, cadmium, chloride, copper, fluoride, lead, mercury, phenols, selenium, silver, and zinc. The ground-water sampling locations are shown in Appendix B.

Land use can affect ground-water quality. The three samples in which the concentration of sulfate exceeded 250 mg/L underlie areas where alluvium is covered by sulfate-rich wastes from steel-processing plants or from coal preparation plants. Sulfate in the fill material is dissolved by precipitation and, in dissolved form, moves through the soil to the saturated zone. Ground water from these areas can be a calcium sulfate type. The only ground-water samples from alluvium that are a calcium sulfate type are from areas where industrial wastes cover the alluvium.

Table 2.5.1-A.--Chemical properties of water from wells in alluvium
[μg/L, micrograms per liter; mg/L, milligrams per liter]

Property or Characteristic	Mean	Median	Minimum	Maximum	Number of samples
pH (units)	---	7.2	6.7	7.9	21
Hardness (mg/L of Ca + Mg as $CaCO_3$)	310	240	150	1,700	24
Calcium (mg/L as Ca)	110	80	52	430	13
Magnesium (mg/L as Mg)	23	11	5.8	150	13
Sodium (mg/L as Na)	53	23	15	220	9
Alkalinity, total (mg/L as $CaCO_3$)	160	150	62	320	24
Sulfate (mg/L as SO_4)	200	97	14	2,400	24
Chloride (mg/L as Cl)	24	18	1.7	100	24
Fluoride (mg/L as F)	0.1	0.1	0.0	0.3	17
Solids, residue at 180°C (mg/L)	586	372	150	4,660	21
Nitrite plus nitrate (mg/L as N)	4.5	1.4	0.10	26	15
Iron (ug/L as Fe)	780	100	0	10,000	23
Manganese (ug/L as Mn)	250	10	0	1,300	15

2.5.2 Water in Bedrock

THE QUALITY OF GROUND WATER GENERALLY
IS ACCEPTABLE FOR DOMESTIC USE

THE QUALITY OF GROUND WATER IN BEDROCK GENERALLY IS ACCEPTABLE FOR DOMESTIC USE. LOCALLY, CONCENTRATIONS OF TOTAL DISSOLVED SOLIDS, MANGANESE, NITRITE PLUS NITRATE, IRON, SULFATE, AND FLUORIDE EXCEED STATE LIMITS FOR PUBLIC-WATER SUPPLIES. HARDNESS DECREASES AND SULFATE IS REDUCED TO HYDROGEN SULFIDE AS GROUND WATER FLOWS FROM THE HILLTOPS TO THE VALLEYS.

The quality of ground water from the bedrock generally is acceptable for domestic use. Table 2.5.2-A is a summary of some of the chemical characteristics of ground water according to rock group and vertical distance from the drainage divide to the bottom of the well. Locally, concentrations of total dissolved solids, manganese, nitrite plus nitrate, iron, sulfate, and fluoride exceed the limits for public-water supplies set by the West Virginia State Board of Health (1981).

The percentage of wells that yield water with concentrations of total dissolved solids, manganese, and iron in excess of the State limits increased with increasing vertical drainage distance. The concentrations of total dissolved solids and manganese each exceeded the limits in 4 of 61 water samples where vertical drainage distance was less than or equal to 225 feet. The number of samples that exceeded total dissolved solids and manganese limits increased to 5 of 19 where vertical drainage distance was greater than 225 feet. All of the sites with vertical drainage distance less than or equal to 225 feet were on hilltops or upper hillsides near hilltops. All but four of the sites with vertical drainage distance greater than 225 feet were on valley bottoms or on the lower part of hillsides near the valley bottoms. The concentration of iron did not exceed 300 ug/L at any of 61 samples where vertical drainage distance was less than or equal to 225 feet; however, the concentration of iron was greater than 300 ug/L in 2 of 19 samples where vertical drainage distance was greater than 225 feet.

Ground water that has recently entered the flow system typically is a calcium bicarbonate and very hard. However, ground water typically is softened by a chemical process known as cation exchange as it flows from hilltops to valleys. The mean hardness was 240 mg/L for samples collected from sites with a vertical drainage distance of less than or equal to 75 feet but only 93 mg/L for samples collected from sites with a vertical drainage distance greater than 225 feet. Hardness is directly related to the concentration of calcium and magnesium ions in water. As ground water moves through the flow system, calcium ions in the water are exchanged for sodium ions on clay surfaces. This causes a decrease in the concentration of calcium ions and a corresponding increase in the concentration of sodium ions in the water. The mean concentration of calcium in samples from sites where the vertical drainage distance was less than or equal to 75 feet and greater than 225 was 76 mg/L and 28 mg/L, respectively. The mean concentration of sodium in samples from sites where the vertical drainage distance was less than or equal to 75 feet and greater than 225 feet was 10 mg/L and 120 mg/L, respectively. Figure 2.5.2-B shows the decrease in calcium ions and corresponding increase in sodium ions based on the percentage of total cations, in milliequivalents per liter.

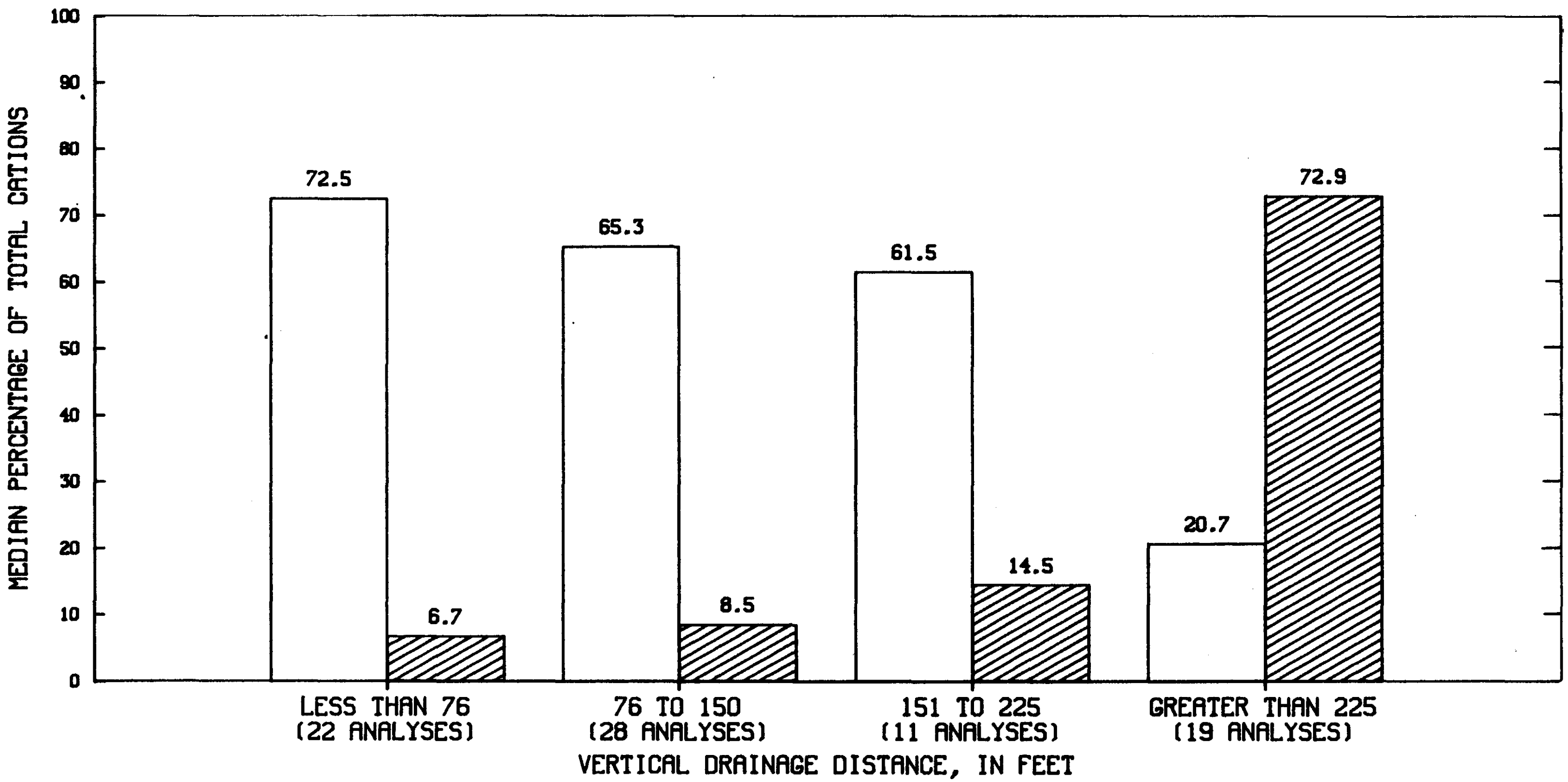
Sulfate reduction is another important process that occurs in the flow system of the bedrock. Sulfate is reduced to hydrogen sulfide as ground water flows from hilltops to valleys. The mean concentration of dissolved sulfate in ground water decreases from 62 mg/L, in sites with a vertical drainage distance less than or equal to 75 feet, to 30 mg/L at sites with a vertical drainage distance greater than 225 feet. Although the samples were not analyzed for hydrogen sulfide, the rotten-egg odor of hydrogen-sulfide gas was noticed at many valley and lower hillside sites. The odor was not noticed at upper hillside or hilltop sites.

The data are insufficient to determine if longwall mining affects ground-water quality. There is some potential for mining to affect ground-water quality inasmuch as the ground-water-flow paths are altered by new or widened fractures caused by mining. Subsidence can cause fracturing, which can increase recharge rates, so that water quality can change as a result of reduced contact time.

Table 2.5.2-A.--Chemical properties of water from bedrock sites

[ug/L, micrograms per liter; mg/L, milligrams per liter]

Category		pH (units)	Hardness (mg/L of Ca + Mg as $CaCo_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Alkalinity, total (mg/L as $CaCo_3$)	Sulfate (mg/L as So_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Solids, residue at 180°C (mg/L)	Nitrite plus nitrate (mg/L as N)	Iron (μg/L as Fe)	Manganese (μg/L as Mn)
Dunkard Group	Mean	--	220	67	14	28	200	54	12	0.2	342	2.5	10	20
	Median	7.4	230	69	12	12	200	46	8.4	0.2	334	1.4	10	0
	Minimum	6.5	4	1.1	0.2	3.5	55	8.5	1.2	0.1	158	0.10	0	0
	Maximum	9.2	550	170	31	190	390	290	99	1.1	825	16	60	470
	Number of samples	72	72	72	72	72	72	72	72	72	71	72	72	72
Monongahela Group	Mean	--	110	33	6.8	140	330	33	44	1.0	472	0.27	410	140
	Median	7.8	120	31	7.8	92	310	25	16	0.9	369	0.10	80	50
	Minimum	7.3	3	0.8	0.3	18	170	3.2	2.4	0.1	247	0.10	0	0
	Maximum	9.0	250	86	14	300	520	76	140	3.1	796	1.6	2500	930
	Number of samples	11	11	11	11	11	11	11	11	11	11	11	11	11
Vertical Distance from drainage divide to well bottom, in feet: ≤ 75	Mean	--	240	76	13	10	170	62	9.2	0.2	326	2.8	10	30
	Median	7.5	240	72	11	8.2	160	51	7.9	0.2	313	2.0	10	0
	Minimum	7.2	140	45	3.0	3.5	100	23	2.1	0.1	167	0.10	0	0
	Maximum	8.1	430	130	26	21	260	230	24	0.3	686	12	60	470
	Number of samples	22	22	22	22	22	21	22	22	22	22	22	22	22
76-150	Mean	--	260	76	16	23	200	57	16	0.2	366	3.2	10	10
	Median	7.4	270	76	18	12	200	42	9.7	0.2	350	2.2	0	0
	Minimum	6.9	62	14	4.7	4.1	73	23	1.2	0.1	186	0.10	0	0
	Maximum	8.0	550	170	31	140	310	290	99	0.3	825	16	20	240
	Number of samples	28	28	28	28	28	28	28	28	28	27	28	28	28
151-225	Mean	--	200	57	14	35	190	47	11	0.2	319	1.1	10	10
	Median	7.5	210	66	14	16	190	40	5.9	0.1	311	0.97	10	0
	Minimum	7.2	54	17	3.0	5.1	160	22	3.4	0.1	226	0.10	0	0
	Maximum	8.0	330	93	24	150	230	85	22	0.3	447	2.7	30	20
	Number of samples	11	11	11	11	11	11	11	11	11	11	11	11	11
> 225	Mean	--	93	28	5.9	120	290	30	30	0.8	410	0.45	240	90
	Median	7.9	100	29	5.6	93	260	25	10	0.5	348	0.10	20	10
	Minimum	6.5	3	0.8	0.2	6.6	54	3.2	2.4	0.1	158	0.10	0	0
	Maximum	9.2	250	86	14	300	530	76	140	3.1	796	5.1	2500	930
	Number of samples	19	19	19	19	19	18	19	19	19	19	18	19	19



EXPLANATION

- Calcuim
- Sodium
- 61.5 Number is median percentage of total cations comprised by sodium or calcium

Figure 2.5.2-B.--Sodium and calcium ions as a percentage of total cations (in milliequivalents per liter) in ground water from sites with various ranges of vertical drainage distance.

3.0 LONGWALL MINING

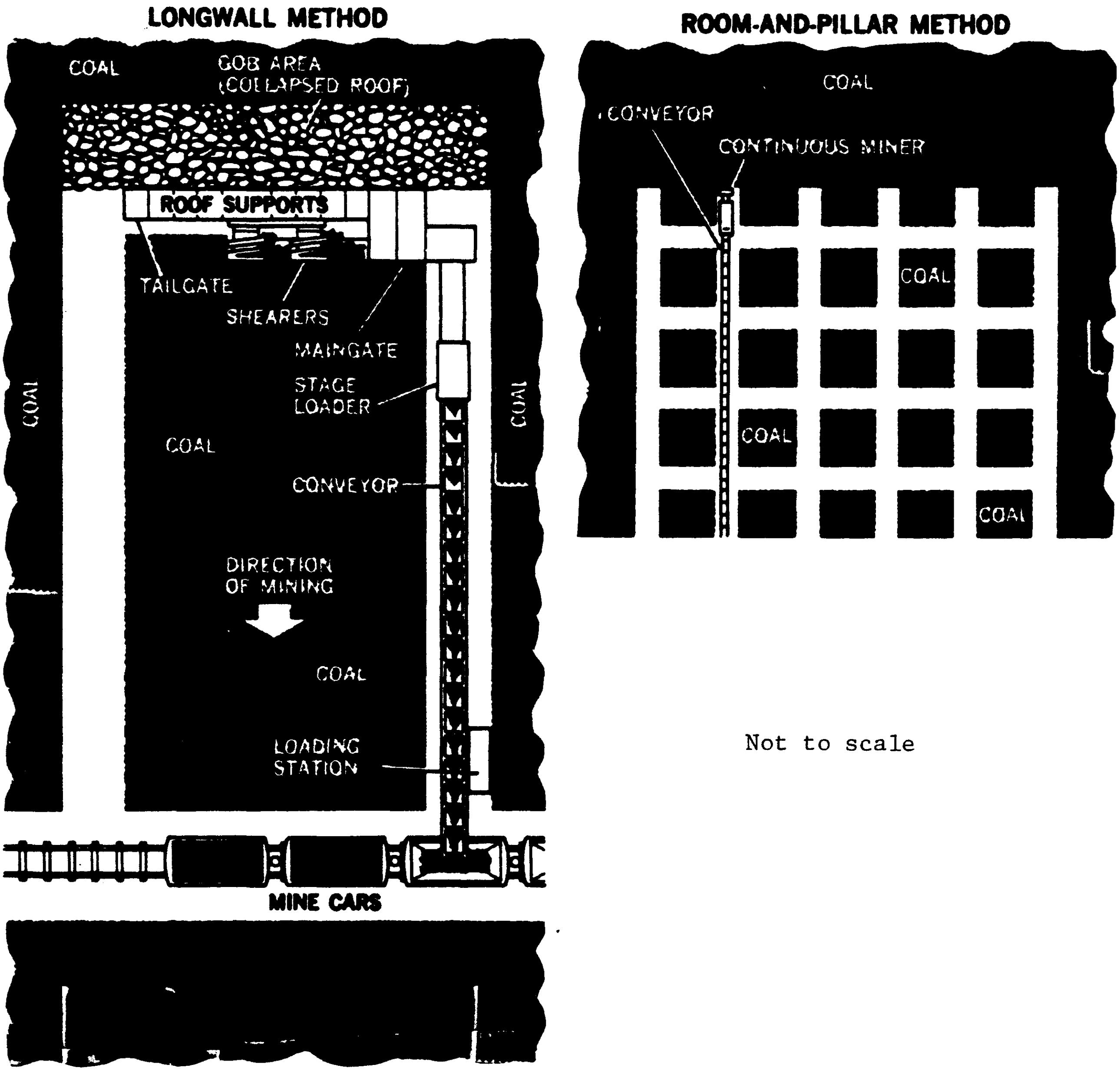
3.1 Longwall-Mining Methods and Coal Production

LONGWALL MINING IS A HIGH-YIELD
METHOD OF COAL MINING

LONGWALL MINING IS A HIGH-YIELD METHOD OF COAL REMOVAL IN WHICH NO ROOF SUPPORTS ARE LEFT IN THE MINED-OUT AREA. THIS METHOD OF MINING IS USED FOR MORE THAN HALF OF THE COAL PRODUCED IN THE COUNTY.

Longwall mining is a high-yield method of coal removal in which no roof supports are left in the mined out area. Coal-removal rates commonly are greater than 75 percent. The first step in longwall mining is the construction of two parallel tunnels, coming from the main tunnel, which are used for haulage, ventilation, and escape. The two tunnels are joined at the rear by a third tunnel. This leaves a rectangular block of coal called a panel. Figure 3.1-A shows a plan view of a typical longwall panel. Longwall panels usually are 500 to 600 feet wide and from 3,000 to 7,000 feet long. The mining machinery is placed in the rear tunnel along the face of the coal seam, and mining progresses toward the main tunnel. This is known as retreat longwall mining. The roof of the mined out area collapses as the mining progresses. The roof is mechanically supported at the mining face to protect the miners and mining machinery from cave-ins.

The Pittsburgh coal seam at the base of the Monongahela Group is the only seam presently mined in the County. Coal mining began prior to 1900, and was restricted to the Ohio River front between Moundsville and the Marshall-Ohio County line. About 4.6 million tons were mined between 1888 and 1908 (Hennen, 1909, p. 535). Mean annual coal production from 1980 through 1985 was 5.1 million tons, more than half of which was mined using the longwall method (West Virginia Department of Mines Annual Reports, 1980 to 1985). The remainder of coal was mined using room-and-pillar methods, in which blocks of coal are left intact for roof support. Maps showing the location and method of mining of active and inactive underground mines as of January 1, 1984, are contained in Appendix D.



Note: Reprinted from Popular Science with permission (c) 1977, Times Mirror Magazines, Inc. Author-Britton, P.

Figure 3.1-A.--Diagram of longwall and room-and-pillar methods of coal mining.

3.2 Ground Movement and Overburden Fracturing

OVERBURDEN COLLAPSE CAN CAUSE LAND SUBSIDENCE

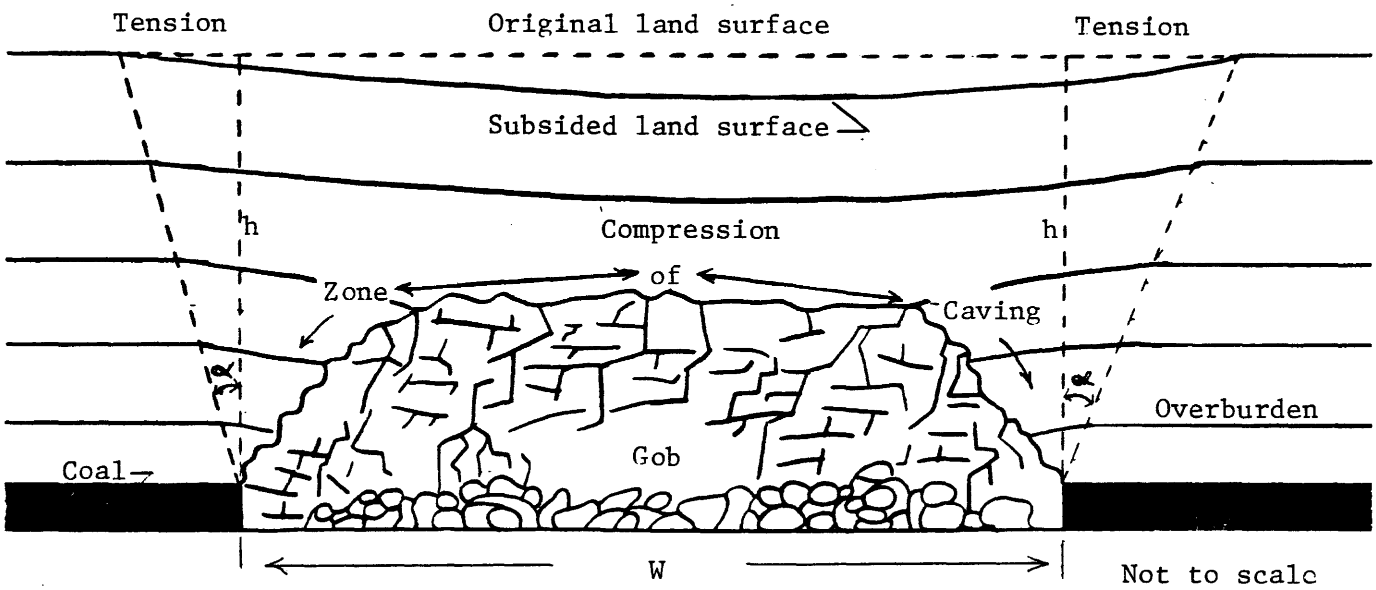
LACK OF SUPPORT THAT RESULTS FROM REMOVAL OF COAL CAUSES SUBSIDENCE AND FRACTURING OF THE OVERBURDEN.

Mining by longwall methods commonly extracts 75 percent or more of the coal and allows the overburden to collapse as the mining face moves forward. A dome-shaped zone of caving forms in the overburden (figure 3.2-A). The zone of caving is highly fractured and extends upwards 30 to 50 times the mining height (Peng and Cheng, 1981). The rock above the zone of caving sags in the shape of a trough. A sinkhole can form if the zone of caving reaches land surface. The size and shape of the subsidence trough depends on a combination of factors. The most important factors are (1) depth and width of mining, (2) lithology and structure of the overburden, (3) mining height, (4) mining face location, and (5) number of mining panels. Each factor is discussed in table 3.2-B.

The degree of subsidence differs locally because of variations in these factors. A computer model was developed by the U.S. Bureau of Mines to estimate the amount of subsidence at land surface based on panel width, mining height, and overburden thickness (Adamek and Jeran, 1985). The model was developed using data from mines in the Pittsburgh coal seam in northern Appalachia. Using the model, subsidence profiles were estimated for a panel width of 550 feet, a mining height of 5.5 feet, and overburden thicknesses of 650 and 950 feet (figure 3.2-C). These values are typical of longwall panels in Marshall County. A constant overburden thickness was assumed across the width of the subsidence profile. The model predicted a maximum subsidence at the center of the panel of 3.22 feet for an overburden thickness of 650 feet and 2.83 feet for an overburden thickness of 950 feet.

Horizontal movement of the overburden also would occur within the subsidence trough. The overburden within the inner half of the subsidence trough initially undergoes extension and then compression as the rock strata sag inward. The outer half of the subsidence trough is subjected only to the initial extension.

Subsidence and horizontal movements of the overburden cause fracturing. Pre-mining fractures may be widened or narrowed. Fractured areas typically are zones of weakness and, as a result, are particularly susceptible to additional fracturing. Overburden movement at ground surface can cause the formation of open fractures, depressions, slips at weak points, and ground upheavals. Hobba (1981, p. 40) reported that 90 percent of 55 subsidence fractures measured near Farmington in Marion County, West Virginia, were oriented in the same direction as major joint systems in the rock.



EXPLANATION

α	Angle of draw
h	Overburden thickness
W	Panel width

Figure 3.2-A.--Generalized cross section of a typical subsidence profile. (Modified from Booth, 1986).

Table 3.2-B.--Factors that influence the shape and extent of the surface subsidence trough (Modified from Peng and Cheng, 1981)

FACTOR	EFFECT ON SURFACE SUBSIDENCE
Depth and Width of Mining	As the width of the mine increases, the subsidence trough deepens and spreads horizontally. However, there is a limit to the amount of subsidence that can occur, called maximum possible subsidence. Critical width is that mining width which causes maximum possible subsidence at a point at land surface. Critical width can be calculated as follows: $Wc = 2\ h\ (\tan\alpha)$, where Wc is the critical width, h is the mining depth, and α is the angle of draw. The angle of draw is the angle between the vertical and a line drawn from the edge of the mine panel to the edge of the subsidence trough. The angle of draw for the eastern United States ranges from 15 to 27 degrees and averages about 25 degrees (Jones, T. Z., and Kohli, K. K., written Communication, October 1983). The mining depth at longwall mines in the County ranges from about 300 to 380 feet under valleys to 700 to 950 feet under ridges. Longwall mine panels range from 500 to 600 feet wide. A panel wider than the critical width does not deepen the subsidence trough at the center, but the maximum possible subsidence may occur over a large part of the panel. Thus, a profile of the subsidence trough generally has a broad, flat bottom. If the mine width is constant, and the depth of mining increases, the subsidence trough will become shallower and narrower, and vice versa.
Lithology and Structure of the Overburden	The strength and deformational properties of the overburden are controlled by rock type and structural features such as joints, faults, and bedding planes. Subsidence troughs typically are shallower and narrower in areas where the percentage of sandstone and limestone within the overburden is high. Overburden containing thick beds of sandstone and limestone is more resistant to subsidence than overburden containing alternating thin layers of shale, sandstone, and limestone. A thick layer of sandstone in the overburden can suppress upward propagation of fractures. The depth and horizontal extent of subsidence in a given area is not constant because of lateral changes in lithology. Shale is the most common rock type in the overburden of the Pittsburgh coal seam (see section 1.3). Sandstone beds are rarely 50 feet thick, and are not persistent. Limestone beds are thickest in the first 300 to 350 feet above the Pittsburgh seam. The Benwood Limestone is commonly 60 feet thick, and is typically interbedded with limy shale. Limestone beds commonly are less than 10 feet thick higher up in the overburden. Sandstone and limestone beds probably reduce subsidence at the surface, but are too thin and weak to eliminate it completely. Joints, faults, and bedding planes are zones of weakness in the overburden; and are especially susceptible to further fracturing.
Mining Height	An increase in mining height will deepen and widen the subsidence trough.
Mining Face Location	The leading edge of subsidence precedes the mining face by about 0.8 times the mining depth. For example, subsidence typically precedes the mining face by about 640 feet where the mining depth is 800 feet below land surface. The amount of subsidence slowly increases as the mine approaches. When the mining face is directly below, the amount of subsidence is about six percent of the total subsidence that will occur for a mining depth of 400 feet, and about nine percent for a mining depth of 800 feet. The rate of subsidence accelerates after the mining face has passed. The total subsidence occurs when the mining face has passed beyond beyond by about 680 to 1,040 feet for mining depths of 400 and 800 feet, respectively. The slower the mining rate, the longer length of time subsidence will occur.
Multiple Panel Mining	The amount of subsidence caused by the passage of one longwall mine panel could increase with the passage of an adjacent panel. The panels typically are parallel and separated by panel entries about 150 feet wide.

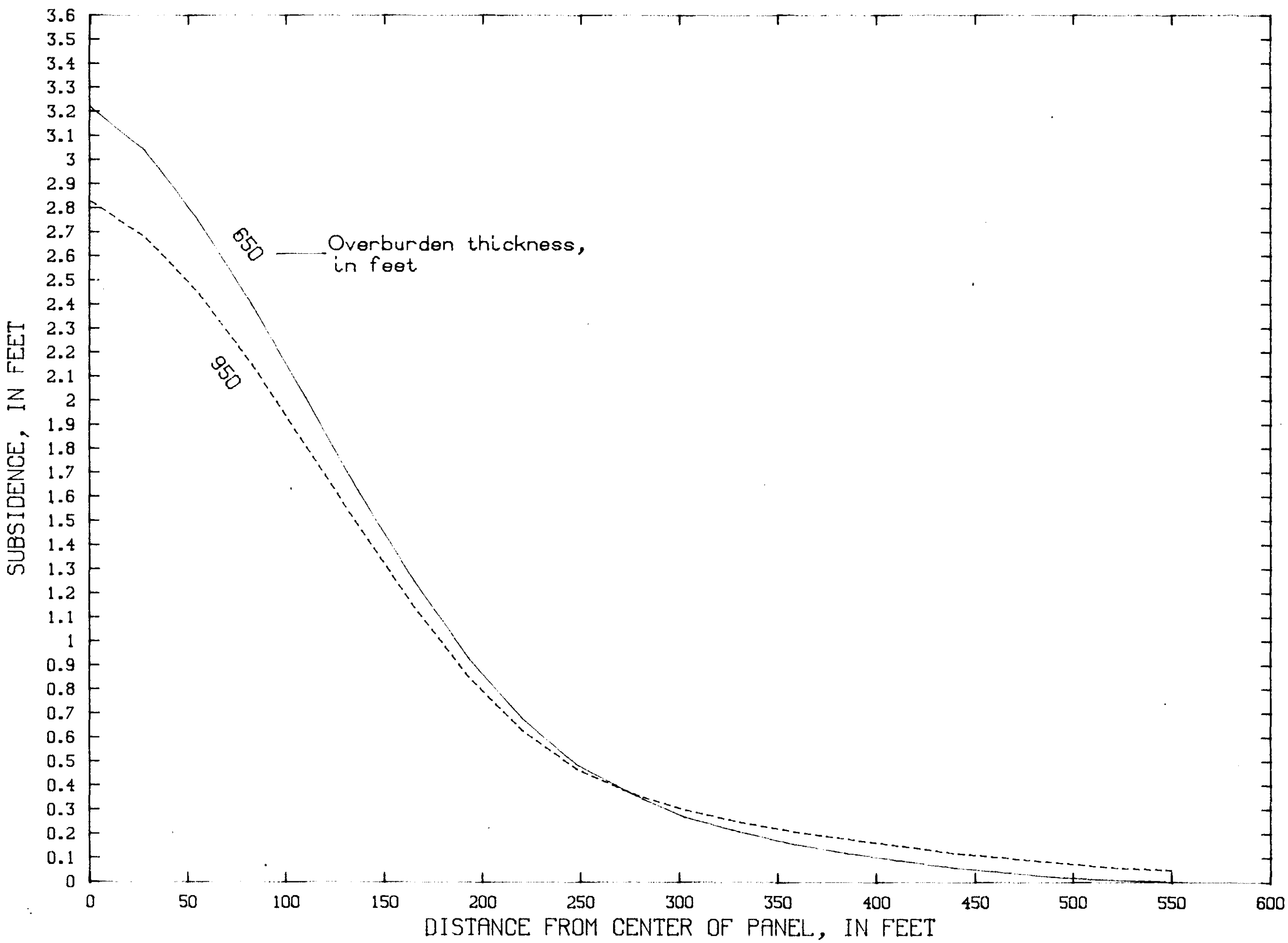


Figure 3.2-C.--Estimated subsidence profiles. (Graph generated from model in Adamek and Jeran, 1985).

4.0 HYDROLOGIC EFFECTS OF LONGWALL MINING

4.1 Transmissivity

LONGWALL MINING INCREASES AQUIFER TRANSMISSIVITY

AQUIFER TESTS SHOWED SIGNIFICANT INCREASES IN TRANSMISSIVITY AT TWO OF THREE SITES AFTER LONGWALL MINING OCCURRED.

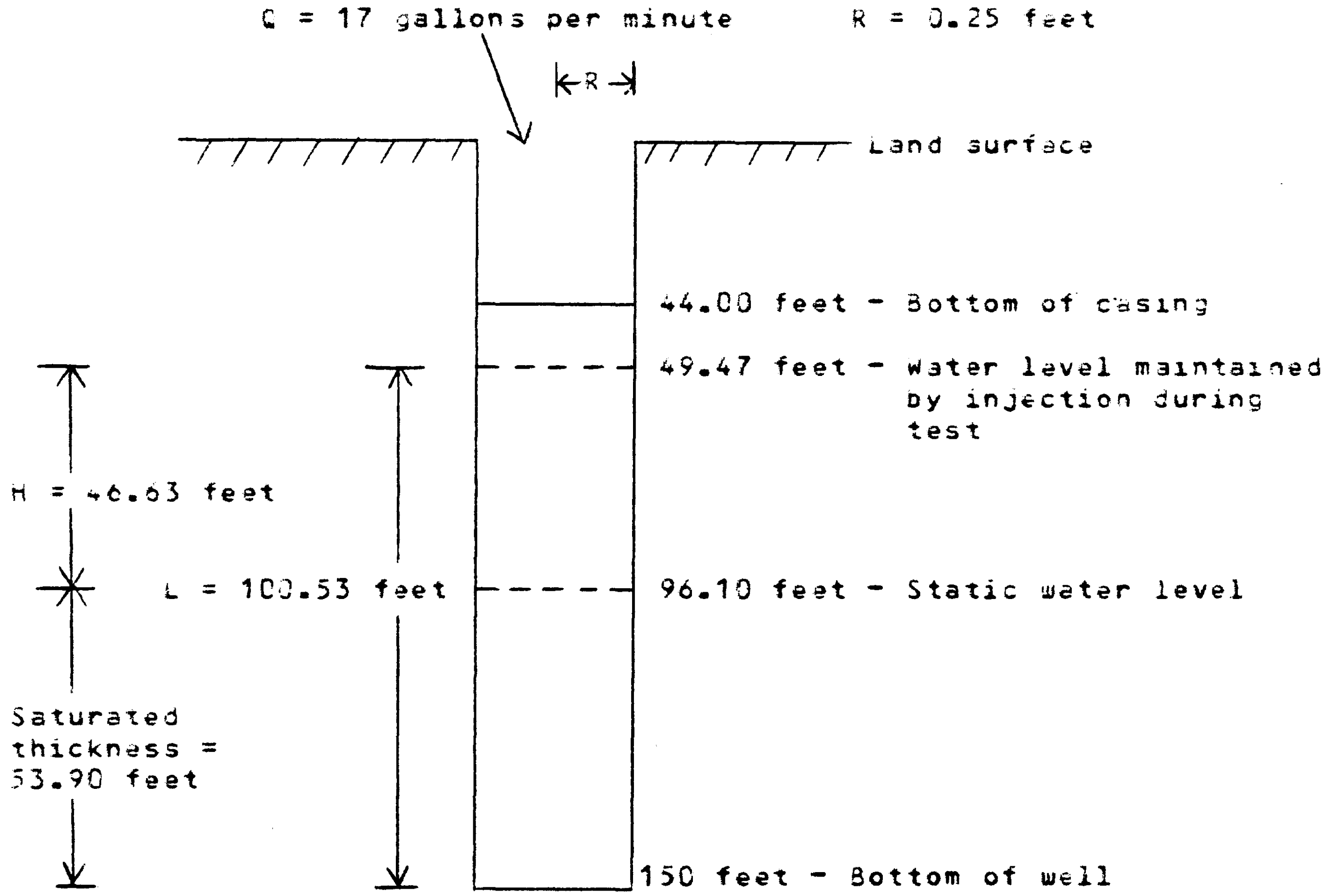
Pre- and post-mining aquifer tests were made at sites 298, 301, and 307. Significant increases in estimated transmissivity occurred at sites 298 and 301. The aquifer tests were made using the single-well injection and recovery methods described in figures 4.1-A and 4.1-B. The tests were made on wells tapping perched aquifers in the overburden. Data from the individual tests are in table 4.1-C.

Pre-mining aquifer tests at site 298 were made using the injection and recovery methods. Pre-mining injection tests were made at selected depth intervals during drilling. Pre-mining transmissivity was 3.7 ft^2/d as determined by the injection method and 10 ft^2/d as determined by the recovery method. Post-mining injection tests indicated that transmissivity had increased to 160 ft^2/d. The mining face had passed under the site about five months prior to the test, and was more than 2,600 feet beyond the site at the time of the test. Site 298 is near the center of the longwall panel, and the overburden thickness is about 820 feet. The recovery method could not be used for post-mining aquifer tests because of a partial collapse of the perforated casing, which prevented the pump from being lowered into the well.

Pre-mining aquifer tests at site 301 were made using the injection method. They were performed at selected depth intervals during drilling. Pre-mining transmissivity was negligible (less than 0.001 ft^2/d), as determined by the injection method. This indicates that few fractures were present. The well slowly filled with water after drilling was completed (hydrograph in Appendix C). The recovery method was not used because of the expected slow recovery rate. Post-mining injection tests indicated that transmissivity had increased to 36 ft^2/d. The mining face had passed under the site about four months prior to the test, and was more than 1,500 feet beyond the site at the time of the test. Site 301 is near the center of the longwall panel, and the overburden thickness is about 810 feet. As in the case of site 298, the recovery method could not be used for post-mining aquifer tests because of a partial collapse of the casing.

Pre- and post-mining aquifer tests at site 307 were made using the recovery method. Estimated transmissivity increased from 0.20 ft^2/d before mining to 0.31 ft^2/d after mining. Subsidence fracturing at this site probably was not sufficient to cause a significant change in transmissivity. Pre- and post-mining caliper logs showed that only 3 sections of the borehole, each 3 feet or less, were altered by subsidence fracturing. The mining face had passed under the site about 3 months prior to the test, and was more than 410 feet beyond the site at the time of the test. Site 307 is near the center of the longwall panel, and the overburden thickness is about 800 feet.

SITE 301 POST-MINING INJECTION TEST



Injection tests were made by discharging water into the borehole, and measuring the rate of flow required to maintain the water level at a constant head above the static water level. Horizontal hydraulic conductivity was estimated using the equation:

$K = (192.5) C_p Q/H$ where K = horizontal hydraulic conductivity, in feet per day

192.5 = conversion from Q, in gallons per minute, to feet cubed per day

$C_p = \frac{\ln(L/R)}{2\pi L}$ when $L \geq 10R$

L = length of test section, in feet

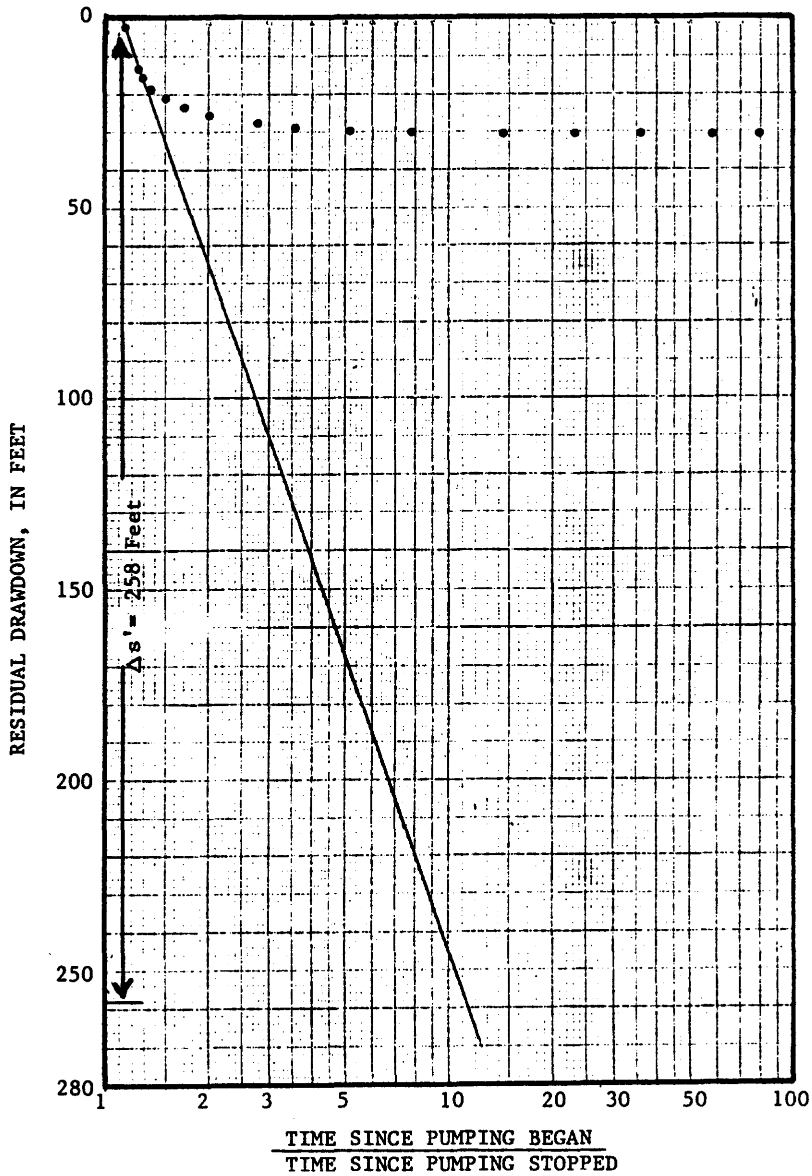
R = radius of hole tested, in feet

Q = injection rate into hole, in gallons per minute

H = difference between static head and the head maintained by injection, in feet

This equation is a modification of an equation presented by the U.S. Department of Interior, Bureau of Reclamation (1974, p. 573-578). Transmissivity was calculated by multiplying the horizontal hydraulic conductivity by the saturated thickness.

Figure 4.1-A.--Description of injection-test method.



Residual drawdown plotted against the ratio of the time since pumping began over time since pumping stopped becomes a straight line on semi-log graphpaper. Transmissivity is then calculated by the equation:

$$T = \frac{(35.3)\ Q}{\Delta s'}$$

where
T is transmissity, in foot squared per day,
Q is pumping rate, in gallons per minute, and
$\Delta s'$ is change in residual drawdown over one log cycle, in feet.
This equation is modified from Driscoll (1986, p.256).

Figure 4.1-B.--Description of the recovery test method.

Table 4.1-C.--Summary of data from aquifer tests

{ft, foot; gal/min, gallon per minute; ft/d, foot per day; ft^2/d, foot squared per day}

Summary of Data from Injection Tests

Site	Test section (ft below land surface)	Static water level (ft below land surface	Test water level (ft below land surface	Injection rate (gal/min)	Hydraulic conductivity (ft/d)	Saturated thickness (ft)	Transmissivity (ft^2/d)
298 (pre-mining)	[1]63.3 -114.00	[2]88.65	0.00	0.14	0.01	-	-
298 (pre-mining)	[1]63.3 -150.00	113.00	0	6.25	.11	37.00	3.7
298 (post-mining)	112.08-150.00	123.28	112.08	17.0	6.16	26.72	160
301 (pre-mining)	44.00-150.00	[2]97.00	0	.01	[3]<0.001	53.00	[3]<0.001
301 (post-mining)	49.47-150.00	96.10	49.47	17.0	.67	53.90	36

(1) Transmissivity for this section was estimated by subtracting the horizontal hydraulic conductivity for the section from 63.3 to 114 feet from the hydraulic conductivity for the section from 63.3 to 150 feet, and then multiplying by the saturated thickness.

(2) The static water level was unknown, and for estimating purposes was assumed to be the midpoint of the well.

(3) The symbol "<" is less than value indicated.

Summary of Data from Recovery Tests

	Test section (ft below land surface)	Static water level (ft below land surface)	Drawdown at end of recovery period (ft below land surface)	Pumping rate (gal/min)	Pumping period (min.)	Recovery period (min.)	Transmissivity (ft^2/d)
298 (pre-mining)	115.00-150.00	115.00	0.08	0.41	75.9	184	10
307 (pre-mining)	25.00-59.00	25.00	13.51	1.44	74.6	291	0.20
307 (post-mining)	29.68-59.00	29.68	7.45	.49	120	253	.31

4.2 Ground-Water Flow System

4.2.1 Ground-water levels

LONGWALL MINING ALTERS GROUND-WATER LEVELS

INCREASES IN PERMEABILITY CAUSED BY LONGWALL MINING HAVE AFFECTED GROUND-WATER LEVELS. THE MEAN WATER-LEVEL DECLINE AFTER MINING WAS 1.56 TO 41.99 FEET.

Increased overburden permeability caused by subsidence fracturing associated with longwall mining alters the ground-water flow system. Subsidence fracturing can cause a decline in ground-water level by increasing the leakage through confining beds and by increasing the storage within the rock. Perched sandstone aquifers underlain by impermeable beds of shale or clay are the main source of water to wells on or near hilltops. Fracturing in confining beds can cause a decline in water level as a result of increased leakage through the fractures into the underlying beds. Subsidence fractures, in particular, can cause water-level declines as ground water moves to occupy the new or widened openings.

Two longwall panels were formed beneath 10 observation wells during the project period. Seven wells were underlain by one longwall panel. The other three wells were underlain by a panel about 4.6 miles from the other panel. All 10 wells were located on hilltops and ranged from 17 to 150 feet in depth. The overburden thickness ranged from 670 to 804 feet. The longwall panels were 500 to 600 feet wide, and the mining height was about 5.5 feet. All of the wells were at or near the center of longwall panels, except wells 227 and 303.

The hydrographs of each well, observed precipitation, and normal precipitation are shown in figure 4.2.1-A. The hydrographs show changes in ground-water levels that occurred when the longwall face had advanced to within a few hundred feet of the wells. The initial effect was a decline in ground-water level followed by a partial recovery as ground-water levels reached a new equilibrium. Water levels did not return to pre-mining levels during the post-mining monitoring period. The time from initial decline to end of partial recovery was no longer than 1 month. This decline and partial recovery was especially noticeable at sites 224, 301, and 303. Booth (1986) notes that the shallow overburden layers first undergo extensional fracturing, followed by partial recompression. The initial water-level decline corresponds to the period of extension fracturing when vertical leakage increases and additional storage space is created. Partial recompression contributes to the partial recovery by closing some of the new fractures and decreasing leakage from the aquifers.

Table 4.2.1-A compares pre-mining and post-mining mean water levels at 8 of the 10 observation wells. The mean post-mining water level ranged from 1.56 to 41.99 feet below mean pre-mining water levels. These declines could be partly caused by dry weather, inasmuch as precipitation was below normal for most of the data-collection period. Thirty-nine observation wells that had not been undermined during the study had water-level data sufficient to do a trend analysis for the study period. These 39 wells include areas not undermined and areas undermined by room-and-pillar or longwall methods prior to the study. Mean annual water levels were calculated for the periods spring 1985 through winter 1985-86 and spring 1986 through winter 1986-87. The 1985-86 period approximates the pre-mining period for six of the eight observation wells that were undermined during the study. Likewise, the 1986-87 period approximates the post-mining period. The mean annual water level declined in 31 of the 39 observation wells that had not been undermined during the study. Excluding site 308, where water levels declined 1.56 feet, the pre-mining to post-mining declines were greater than the trend analysis declines in 35 of the 39 wells. This suggests that the declines in the eight observation wells that were undermined during the study were caused by a combination of the hydraulic effect of longwall mining and dry weather. Elevations of the measuring points at each well were not determined before or after mining, so it is unknown if they were affected by subsidence.

Figure 4.2.1-C compares water levels between wells undermined by longwall methods and all other wells. These other wells are in areas not affected by mining and areas undermined by room-and-pillar methods. Wells were considered to be undermined if they were within an angle of draw of 25 degrees from the edge of a longwall panel. The mean seasonal depth to water was lower for wells undermined by longwall methods than for other wells at each depth range. This suggests that longwall mining typically causes a decline in ground-water levels.

There were more dry wells in longwall-mined areas than in other areas. Twenty-nine percent of the wells in longwall mined areas were dry at least once during the study period compared to only 3 percent of the wells in other areas. Wells less than 50 feet deep were more likely to go dry than wells greater than or equal to 50 feet deep. In longwall mined areas, 5 of 10 wells less than 50 feet deep were dry in the early fall when ground-water levels are usually at their lowest. During the same period, only 3 of 18 wells greater than or equal to 50 feet deep went dry.

Table 4.2.1-A--Summary of pre-mining and post-mining ground-water levels.

[ft, feet]

Well number	Mean Annual pre-mining water level (ft below land surface)	Mean Annual post-mining water level (ft below land surface)	Change in mean annual water level (ft)
223	8.94	16.12	- 7.18
224	36.78	78.77	-41.99
298	112.52(1)	121.59	- 9.07
303	26.97	52.68	-25.71
305	14.78	17.52	- 2.74
306	18.64	23.22	- 4.58
307	24.11	29.48	- 5.37
308	16.85(2)	18.41	- 1.56

Note: Wells 223, 224, 305, 306, and 308 were dry during the post-mining period. The depth of the well was used as an estimate of the water level. The number of visits the wells were dry are as follows: well 223--dry 14 out of 34 visits, well 224--dry 7 out of 35 visits, well 305--dry 10 out of 23 visits, well 306--dry 18 out of 26 visits, well 308--dry 5 out of 14 visits.

Well: 227 was not included in the table because of a lack of pre-mining data.

Well: 301 was not included in the table because the borehole was dry when drilled. The hydrograph for well 301, in illustration 4.2.1-B shows a constantly rising water level prior to mining as ground water slowly seeped into the well.

(1) Based on mean water level for summer, fall.

(2) Based on mean water level for summer, fall, and winter.

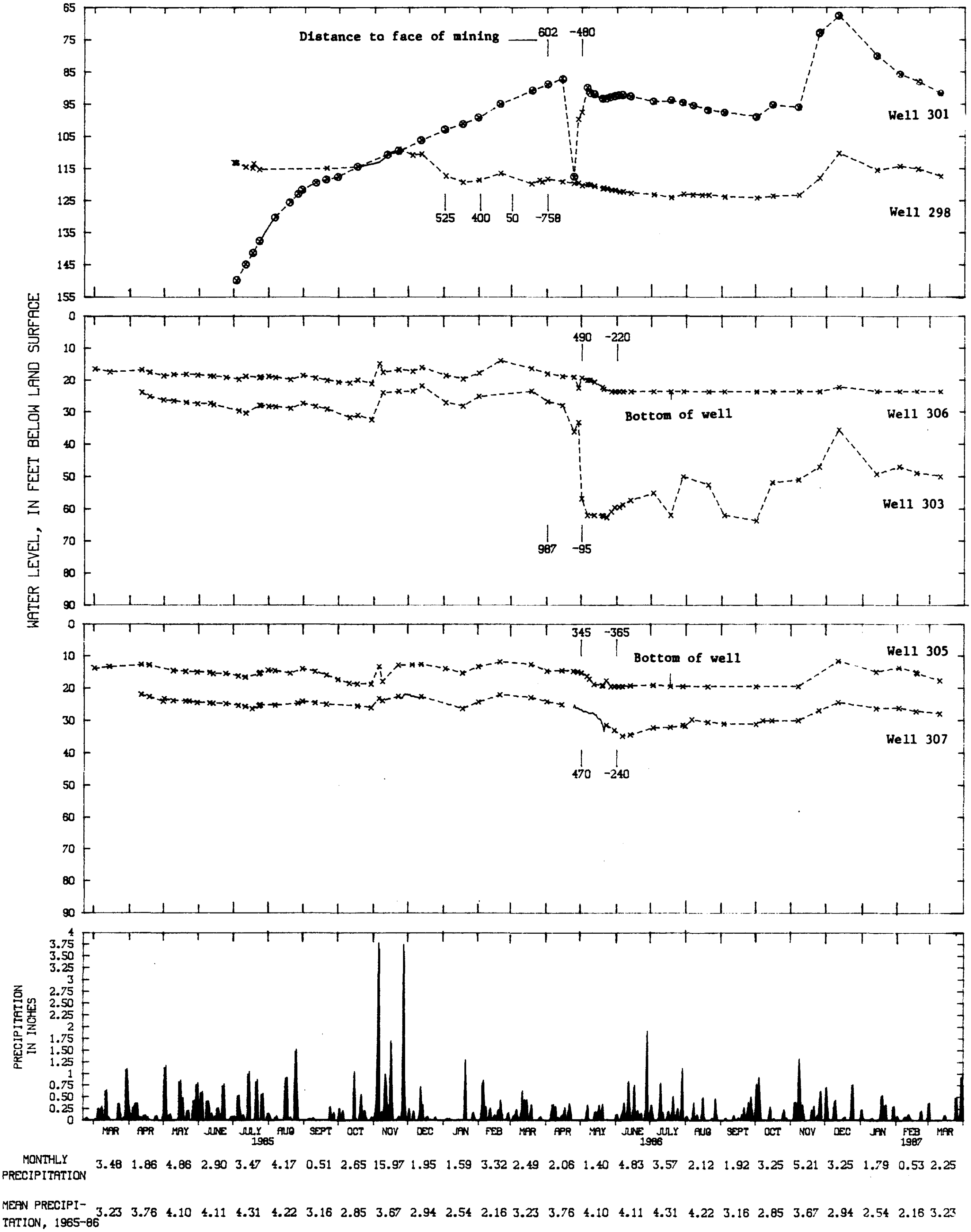


Figure 4.2.1-B.--Hydrographs of pre-mining and post-mining ground-water levels.

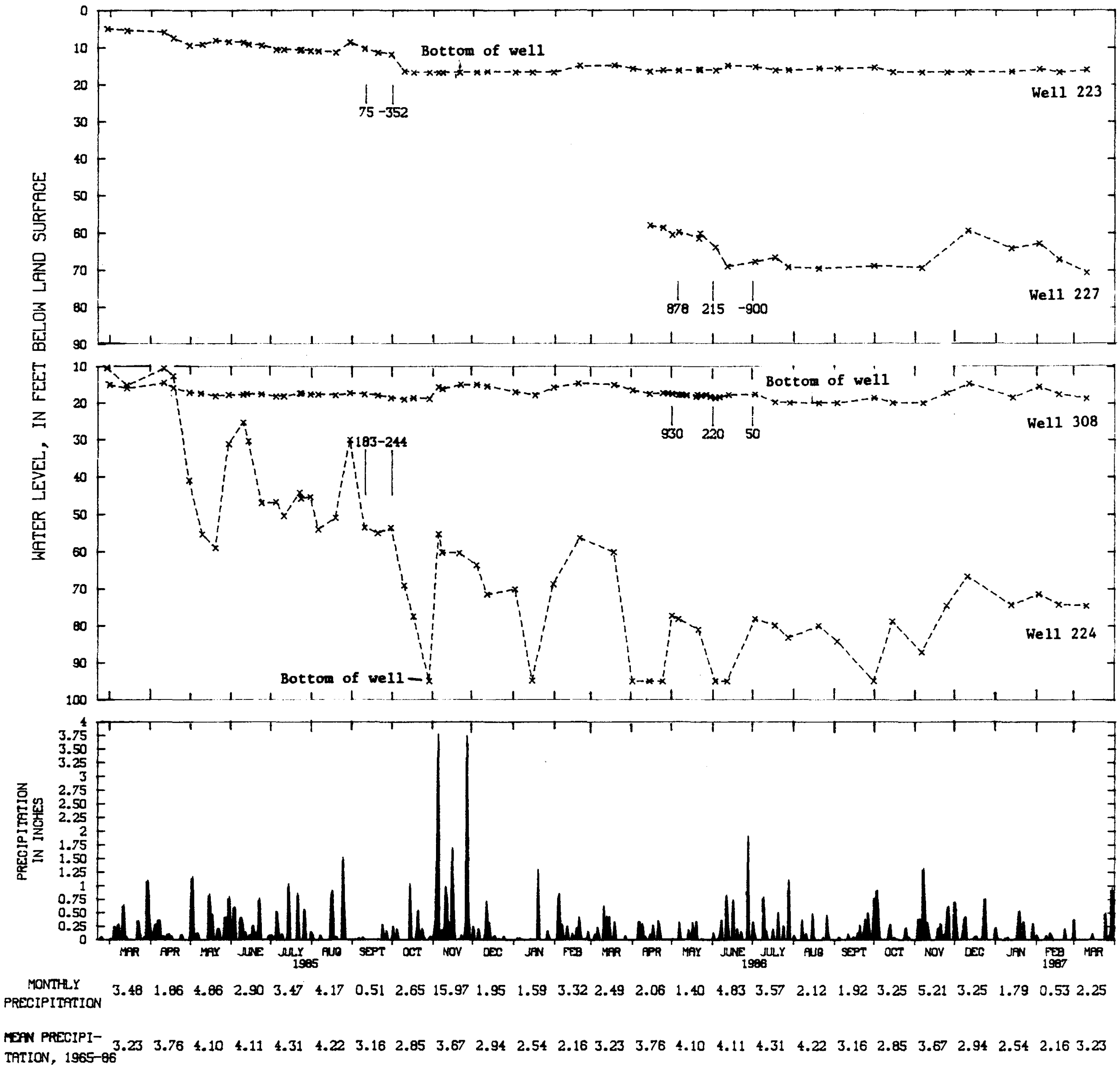


Figure 4.2.1-B.--Hydrographs of pre-mining and post-mining ground-water levels.--Continued

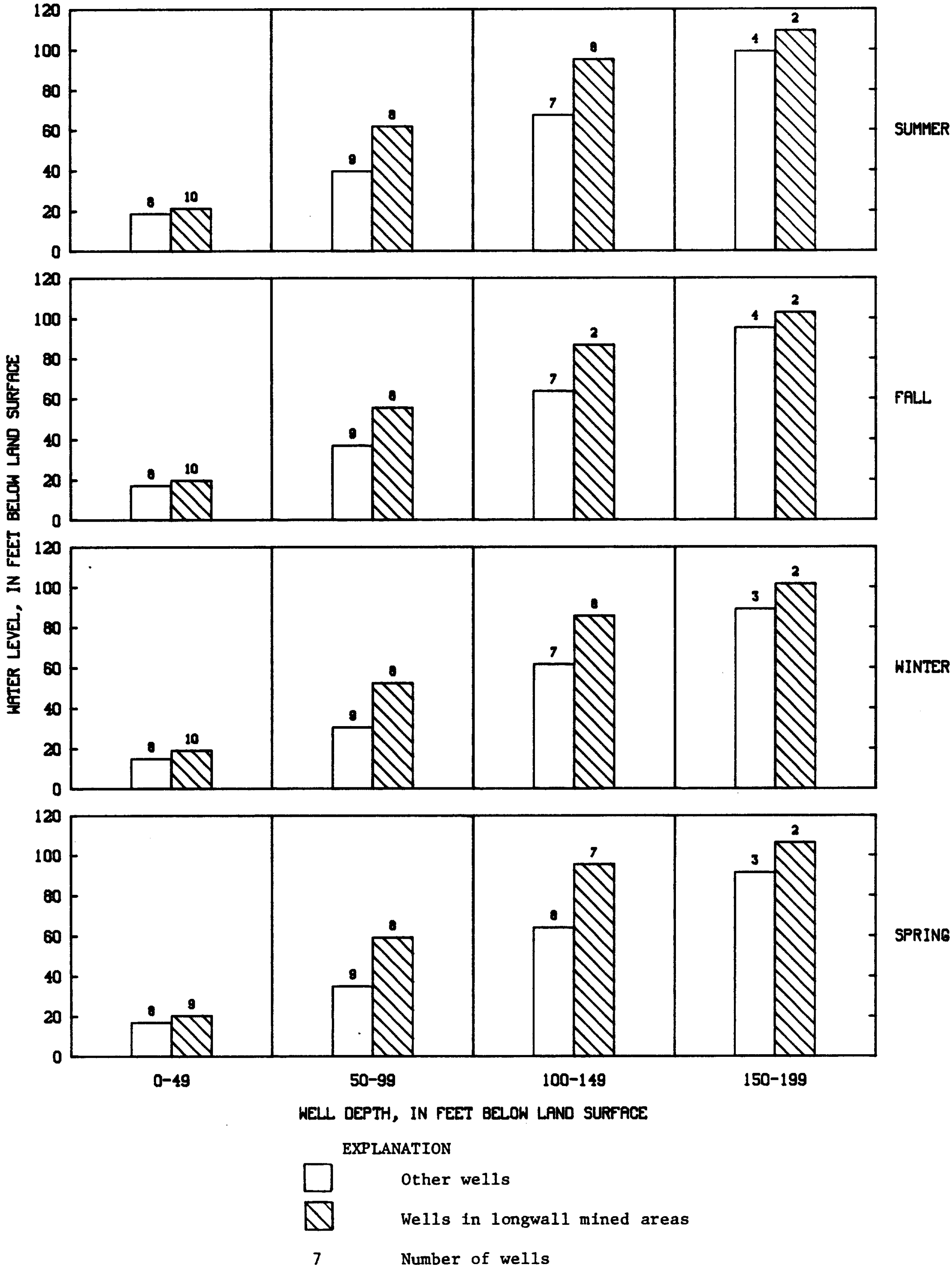


Figure 4.2.1-C.--Summary of mean ground-water levels from wells in areas of longwall mining and wells in other areas, by well depth and season.

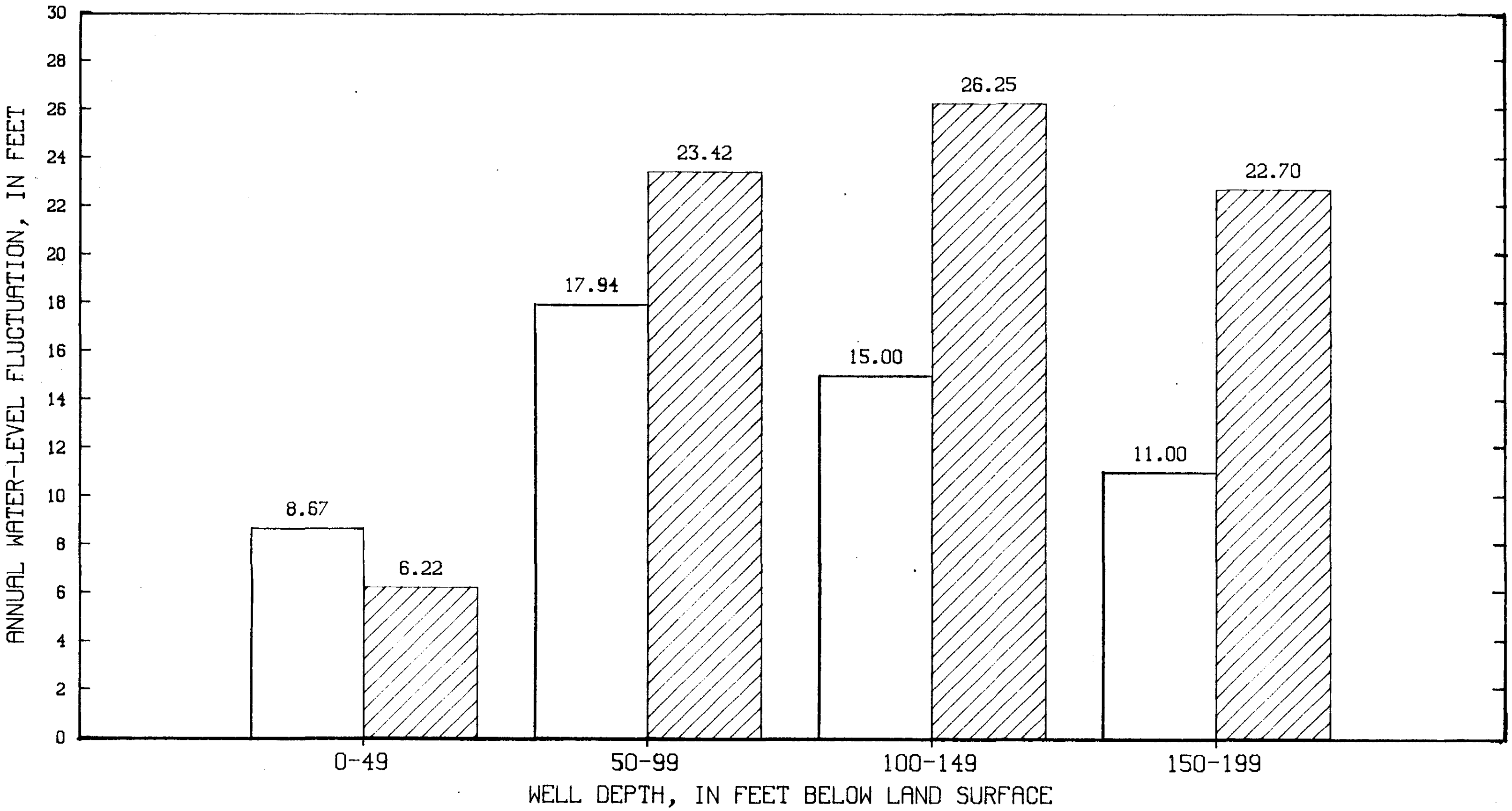
4.2.2 Water-Level Fluctuations

LONGWALL MINING CAN INCREASE WATER-LEVEL FLUCTUATIONS IN WELLS

LONGWALL MINING CAN CAUSE AN INCREASE IN WATER-LEVEL FLUCTUATIONS IN WELLS. THE WATER LEVEL IN WELLS IN LONGWALL-MINED AREAS FLUCTUATED AT LEAST 5.48 FEET PER YEAR MORE THAN THE WATER LEVEL IN WELLS IN OTHER AREAS, EXCEPT IN WELLS LESS THAN 50 FEET DEEP.

Longwall mining can cause an increase in water-level fluctuations. Figure 4.2.2-A shows the mean annual water-level fluctuation in wells of several depth ranges at longwall-mined areas and other areas. The mean annual fluctuation was calculated from water-level data collected between spring 1985 and spring 1987. Other areas include unmined areas and areas undermined by room-and-pillar methods. Annual water-level fluctuation is the difference between the highest and lowest depths to water measured during a year. Excluding wells less than 50 feet deep, the mean annual fluctuation was at least 5.48 feet more in wells in longwall-mined areas than in wells in other areas. However, the mean annual fluctuation of 6.22 feet for wells that are less than 50 feet deep in longwall-mined areas is conservative because 5 of the 10 wells in this depth range were dry at least once during the study. In these cases, well depth was used as an estimate of the ground-water level, when, in reality, the water level was below the bottom of the well.

Surficial subsidence fractures caused by longwall mining increase the amount and rate of recharge from precipitation. Underground subsidence fractures increase the rate of ground-water movement to and through aquifers. Therefore, post-mining ground-water levels typically rise more rapidly during and immediately after precipitation than pre-mining ground-water levels. Post-mining ground-water levels also decline more rapidly after precipitation. The hydrograph of well site 303 in Appendix C shows a pre-mining range in water level of 10.64 feet and a post-mining range of 30.50 feet. A longwall panel was beneath this site in the spring of 1986.



EXPLANATION

☐	Wells in other areas
▨	Wells in longwall-mined areas
15.00	Number is annual water-level fluctuation, in feet

Figure 4.2.2-A.--Annual water-level fluctuation by depth range for wells in longwall-mined and other areas.

4.0 HYDROLOGIC EFFECTS OF LONGWALL MINING (Continued)

4.2 Ground-Water Flow System (Continued)

4.2.3 Spring Discharges

LONGWALL MINING CAN DECREASE SPRING DISCHARGE

THE MEAN ANNUAL SPRING DISCHARGE WAS 0.32 GAL/MIN IN LONGWALL MINED AREAS AND 0.94 GAL/MIN IN UNMINED AREAS. DISCHARGE DECREASED AT THREE OBSERVATION SPRINGS ABOVE LONGWALL-MINE PANELS.

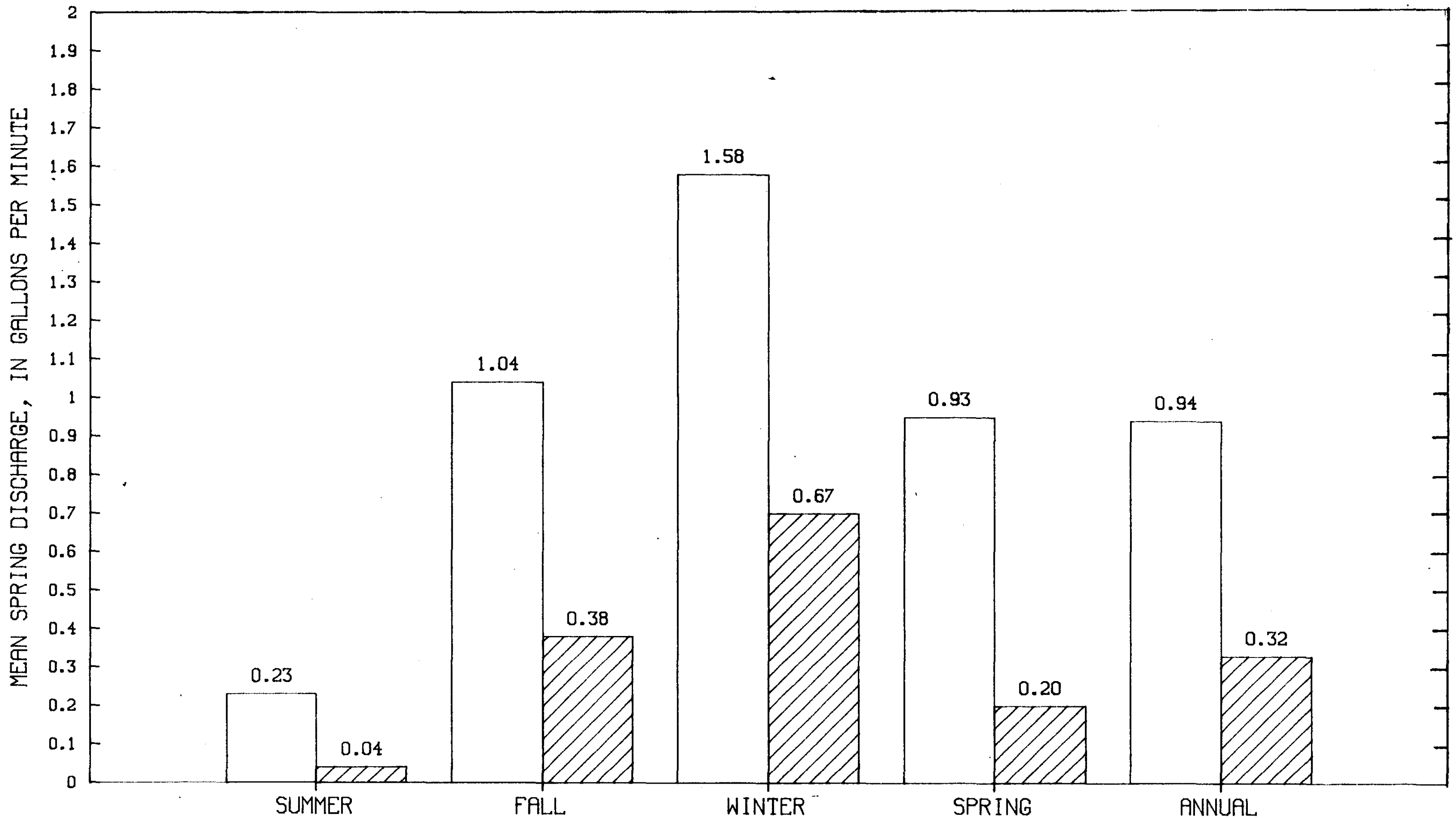
Springs and seeps are formed where ground water is diverted to hillsides by a semiconfining layer of clay or shale. A decrease in springflow can occur if subsidence fracturing causes increased vertical leakage of water through the semiconfining layer. Figure 4.2.3-A summarizes discharge data from 13 springs into unmined and longwall-mined categories. The mean annual discharge was significantly lower for springs in areas where longwall mining had occurred (0.32 gal/min) than for springs in unmined areas (0.94 gal/min). Mean seasonal discharges also were consistently lower for springs in longwall mined areas than for springs in unmined areas. No flow was observed at least once at all of the seven springs in longwall mined areas but at only three of the nine springs in unmined areas. The hydrographs of all monitored springs are presented in Appendix C.

Spring sites 72, 75, 209, 210, 309, 310, 316, 337, and 390 were undermined by the longwall method before data collection began. Approximate dates of undermining are as follows: site 72--May 1984; site 75--March 1983; site 209--January 1984; site 210--January 1983; site 309--December 1984; site 310--January 1985; site 316--January 1984; site 337--November 1979; and site 390--January 1984. These sites were visited from February 27 to May 16, 1985--a time when springs usually flow. Sites 72, 75, 210, 309, 316, and 337 were dry when visited. Sites 209, 310, and 390 were flowing at 0.75 gal/min, 0.12 gal/min, and 0.75 gal/min, respectively. Maps showing the location of these springs are presented in Appendix B.

Longwall mining can cause new springs or seeps to form. Several land owners reported the presence of new springs after longwall mining came beneath an area. These new springs typically were formed downslope from a spring that had decreased in flow.

Discharge decreased after longwall mining at three overlying springs during the study. Spring site 225 was monitored for 3 months before mining and for 22 months after mining. Longwall mining occurred under the site in May 1985. The overburden thickness is about 780 feet. The mean pre-mining discharge was 4.08 gal/min, and the spring was not observed to be dry. The spring went dry within 1 month after being undermined and had not resumed flow as of March 1987. Spring site 228 was monitored for about 14 months before mining, and had a mean annual discharge of 0.70 gal/min. The minimum measured pre-mining discharge was 0.06 gal/min on October 29, 1985. A longwall panel was beneath the hilltop near the spring in June 1986, but not beneath the spring's discharge point. The spring is located about 175 feet from the edge of the longwall panel, and the overburden thickness is about 810 feet. The spring was dry within 1 month after mining had occurred and had not resumed flow as of March 1987. Spring site 300 is above the center of a longwall panel and is about 60 to 70 feet below the top of the ridge. The overburden thickness is about 750 feet. Discharge was monitored for 11 months before mining and for 1 year after mining. A longwall panel was located beneath the site in March 1986. The mean annual discharge declined from 1.66 gal/min before mining to 0.92 gal/min after mining. Minimum discharges were 0.31 gal/min before mining and zero after mining.

The reduced flow at sites 225, 228, and 300 probably was caused in part by dry weather, because precipitation was below normal for most of the study period. Discharge data from eight springs in areas not affected by mining during the study were used for a trend analysis. Mean discharges were calculated for the periods spring 1985 through winter 1985-86 and spring 1986 through winter 1986-87. Mean discharge decreased at seven of the eight springs from 1985-86 to 1986-87. Decreases in discharge ranged from 0.06 to 0.72 gal/min, but none of the springs went dry. This suggests that the decrease in discharge at sites 225, 228, and 300 were, in part, caused by dry weather.



EXPLANATION

☐	Unmined areas
▨	Longwall-mined areas
1.58	Number is mean spring discharge, in gallons per minute

Figure 4.2.3-A.--Variation in mean spring discharge for longwall-mined and unmined areas.

5.0 SUMMARY

Marshall County is a 315-square-mile area at the base of the Northern Panhandle of West Virginia. It is bordered by Pennsylvania to the east, Ohio to the west, Ohio County to the north, and Wetzel County to the south. The topography is characterized by long, narrow ridges with steep slopes and narrow valleys. Sixty-four percent of the land is forested. Agricultural land, primarily pasture, comprises about 31 percent of the land area.

Data were collected for the study from February 1985 through March 1987. Data collection included a well and spring inventory, water level and spring discharge monitoring, aquifer testing, geophysical logging, ground-water sampling for chemical analysis, and observation well drilling.

Mean annual precipitation ranges from about 38.50 to 42.25 inches. July typically is the wettest month and February, the driest. Snowfall averages about 30 inches per year.

Two bedrock units crop out. The Dunkard Group is exposed throughout the County except along the Ohio River and the lower reaches of the tributaries to the Ohio River, where the Monongahela Group is exposed. The bedrock consists of layers of shale, sandstone, limestone, and coal. Shale is the most common type of rock. The rocks generally dip to the southeast. The axis of the anticlines and synclines have a northeast-southwest trend.

Unconsolidated alluvial deposits of clay, silt, sand, and gravel cover the bedrock on the Ohio River floodplain and the lower reaches of the Ohio River's tributaries. The thickness of alluvial deposits ranges from less than 10 feet to more than 100 feet. In many places the alluvium has been covered by fill material, such as slag from steel-processing plants and wastes from coal-preparation plants.

Approximately 13.1 Mgal/d of ground water was withdrawn in 1985 for industrial, public supply, mining, and domestic self-supplied uses. Average daily withdrawals by type of use were as follows: industrial--9.04 Mgal, public supply--2.17 Mgal, mining--1.63 Mgal, and domestic self-supply--0.25 Mgal.

Precipitation is the sole source of ground water in bedrock aquifers. Ground water flows from hilltops to valleys. The mean reported yield for bedrock wells is 5.2 gal/min, and the mean annual spring discharge is 0.94 gal/min. Ground water in the alluvium of the Ohio River floodplain is derived from infiltration of precipitation, inflow from the surrounding bedrock, seepage from streams, and induced inflow from the Ohio River. Most wells that tap the alluvium are capable of yielding several hundred gallons per minute. Radial collectors that induce infiltration from the Ohio River may yield several thousand gallons per minute.

5.0 SUMMARY (Continued)

The chemical quality of ground water generally is acceptable for domestic use. Locally, concentrations of manganese, iron, sulfate, total dissolved solids, nitrite plus nitrate, fluoride, and arsenic exceed State limits for public water supply.

Ground water that has recently entered the bedrock flow system generally is calcium bicarbonate in type and very hard. However, hardness decreases and sulfate is reduced to hydrogen sulfide as ground water flows from the hilltops to valleys. Water from the alluvium typically is a calcium bicarbonate type and very hard. Fill material can be a source of sulfate to ground water in the alluvium, and, in some areas, sulfate is the predominant anion.

All of the coal mined in the County is from the Pittsburgh seam. Mean annual coal production from 1980 through 1985 was 5.1 million tons, more than half of which was mined by using the longwall method. Roof collapse as a result of longwall mining causes vertical and horizontal movement within the overburden, resulting in a trough-shaped land-subsidence profile. The most important factors governing the depth, areal extent, and upward propagation of subsidence are (1) depth and width of mining, (2) lithology and structure of the overburden, (3) mining height, (4) mining face location, and (5) number of mining panels. The maximum estimated subsidence at the center of the trough ranged from 3.22 feet to 2.83 feet for a panel width of 550 feet, a mining height of 5.5 feet, and overburden thicknesses of 650 and 950 feet, respectively.

Subsidence fracturing increases the permeability and storage of the overburden. Pre- and post-mining aquifer tests indicated significant increases in transmissivity at two of three sites. Estimated transmissivity increased from 3.7 to 160 ft^2/d, and from less than 0.001 to 36 ft^2/d at two sites. The transmissivity at the third site increased from 0.20 to 0.31 ft^2/d.

Increases in permeability of the overburden alter the ground-water flow system and causes changes in ground-water levels, water-level fluctuation, and spring discharge. The mean water-level decline in each of eight observation wells ranged from 1.56 to 41.99 feet after mining. These declines were caused by the combined effects of mining and dry weather. Water levels were also monitored in wells in areas undermined by the longwall method prior to this study. The mean seasonal water level ranged from 2.64 to 31.35 feet lower in wells in longwall-mined areas compared to wells in other areas. Twenty-nine percent of the wells in longwall-mined areas were dry at least once during the study period compared to only 3 percent of the wells in other areas. Longwall mining can cause an increase in water-level fluctuations. Except for wells less than 50 feet deep, the mean annual water-level fluctuation was at least 5.48 feet per year more for wells in longwall-mined areas than for wells in other areas. For example, the pre-mining fluctuation in mean annual water level in well 303 was 10.64 feet, and the post-mining fluctuation in mean annual water level was 30.50 feet.

5.0 SUMMARY (Continued)

Longwall mining can decrease spring discharge. The mean annual discharge was 0.32 gal/min for springs in areas of longwall mining and 0.94 gal/min for springs in unmined areas. Discharge decreased at three springs above longwall-mine panels. After longwall mining, several land owners reported the formation of new springs where no springs had flowed prior to mining.

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APPENDIX A

APPENDIX A

Table A-1 Records of wells and springs

Explanation

Topographic setting:

- H - hilltop
- S - hillside
- V - valley

Geologic formation:

- A - Quaternary Alluvium
- D - Dunkard Group
- M - Monongahela Group

Site type:

- D - dug well
- DR - drilled well
- S - spring
- R - radial collector

Remarks:

- C - chemical analyses
- LC - caliper log
- LD - drillers log
- LE - electric resistivity log
- LG - gamma ray log
- M - USGS water level or spring discharge monitoring site
- T - aquifer test
- __ - no data

Note: In the water level column, R and M stand for reported and measured, respectively. In the remarks column, adequate and inadequate refer to the number of people that the site supplies, and do not refer the maximum number of people that the site will supply unless otherwise indicated.

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
1	394316-0804654	D	1290	H	D	05/21/85	1860	35	–	36	25.05M	–	–
2	394317-0804652	DR	1290	H	D	05/21/85	1970	154	10	6	–	–	C, inadequate for domestic use in dry weather
3	394320-0804926	DR	700	V	A	04/11/50	1940	22	–	8	12.00 R	–	–
4	394325-0804925	S	720	S	D	04/11/50	–	–	–	–	–	3.0	–
5	394328-0804542	D	1330	H	D	04/23/85	–	22	–	24	13.55 M	–	–
6	394332-0803216	DR	1380	H	D	02/11/82	–	130	–	6	50.00 R	5.0	adequate for 1 family
7	394333-0804935	DR	660	V	D, M	04/11/50	–	99	56	–	–	–	50 feet of gravel cased
8	394335-0804934	DR	700	V	A	04/12/50	–	50	–	8	11.50 M	–	–
9	394337-0804237	DR	1400	S	D	08/05/82	1959	100	–	6	–	–	C, adequate for 10 people
10	394345-0804557	DR	1310	S	D	05/21/85	–	–	–	–	30.39 M	–	M
11	394346-0803543	DR	1260	S	D	07/30/85	1983	314	40	6	107.03 M	0.25	C, 8 inch casing from 0 - 40 feet
12	394350-0804304	DR	1370	S	D	04/23/85	1969	150	20	6	20.00 R	2.5	sometimes pumps dry in dry weather
13	394359-0804032	DR	1290	H	D	05/24/85	1895	92	20	6	52.25 M	–	C, pumps dry sometimes in dry weather
14	394408-0804912	DR	1250	H	D	04/23/85	1907	34	18	6	10.35 M	–	C
15	394413-0804326	D	1390	H	D	04/23/85	1900	38	–	45	27.00 R	–	pumps dry occasionally
16	394413-0804445	DR	1330	H	D	04/23/85	1982	110	20	8	50.00 R	5.0	C
17	394415-0804447	S	1300	S	D	04/23/85	–	–	–	–	–	0.20	C, M
18	394417-0803804	D	1310	H	D	05/24/85	1850	30	–	42	23.53 M	–	–
19	394419-0804729	DR	1340	H	D	08/09/82	1967	65	40	6	–	1.0	–
20	394421-0805038	DR	640	V	A	08/30/82	1966	69	56	10	30.00 R	283	C
21	394424-0803642	DR	1350	H	D	08/04/82	1961	65	–	6	45.00 R	–	C, pumped dry once when watering garden
22	394426-0803833	DR	1370	H	D	05/24/85	1982	100	18	8	–	–	C

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
23	394432-0805033	DR	680	V	D,M	04/12/50	1940	39	33	3	33.00 R	-	-
24	394433-0805039	D	660	V	A	04/04/50	-	80	-	36	66.65 M	-	-
25	394434-0805056	DR	660	V	A	04/12/50	-	65	-	-	-	-	pumped continously at low rate
26	394439-0805102	D	646	V	A	05/10/50	1950	68	-	20	34.00 M	650	T, LD
•27	394443-0804233	DR	1380	S	D	04/25/85	1961	120	20	10	-	0.33	C, water level gets low in late summer
28	394443-0805105	DR	654	V	A	08/04/42	1942	85	65	20	53.00 R	850	T, C
29	394446-0805113	DR	650	V	A	04/17/42	1942	80	67	8	42.50 R	400	T, C
30	394450-0805117	DR	650	V	A	06/17/52	1942	81	69	20	51.00 M	700	-
31	394458-0804919	D	1300	H	D	04/23/85	1880	40	-	-	19.73 M	-	-
32	394458-0805120	R	650	V	A	1943	1943	-	-	-	-	10,000	hydraulically connected to Ohio River
33	394459-0805115	DR	673	V	A	03/05/54	1952	99	84	10	65.74 M	250	T
34	394459-0805115	DR	669	V	A	03/05/54	1942	90	88	12	62.00 R	250	-
35	394459-0805115	DR	672	V	A	03/05/54	1945	90	88	12	62.00 R	250	-
36	394501-0803832	S	1400	S	D	05/24/85	-	-	-	-	-	-	adequate supply for 3 people
37	394504-0804020	DR	1350	H	D	05/24/85	1977	-	-	-	-	-	C
38	394504-0804314	DR	1290	H	D	04/25/85	1970	75	-	10	47.33 M	-	-
39	394504-0804921	D	1270	H	D	04/23/85	1900	35	-	36	20.00 R	-	adequate supply for 1 family
40	394505-0805113	DR	690	V	M	04/12/50	1942	108	103	6	27.00 R	-	first drilled to 98 feet and went dry
41	394508-0805112	DR	670	V	A	04/13/50	1942	98	-	-	-	-	-
42	394509-0804516	S	1230	S	D	05/22/85	-	-	-	-	-	-	-
43	394512-0804519	D	1310	H	D	05/22/85	1840	44	-	48	36.30 M	-	-
44	394517-0804749	DR	1350	H	D	04/23/85	1977	144	20	8	48.44 M	-	-
45	394535-0805140	DR	670	V	A	04/17/42	1941	96	-	6	71.00 R	-	C
46	394539-0805135	DR	670	V	A	04/12/50	-	85	-	-	-	-	-
47	394549-0805144	DR	650	V	A	04/13/50	1931	80	-	-	43.00 R	-	-
48	394552-0803139	S	1460	S	D	07/30/85	-	-	-	-	-	-	C, flows all year
49	394552-0805141	DR	670	V	M	04/13/50	1949	108	90	8	53.00 R	-	-
50	394553-0803952	DR	730	V	D	08/04/32	1963	84	62	8	13.00 R	-	adequate supply for 3 families
51	394553-0805143	DR	650	V	M	08/26/32	1925	80	66	6	-	-	C
52	394556-0805140	DR	660	V	A	04/17/42	1941	100	100	6.6	72.00 R	-	lowest 10 feet of casing perforated
53	394558-0804250	DR	710	V	M	04/26/85	1984	45	21	16	17.20 M	-	-
54	394558-0805144	DR	650	V	A	04/13/50	1933	89	80	8	-	-	-
55	394600-0804241	DR	740	S	D	04/26/85	1965	48	22	-	-	-	adequate supply for 2 houses and 5 camps
56	394601-0805142	DR	650	V	A	04/04/50	-	65	-	-	-	-	adequate supply for 2 families
57	394603-0804236	DR	720	V	D	04/26/85	1984	48	30	16	17.76 M	-	M, T
58	394609-0804824	DR	1330	H	D	04/23/85	1977	78	20	6	73.55 M	-	C, goes dry in late summer-early fall

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
59	394611-0804552	DR	1300	H	D	05/22/85	1968	94	20	7	30.00 R	4.00	C
60	394617-0804825	D	1310	H	D	04/21/85	1890	45	–	–	30.00 R	–	–
61	394620-0805133	DR	640	V	M	04/17/42	–	76	–	5	33.30 R	2.00	–
	394620-0805133	DR	640	V	M	04/13/50	1949	108	84	6	–	–	salty taste
62	394625-0804548	D	1350	H	D	05/22/85	1850	42	–	36	23.00 M	–	–
63	394628-0804559	DR	1330	S	D	05/22/85	–	–	–	6	–	–	–
64	394632-0803441	DR	1380	H	D	07/30/85	1980	307	21	10	238.60 M	0.25	C, M
65	394633-0803339	DR	1340	H	D	08/11/82	1952	46	–	6	34.00 M	–	–
66	394637-0804319	D	690	V	M	04/24/85	1880	–	–	–	–	–	C
67	394639-0804351	DR	710	V	D,M	08/04/82	1964	93	–	6	–	–	hydrogen sulfide gas present
68	394643-0803747	DR	1380	H	D	07/30/85	1970	125	21	8	–	1.50	C
69	394648-0804902	DR	1310	H	D	08/10/82	–	80	–	6	–	–	originally drilled to 85 feet
70	394700-0805019	S	700	S	D	04/18/50	–	–	–	–	–	2.00	discharge varies seasonally
71	394707-0803914	DR	1350	H	D	05/23/85	1978	125	28	8	15.50 M	–	–
72	394708-0804651	S	1160	S	D	05/16/85	–	–	–	–	–	0.00	no flow since 07/84
73	394709-0804016	D	1330	S	D	05/23/85	1850	50	–	60	35.00 R	–	–
74	394710-0804617	S	1210	S	D	05/16/85	–	–	–	–	–	0.00	no flow since 06/83
75	394716-0804617	S	1210	S	D	05/16/85	–	–	–	–	–	0.00	no flow since 06/83
76	394724-0804845	S	1150	S	D	05/21/85	–	–	–	–	–	–	–
77	394725-0804639	S	1180	S	D	04/25/85	–	–	–	–	–	0.12	C, M
78	394725-0804947	D	640	V	A	04/18/50	–	35	–	60	5.44 M	–	goes dry in summer
79	394729-0804844	DR	1240	S	D	05/21/85	1969	71	20	8	9.19 M	–	M
80	394733-0804930	D	660	V	M	04/18/50	1920	28	–	48	15.00 R	–	–
81	394737-0804700	DR	1210	S	D	04/25/85	1975	90	–	6	45.27 M	–	M
82	394738-0804700	DR	1210	S	D	04/25/85	–	122	–	3	54.72 M	–	M
83	394738-0804828	DR	1210	H	D	05/21/85	1969	80	20	8	55.00 R	–	–
84	394738-0804830	D	1210	H	D	05/21/85	1880	–	–	72	–	–	–
85	394739-0804848	DR	1210	H	D	05/21/85	1963	125	23	10	26.34 M	10.00	–
86	394740-0804848	DR	1210	H	D	05/21/85	1974	125	20	8	–	5.00	–
87	394741-0804759	D	710	V	M	05/22/85	–	11	–	30	7.95 M	–	–
88	394741-0804847	D	1210	H	D	05/21/85	1850	22	–	36	9.45 M	–	–
89	394742-0804758	DR	710	V	M	05/22/85	–	53	–	–	–	–	C
90	394742-0804805	S	790	S	D	05/22/85	–	–	–	–	–	0.40	–
91	394743-0804106	DR	1330	H	D	05/24/85	1974	165	19	10	105.00 M	–	C
92	394743-0804536	DR	670	V	M	04/23/85	1960	65	20	8	–	–	C
93	394745-0804304	DR	740	S	D	04/24/85	–	14	–	12	2.91 M	–	–

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
94	394747-0804828	DR	1110	S	D	05/21/85	–	91	–	6	–	–	–
95	394748-0804526	DR	710	V	M	04/25/85	1984	55	20	8	–	–	iron stains present
96	394748-0804702	DR	1290	S	D	04/25/85	1960	125	–	6	–	–	–
97	394752-0804525	S	720	S	D	04/23/85	–	–	–	–	–	–	dry once in last 45 years
98	394754-0804714	DR	1200	H	D	04/25/85	1959	81	35	6	–	–	–
99	394756-0804653	D	1210	S	D	04/25/85	–	26	–	36	23.40 M	–	M
100	394800-0804733	DR	1230	S	D	04/25/85	1950	98	26	6	67.68 M	–	M
101	394803-0803141	D	1430	H	D	06/07/85	–	70	–	48	61.76 M	–	C, M
102	394818-0804903	DR	720	V	M	04/20/50	–	45	–	–	–	–	–
103	394820-0804734	DR	1070	S	D	08/09/82	–	55	–	6	20.00 M	–	C, M
104	394822-0804905	DR	650	V	A	04/20/50	–	65	–	–	25.00 R	–	–
105	394824-0804018	DR	1350	H	D	05/24/85	1969	90	–	4	–	–	–
106	394824-0804906	DR	630	V	A	08/11/82	1950	65	–	6	–	6.00	C
107	394830-0804227	S	1370	S	D	04/24/85	–	–	–	–	–	0.64	C, M
108	394830-0804641	DR	670	V	M	04/24/85	1972	–	–	–	–	–	–
109	394831-0804640	DR	670	V	M	04/24/85	1970	90	–	–	20.00 R	15.00	iron and manganese stains present
110	394832-0804224	D	1420	H	D	04/24/85	1880	43	–	56	–	–	C
111	394833-0803831	DR	1340	S	D	08/10/82	1975	100	18	6	38.00 M	2.50	C
112	394833-0804809	DR	660	S	M	05/22/85	1960	80	20	6	50.00 R	–	hydrogen sulfide gas present
113	394834-0804054	DR	1330	H	D	04/25/85	1956	90	20	8	–	–	–
114	394835-0804054	DR	1330	H	D	04/25/85	–	165	20	12	57.00 M	–	M, LC, LG
115	394837-0804414	DR	1350	H	D	04/24/85	1979	125	–	–	–	–	–
116	394839-0803448	DR	1400	S	D	07/30/85	1970	115	–	8	44.48 M	–	C
117	394840-0804406	S	1170	S	D	04/25/85	–	–	–	–	–	0.01	occasionally dry last few years only
118	394845-0804410	DR	1350	H	D	04/24/85	1964	120	10	8	41.40 M	–	–
119	394845-0804839	D	630	V	A	04/20/50	–	29	–	120	12.33 M	–	formerly supplied town of Captina
120	394848-0803411	S	1360	S	D	06/05/85	–	–	–	–	–	0.45	C
121	394851-0803414	DR	1335	S	D	06/05/85	1983	123	16	10	–	–	dry after 3 loads automatic washer
122	394851-0804850	DR	650	V	A	04/20/50	1918	75	–	4	45.00 R	–	–
123	394854-0804730	DR	700	V	M	04/26/85	1940	100	–	6	–	–	–
124	394855-0804731	DR	700	V	M	04/26/85	1970	60	40	10	–	–	–
125	394859-0803530	DR	1320	H	D	08/11/82	–	230	–	8	–	–	–
126	394903-0803443	S	1350	S	D	04/25/85	–	–	–	–	–	3.69	C, dry for first time in 30 years in 1984
127	394904-0804757	DR	670	V	M	04/20/50	1949	102	–	–	66.00 R	1.60	–
128	394909-0804854	DR	650	V	A	08/12/82	–	85	–	–	24.00 R	150	C
129	394913-0803722	DR	1410	S	D	05/23/85	1982	165	19	8	45.00 R	6.70	C, plastic perforated casing 19-165 feet

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
130	394915-0804851	DR	670	V	A	04/20/50	–	70	–	–	–	–	wells 130 and 135 supply 58 families
131	394916-0804800	D	650	V	A	04/20/50	–	30	–	48	–	–	–
132	394918-0804702	DR	1230	H	D	04/25/85	1951	70	60	8	–	–	C
133	394918-0804702	D	1230	H	D	04/25/85	1850	31	–	36	17.22 M	–	dry in fall
134	394922-0804113	DR	1390	H	D	08/10/82	1974	105	–	10	–	7.00	–
135	394925-0804855	DR	670	V	M	04/20/50	–	90	–	–	–	–	–
136	394939-0803136	DR	1150	V	D	08/10/82	1974	58	22	8	11.00 R	8.00	C
137	394941-0804157	DR	1330	S	D	04/25/85	1971	69	11	8	19.07 M	2.00	–
138	394943-0803449	DR	1040	V	D	01/16/42	1940	250	22	6	43.00 R	7.50	C
139	394944-0803152	DR	1130	V	D	06/05/85	1982	42	30	8	4.15 M	–	C, adequate for 2 people
140	394944-0803452	DR	1040	V	D	01/16/42	1940	200	22	6	43.00 R	6.00	–
141	394944-0803456	DR	1040	V	D	01/16/42	1940	140	22	6	43.00 R	11.00	yield 50 gal. per min. when drilled
142	394945-0804211	D	1300	H	D	04/25/85	–	11	–	36	3.00 R	–	–
143	394948-0803931	DR	1350	H	D	07/30/85	1969	125	–	–	–	–	adequate for 4 people if careful
144	394950-0804907	DR	660	V	A	04/25/50	1942	100	–	–	–	–	–
145	394952-0803930	DR	1350	H	D	07/30/85	1972	125	15	10	106.48 M	–	C
146	394956-0804903	DR	670	V	M	04/25/50	1948	113	105	–	63.00 R	–	–
147	395002-0804917	DR	650	V	A	08/31/82	–	83	–	–	–	–	C
148	395003-0804339	DR	1370	H	D	04/24/85	–	90	–	–	–	–	–
149	395012-0803600	DR	1010	V	D	05/23/85	–	30	–	6	–	–	–
150	395012-0804010	DR	1290	H	D	05/24/85	1983	120	19	8	64.18 M	0.67	–
151	395013-0804006	DR	1310	H	D	05/24/85	1975	113	21	8.5	41.95 M	–	–
152	395025-0804908	DR	670	V	A	04/26/50	1917	80	–	6	60.00 R	–	–
153	395027-0804208	DR	810	V	D	05/23/85	1965	50	20	8	–	–	–
154	395027-0804232	D	790	V	D	05/23/85	1850	25	–	36	7.00 R	–	–
155	395027-0804651	DR	1220	H	D	08/10/82	1971	75	19	8	58.00 R	4.00	calcium deposits
156	395033-0804606	DR	1350	H	D	04/25/85	–	65	–	–	–	–	–
157	395048-0803131	DR	1220	S	D	06/05/85	1971	120	6	10	31.00 R	–	C, adequate for 2 people
157-A	395048-0803340	DR	1080	V	D	–	–	140	–	8	–	–	M
158	395056-0803441	S	1110	S	D	06/05/85	–	–	–	–	–	–	C, adequate for 2 people
159	395104-0803802	DR	1390	H	D	05/23/85	1900	110	20	6	83.00 R	–	C
160	395106-0803801	D	1370	H	D	05/23/85	1852	28	–	36	18.28 M	–	–
161	395110-0804310	DR	770	V	D	05/23/85	–	38	15	12	8.60 M	–	–
162	395115-0803626	DR	1410	H	D	05/23/85	1975	–	–	–	–	–	inadequate for 1 family in summer
163	395127-0804035	DR	1270	H	D	05/24/85	1980	110	20	10	70.00 R	–	–
164	395127-0804036	DR	1270	H	D	05/24/85	1979	155	18	10	36.80 M	–	inadequate for 1 family

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)		Yield (gallons per minute)	Remarks
165	395127-0804345	DR	740	V	D	08/10/82	1957	38	-	6	-		-	C
166	395132-0804228	DR	1290	H	D	02/25/85	1950	108	-	6	66.77	M	-	C, M
167	395137-0803438	DR	1340	H	D	08/10/82	1967	225	20	8	-		-	used for dairy - dry sometimes in summer
168	395137-0804429	DR	1230	S	D	04/25/85	1970	75	16	10	-		-	use 2500 gpd in spring-dry sometimes in win.
169	395139-0804432	DR	1240	H	D	04/25/85	1970	73	10	13.5	70.00	M	-	dry except in spring
170	395141-0803915	D	1270	H	D	05/24/85	-	47	-	42	36.00	M	-	-
171	395142-0804512	D	1290	H	D	04/25/85	-	150	20	6	-		-	dry frequently
172	395143-0804511	DR	1310	H	D	04/25/85	-	110	-	8	-		-	dry frequently
173	395148-0804605	DR	1290	H	D	04/25/85	1950	125	-	-	-		-	-
174	395149-0804605	DR	1290	H	D	04/25/85	1937	43	20	8	20.80	M	-	M
175	395156-0804206	DR	1300	S	D	02/25/85	1915	75	60	8	-		-	-
176	395157-0804148	S	1220	S	D	02/25/85	-	-	-	-	-		0.00	owner reports dry since 1980
177	395158-0804141	S	1240	S	D	02/25/85	-	-	-	-	-		1.00	M
178	395201-0804150	S	1230	S	D	02/25/85	-	-	-	-	-		0.33	-
179	395202-0804333	DR	750	S	M	05/23/85	1925	42	20	6	-		-	-
180	395204-0804203	DR	1360	H	D	02/25/85	1915	115	60	8	-		-	-
181	395204-0804203	DR	1360	H	D	02/25/85	1965	105	-	10	85.00	R	0.06	-
182	395206-0803803	DR	1280	H	D	08/10/82	1980	135	-	-	93.00	M	3.30	-
183	395207-0804122	DR	1280	H	D	02/25/85	1967	110	-	6	-		0.83	C
184	395207-0804207	D	1290	S	D	02/26/85	-	30	-	48	24.55	M	-	M
185	395207-0804207	DR	1290	S	D	02/26/85	1958	110	-	8	-		0.04	-
186	395217-0804220	D	1310	H	D	02/25/85	-	28	-	48	22.47	M	-	M
187	395220-0804225	DR	1310	H	D	02/26/85	1981	137	20	8	dry		-	M
188	395221-0804235	S	1220	S	D	02/25/85	-	-	-	-	-		-	flows all year
189	395226-0803449	DR	1340	H	D	06/04/85	1956	125	40	10	-		-	C, adequate for 5 people
190	395226-0804233	D	1265	S	D	02/25/85	1895	35	-	48	8.48	M	-	M
191	395226-0804236	S	1200	S	D	02/25/85	-	-	-	-	-		-	flows all year
192	395227-0804028	DR	1290	H	D	02/25/55	1965	195	21	8	-		-	-
193	395229-0803143	DR	1450	S	D	06/04/85	-	98	-	10	-		-	C, adequate for 6 people
194	395231-0803706	DR	1050	V	D	06/05/85	1954	36	6	6	14.10	M	-	C, M adequate for 8 people
195	395243-0804234	DR	1210	H	D	02/25/85	1960	100	20	8	-		0.33	C
196	395246-0804241	D	1210	H	D	02/26/55	-	20	-	36	9.82	M	-	M
197	395252-0804115	DR	790	V	D	02/26/85	1970	41	20	6	-		-	1 family-pump dry if use aut. washer
198	395257-0804043	DR	800	V	D	02/26/85	1977	45	15	8	-		-	adequate for 4 people
199	395258-0804046	DR	800	V	D	02/26/85	1963	25	15	8	-		-	adequate for 5 people
200	395300-0804054	DR	800	V	D	02/26/85	1956	57	-	6	20.00	R	-	-

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
201	395300-0804056	DR	800	V	M	02/26/85	1979	73	60	8	11.63 M	0.87	hydrogen sulfide gas present
202	395300-0804056	DR	800	V	M	02/26/85	1968	89	70	8	11.71 M	-	M, inadequate for 5 people
203	395305-0804710	DR	650	V	A	05/10/50	1949	75	50	6	40.00 R	-	-
204	395308-0803842	DR	960	S	D	05/02/85	-	47	-	8	23.05 M	-	C
205	395309-0804153	DR	760	V	M	02/26/85	1968	37	-	8	-	-	adequate for 3 people
206	395312-0804510	DR	1250	H	D	08/12/82	1955	85	-	6	60.00 R	-	-
207	395313-0804108	S	1140	S	D	02/28/85	-	-	-	-	-	0.00	owner reports dry since 1984
208	395315-0804115	DR	1270	H	D	02/28/85	1976	76	40	10	-	-	-
209	395315-0804115	D	1270	H	D	02/28/85	-	12	6	120	2.20 M	-	M
210	395323-0804130	S	1180	S	D	02/27/85	-	-	-	-	-	0.00	dry since 12/82-adequate for 2 people before
211	395324-0804203	DR	740	V	M	02/26/85	1954	30	-	6	-	-	adequate for 2 people
212	395325-0804718	D	680	V	A	05/11/50	1949	41	-	24	34.00 R	-	-
213	395332-0804011	DR	1280	H	D	02/27/85	-	65	15	10	20.00 R	-	-
214	395335-0804722	DR	700	V	M	05/11/50	1947	77	-	6	47.00 R	-	gas in water from coal seam
215	395335-0804746	DR	640	V	A	08/26/82	-	78	-	10	-	350	C
216	395336-0804730	D	710	V	A	05/11/50	1850	90	-	36	87.00 R	-	adequate for 2 families
217	395336-0804731	DR	770	V	M	09/07/53	1953	110	92	6	77.50 R	1.17	-
218	395336-0804731	DR	650	V	M	09/07/53	1953	70	52	6	62.00 R	5.00	hydrogen sulfide gas present
219	395337-0804019	DR	1360	H	D	02/26/85	1977	86	13	8	60.52 M	-	M
220	395337-0804119	S	1180	S	D	02/27/85	-	-	-	-	-	0.00	owner reports dry since 08/84
221	395338-0804012	S	1200	S	D	02/27/85	-	-	-	-	-	2.33	M
222	395342-0804109	S	1170	S	D	02/27/85	-	-	-	-	-	0.50	-
223	395346-0804017	D	1310	H	D	02/27/85	-	17	-	36	4.91 M	-	M
224	395346-0804019	DR	1310	H	D	02/27/85	1964	95	-	8	10.44 M	0.06	C, M
225	395348-0804108	S	1260	S	D	02/27/85	-	-	-	-	-	4.50	M
226	395355-0803207	DR	1370	H	D	08/11/82	1972	80	-	8	30.00 R	20.00	-
227	395358-0804024	DR	1330	H	D	04/14/86	-	115	-	8	58.07 M	-	M
228	395402-0804027	S	1300	S	D	02/27/85	-	-	-	-	-	1.31	C, M
228-A	395404-0804816	DR	640	V	A	08/13/52	-	68	-	12	-	530	C
229	395406-0803544	DR	1360	H	D	08/11/82	1973	110	37	-	55.00 R	5.00	-
220	395406-0804036	DR	1360	H	D	02/26/85	1928	62	20	8	-	-	adequate for 5 people
231	395417-0803207	DR	1390	H	D	06/06/85	1970	115	20	12	50.00 R	-	-
232	395417-0804535	DR	670	V	M	05/17/50	1949	84	-	6	-	-	not adequate at 50 feet so drilled to 84 feet
233	395417-0804535	DR	650	V	M	08/06/61	-	150	20	6	110.00 R	-	salty taste
234	395417-0804739	S	770	V	A	05/18/50	-	-	-	-	-	3.00	-
235	395418-0803355	DR	970	V	D	05/03/85	1905	100	-	8	-	-	-

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
236	395418-0804246	DR	730	V	A	05/18/50	–	82	–	6	62.00 R	–	–
237	395418-0804746	D	710	V	A	05/18/50	–	28	–	48	–	–	–
237-A	395418-0804817	DR	640	V	A	04/12/52	–	75	–	12	–	450	C
238	395418-0804818	R	632	V	A	03/05/54	–	62	–	156	44.00 R	3500	LD, T
239	395419-0804745	DR	720	V	M	05/18/50	1945	120	–	6	–	2.06	–
240	395421-0803509	DR	1360	H	D	05/02/85	1940	125	100	8	–	–	C
241	395423-0803714	DR	1260	S	D	05/17/85	1963	95	–	8	–	–	adequate for 5 people
242	395424-0804318	DR	1170	H	D	06/04/85	1945	69	–	10	–	12.00	–
243	395425-0804654	S	1150	S	D	07/30/85	–	–	–	–	–	0.12	C
244	395428-0803808	S	1310	S	D	06/04/85	–	–	–	–	–	1.38	C
244-A	395428-0804823	DR	630	V	A	04/21/52	–	73	–	12	–	500	C
245	395428-0804824	R	630	V	A	03/05/54	1952	60	–	156	46.00 R	3500	LD, T
246	395431-0803809	DR	1360	H	D	06/04/85	–	70	–	6	–	–	C, adequate for 2 people
247	395432-0803815	S	1260	S	D	06/04/85	–	–	–	–	–	–	flows all year
248	395433-0803811	S	1310	S	D	06/04/85	–	–	–	–	–	–	flows all year
249	395435-0804012	DR	1350	H	D	08/12/82	1942	63	–	6	33.00 R	–	C, adequate for 1 family
250	395437-0803843	DR	1340	H	D	05/02/85	1976	98	18	10	49.03 M	–	M, LC, LG
251	395438-0803842	DR	1340	H	D	05/02/85	1974	117	–	10	59.53 M	–	–
251-A	395458-0804749	DR	640	V	A	08/13/52	–	68	–	12	–	530	C
251-B	395440-0804821	DR	630	V	A	08/22/53	–	59	–	12	–	520	C
252	395459-0804442	DR	680	V	A	04/17/42	–	100	–	8	60.00 R	200	T
253	395459-0804749	R	635	V	A	03/18/54	1953	67	–	156	–	2000	LD
254	395502-0804442	DR	680	V	A	04/17/42	–	100	–	8	60.00 R	300	T
255	395506-0804106	DR	1280	H	D	05/24/85	1984	103	20	10	85.50 M	1.92	M, LC, LG
256	395526-0803153	DR	1310	H	D	05/17/85	–	42	–	6	22.23 M	–	C, M, adequate for 4 people
257	395537-0804515	DR	642	V	A	04/18/42	1931	68	48	15	29.00 R	750	C, T, composite sample with sites 259, 261
258	395538-0803959	DR	1310	H	D	05/03/85	–	143	25	10	23.36 M	–	M, LC, LD, LE, T, inadequate for domestic use
259	395540-0804517	DR	645	V	A	04/18/42	1931	68	48	15	30.00 R	750	C, T, composite sample with sites 257, 261
260	395546-0803814	DR	1200	S	D	05/02/85	1958	75	26	8	30.00 R	–	C
261	395546-0804520	DR	647	V	A	04/18/42	1937	70	–	18	30.00 R	750	C, composite sample with sites 257, 259
262	395547-0804142	DR	1270	H	D	06/06/85	1960	168	–	12	–	–	C, adequate for 4 people
263	395558-0803336	S	1170	S	D	06/05/85	–	–	–	–	–	3.50	C, adequate for 5 people
264	395600-0804318	S	1200	S	D	09/25/42	–	–	–	–	–	1.20	reported never dry in 75 years
265	395601-0804519	DR	650	V	A	05/17/50	1948	98	–	10	60.00 R	250	C
266	395601-0804528	DR	640	V	A	06/26/84	1962	75	64	30	37.00 R	450	casing diameter 24 inches from 0-37 feet
267	395603-0803333	DR	1290	H	D	06/05/85	–	90	–	8	–	–	inadequate for domestic use

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
268	395603-0803333	DR	1290	H	D	06/05/85	—	91	—	4	—	—	inadequate for domestic use, filled with cement
269	395606-0804515	DR	650	V	A	05/17/50	1947	104	—	10	60.00 R	130	C
270	395606-0804520	DR	660	V	A	05/17/50	1941	100	—	8	60.00 R	130	C
271	395608-0804523	DR	650	V	A	05/31/50	—	100	—	10	64.48 M	—	M
272	395609-0804530	DR	640	V	A	08/13/82	1978	66	11	24	—	600	C
273	395609-0804530	DR	640	V	A	06/26/84	1960	64	54	20	37.00 R	352	casing diameter is 26 inches from 0-48 feet
274	395610-0804513	DR	680	V	A	04/18/42	1940	109	109	8.5	60.00 R	200	casing perforated from 101-109 feet
275	395610-0804525	DR	660	V	A	05/17/50	1942	98	—	10	60.00 R	150	C
276	395613-0804532	DR	640	V	A	06/26/84	1965	67	47	24	37.00 R	330	—
277	395615-0804532	DR	640	V	A	06/26/84	1966	64	44	12	37.00 R	250	—
278	395616-0803253	DR	1320	H	D	08/11/82	1978	175	30	8	—	13.00	C
279	395617-0804533	DR	640	V	A	06/26/84	1960	67	52	24	37.00 R	421	casing diameter is 30 inches from 0-46 feet
280	395619-0803739	DR	1180	S	D	04/23/85	—	—	—	—	—	—	—
281	395620-0803741	DR	1200	S	D	04/23/85	1940	135	—	—	—	—	—
282	395621-0804534	DR	640	V	A	06/26/84	1961	70	55	26	37.00 R	—	—
283	395626-0803532	DR	1280	S	D	05/03/85	1950	90	20	8	50.00 R	—	C, inadequate for 1 family in late summer
284	395632-0803533	DR	1340	H	D	05/03/85	1979	80	—	8	—	—	—
285	395646-0804511	DR	680	V	A	06/28/84	—	85	—	6	—	65.00	—
286	395646-0804512	DR	680	V	A	06/28/84	—	100	—	8	—	99.00	—
287	395647-0804509	DR	680	V	A	06/28/84	1962	85	—	—	—	100	—
288	395649-0804529	DR	670	V	A	08/11/82	—	90	—	12	—	—	C
289	395650-0804532	DR	670	V	A	06/27/84	1940	90	—	8	—	100	C, composite sample with site 291
290	395651-0804529	DR	670	V	A	06/27/84	1969	98	—	12	—	250	—
291	395655-0804531	DR	650	V	A	11/19/43	—	100	—	8	—	100	C, composite sample with site 289
292	395658-0804448	DR	680	V	M	06/06/85	—	37	—	6	10.45 M	—	C, M, hydrogen sulfide gas present
293	395713-0803631	DR	1300	H	D	08/12/82	1968	96	22	8	70.00 R	8.00	—
294	395722-0804352	DR	720	V	M	04/25/85	1973	38	—	8	—	—	—
295	395723-0804353	DR	720	V	M	04/25/85	1965	35	30	8	—	—	—
296	395726-0804040	S	1270	S	D	06/06/85	—	—	—	—	—	1.00	C, adequate for 4 people
297	395730-0803832	S	1240	S	D	04/18/85	—	—	—	—	—	1.50	—
298	395731-0803826	DR	1318	H	D	06/28/85	1985	150	63	6	121.50 M	—	M, T, LD, LG
299	395731-0803909	DR	1330	H	D	03/01/85	1965	115	—	8	—	—	adequate for 5 people
300	395733-0803837	S	1250	S	D	04/18/85	—	—	—	—	—	2.12	C, M
301	395734-0803841	DR	1300	H	D	07/03/85	1985	150	44	6	144.77 M	—	M, T, LD, LG
302	395734-0804220	DR	840	V	D	08/12/82	1972	35	10	6	6.00 R	—	hydrogen sulfide gas present, adequate for 1 family
303	395735-0803848	DR	1300	H	D	04/11/85	1957	96	—	8	23.86 M	—	C, M, T

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
304	395736-0803306	DR	840	S	M	04/30/85	1981	82	40	8	32.04 M	0.50	C
305	395736-0803848	D	1310	H	D	03/01/85	–	20	–	36	13.83 M	–	M, T
306	395737-0803849	DR	1310	H	D	03/01/85	–	24	–	3	16.45 M	–	M
307	395737-0803849	DR	1310	H	D	04/11/85	–	59	17	8	21.93 M	–	LC, LE, LG, M, T
308	395738-0803900	D	1320	H	D	03/01/85	–	20	–	36	15.05 M	–	M
309	395739-0803843	S	1180	S	D	03/01/85	–	–	–	–	–	–	site wet, but no flow
310	395744-0803843	S	1160	S	D	03/01/85	–	–	–	–	–	0.12	–
311	395745-0803837	DR	1300	H	D	03/01/85	–	150	–	8	–	–	–
312	395746-0803838	D	1300	H	D	03/01/85	–	35	–	36	22.00 R	–	owner reports dry since summer 1984
313	395747-0803117	DR	840	V	M	05/01/85	1963	100	30	8	19.30 M		C, LD
314	395747-0803117	DR	840	V	M	05/01/85	1963	55	40	8	–	–	–
315	395748-0803853	S	1100	S	D	03/01/85	–	–	–	–	–	0.01	M
316	395752-0803847	S	1200	S	D	03/01/85	–	–	–	–	–	0.00	owner reports dry since 02/84
317	395800-0803508	DR	800	V	M	04/30/85	–	55	–	6	11.81 M	–	C
318	395805-0803608	DR	790	V	M	04/23/85	1981	43	40	12	–	–	–
319	395807-0803602	DR	780	V	M	04/23/85	1983	40	35	6	–	–	–
320	395807-0804302	DR	1300	H	D	06/06/85	1965	157	10	8	117.72 M	10.00	C, M, 6 inch perforated casing from 17-157 feet
321	395815-0804315	DR	1220	H	D	06/06/85	–	130	–	8	–	–	inadequate for domestic use
322	395824-0803923	S	1170	S	D	02/28/85	–	–	–	–	–	0.00	owner reports dry since 10/81
323	395828-0803656	DR	860	S	M	05/01/85	1959	100	–	6	–	–	C
324	395830-0803951	DR	1300	H	D	02/27/85	1984	130	–	10	84.62 M	–	M
325	395831-0803924	S	1240	S	D	02/28/85	–	–	–	–	–	0.00	owner reports dry since 10/81
326	395832-0803930	DR	1280	H	D	02/27/85	1976	109	30	10	83.62 M	–	M
327	395833-0803926	DR	1300	H	D	02/28/85	1981	140	20	10	100.45 M	2.00	C, LC, M
328	395834-0803927	D	1300	H	D	02/28/85	–	22	–	36	–	–	owner reports dry since 12/80
329	395836-0803935	DR	1260	H	D	02/28/85	1978	130	20	12	–	–	owner reports dry more often after site undermined
330	395837-0803924	DR	1310	H	D	02/27/85	1979	122	19	10	93.50 M	–	LC, LG, M
331	395837-0803925	DR	1310	H	D	02/27/85	1962	120	20	8	–	–	inadequate for domestic use before site undermined
332	395840-0804212	DR	1360	H	D	06/04/85	1941	65	–	6	–	–	adequate supply for 6 people
333	395846-0803858	D	1230	H	D	02/27/85	–	35	–	36	19.95 M	–	M, T
334	395847-0803858	DR	1230	H	D	02/27/85	–	92	20	8	–	–	Sites 334 and 335 used together for small dairy.
335	395847-0803859	DR	1230	H	D	02/27/85	–	92	20	8	–	–	After sites undermined, yield inadequate for use.
336	395849-0803858	S	1160	S	D	02/27/85	–	–	–	–	–	0.12	M
337	395849-0803900	S	1150	S	D	02/27/85	–	–	–	–	–	0.00	owner reports dry since 08/81
337-A	395852-0804359	DR	660	V	M	06/28/84	1955	120	–	10	–	–	–
337-B	395853-0804400	DR	660	V	A	06/28/84	1955	120	–	8	–	300	–

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
338	395853-0804404	DR	650	V	A	08/26/82	1956	70	–	16	–	325	C
338-A	395855-0804400	DR	660	V	A	06/28/84	1955	120	–	10	–	225	–
338-B	395855-0804402	DR	660	V	A	06/28/84	1965	65	–	16	24.00 R	–	–
339	395857-0804400	DR	650	V	A	11/09/49	1940	75	–	8	43.00 R	300	C, T, composite sample with sites 340, 341
340	395857-0804400	DR	650	V	A	11/09/49	1940	75	–	10	43.00 R	300	C, T, composite sample with sites 339, 341
341	395857-0804400	DR	650	V	A	11/09/49	1940	75	–	10	43.00 R	300	C, T, composite sample with sites 339, 340
342	395913-0804303	DR	1240	H	D	08/12/82	–	–	–	–	–	–	C, adequate supply for 1 family
343	395914-0803854	DR	1260	H	D	08/12/82	1967	133	15	10	88.00 M	–	M, adequate supply for watering 2 dozen cows
344	395914-0803956	S	1190	S	D	02/28/85	–	–	–	–	–	0.00	owner reports dry since 1979
345	395918-0804006	S	1230	S	D	02/28/85	–	–	–	–	–	–	owner reports flows all year
346	395921-0803909	DR	1260	H	D	02/28/85	1976	158	20	8	–	–	–
347	395921-0803909	DR	1260	H	D	02/28/85	1958	100	20	6	55.00 R	–	owner reports well went dry in 1975
348	395921-0803929	S	1070	S	D	02/28/85	–	–	–	–	–	0.00	owner reports dry since 1979
349	395921-0804006	S	1220	S	D	02/23/85	–	–	–	–	–	–	C, owner reports flows all year
350	395924-0803947	S	1120	S	D	02/28/85	–	–	–	–	–	0.00	owner reports dry since 1979
351	395924-0804006	DR	1260	H	D	02/28/85	–	80	–	6	–	–	C, inadequate for domestic use in dry weather
352	395925-0803218	DR	1360	H	D	04/30/85	1983	151	20	8	79.80 M	–	C, adequate supply for 1 family
353	395927-0803813	DR	1260	H	D	02/28/85	1959	100	18	8	–	–	adequate supply for domestic use
354	395927-0803953	S	1200	S	D	02/28/85	–	–	–	–	–	0.00	owner reports dry since 1979
355	395938-0803207	DR	1320	S	D	08/17/82	–	102	–	6	–	–	adequate for 1 family if careful
356	395940-0803509	DR	1120	S	D	05/01/85	1979	117	15	10	–	–	C
357	395940-0803904	D	1230	H	D	02/28/85	–	33	–	48	21.24 M	–	M, T
358	395943-0803907	DR	1230	H	D	04/17/85	1954	114	–	6	72.60 M	16.00	–
359	395944-0803934	DR	1245	S	D	04/17/85	1975	101	21	10	35.34 M	–	M, adequate for 2 people
360	395944-0803939	DR	1230	S	D	04/17/85	1961	157	40	8	–	–	adequate for 4 people
361	395946-0803912	DR	1245	H	D	04/17/85	1981	144	20	10	102.63 M	–	M, LC, LG
362	395946-0803912	DR	1245	H	D	04/17/85	1954	100	–	6	56.53 M	–	inadequate for domestic use
363	395949-0803921	S	1240	S	D	04/17/85	–	–	–	–	–	–	discharge point changed from 1 to many in 1984
364	400003-0803617	DR	1270	H	D	06/06/85	–	–	–	–	–	–	C, adequate for 3 people
365	400006-0803822	DR	740	V	M	05/03/85	1982	56	20	8	50.36 M	1.92	M, yield value was when drilled-much less now
366	400021-0803805	DR	740	V	M	05/16/85	1965	38	–	8	10.35 M	–	recovers to static in 4 hours after pumped dry
367	400024-0803806	DR	740	V	M	05/16/85	1982	140	–	10	14.94 M	4.40	LG, 6 inch perforated casing from 0-140 feet
368	400027-0803837	DR	720	V	M	05/02/85	1965	50	–	6	–	–	inad. for dom. use since 05/82-adeq. for 4 people before
369	400027-0803838	DR	720	V	M	05/02/85	1975	28	–	6	20.03 M	–	inad. for dom. use since 05/82 - no problems before
370	400030-0803814	DR	720	V	M	04/30/85	1982	160	–	10	93.65 M	1.50	M
371	400030-0803814	DR	720	V	M	04/30/85	1973	50	–	8	–	–	inad. for dom. use since 06/80 - no problems before

Table A-1--Records of wells and springs (continued)

Site number	Latitude - Longitude	Site type	Elevation (feet)	Topo-graphic setting	Geo-logic unit	Date of visit	Year drilled	Well depth (feet)	Casing length (feet)	Well diameter (inches)	Water level (feet)	Yield (gallons per minute)	Remarks
372	400031-0803815	DR	720	V	M	04/30/85	1963	52	–	8	–	5.00	Yield was when drilled-inad. for dom. use now
373	400031-0803817	DR	720	V	M	04/30/85	1983	162	–	10	–	1.50	–
374	400031-0803817	DR	720	V	M	04/30/85	1983	160	–	12	98.32 M	6.60	C, M, hydrogen sulfide gas present
375	400032-0803813	DR	720	V	M	04/30/85	1981	156	–	8	–	0.50	–
376	400032-0803813	DR	720	V	M	04/30/85	1981	134	23	10	48.10 M	0.50	LC, LG, M, T
377	400032-0803847	DR	780	S	M	05/02/85	1960	156	–	6	–	–	adequate for 8 people
378	400035-0803812	DR	735	V	M	05/02/85	1984	65	40	10	24.92 M	–	M, adequate for 3 people
379	400035-0803858	DR	740	V	M	05/03/85	1974	50	–	6	25.37 M	–	M, adequate for 3 people
380	400041-0803341	D	1420	H	D	04/30/85	1795	41	–	–	25.78 M	–	C
381	400042-0803657	S	1240	S	D	03/06/85	–	–	–	–	–	5.83	–
382	400043-0803122	DR	1340	H	D	04/30/85	–	75	–	10	–	–	C
383	400048-0804236	DR	1240	H	D	05/21/85	1984	98	20	10	75.87 M	–	C, adequate for 4 people
384	400049-0804234	DR	1240	H	D	05/21/85	1973	89	20	10	44.63 M	–	–
385	400050-0804413	DR	650	V	A	08/31/82	–	–	–	–	–	–	C
386	400054-0803740	DR	1310	H	D	03/19/85	1981	64	18	10	dry M	1.17	LC, LG, M, originally drilled to 130 feet-caved in
387	400055-0803708	S	1270	S	D	03/15/85	–	–	–	–	–	0.00	owner reports dry since summer 1983
388	400057-0803719	DR	1325	H	D	03/15/85	1977	83	20	10	35.60 M	21.00	LC, M, T
389	400100-0803712	S	1280	S	D	03/15/85	–	–	–	–	–	0.00	owner reports dry since summer 1983
390	400103-0803654	S	1240	S	D	03/06/85	–	–	–	–	–	0.75	–
391	400104-0803647	S	1260	S	D	03/06/85	–	–	–	–	–	0.38	C, M
392	400104-0803655	S	1250	S	D	03/06/85	–	–	–	–	–	0.75	–
393	400104-0803706	DR	1310	H	D	03/19/85	1983	190	–	8	–	–	inadequate for 5 people
394	400104-0803706	DR	1310	H	D	03/19/85	1983	130	–	8	–	–	adequate for 5 people when used with site 393
395	400105-0803652	D	1300	H	D	03/06/85	–	26	–	48	23.00 M	–	dry in fall
396	400116-0804042	S	1210	S	D	05/21/85	–	–	–	–	–	0.50	C, M
397	400116-0804037	DR	1230	H	D	05/20/85	–	140	24	8	–	–	C, adequate for 2 people
398	400120-0803607	DR	1290	H	D	03/06/55	1950	45	–	12	–	–	adequate for 2 people
399	400120-0803645	DR	1350	H	D	07/23/85	1973	98	18	10	48.37 M	4.50	LC, LG, M, T
400	400124-0803644	DR	1340	S	D	03/15/85	1976	150	–	10	100.80 M	–	M, adequate for 1 family
401	400125-0803646	DR	1220	S	D	03/19/85	1972	100	–	8	95.72 M	–	adequate for 2 people, inadequate for 7 people
402	400128-0803636	DR	1340	S	D	03/15/85	1974	102	17	10	53.50 M	4.00	M
403	400130-0803630	DR	1240	S	D	03/19/85	1976	96	12	8	56.97 M	–	M, adequate for 5 people
404	400133-0803635	DR	1340	S	D	03/15/85	–	56	24	13.5	50.87 M	–	–
405	400143-0803643	S	1230	S	D	04/17/85	–	–	–	–	–	1.00	M
406	400147-0803647	DR	1340	H	D	04/17/85	1952	115	27	12	90.42 M	3.00	M

APPENDIX B

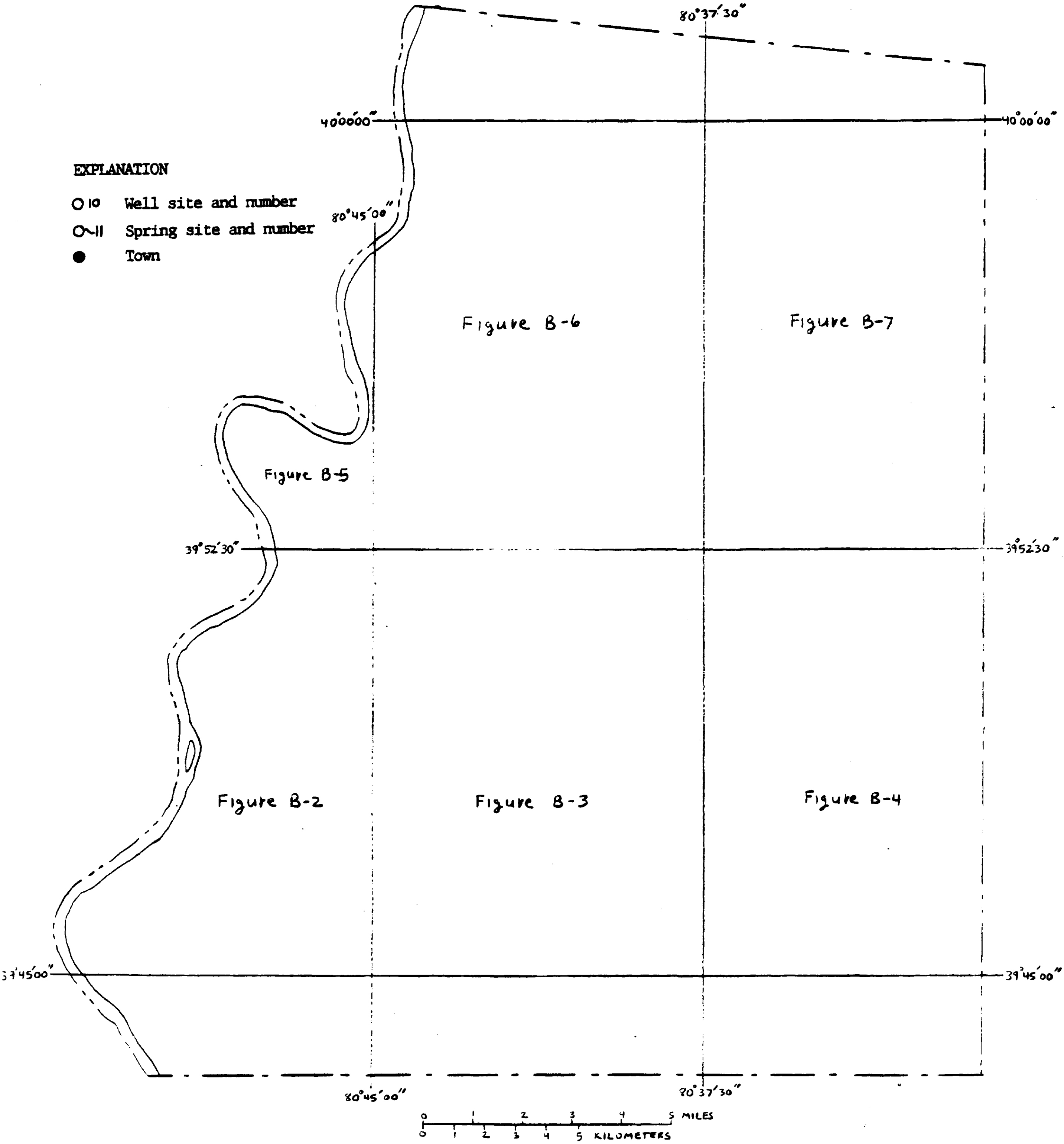


Figure B-1.--Location of figures B-2 to B-7.

Note: Base map from the West Virginia Geological and Economic Survey.

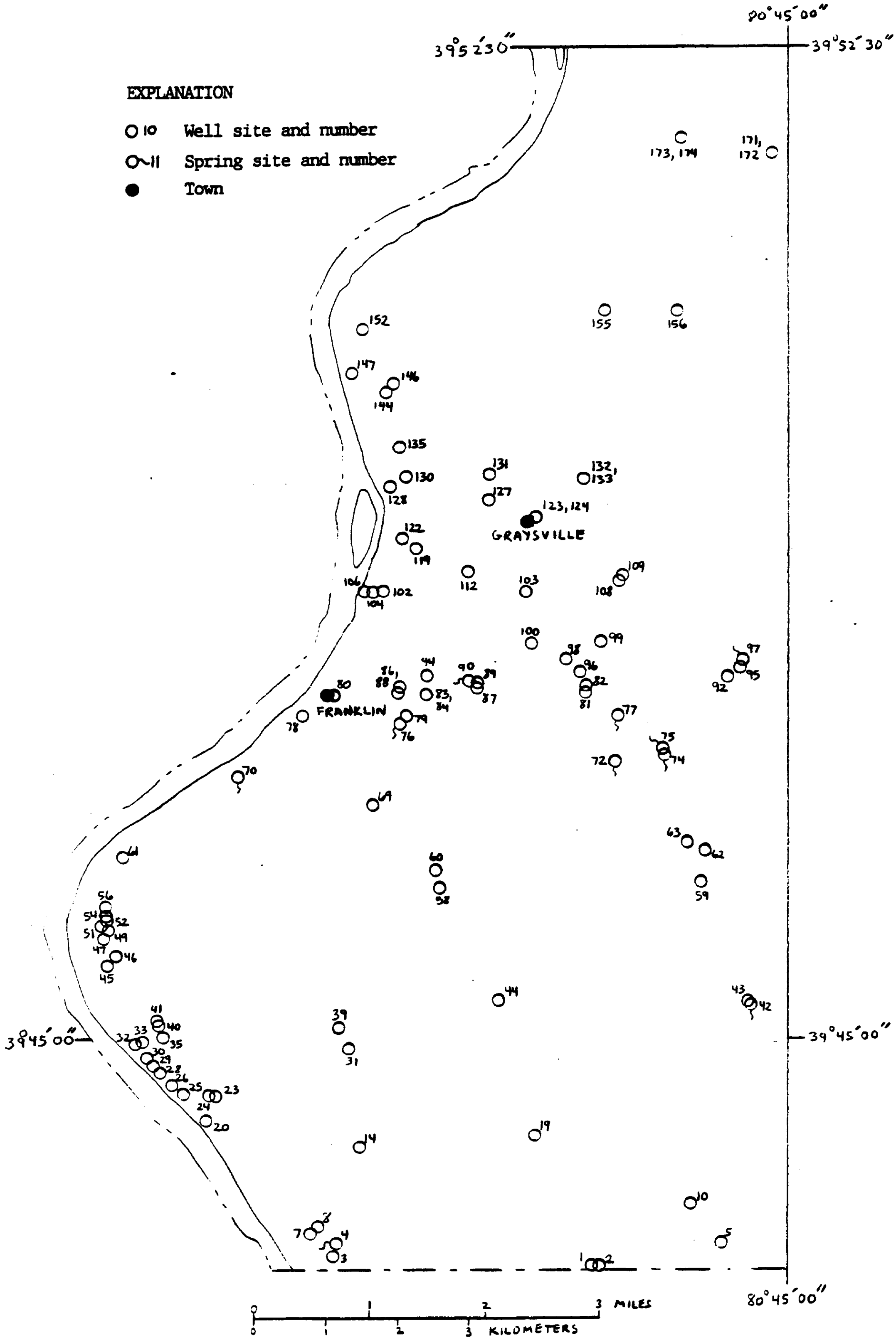


Figure B-2.--Location of well and spring sites.

Note: Base map from the West Virginia Geological and Economic Survey.

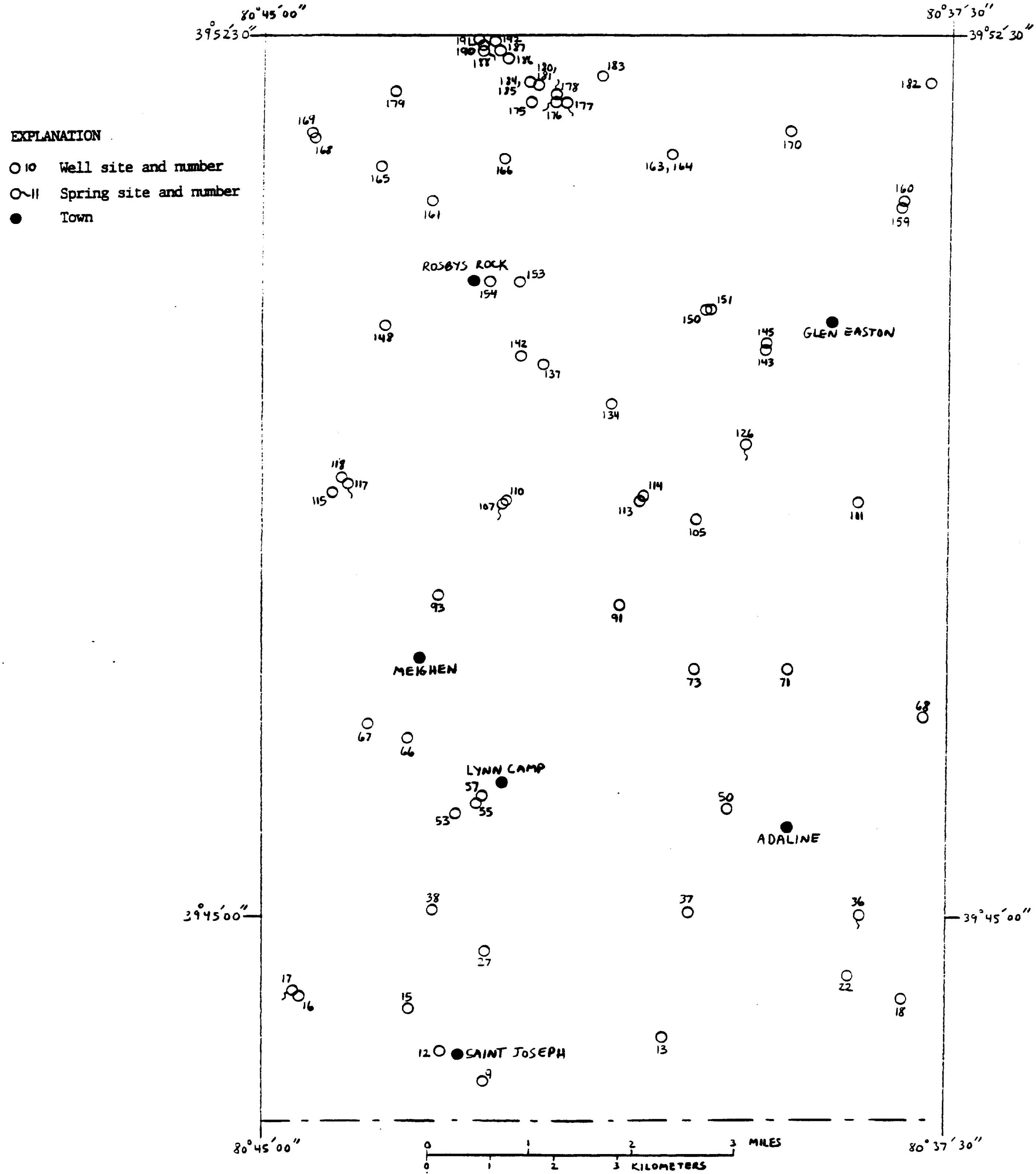


Figure B-3.--Location of well and spring sites (continued).

Note: Base map from the West Virginia Geological and Economic Survey.

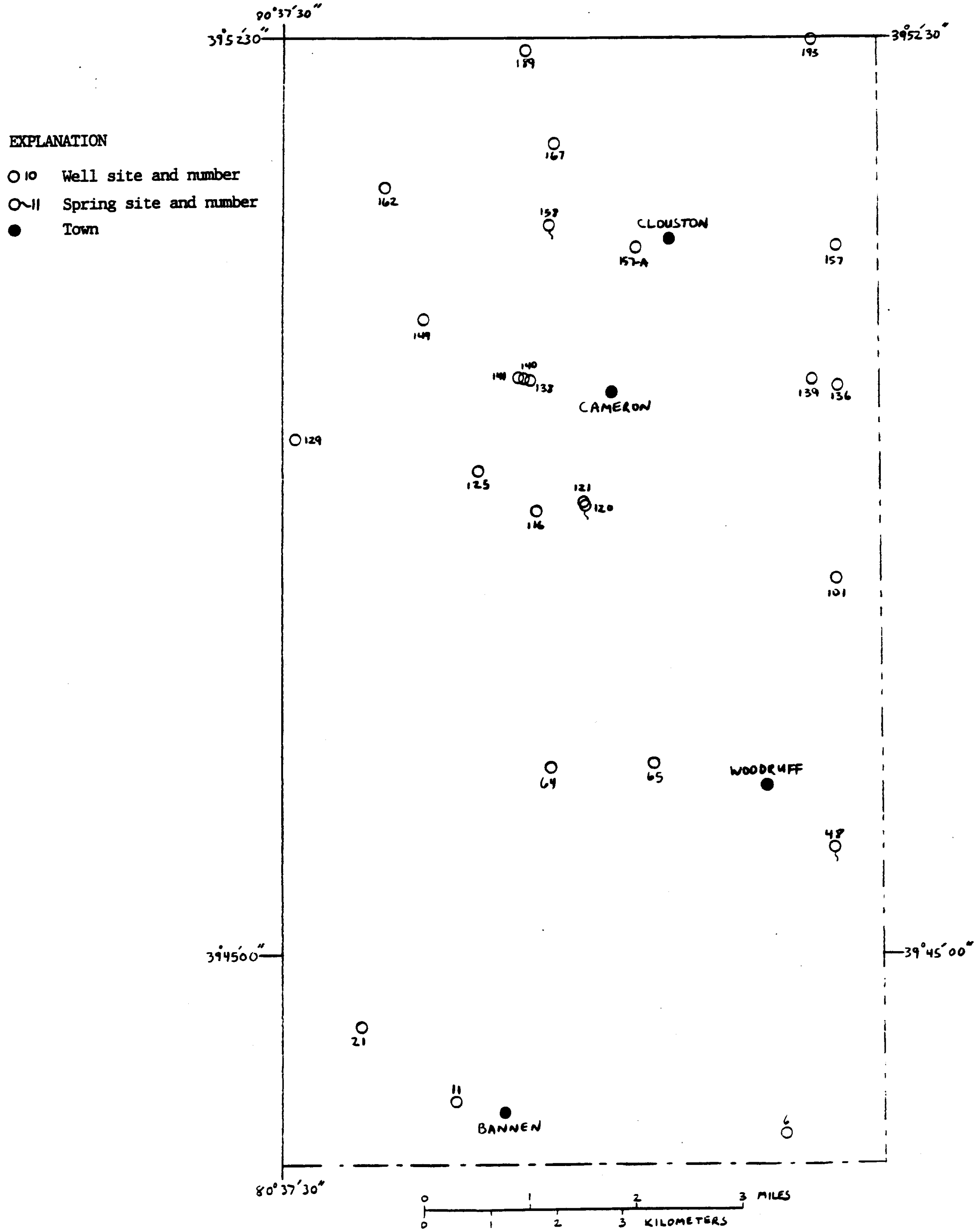


Figure B-4.—Location of well and spring sites (continued).

Note: Base map from the West Virginia Geological and Economic Survey.

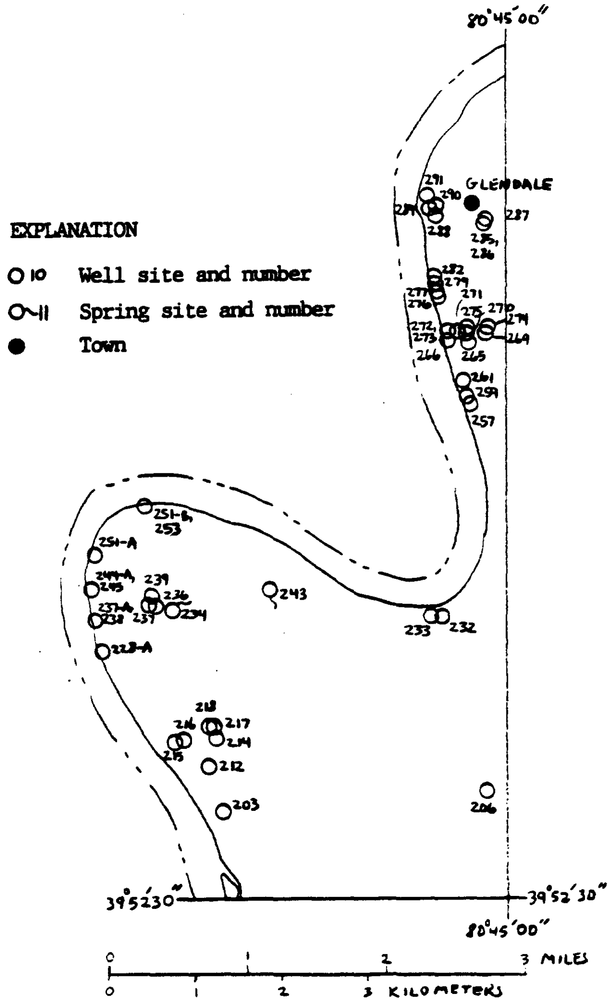


Figure B-5.—Location of well and spring sites (continued).

Note: Base map from the West Virginia Geological and Economic Survey.

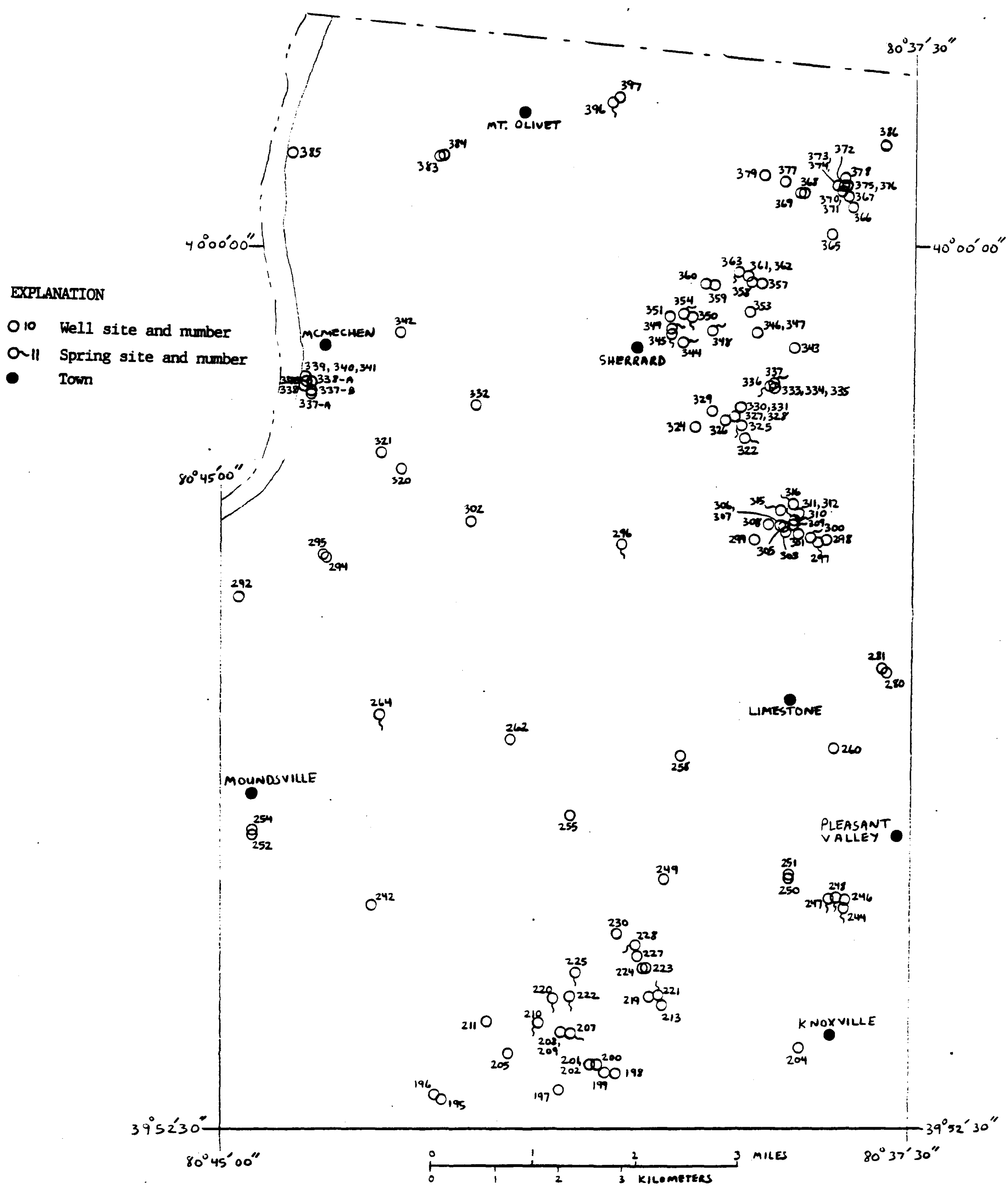


Figure B-6.—Location of well and spring sites (continued).

Note: Base map from the West Virginia Geological and Economic Survey.

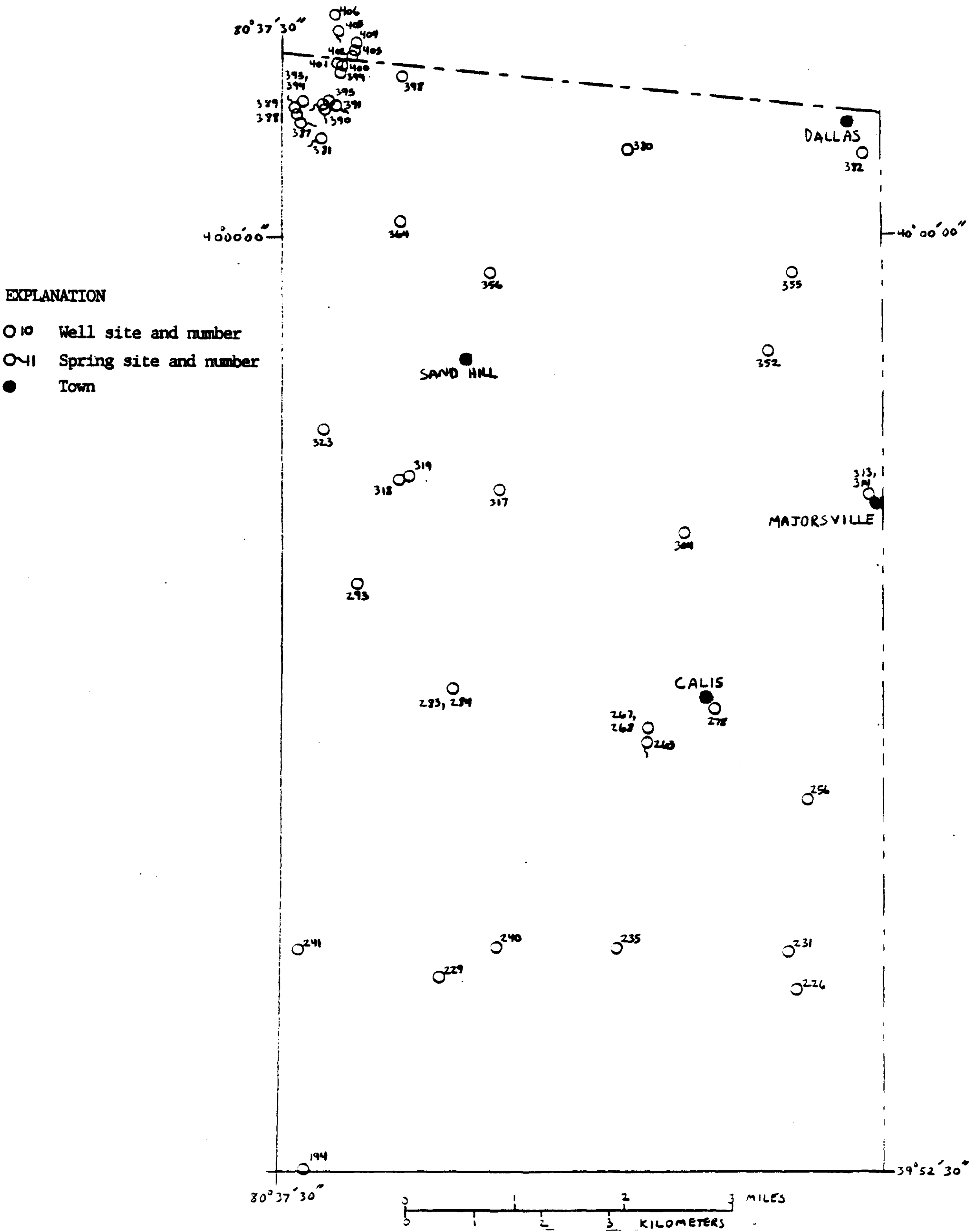


Figure B-7.--Location of well and spring sites (continued).

Note: Base map from the West Virginia Geological and Economic Survey.

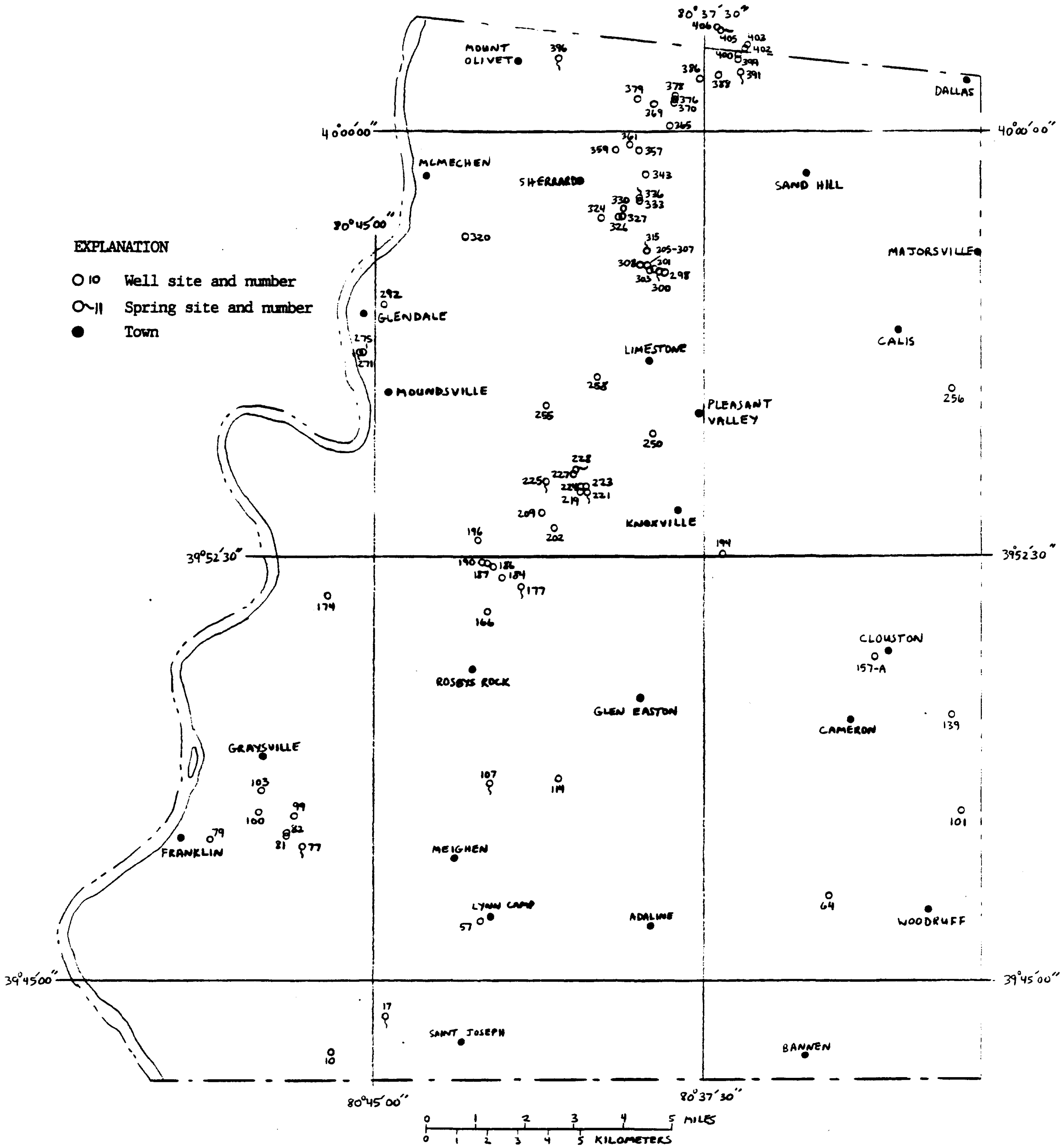


Figure B-8.--Location of water level and spring discharge monitoring sites.

Note: Base map from the West Virginia Geological and Economic Survey.

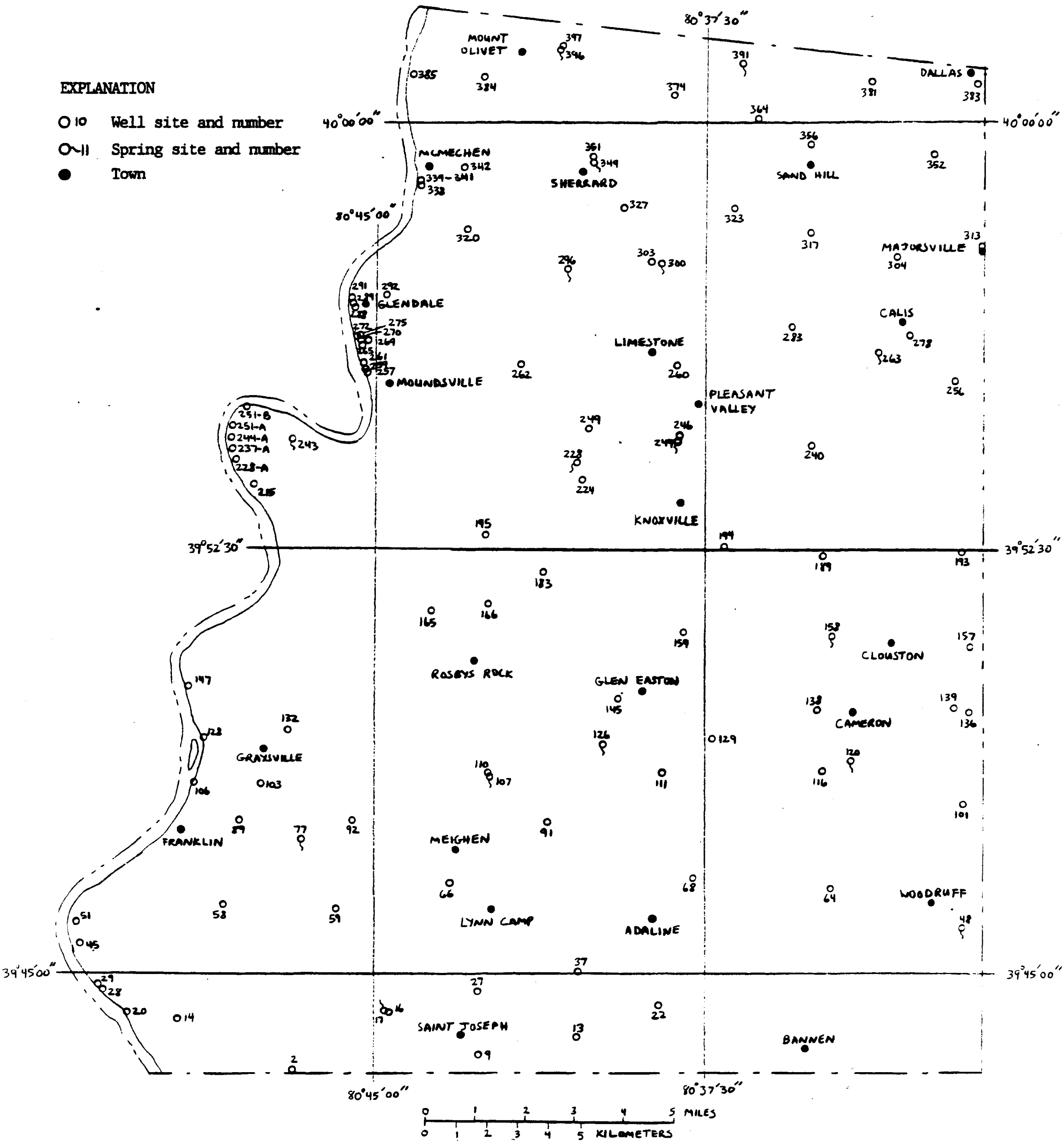
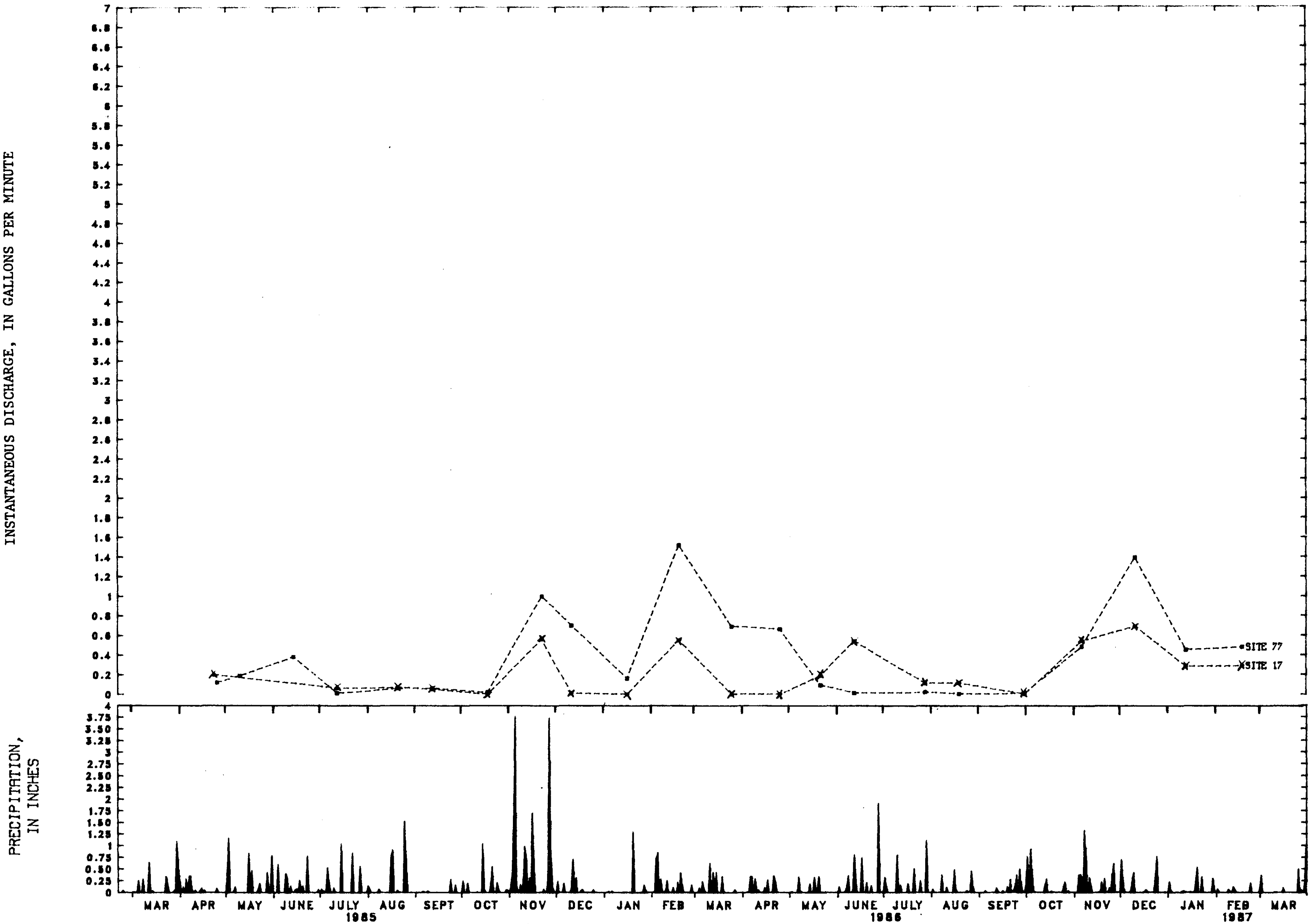


Figure B-9.--Location of ground-water sampling sites.

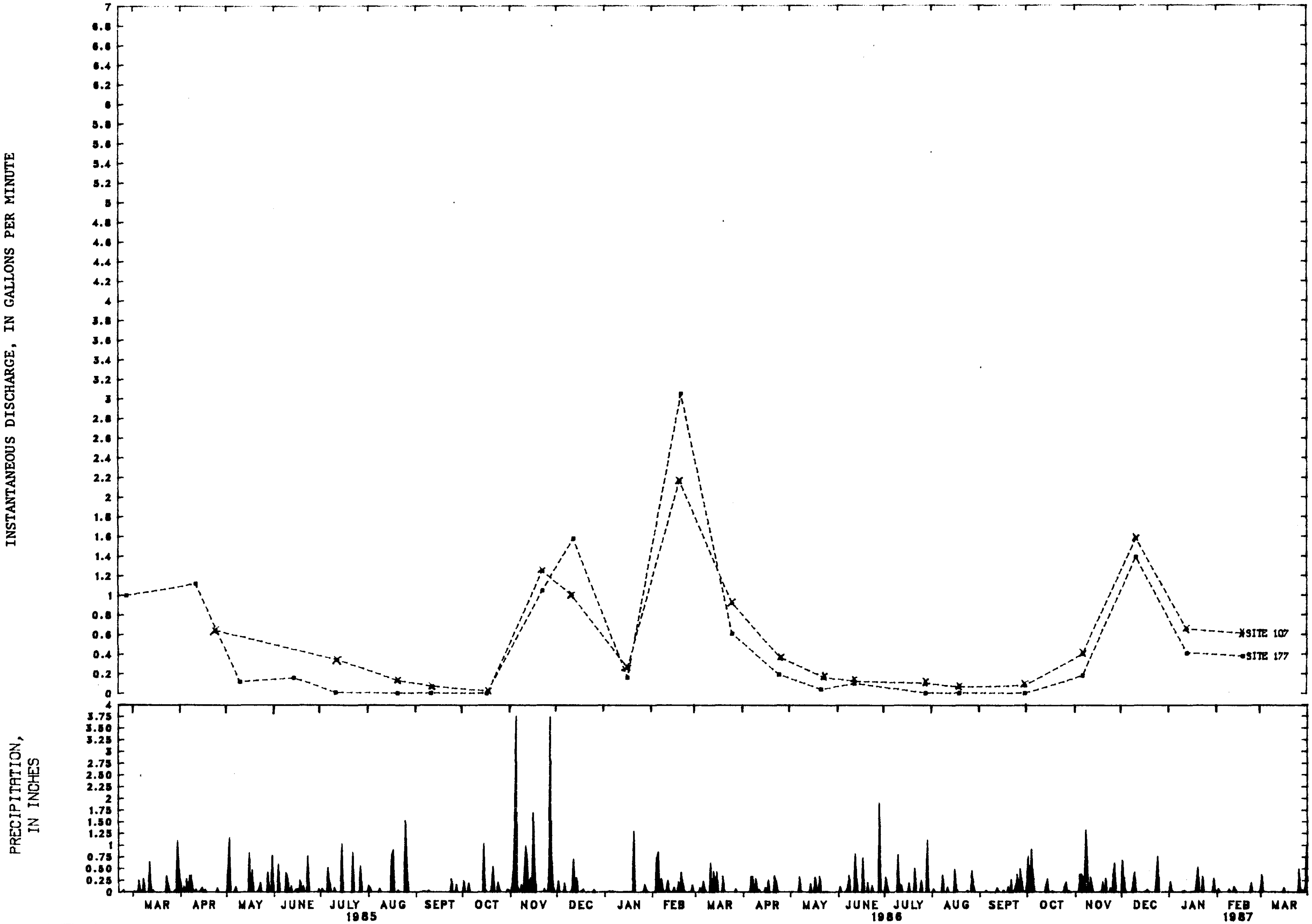
Note: Base map from the West Virginia Geological and Economic Survey.

APPENDIX C

Note: Appendix C consists of hydrographs of spring discharges and water levels in wells. The first seven pages are spring hydrographs and the remainder are hydrographs of water levels in wells. The hydrographs are arranged in the order of increasing site number. Dashed lines and symbols denote instantaneous water level measurements. Solid lines denote daily noon measurements made using a digital recorder. The vertical and horizontal scales of each hydrograph are the same, unless otherwise noted, so that the hydrographs can be easily compared. Precipitation data was compiled by the National Weather Service observer at Moundsville, WV. The graph of precipitation represents daily values. The monthly precipitation is the sum of the daily values. The mean precipitation for the period 1965-86 was calculated from the monthly values for the period.

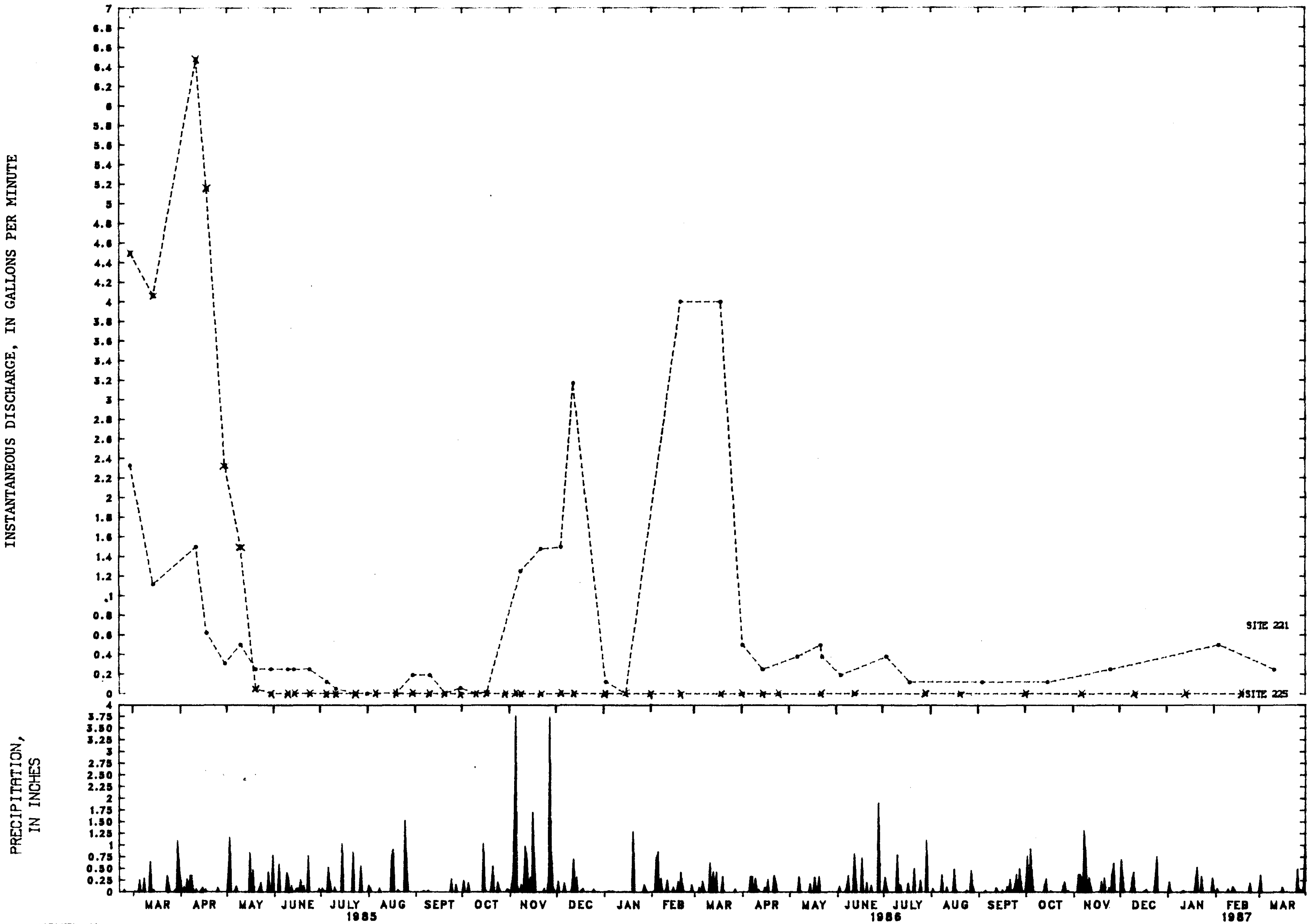


	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

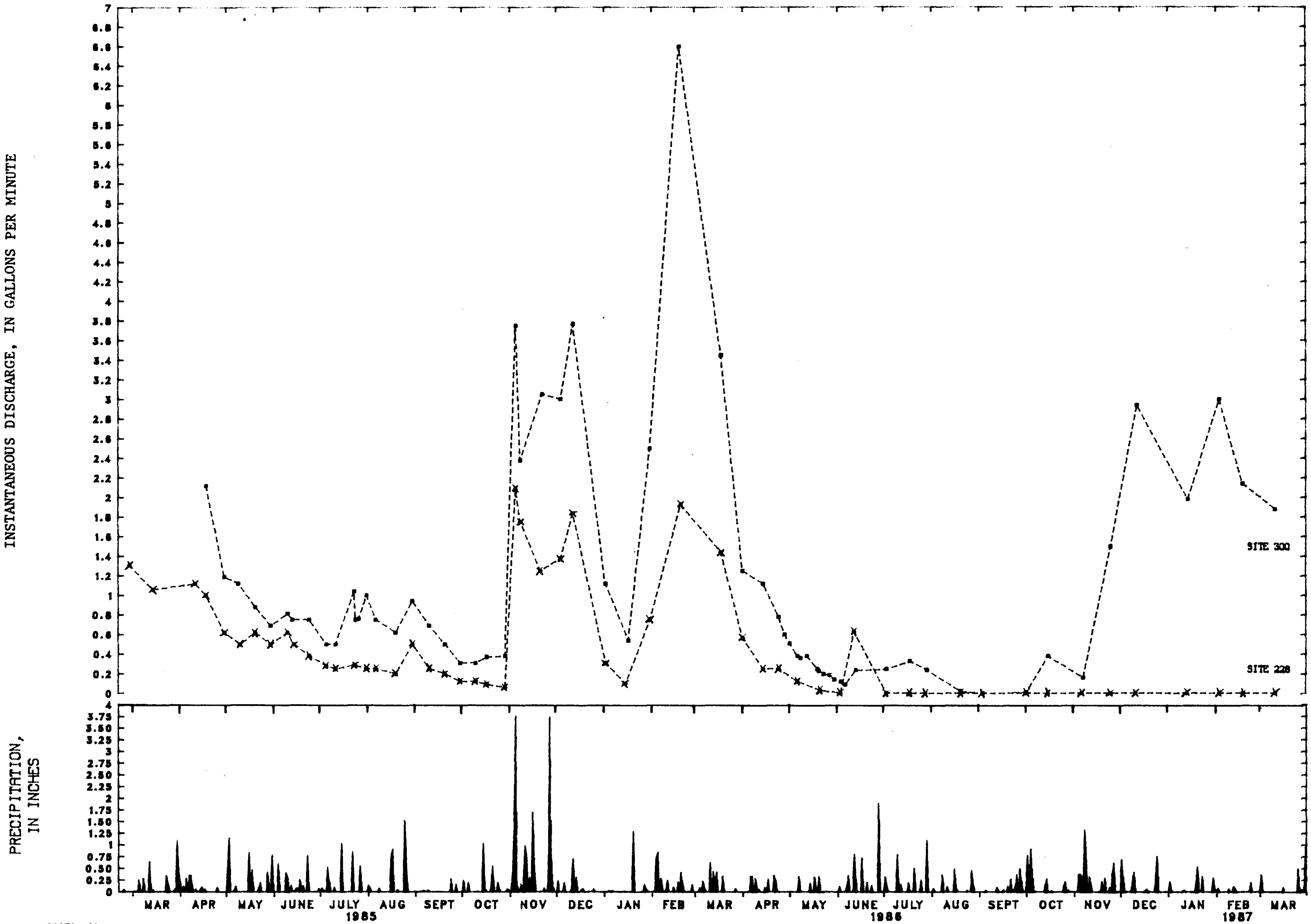


	MAR	APR	MAY	JUNE	JULY 1985	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

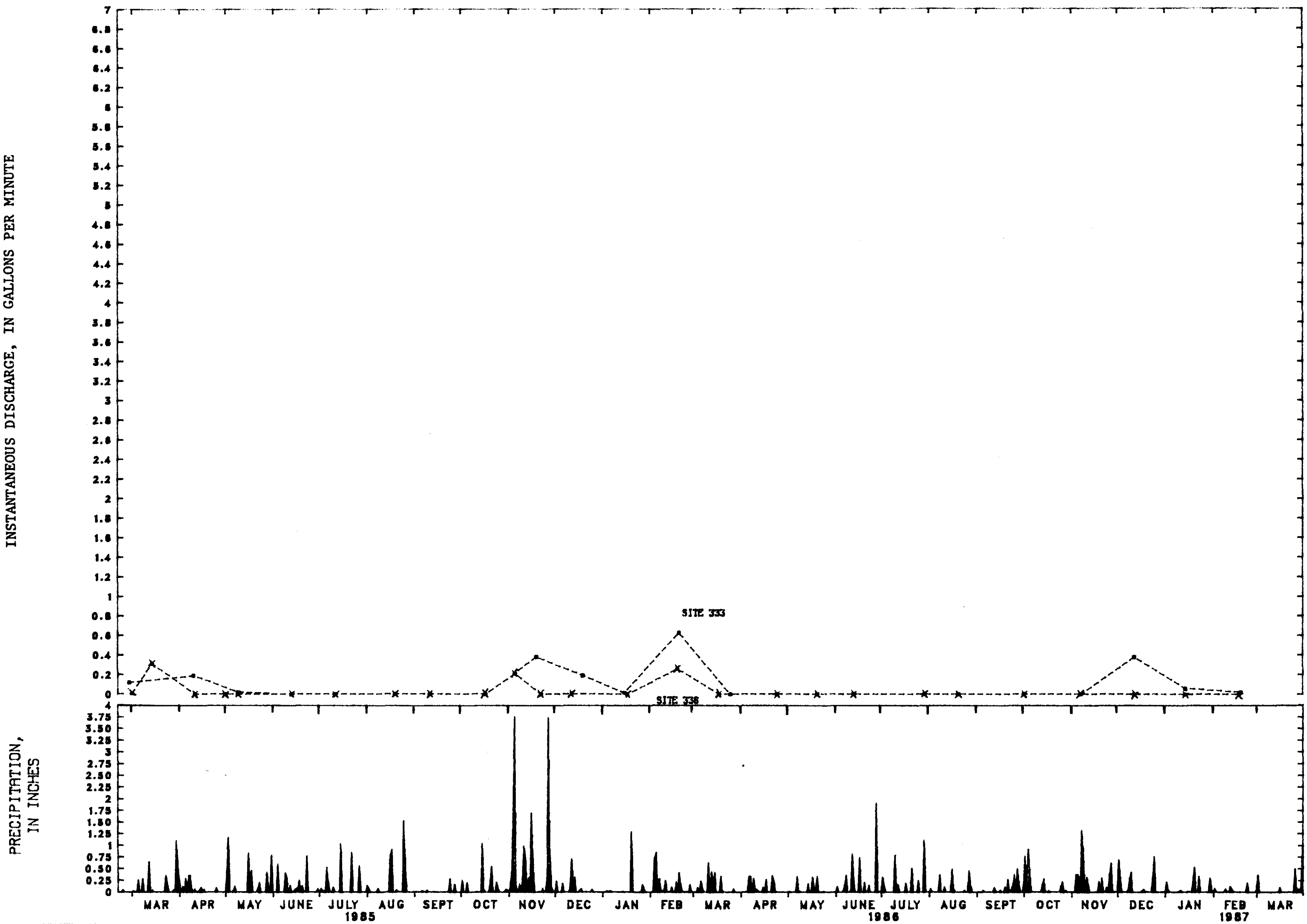
	APR	MAY	JUNE 1986	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB 1987	MAR
MONTHLY PRECIPITATION	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

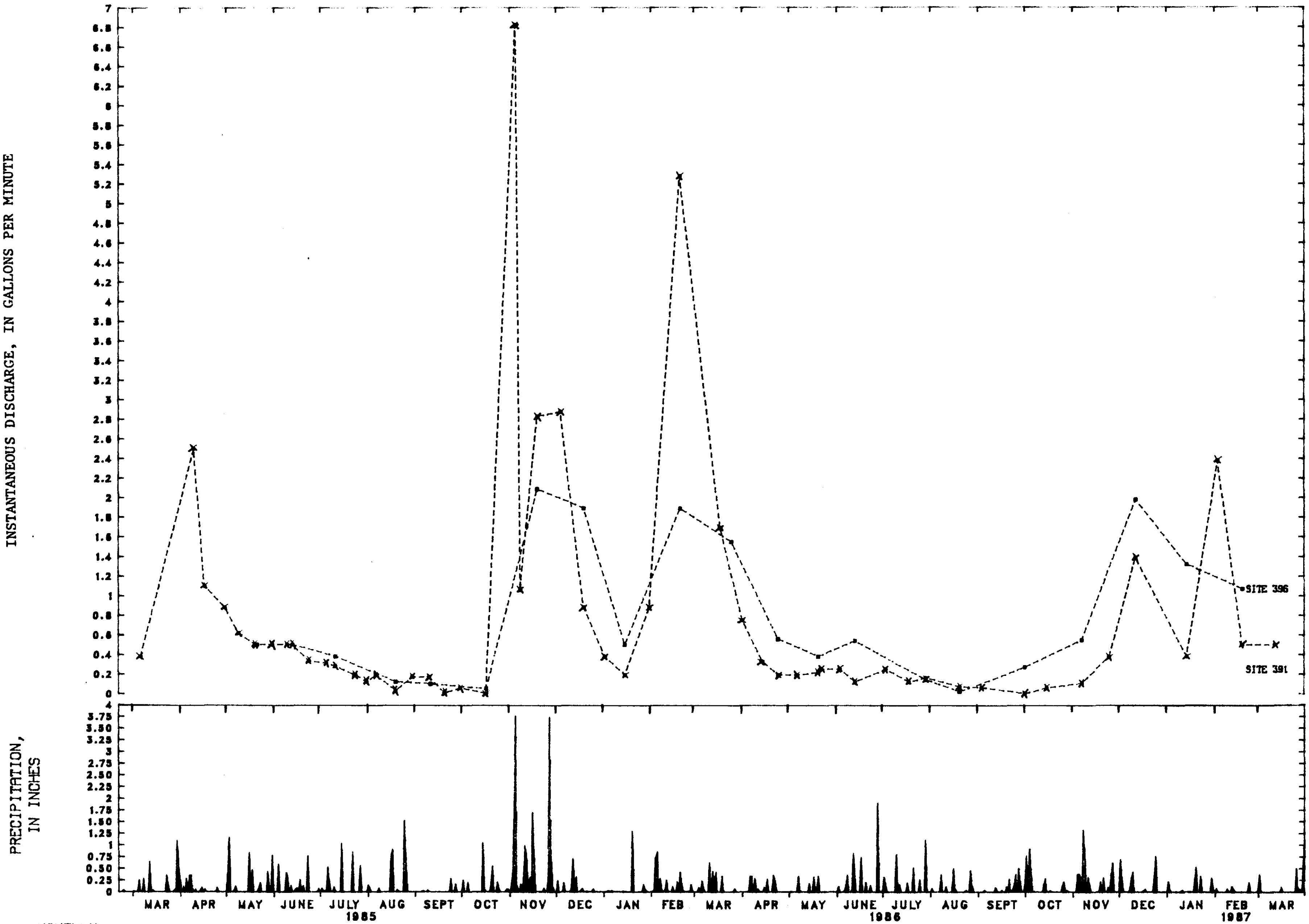


MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

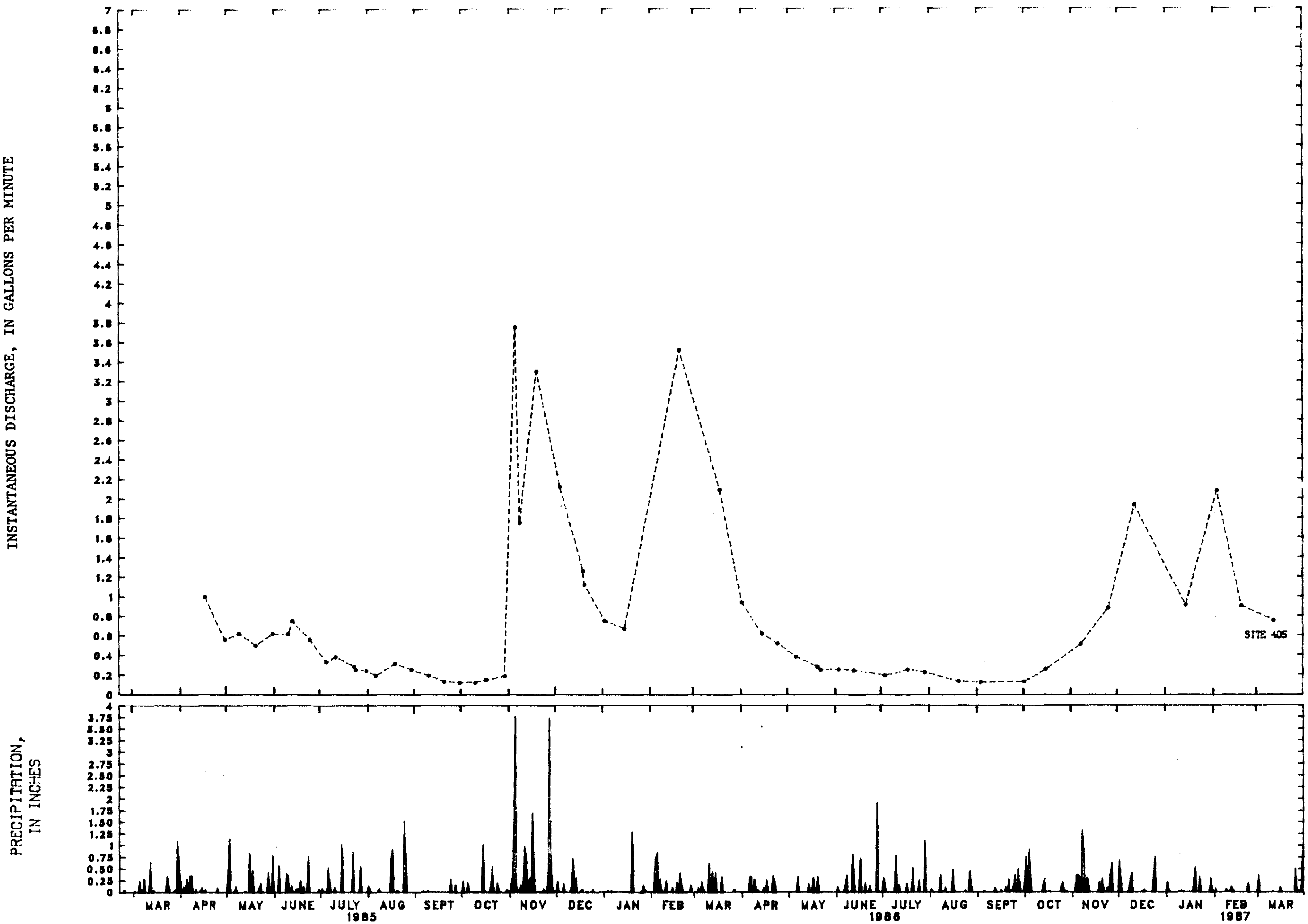


	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

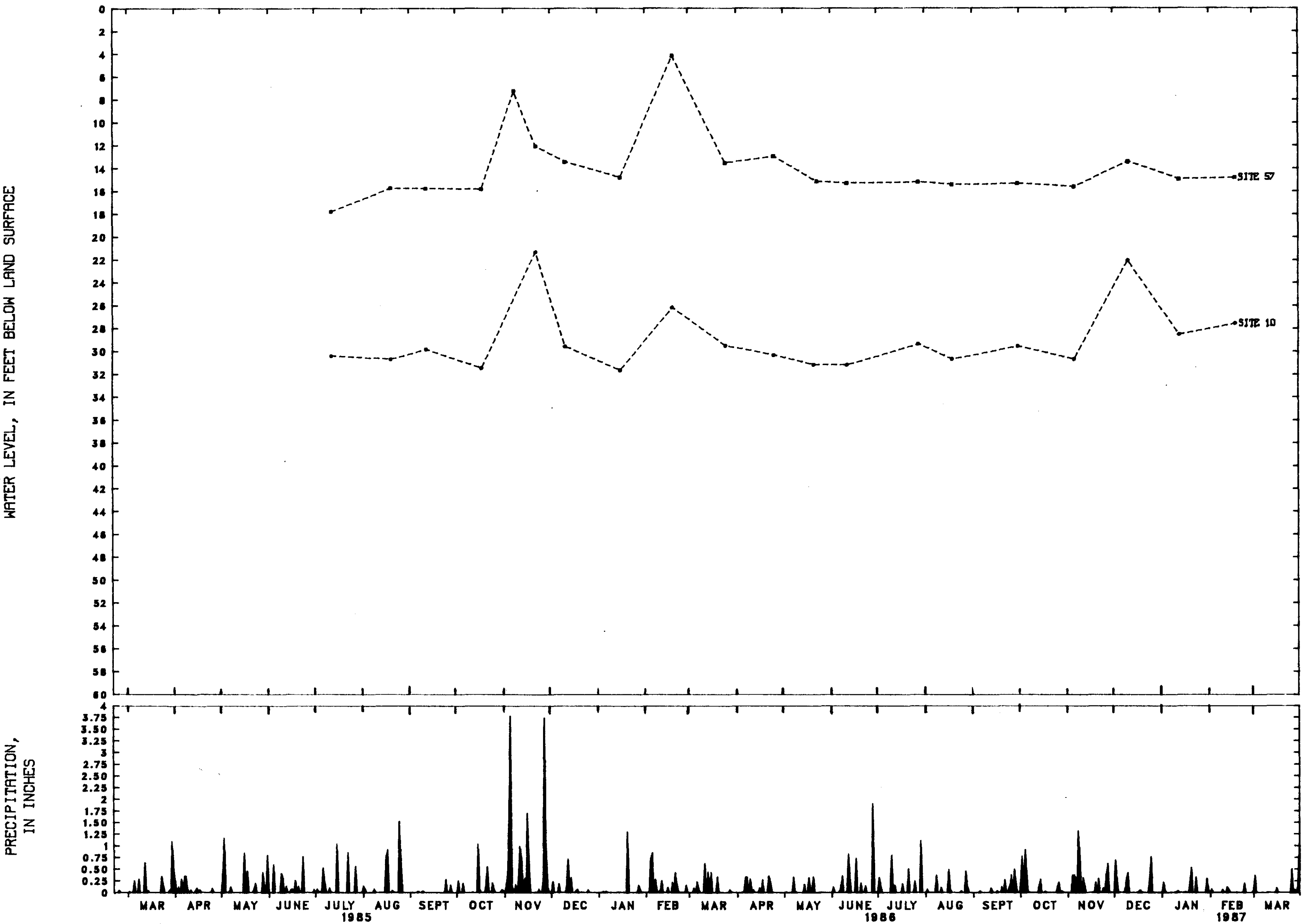
	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



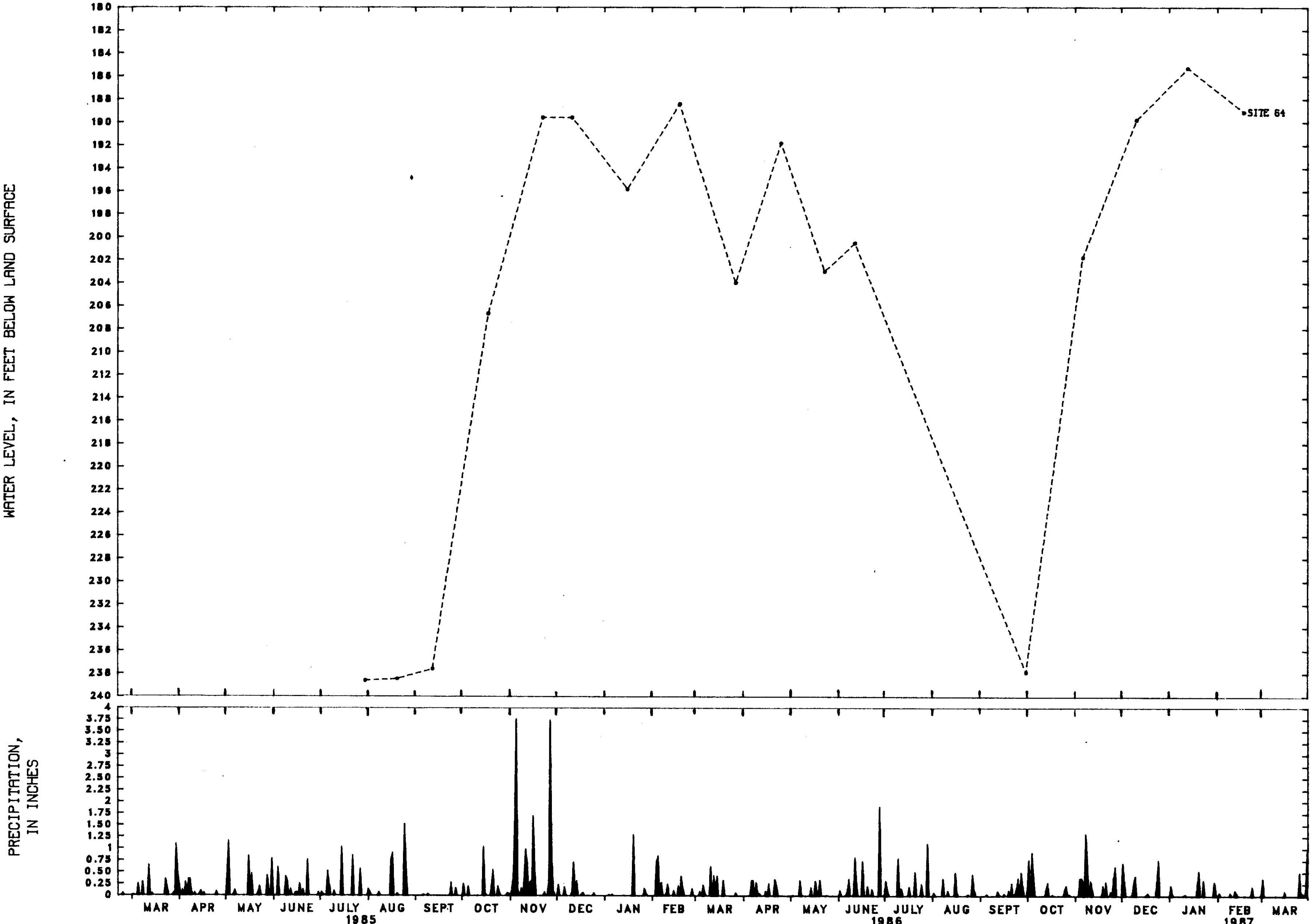
	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



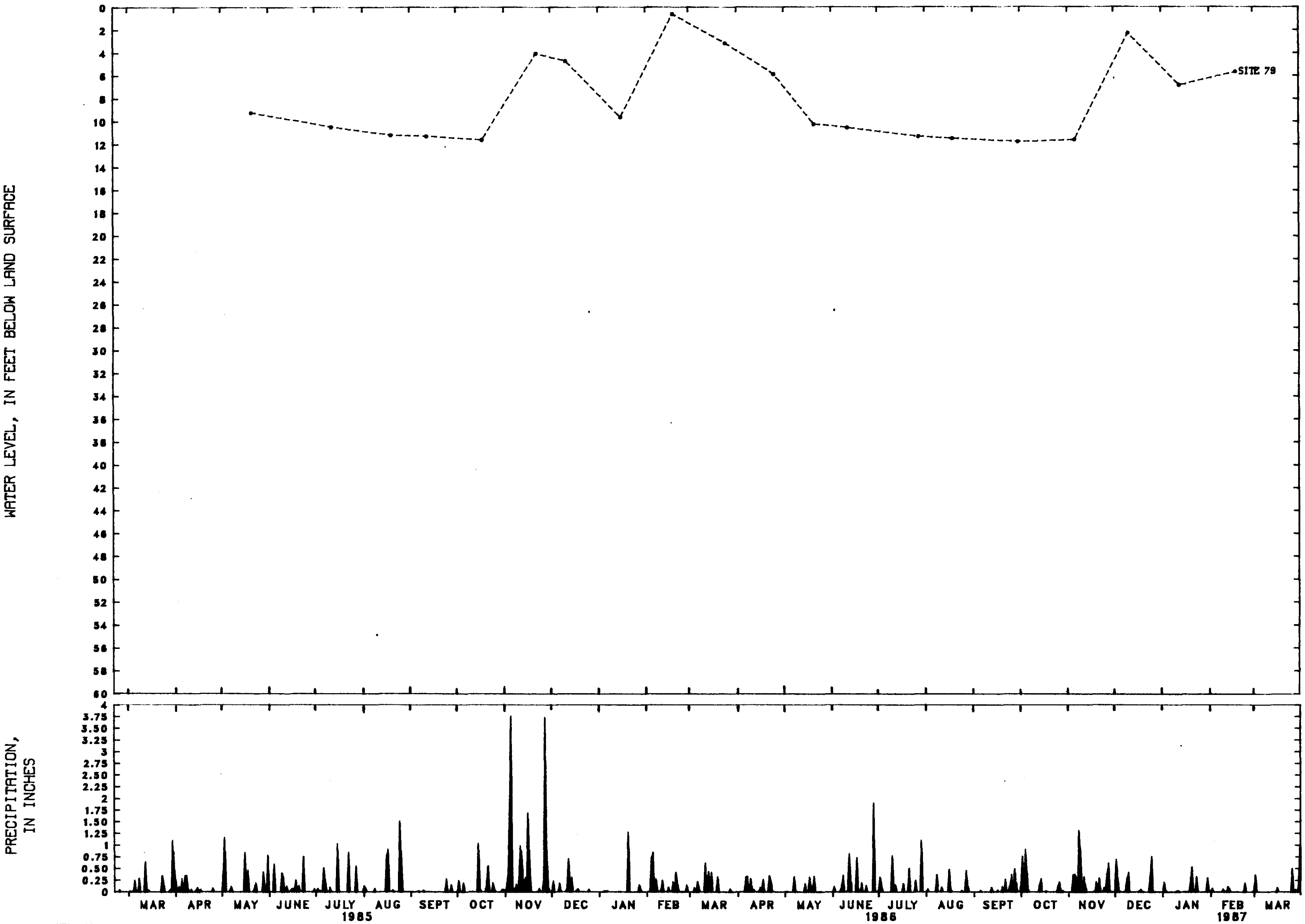
	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17'	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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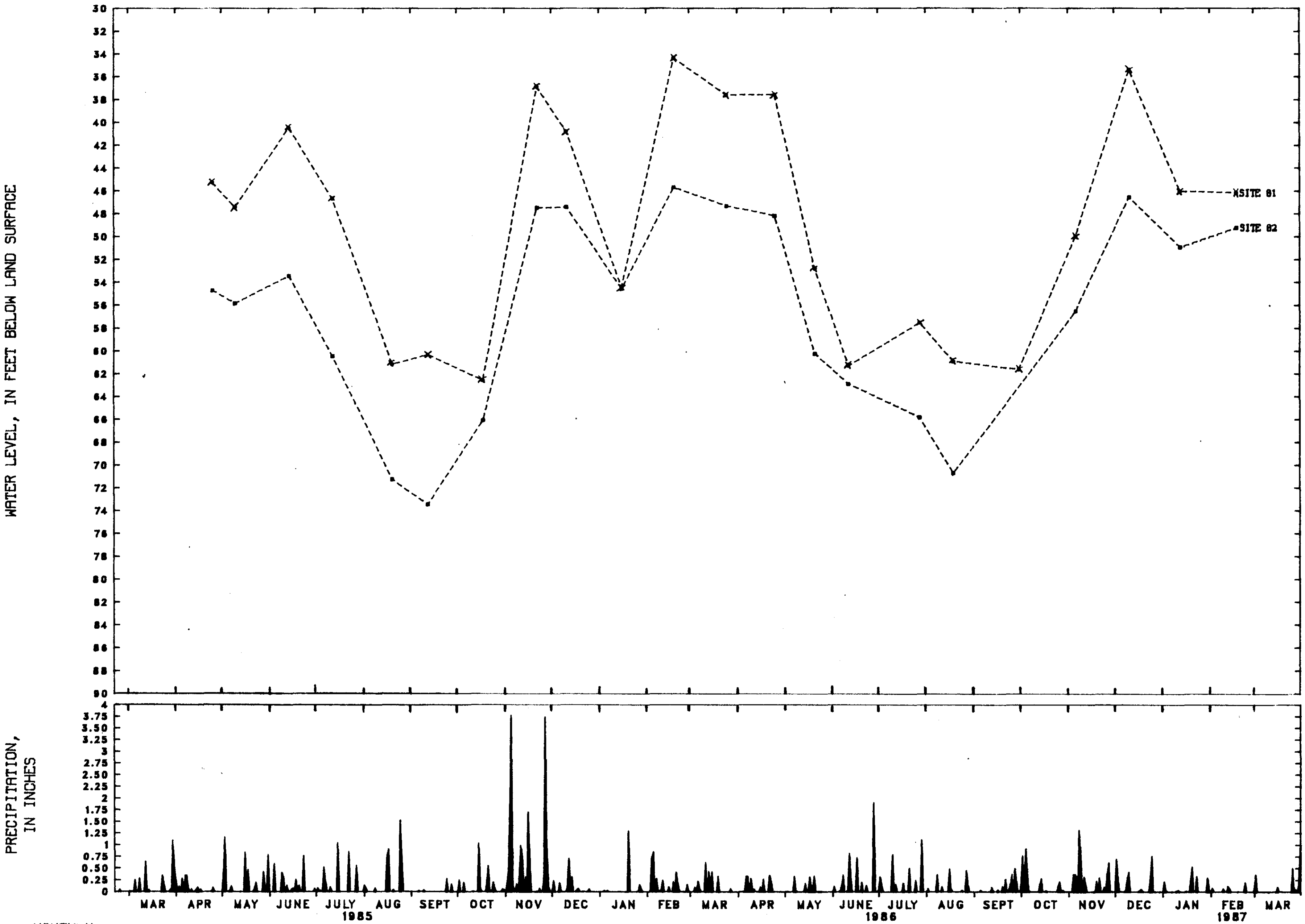
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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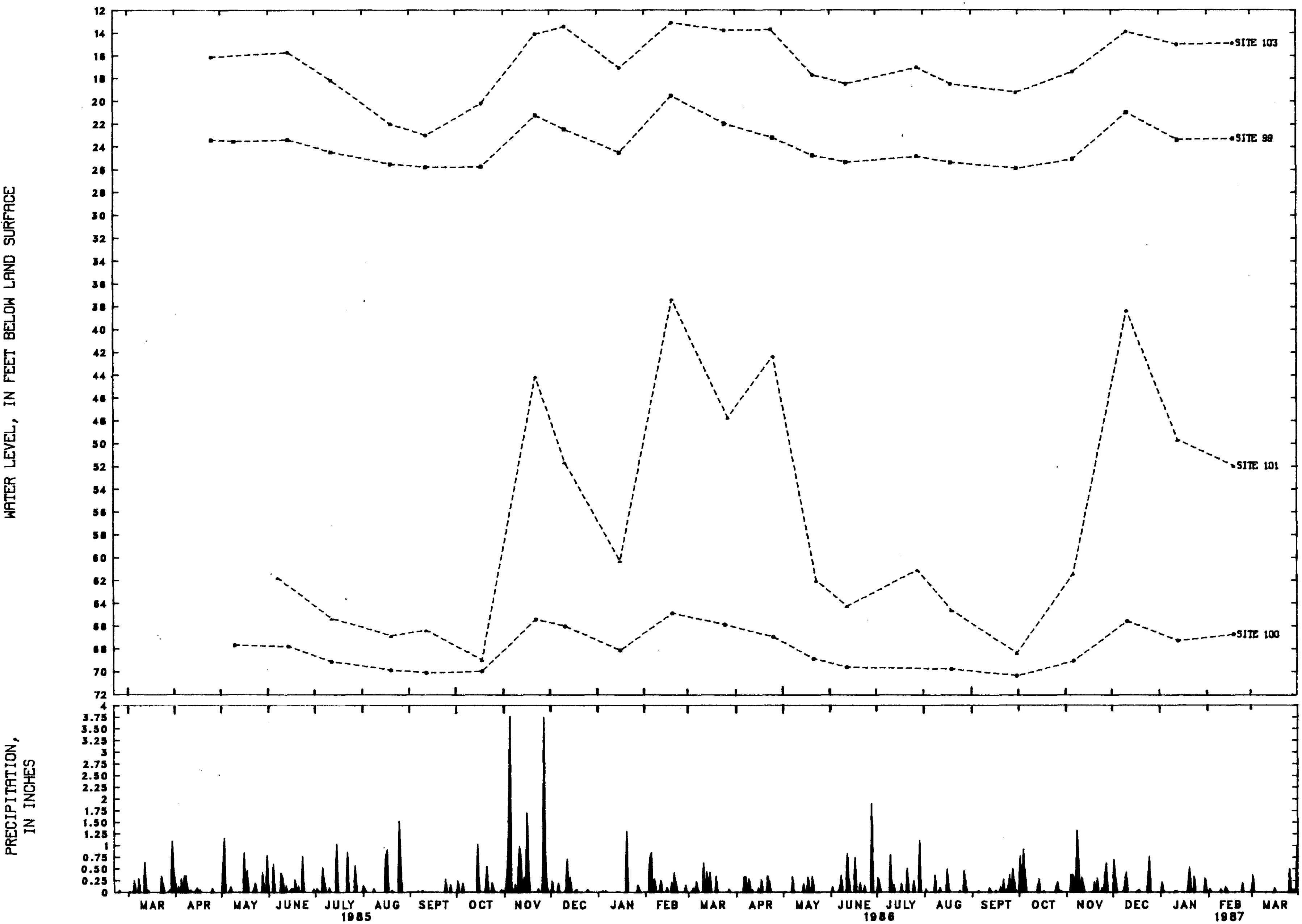
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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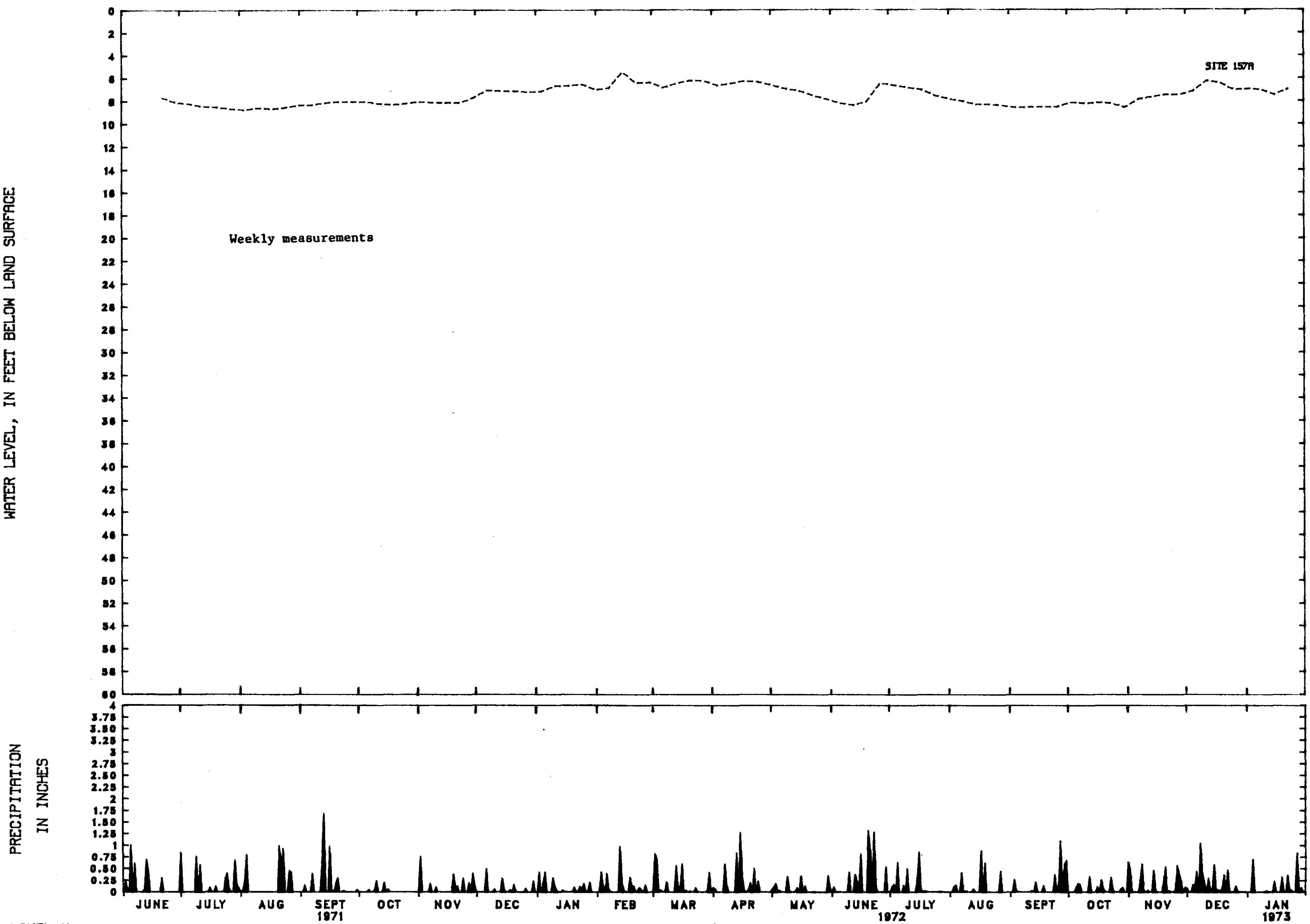
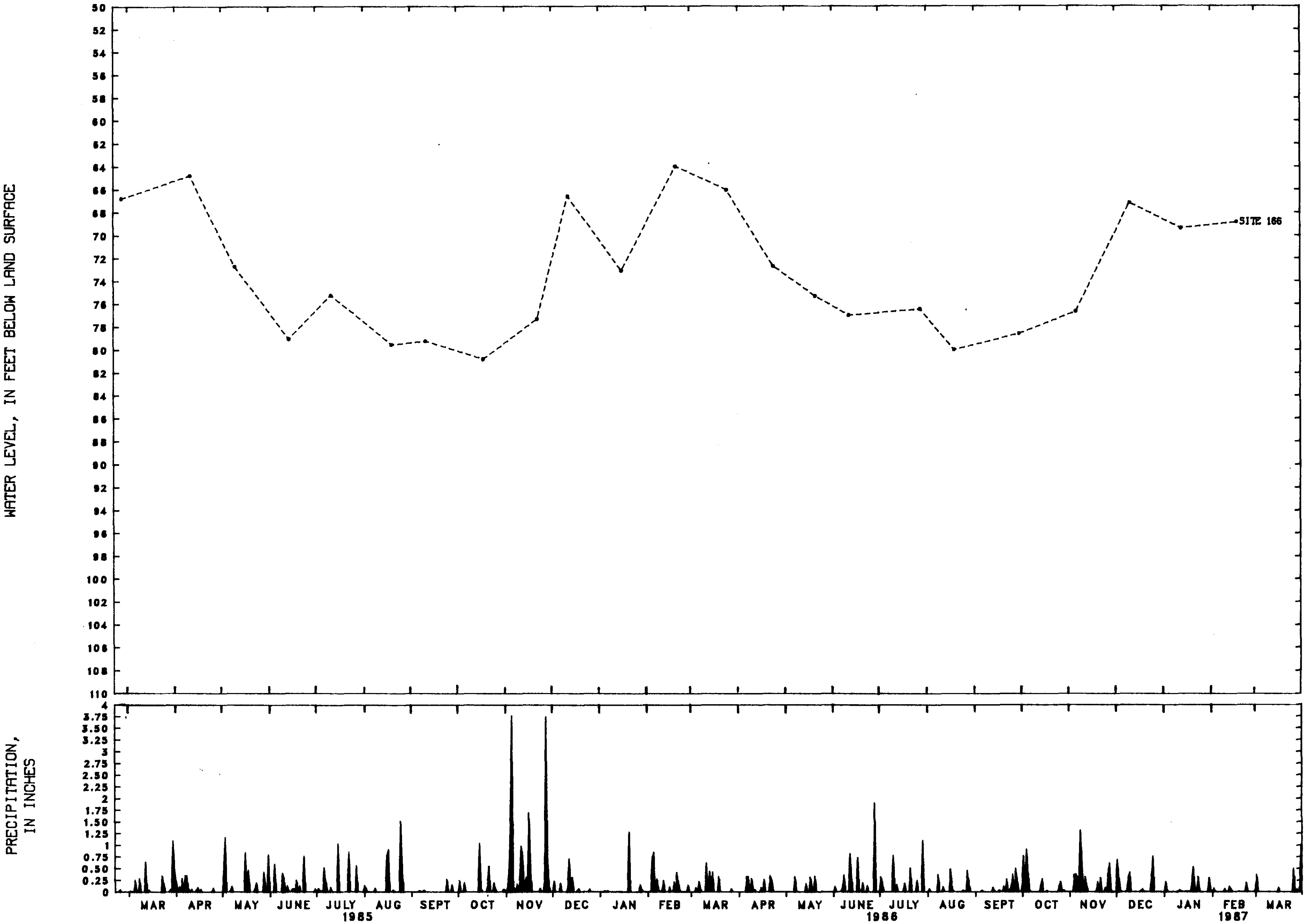
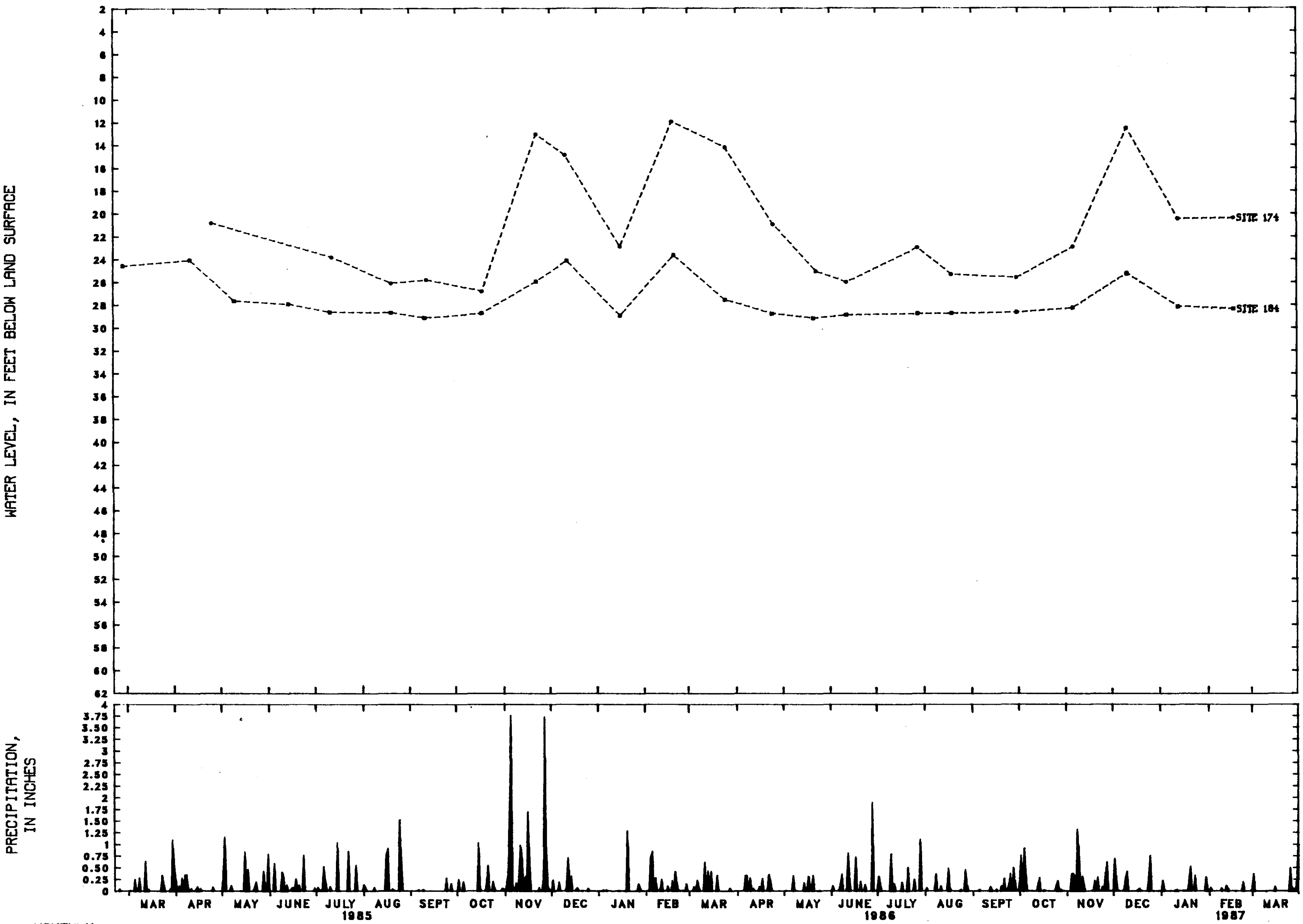
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



MONTHLY PRECIPITATION	3.45	4.11	4.44	4.49	0.59	2.74	1.43	2.26	3.10	3.76	4.43	1.83	6.40	2.75	2.77	3.69	1.72	4.61	4.66	2.70
MEAN PRECIPITATION, 1965-86	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54



MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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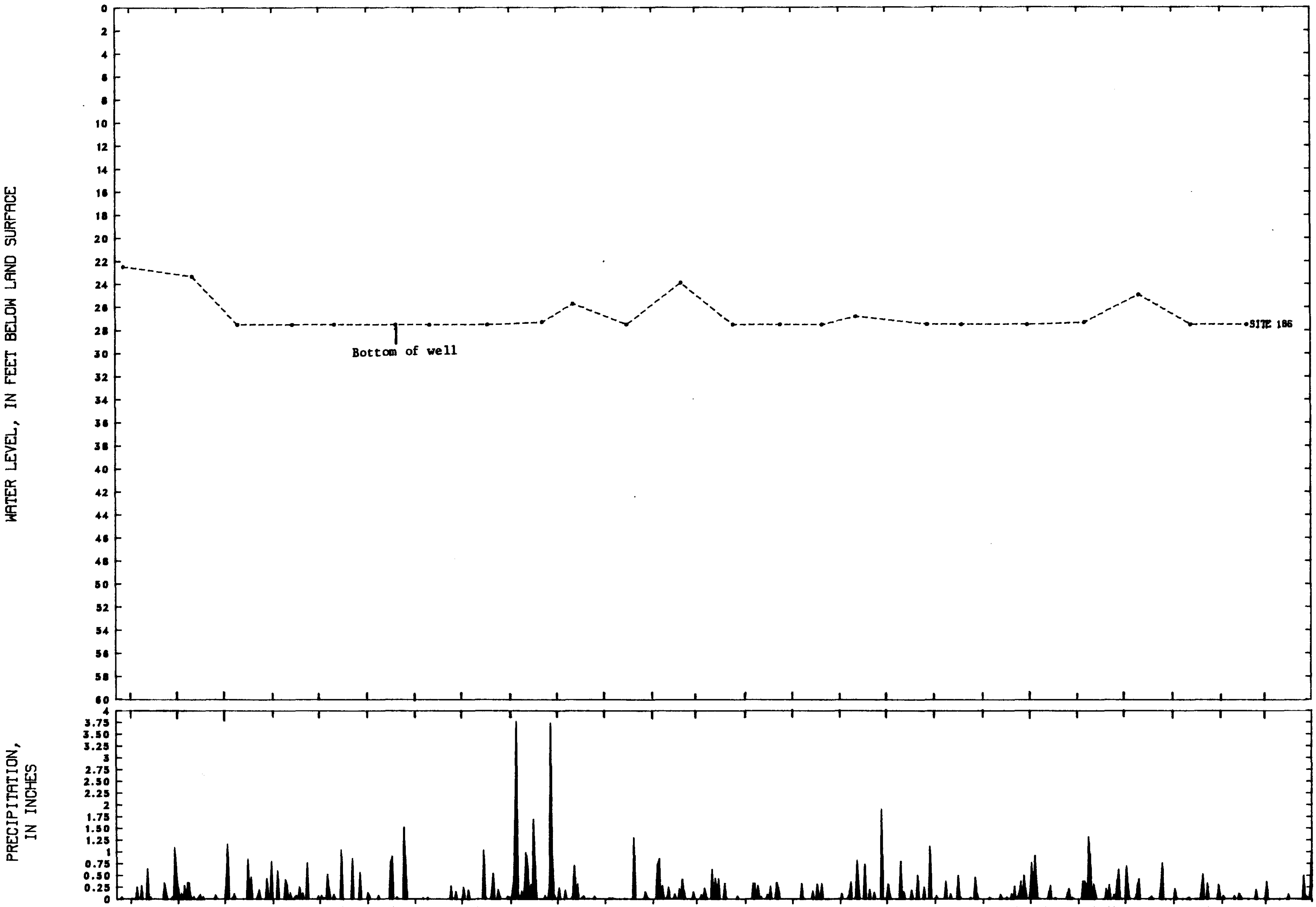
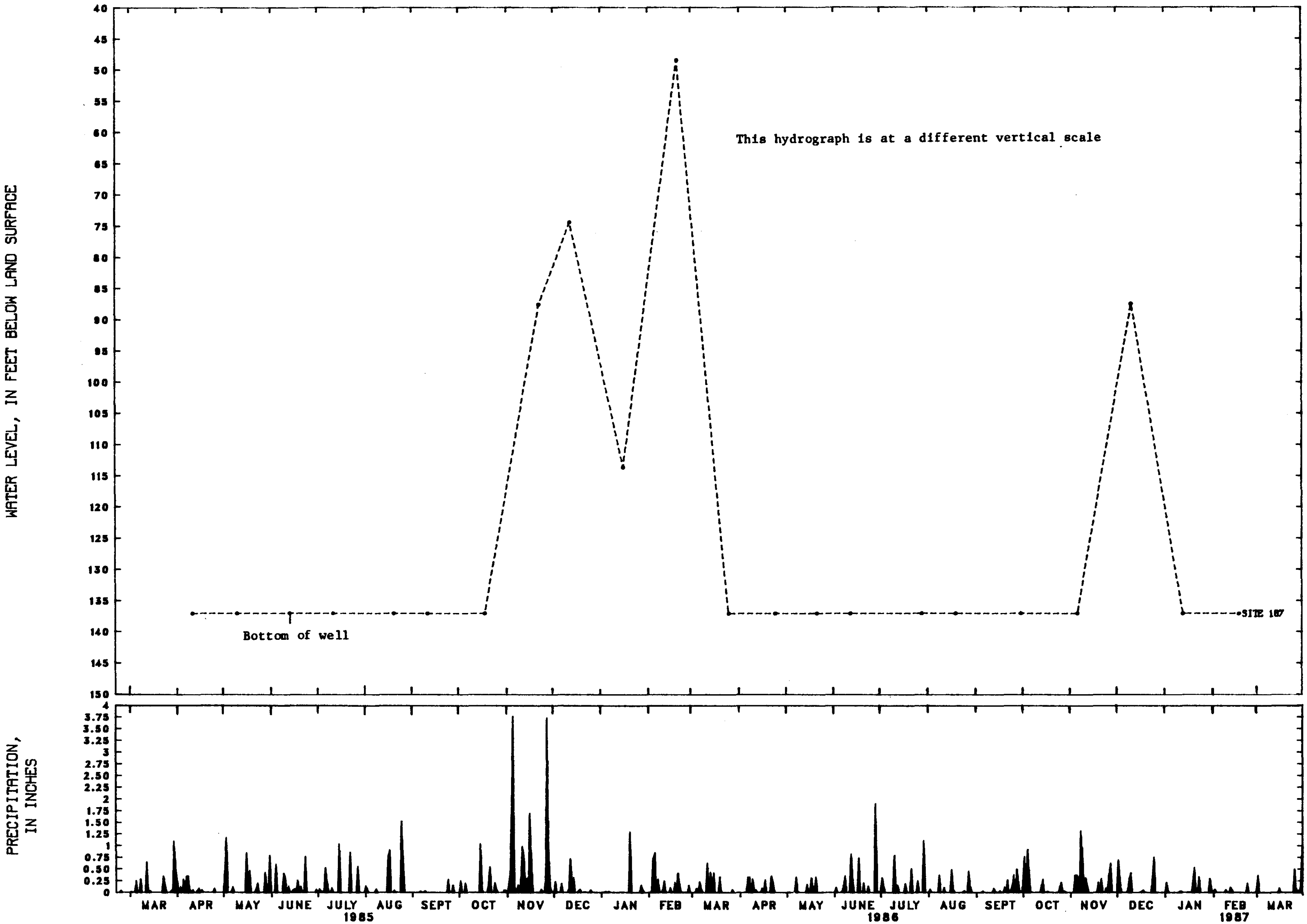
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

	APR	MAY	JUNE 1986	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB 1987	MAR
MONTHLY PRECIPITATION	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



	MAR	APR	MAY	JUNE	JULY 1985	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE 1986	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB 1987	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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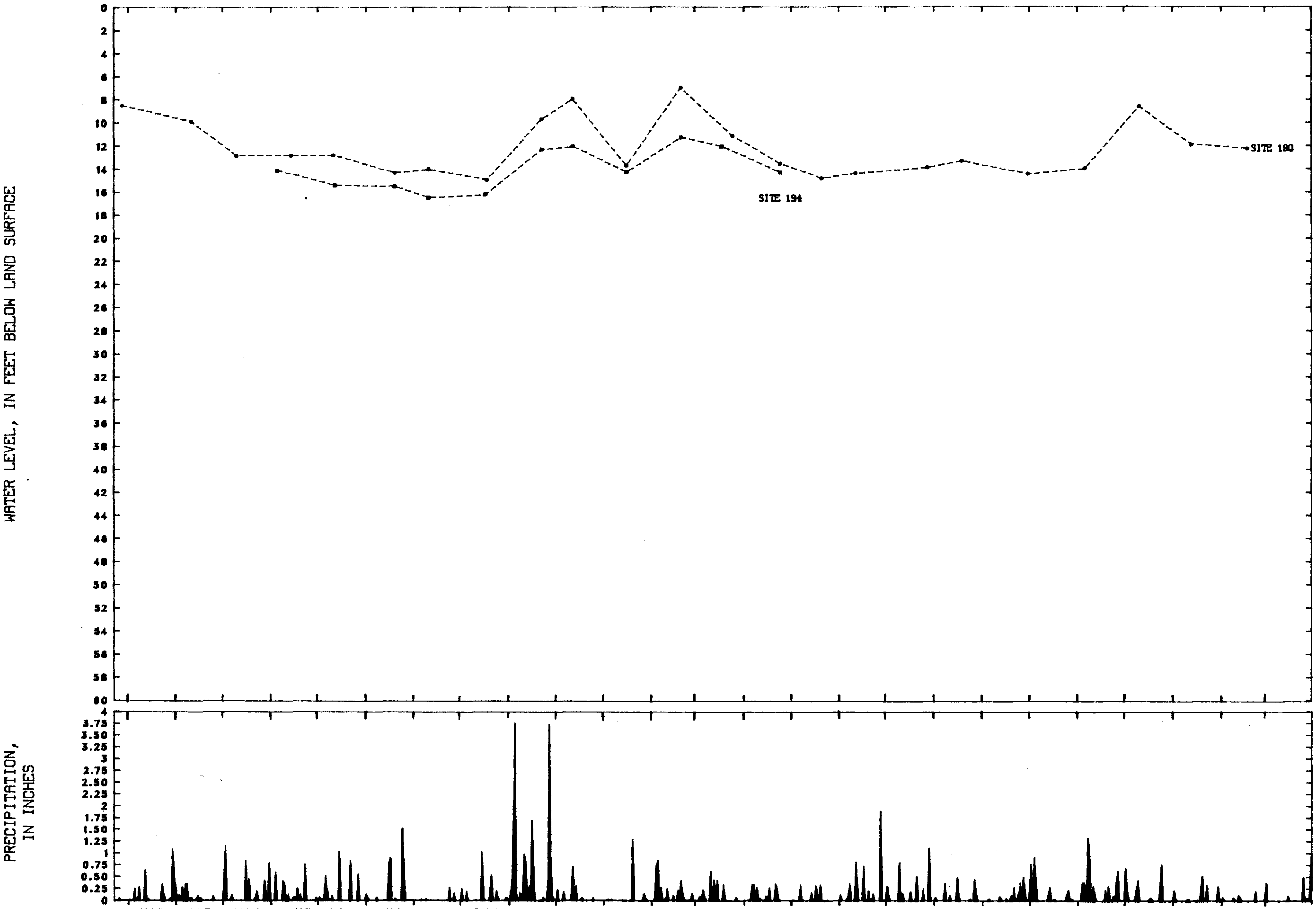
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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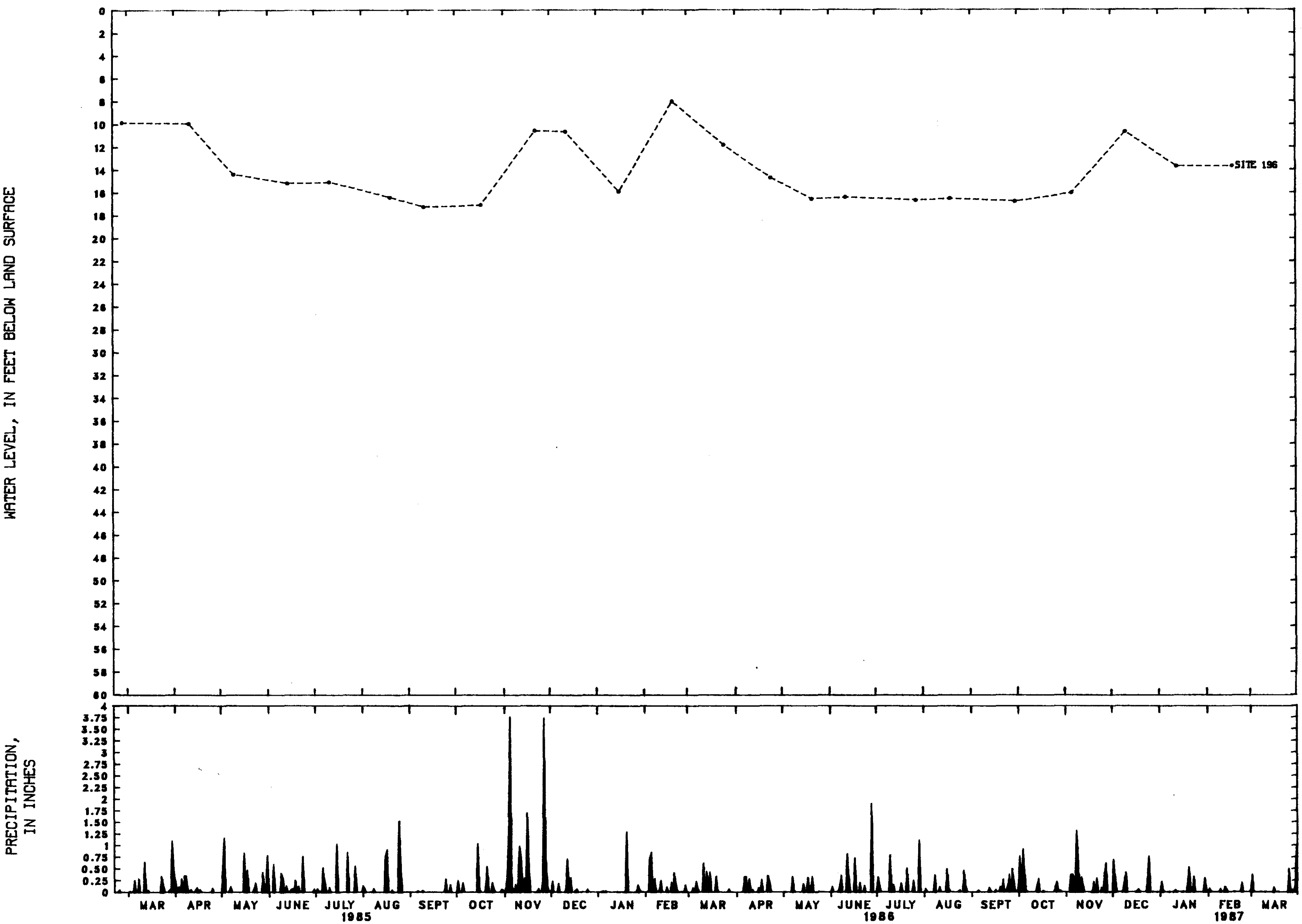
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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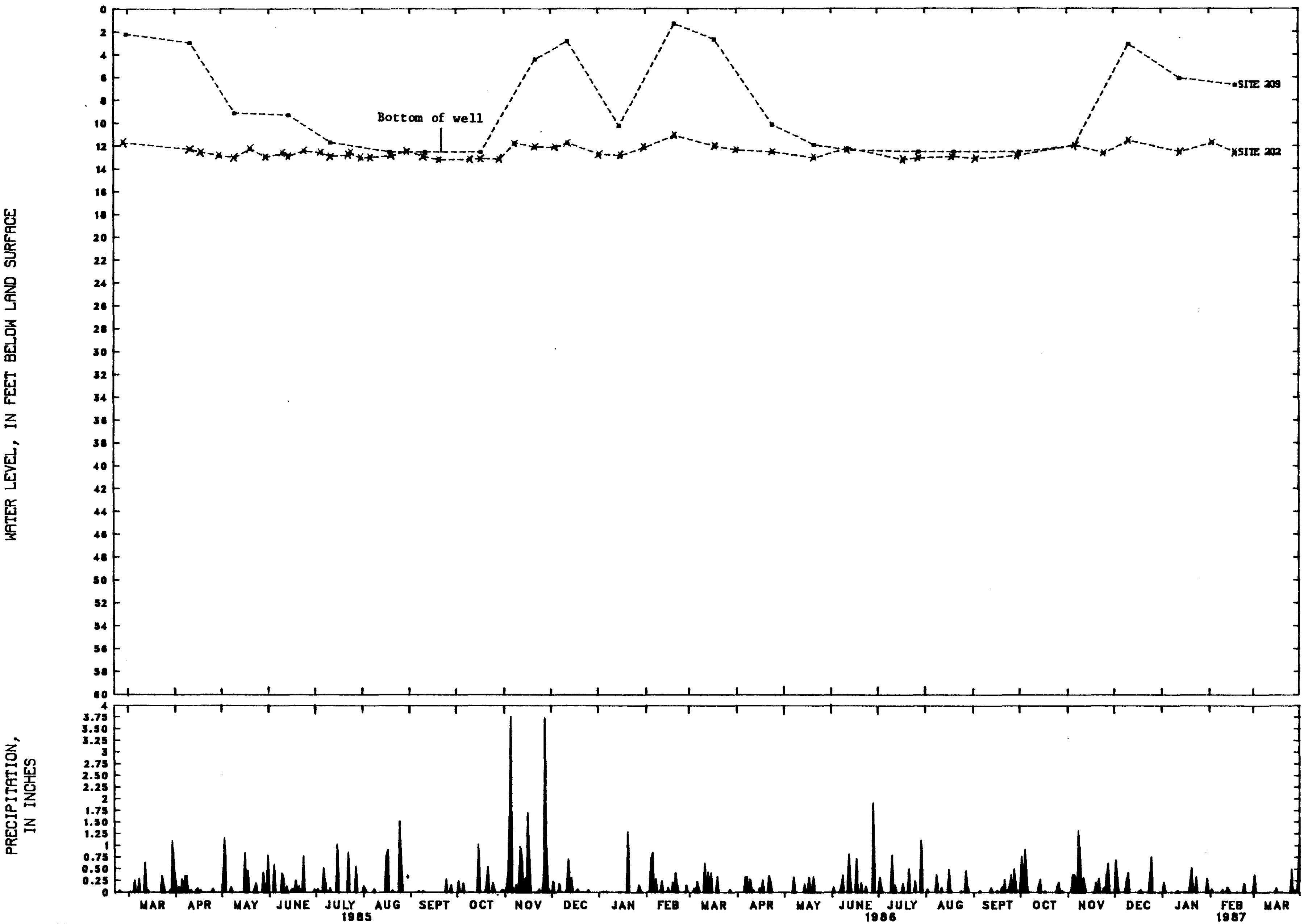
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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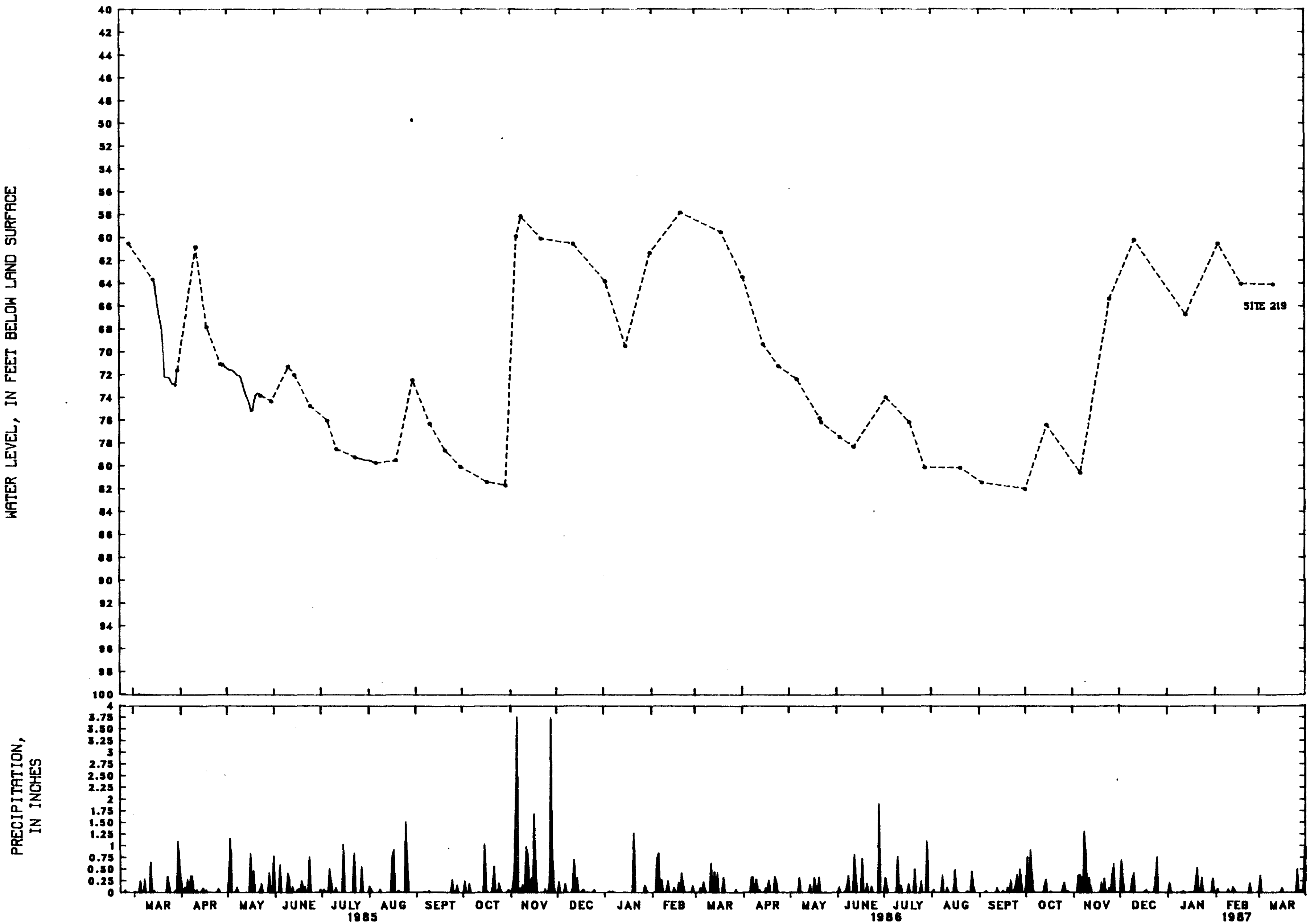
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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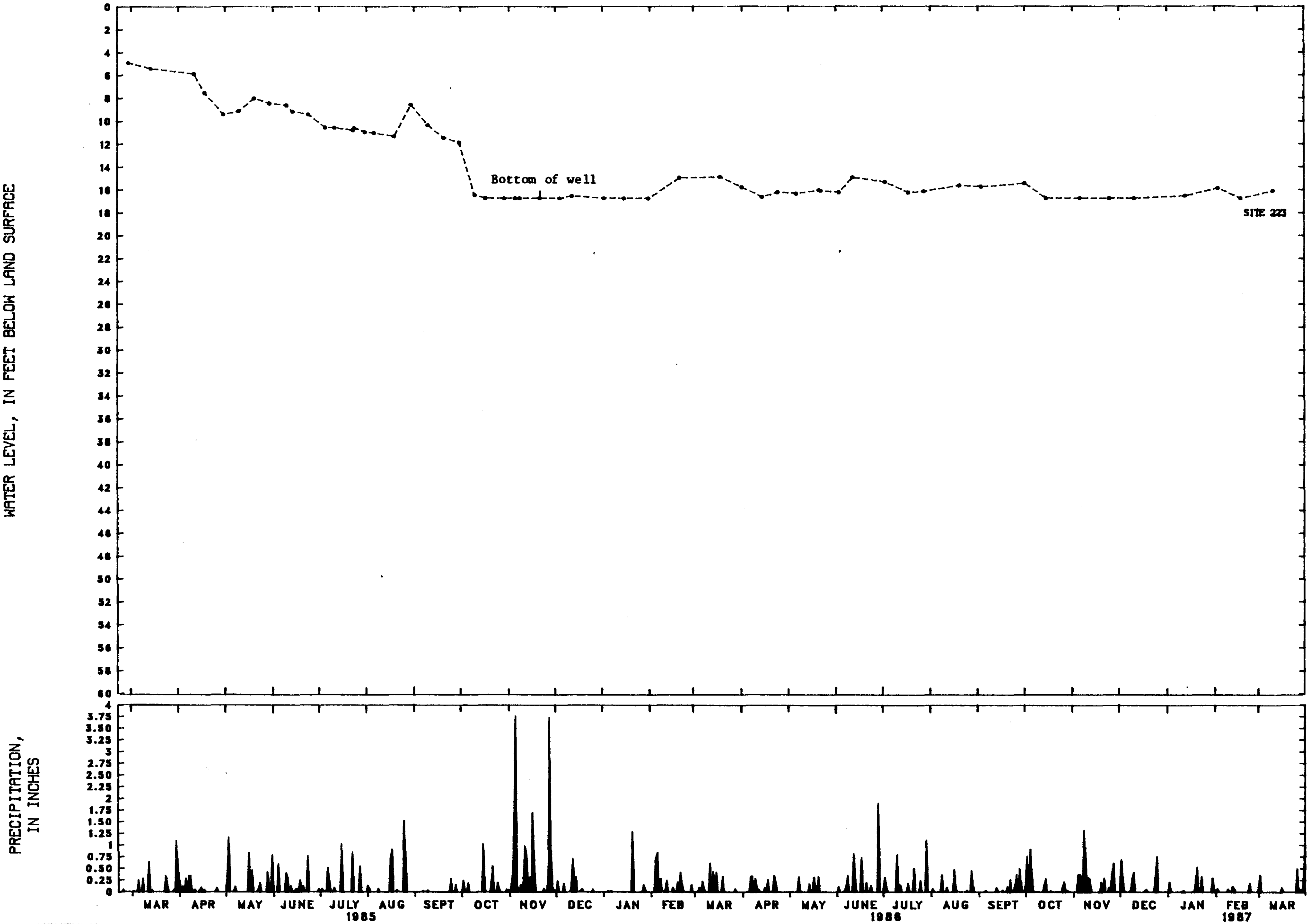
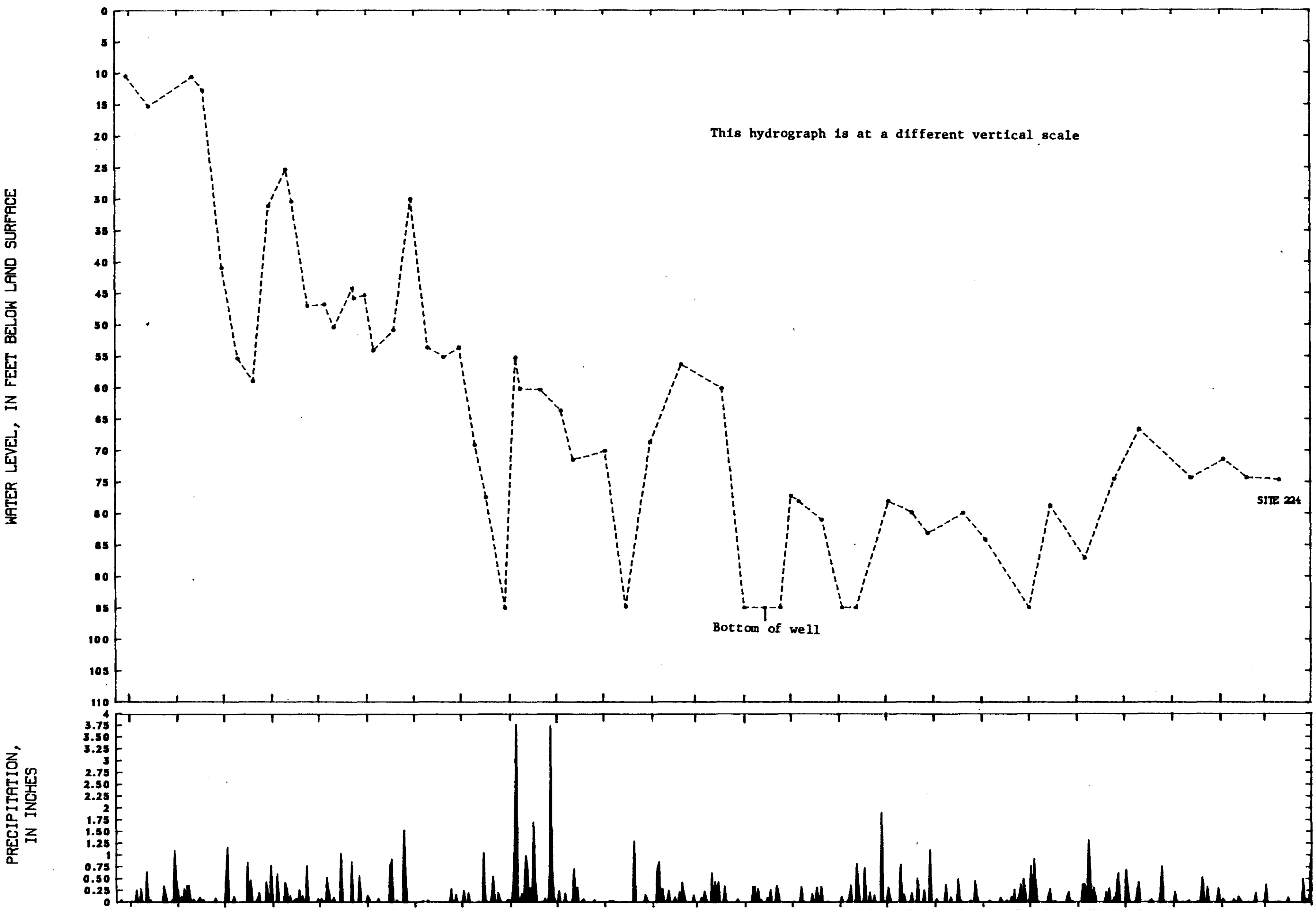
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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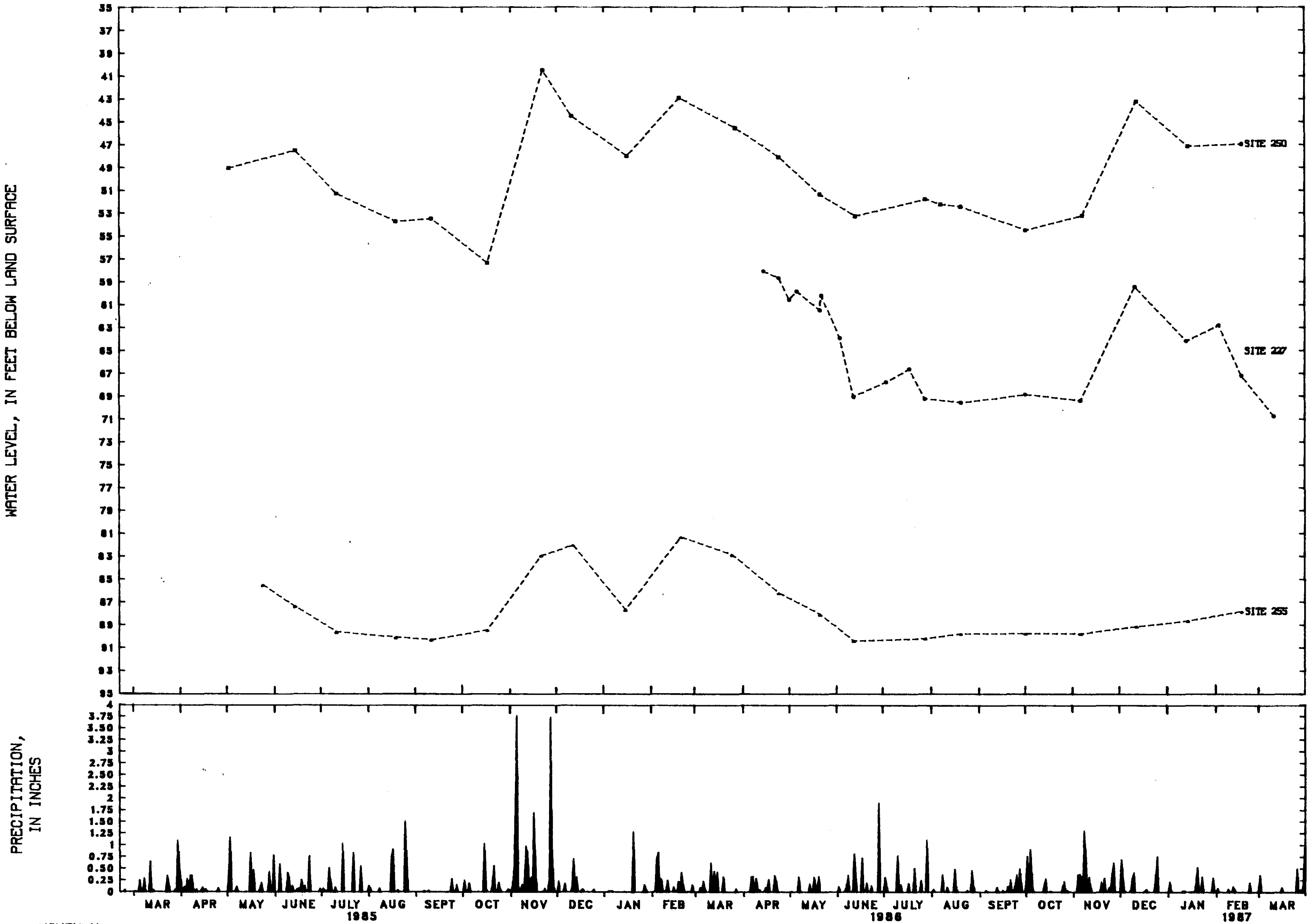
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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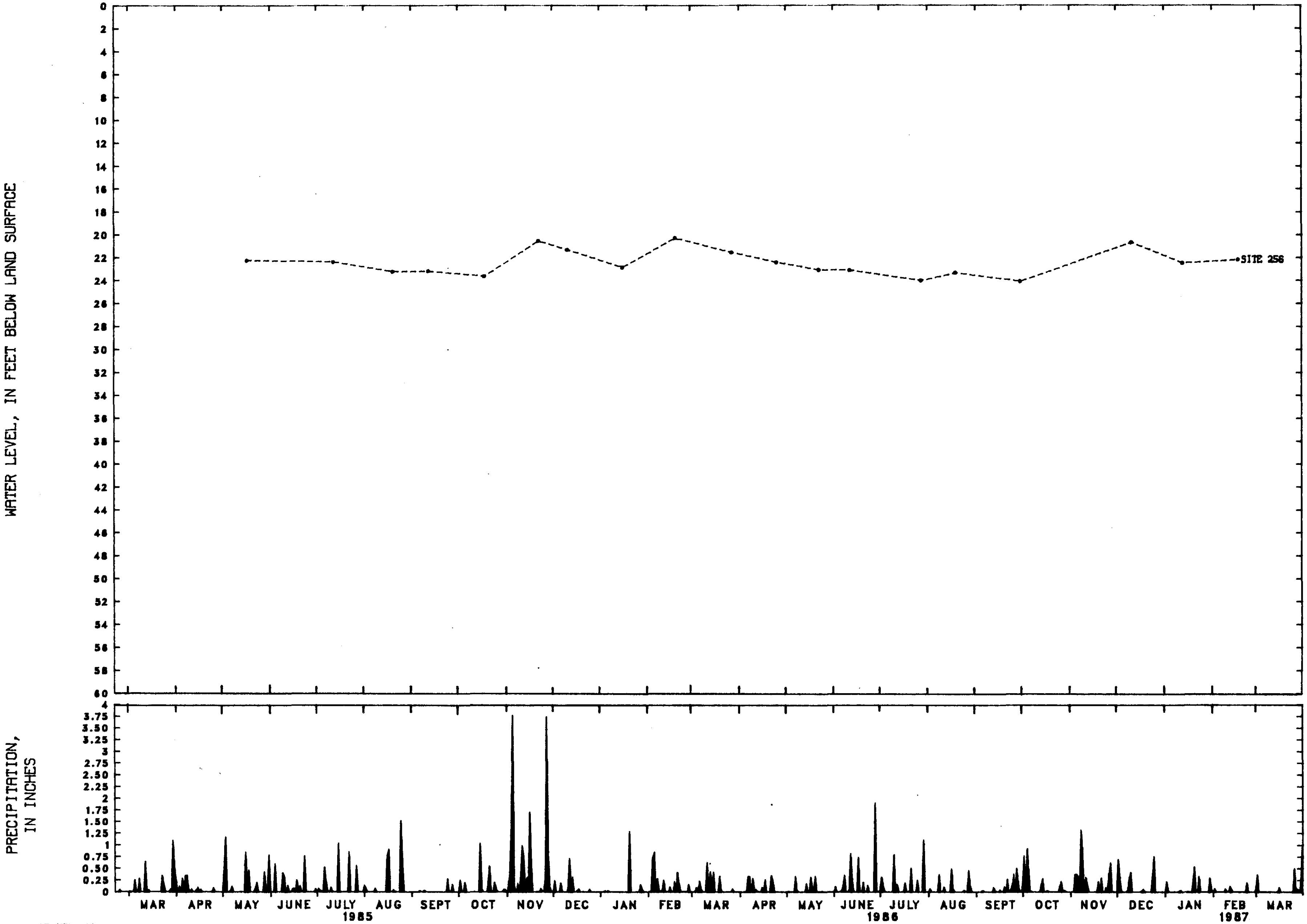
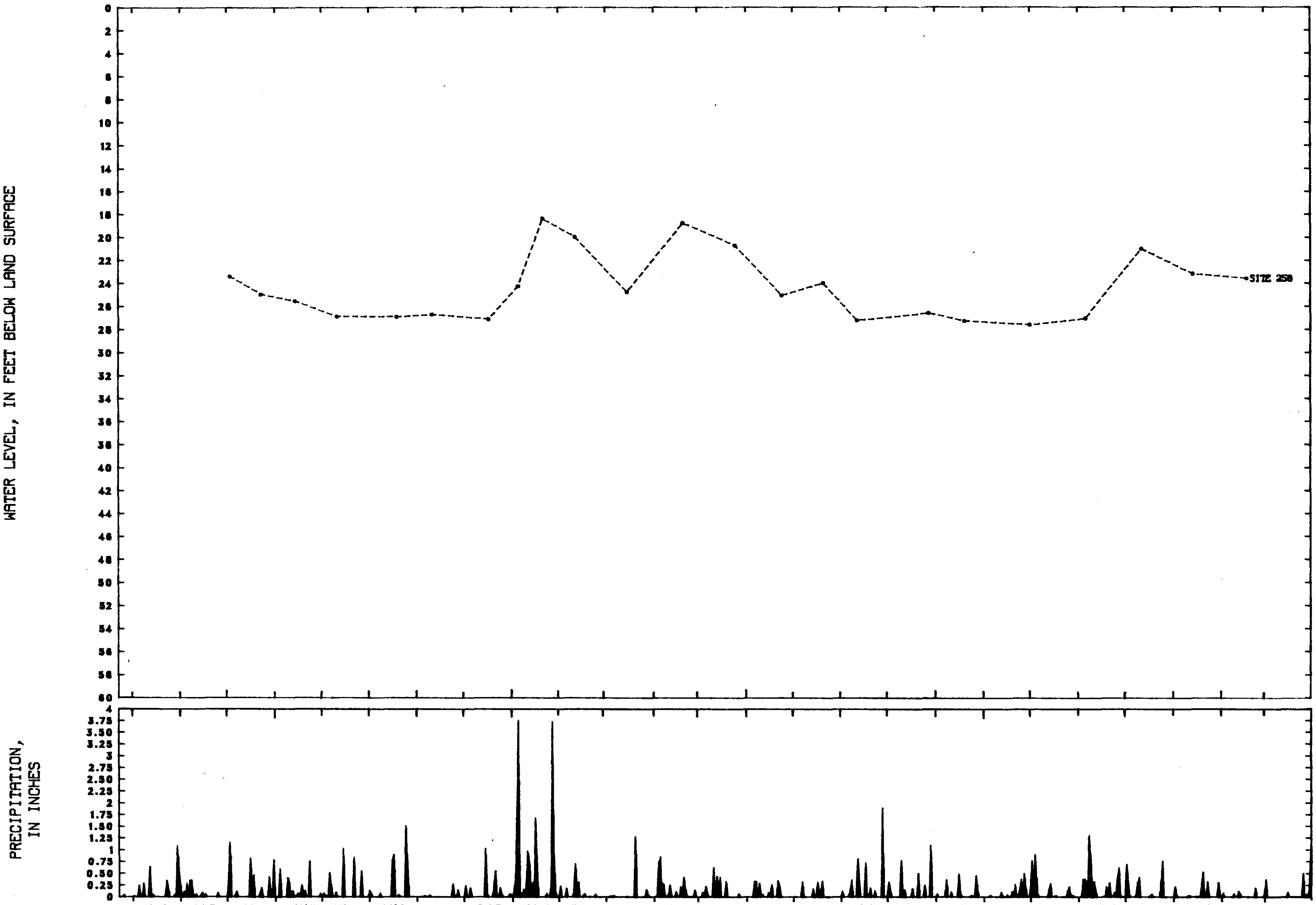
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



	MAR	APR	MAY	JUNE	JULY 1985	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

	APR	MAY	JUNE 1986	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB 1987	MAR
MONTHLY PRECIPITATION	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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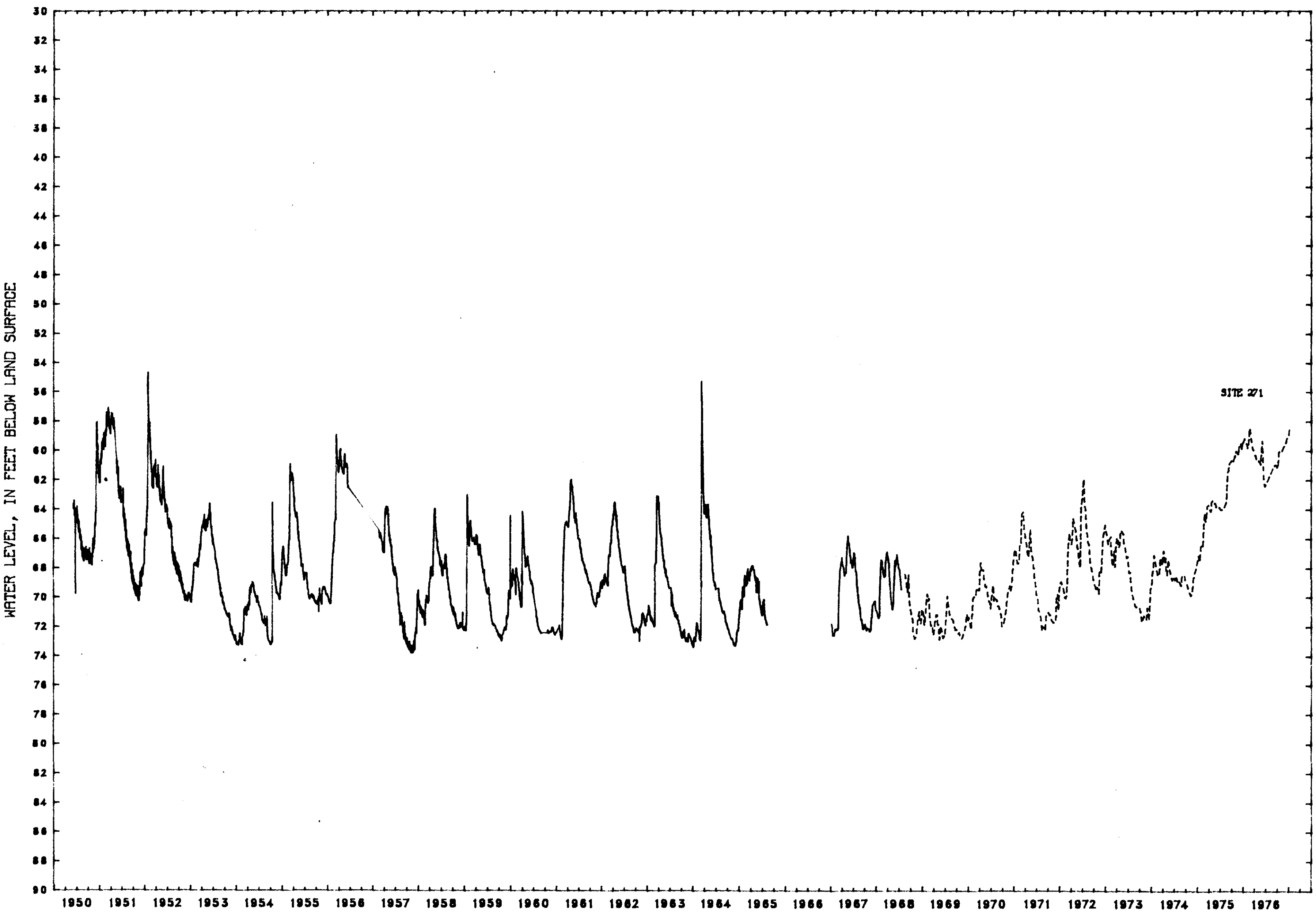
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23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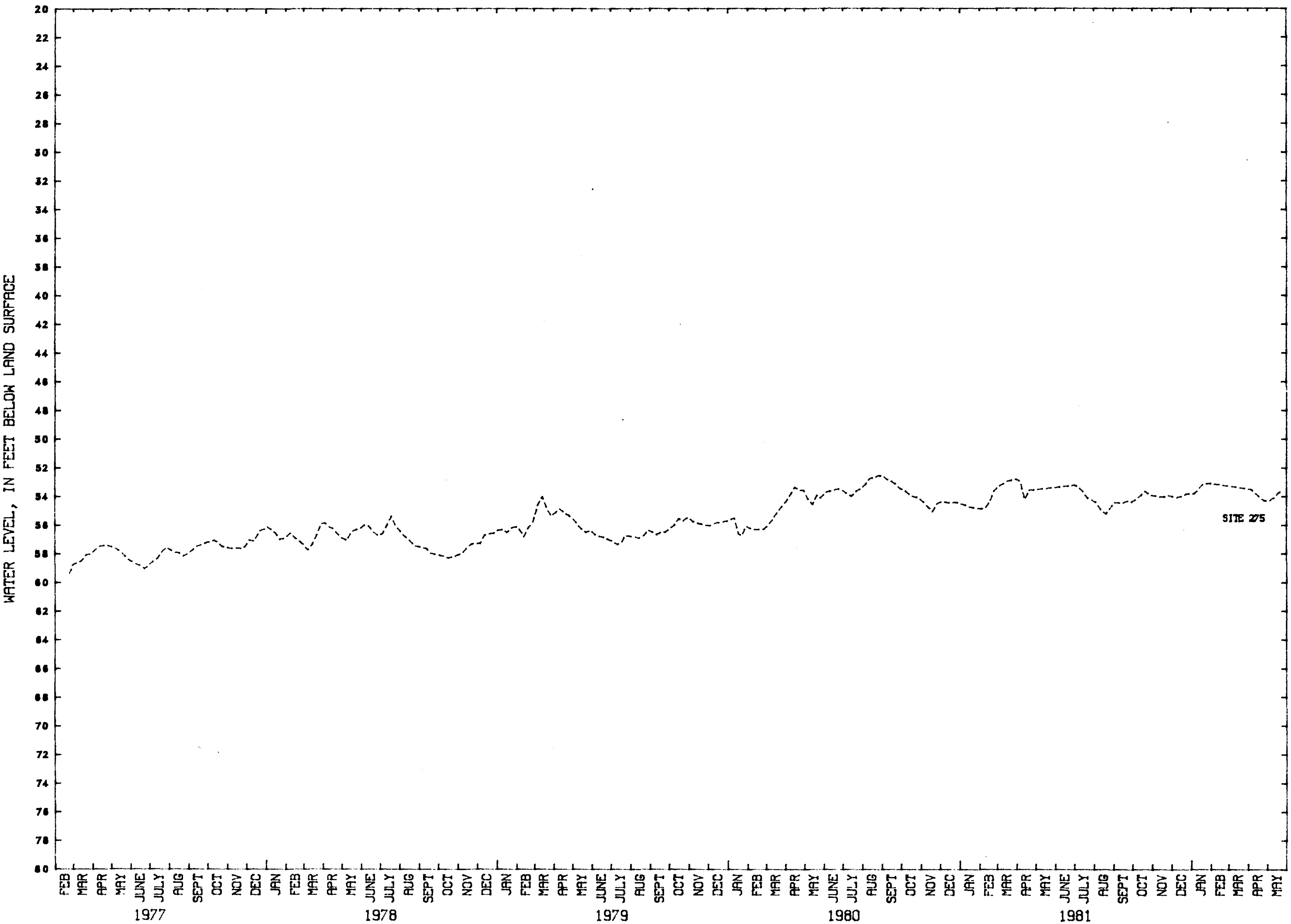
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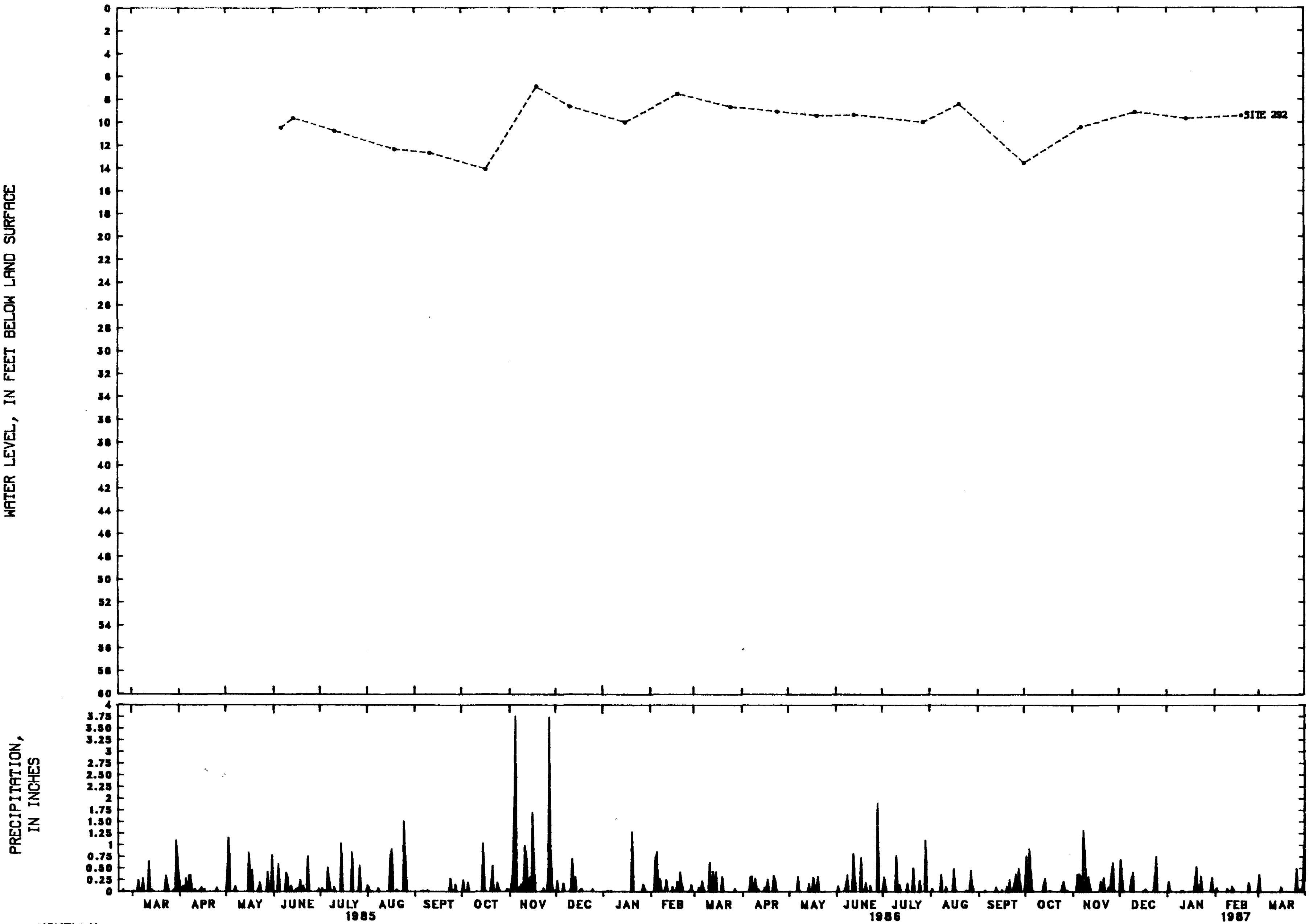
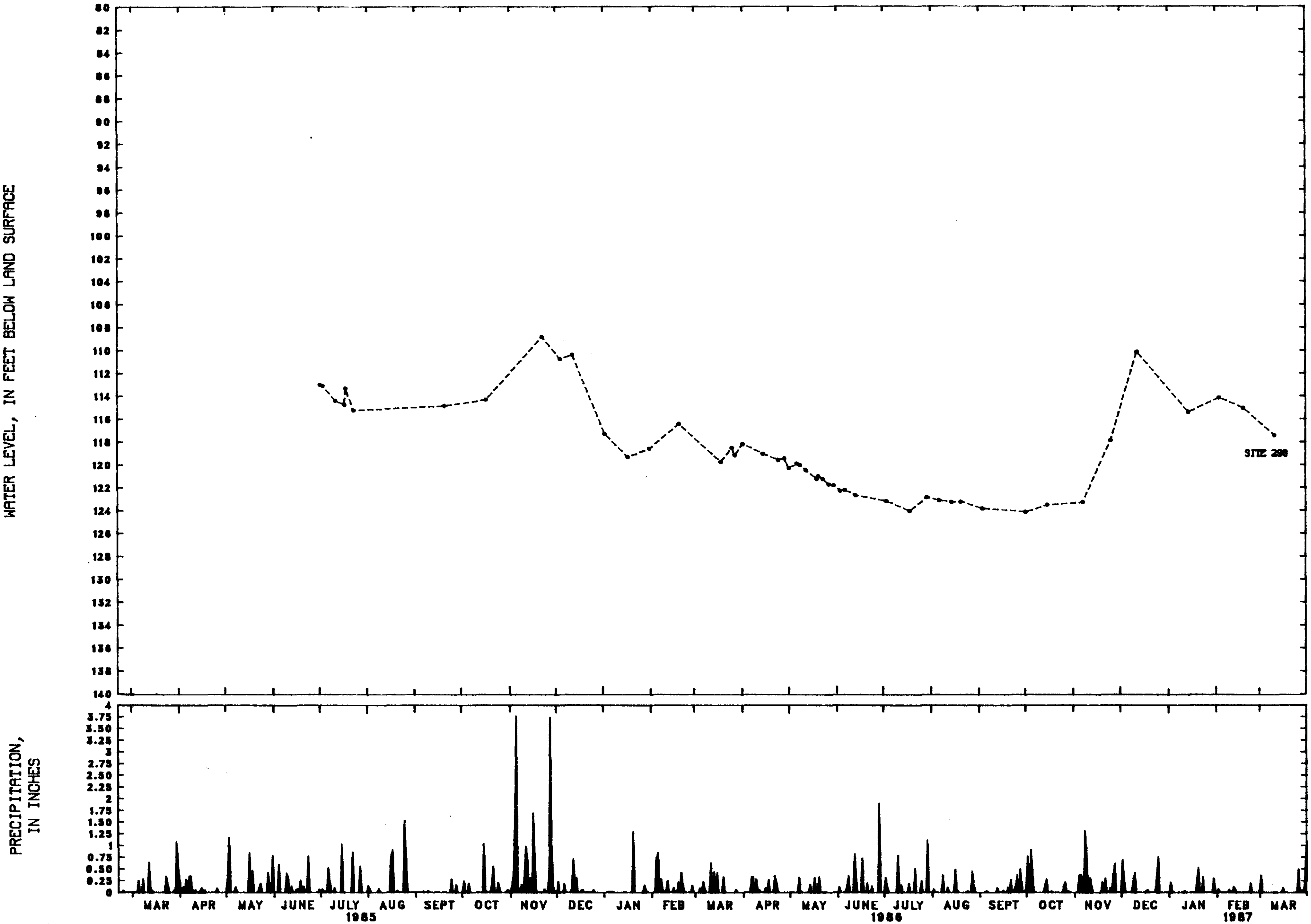
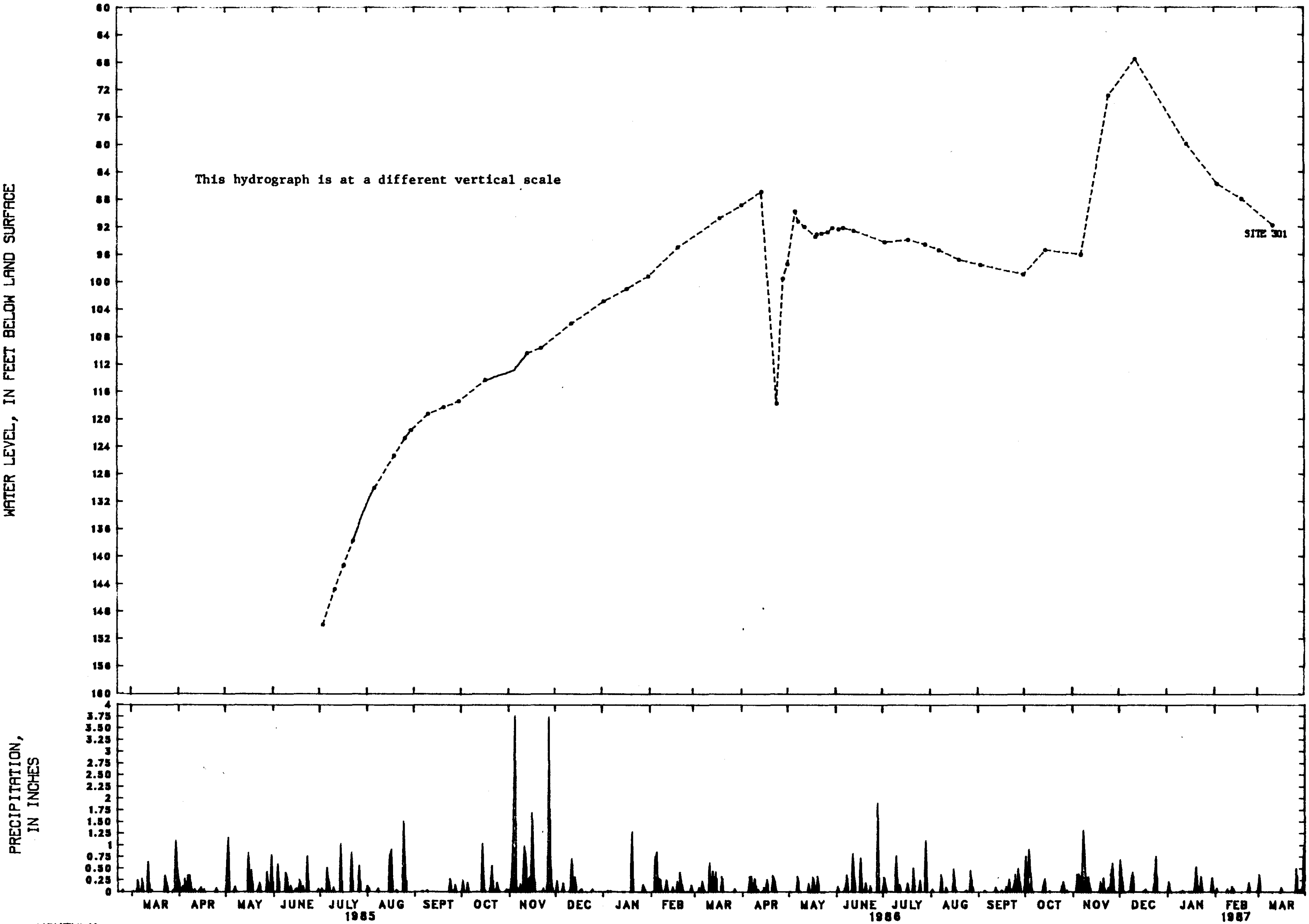


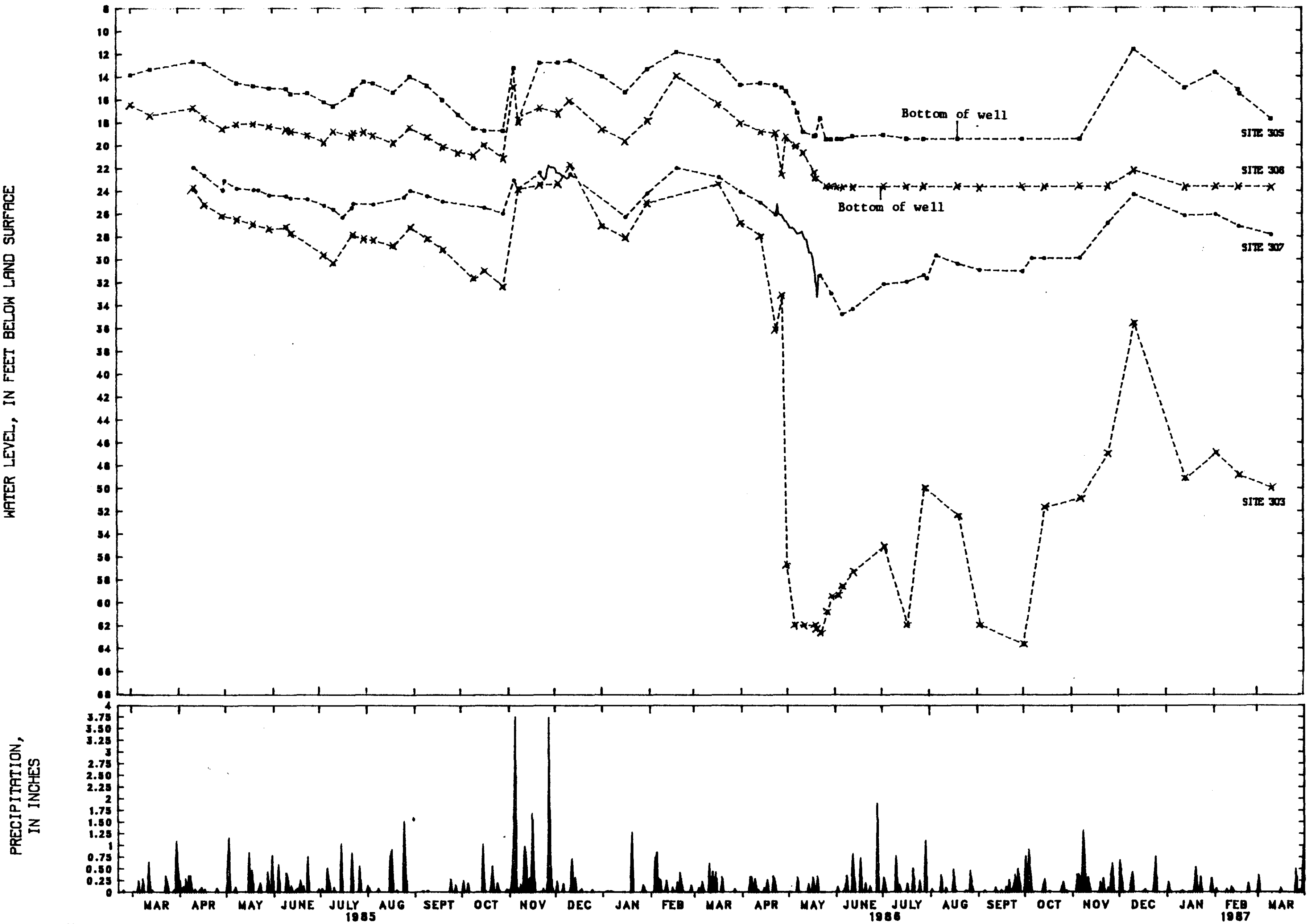
	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



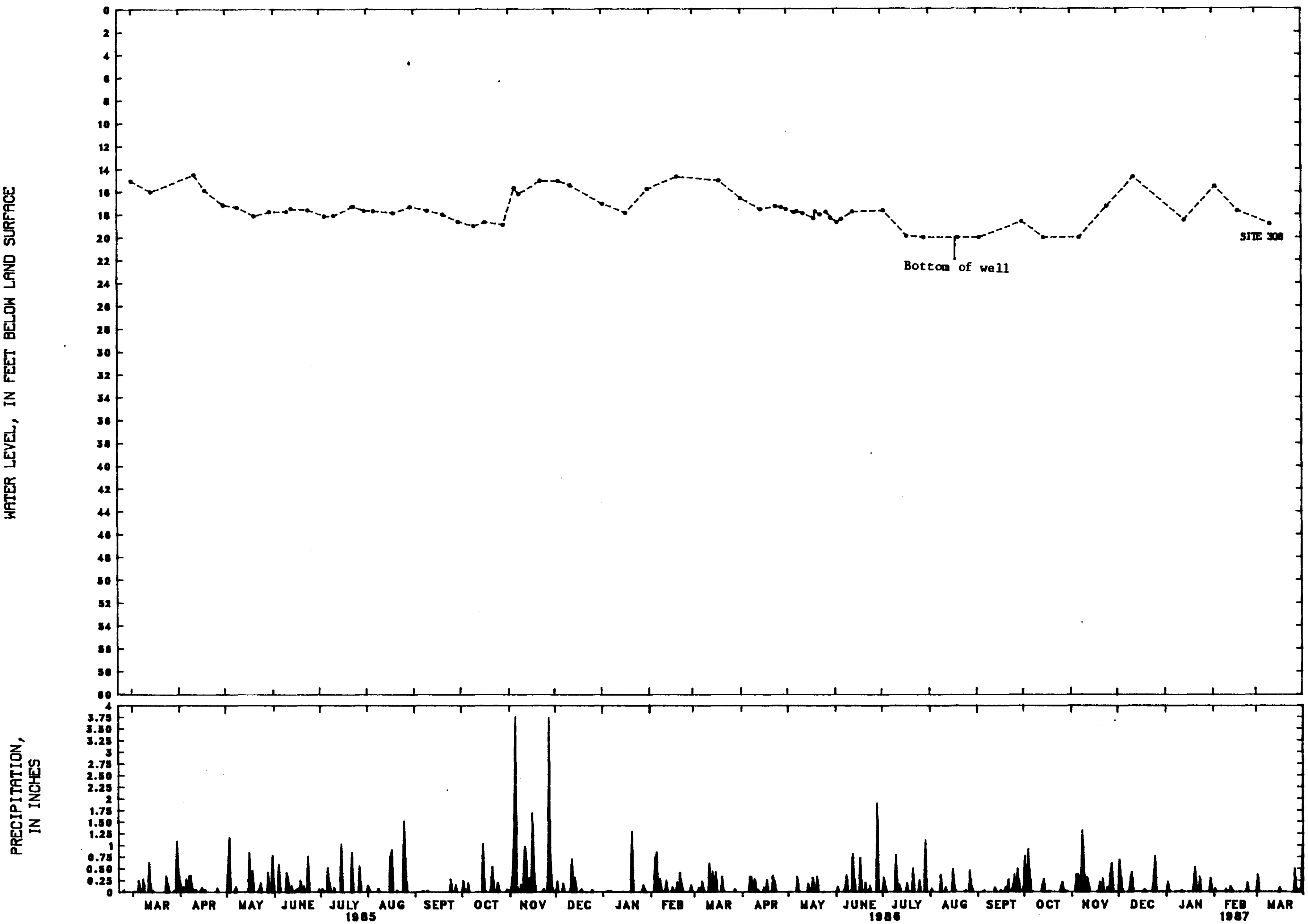
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



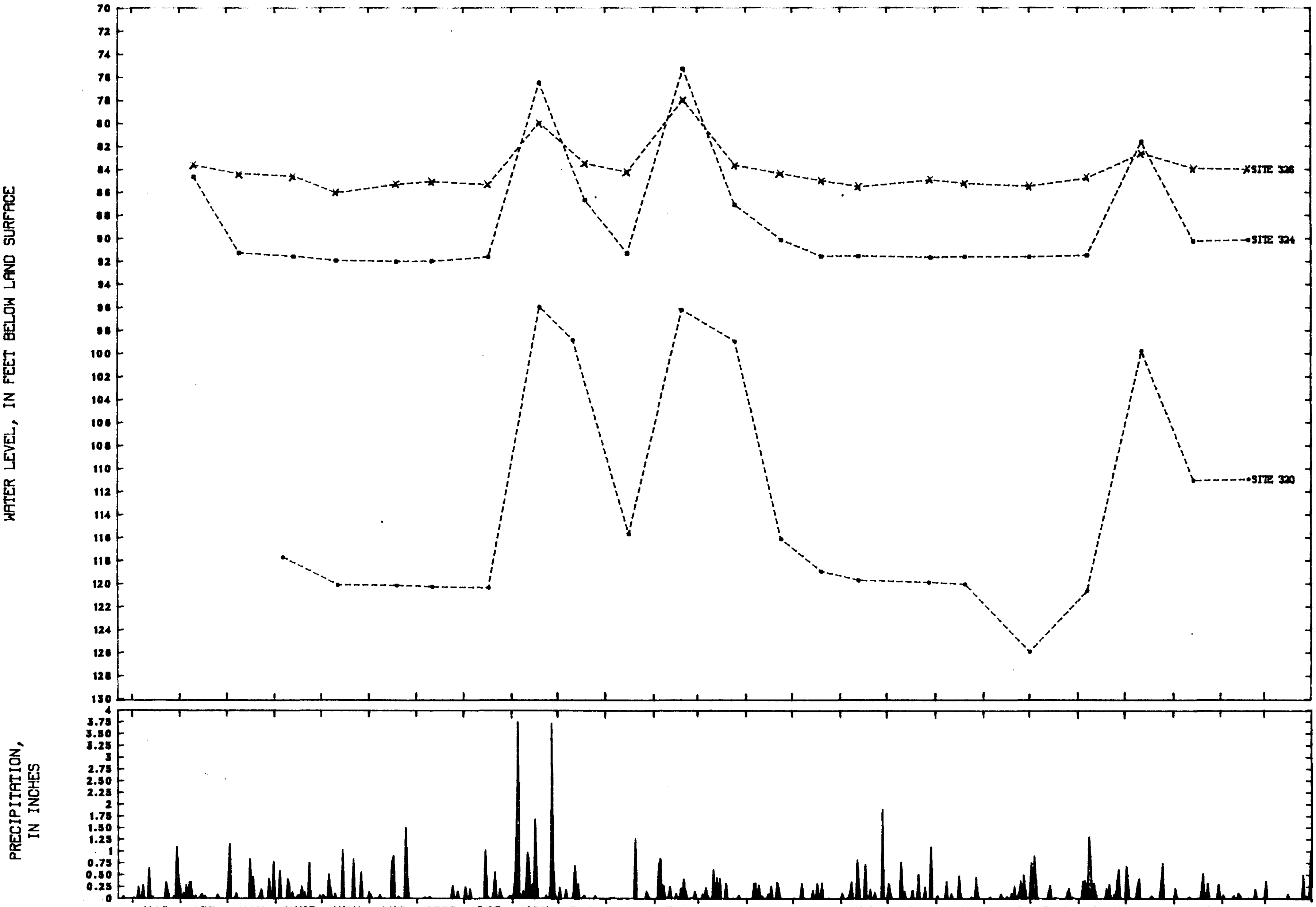
MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23



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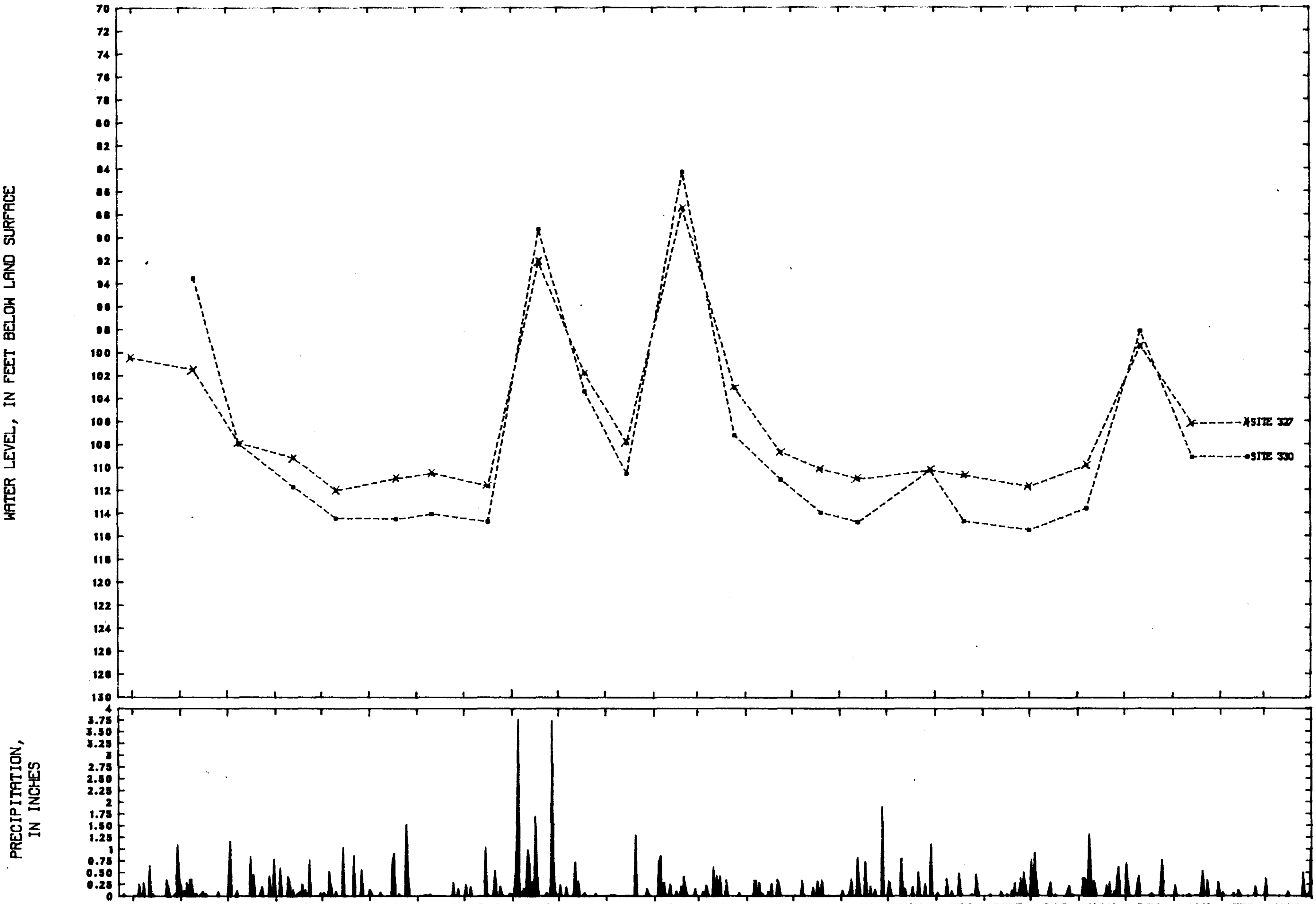

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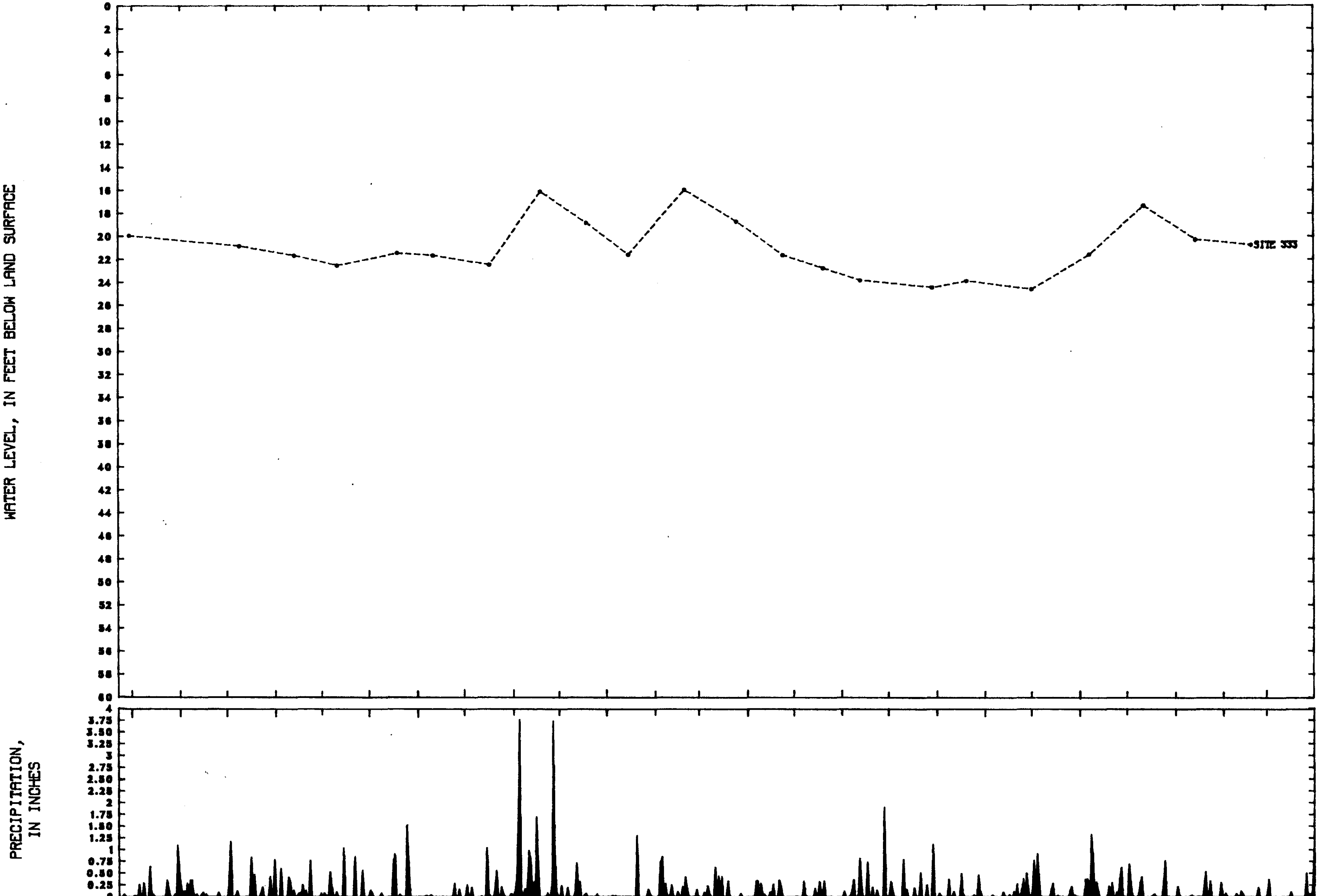

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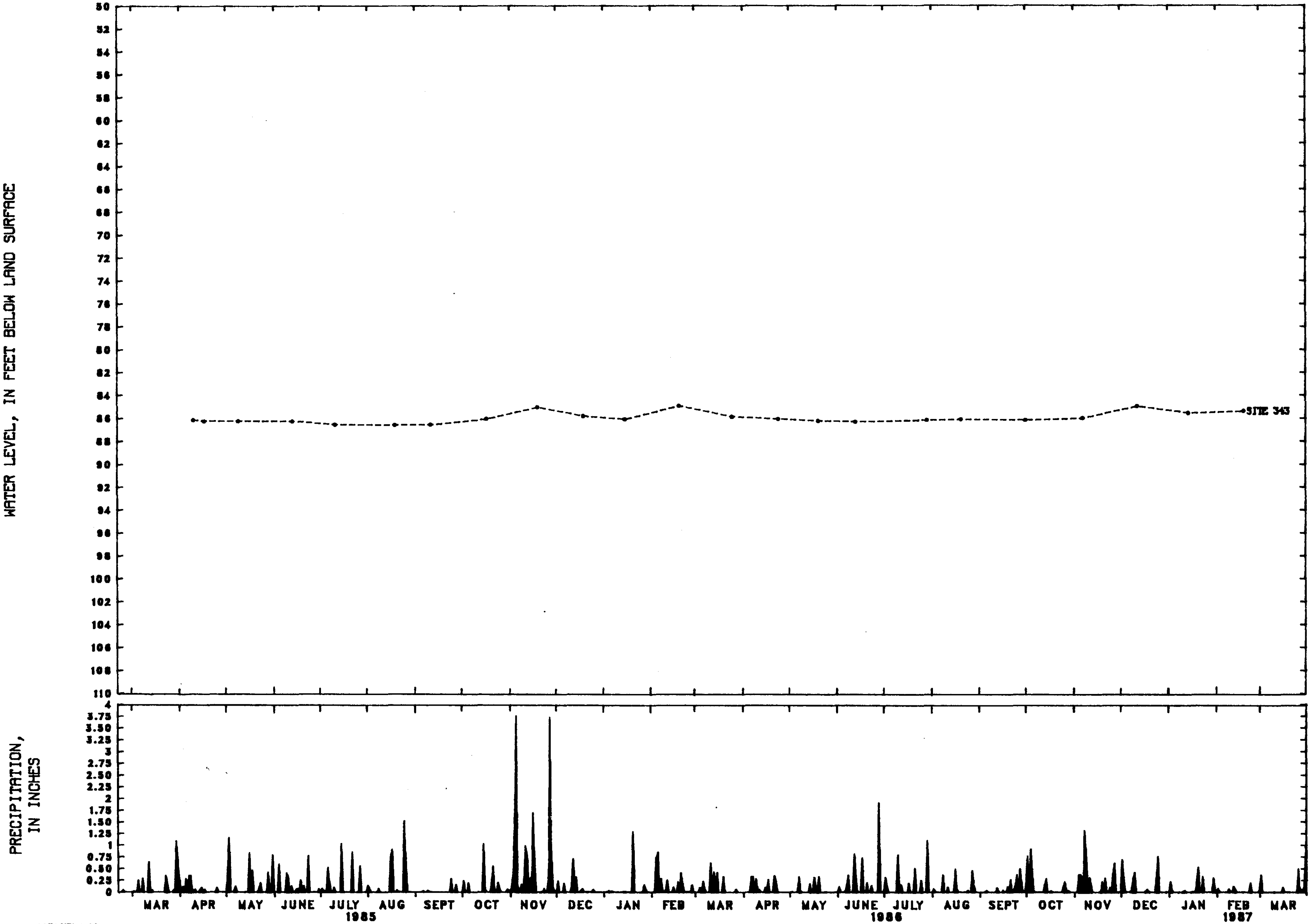

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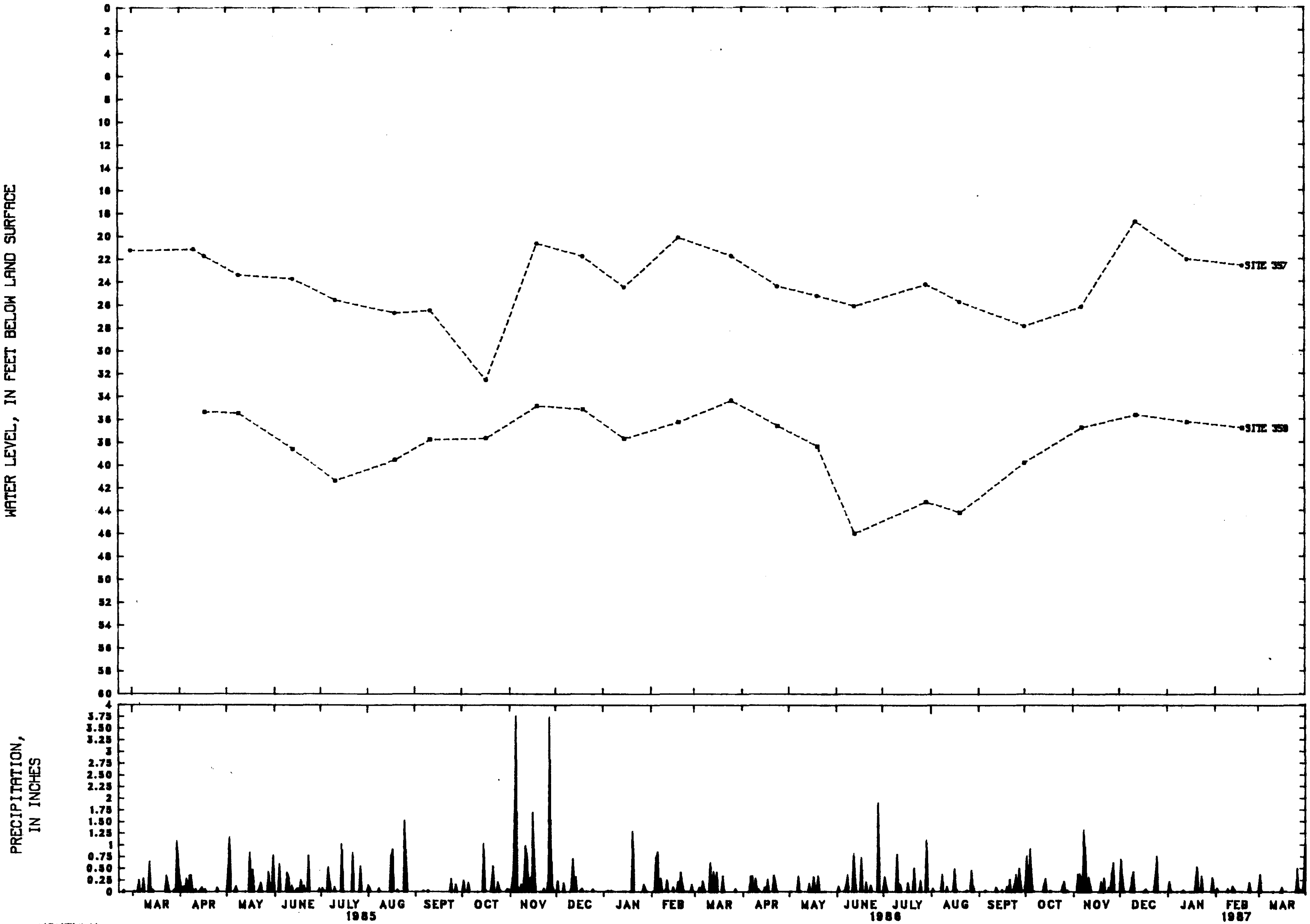

MONTHLY PRECIPITATION	3.48	1.86	4.86	2.90	3.47	4.17	0.51	2.65	15.97	1.95	1.59	3.32	2.49	2.06	1.40	4.83	3.57	2.12	1.92	3.25	5.21	3.25	1.79	0.53	2.25
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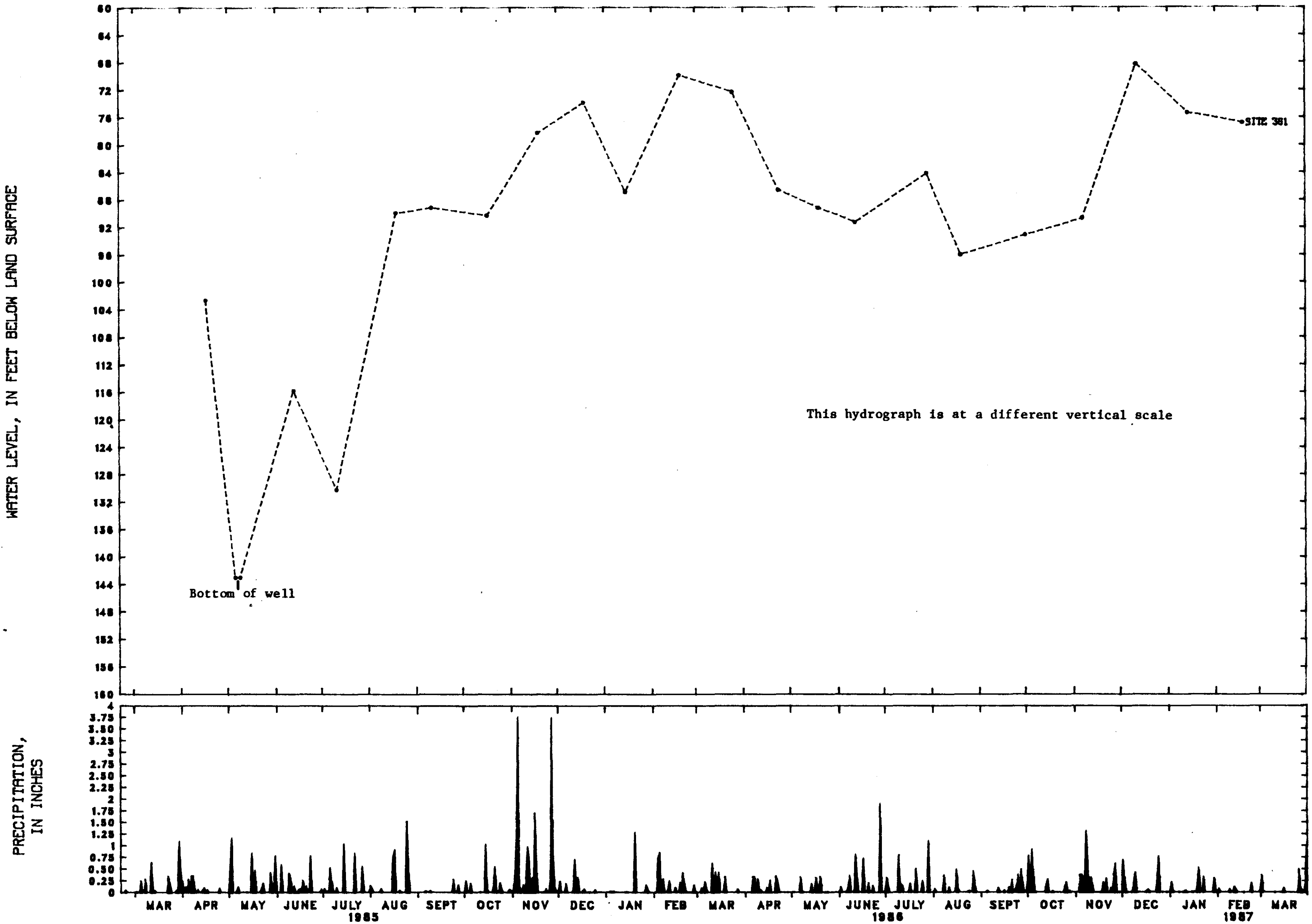

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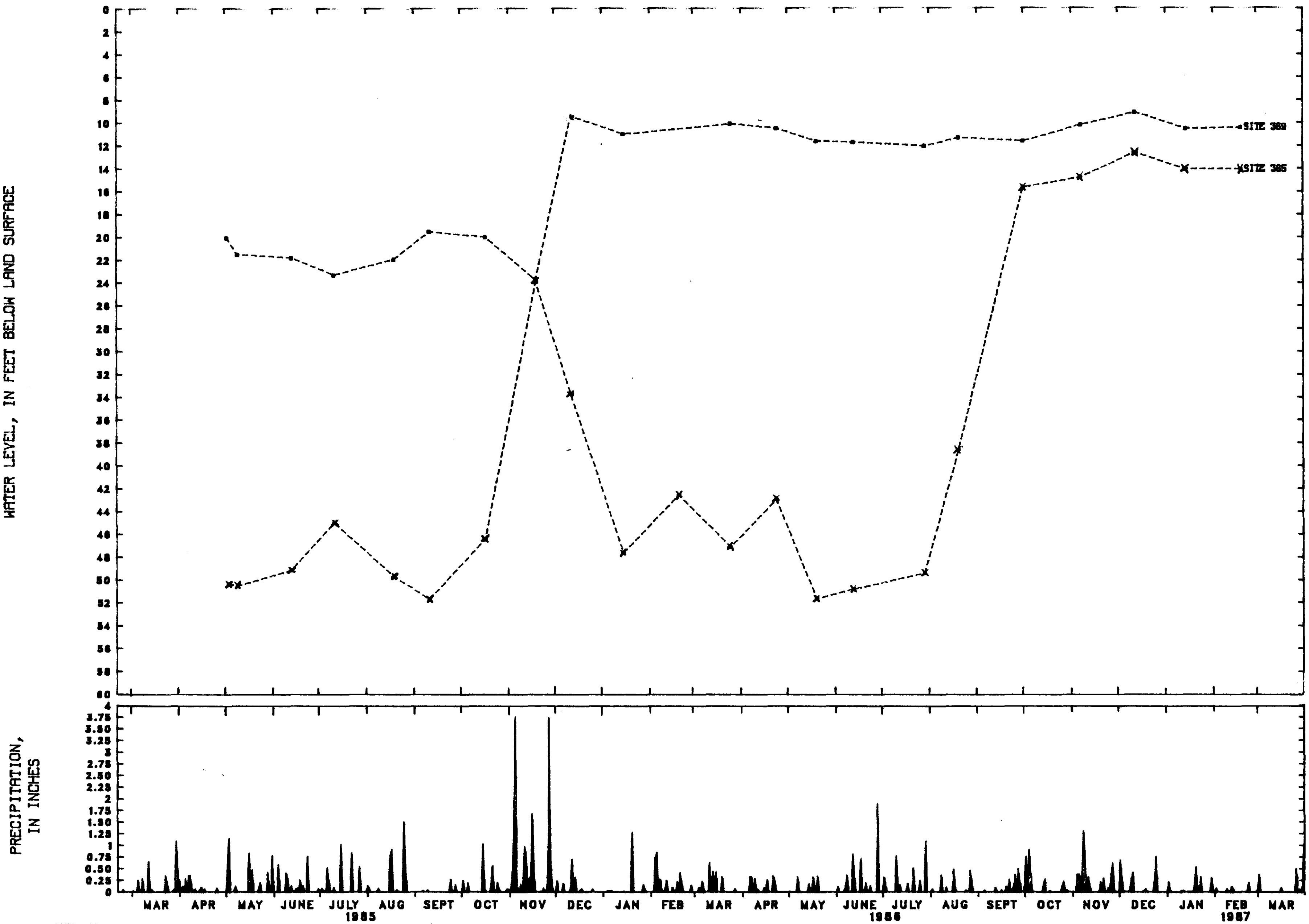

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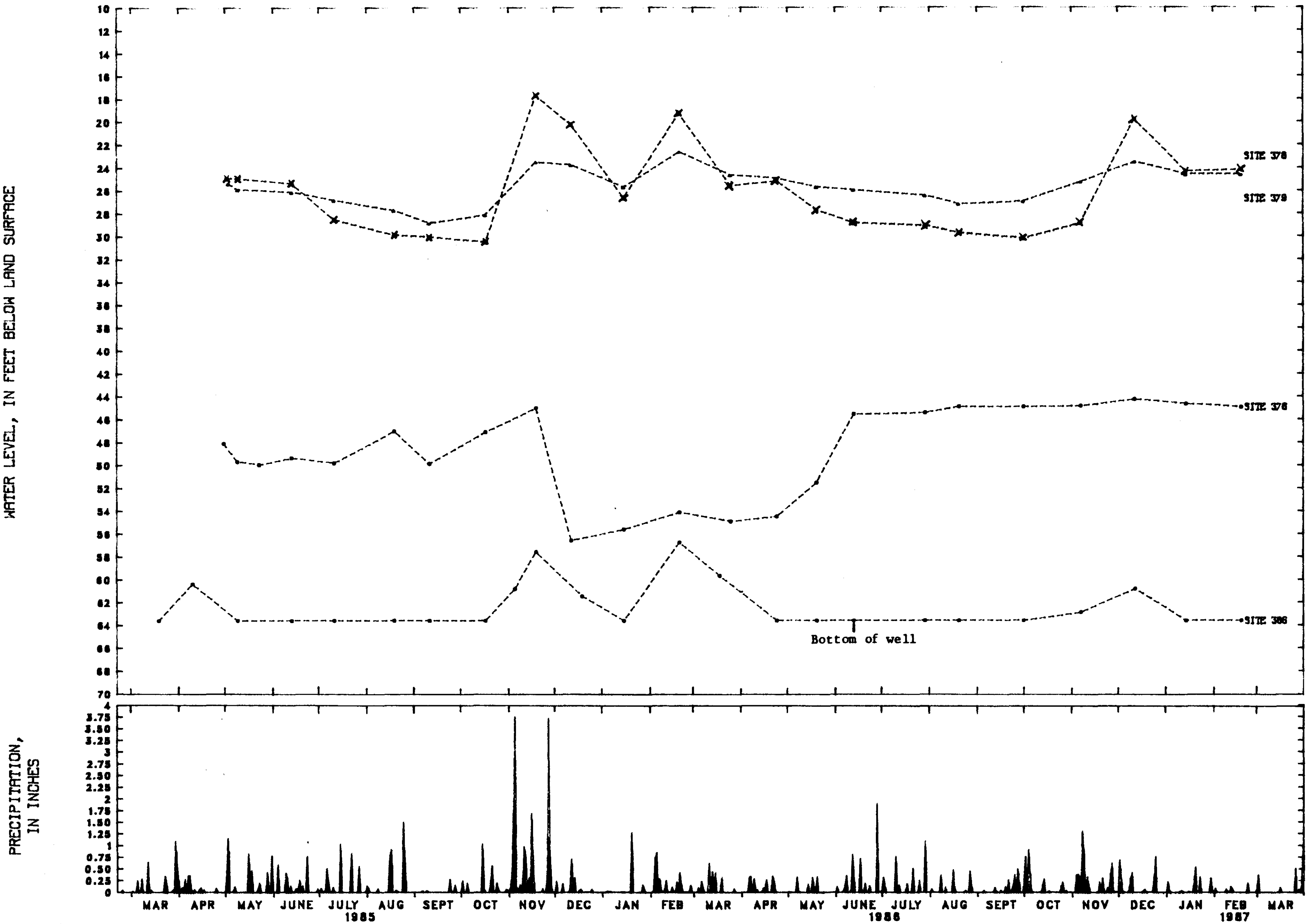

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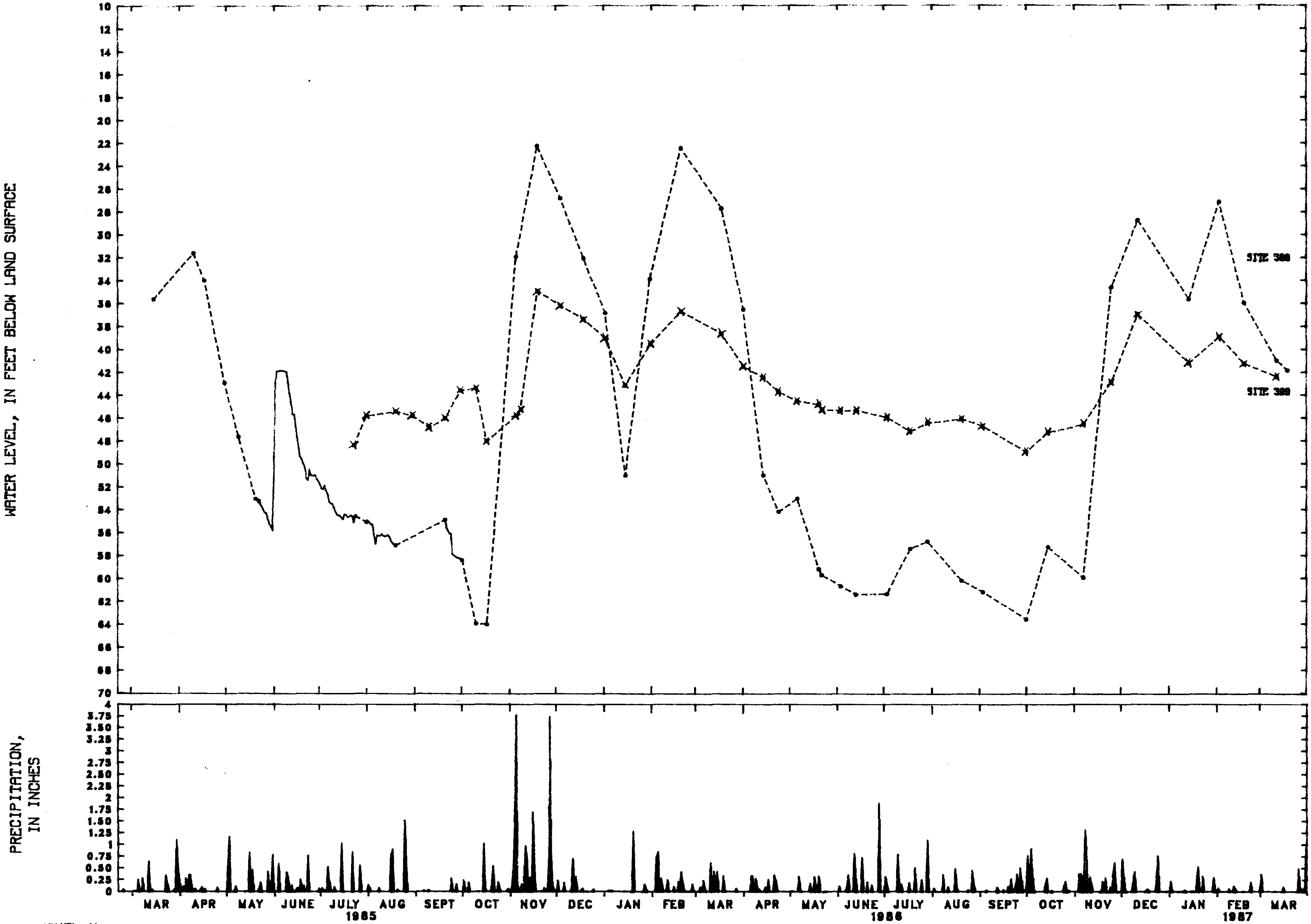

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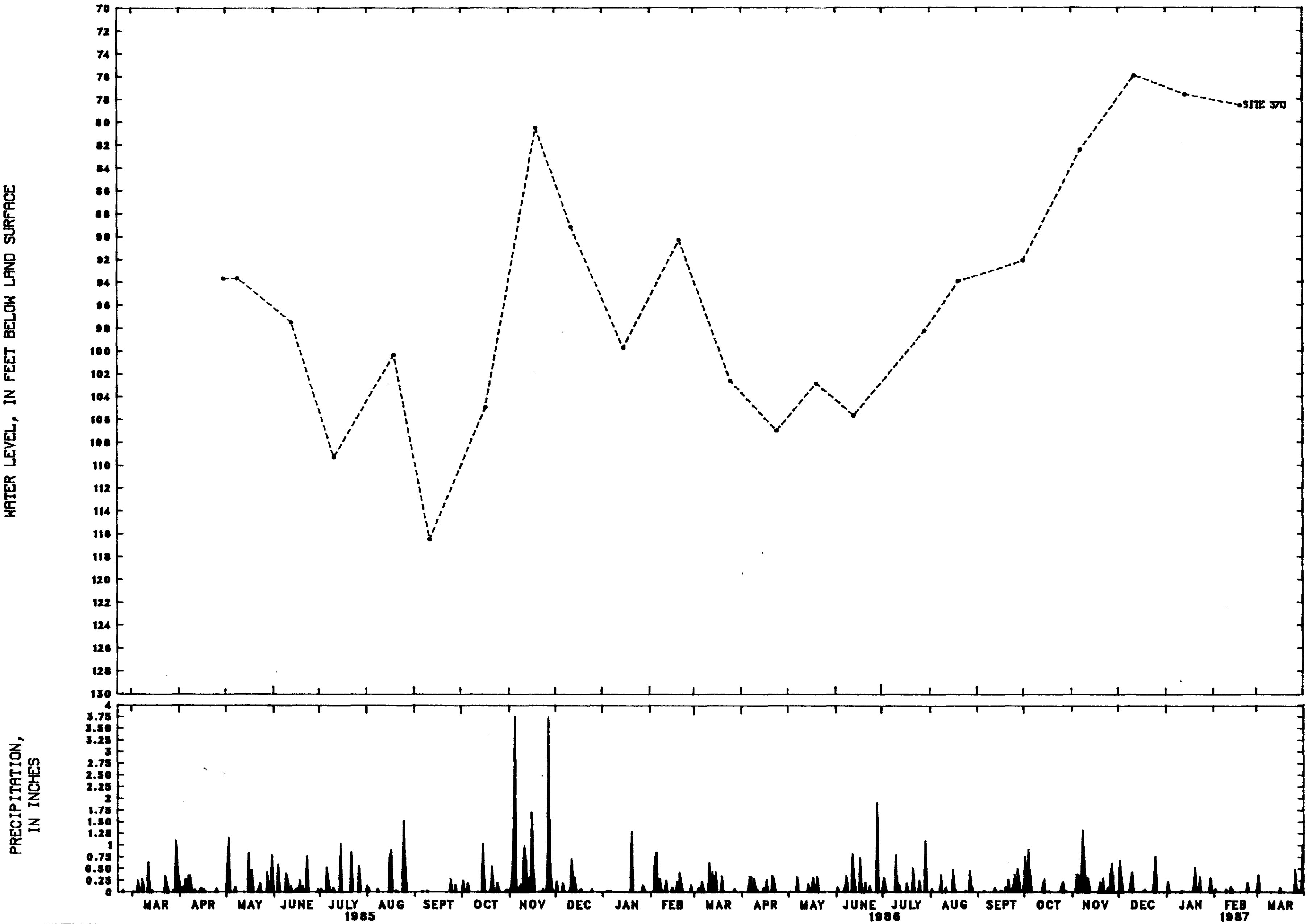

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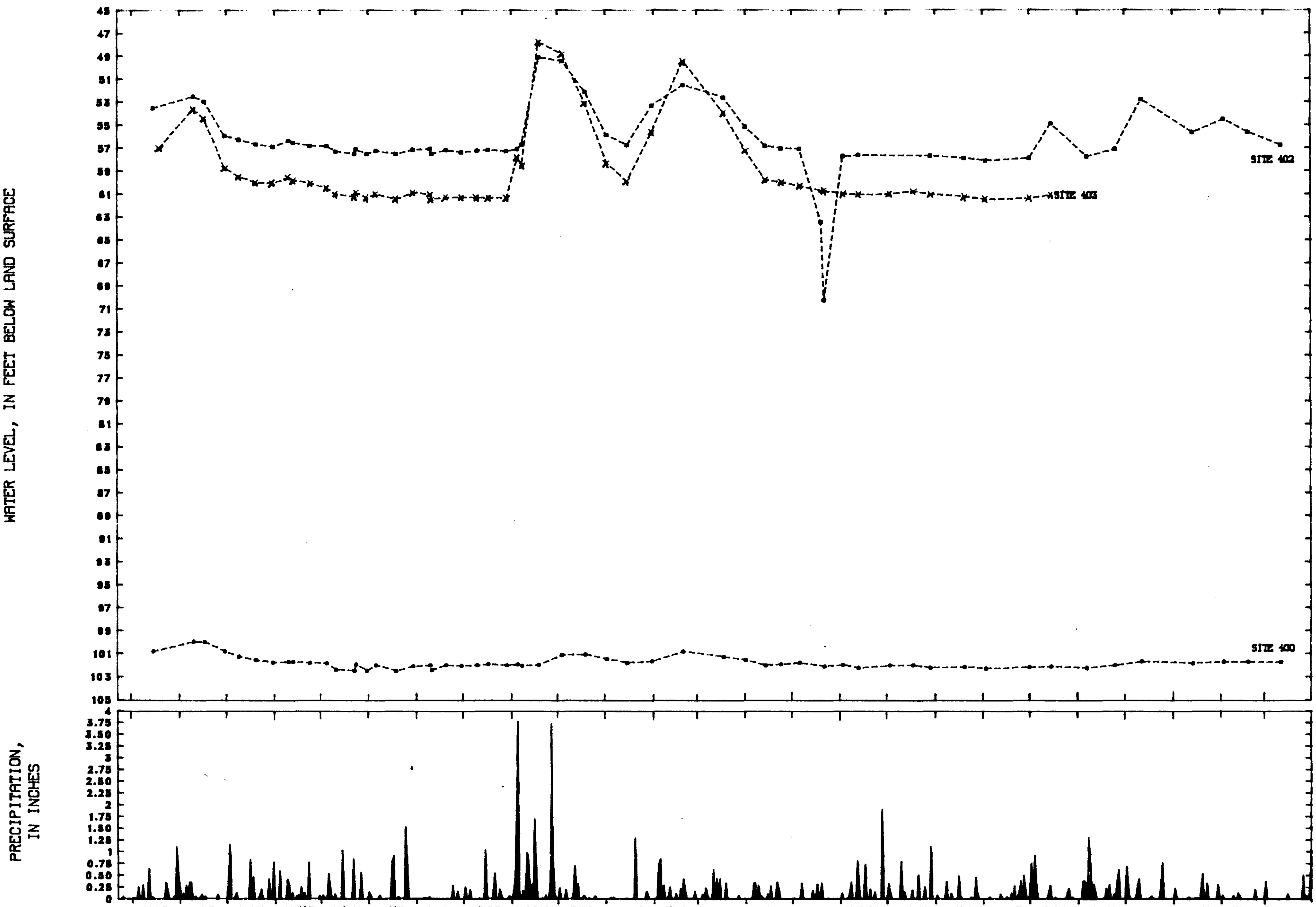

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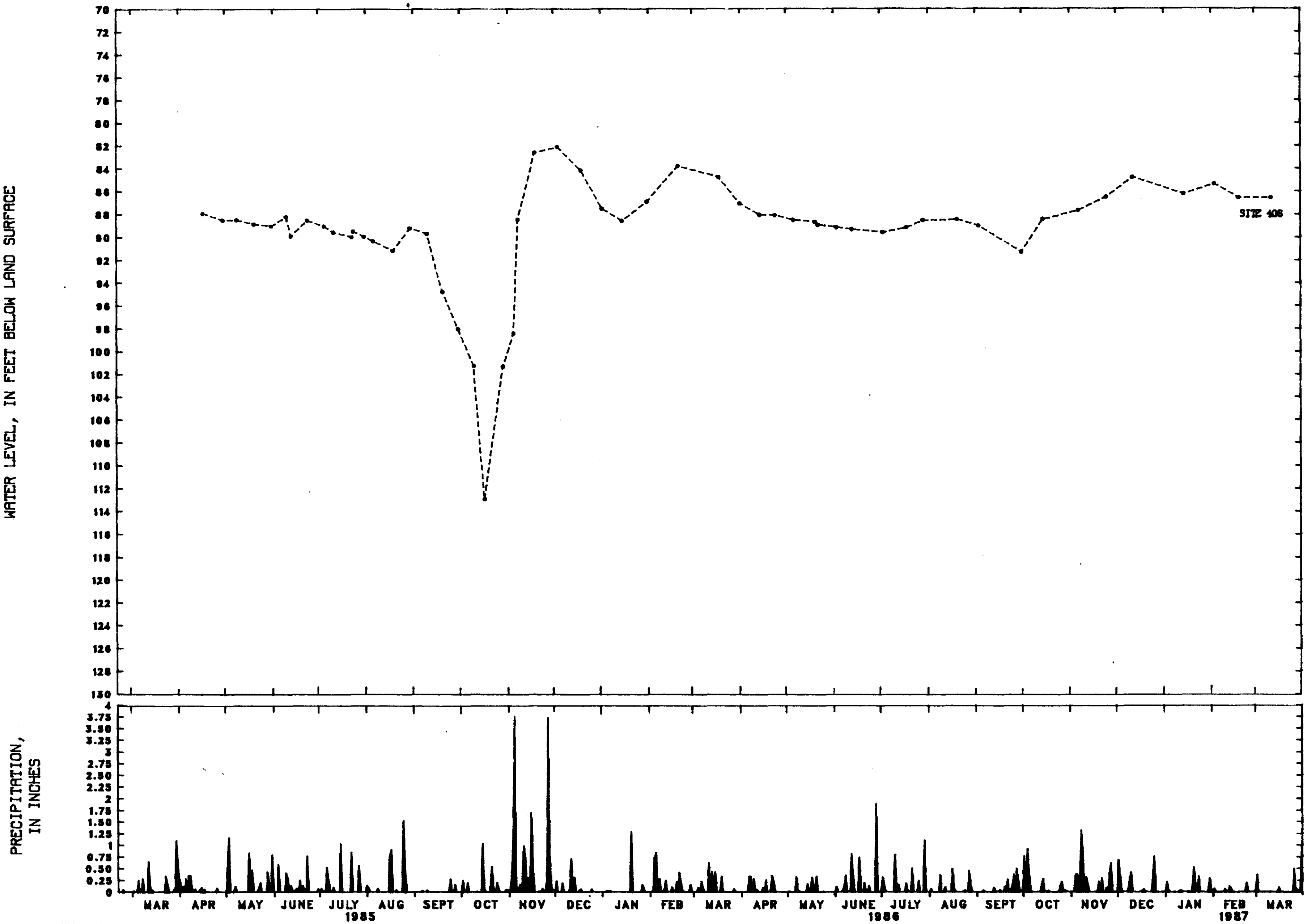

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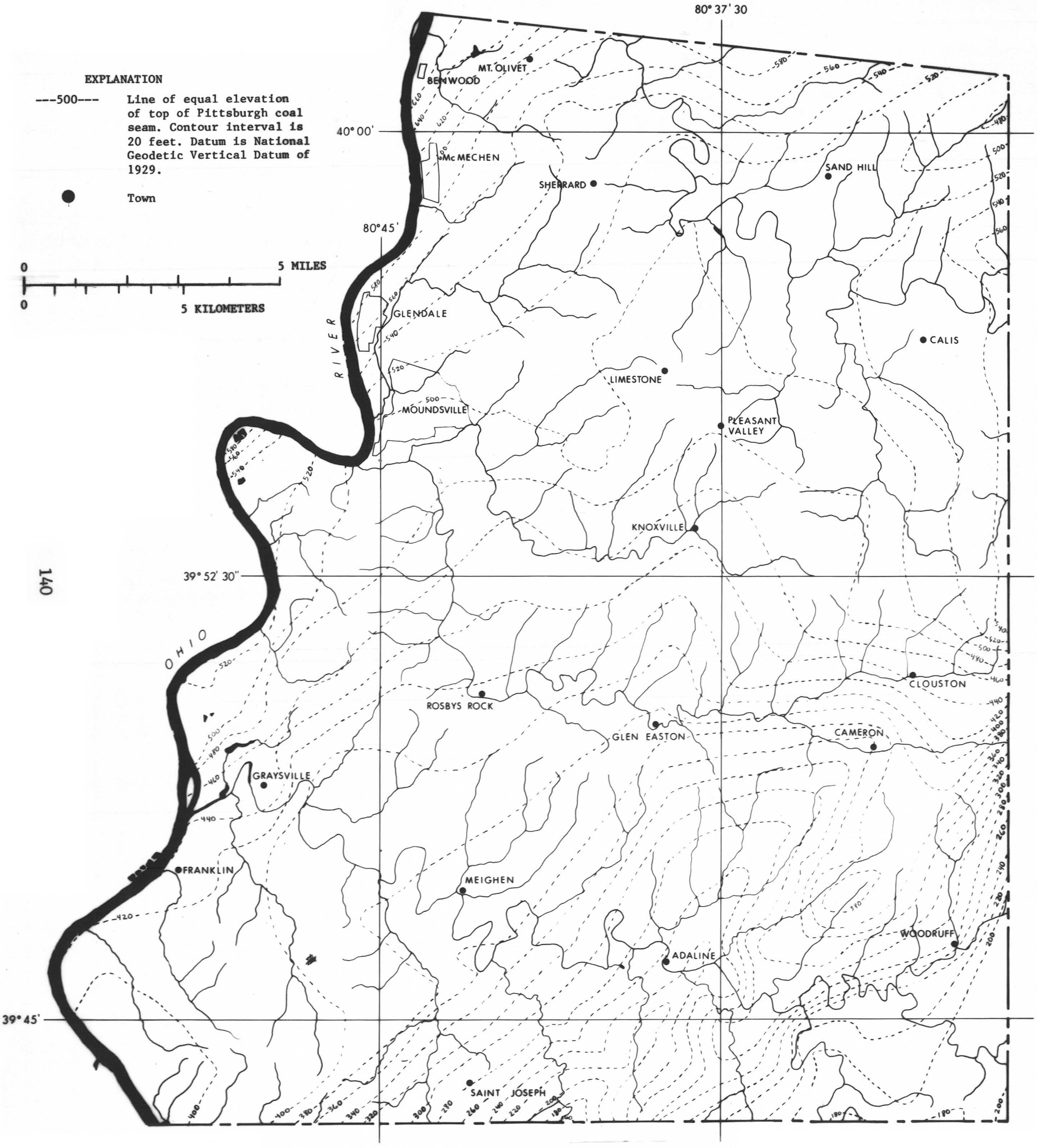
MEAN PRECIPITATION, 1965-86	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23	3.76	4.10	4.11	4.31	4.22	3.16	2.85	3.67	2.94	2.54	2.16	3.23

APPENDIX D

88-4006



140

Figure D-1.--Configuration of the top of the Pittsburgh coal seam. (Modified from maps of the West Virginia Geological and Economic Survey).

88-4006

(2)

Base map: U.S. Geological Survey 7.5 minute topographic quadrangle

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

1. ABANDONED ROOM AND PILLAR MINING
2. ACTIVE ROOM AND PILLAR MINING
3. MINED OUT LONGWALL PANELS
4. PROJECTED LONGWALL MINING

BUSINESSBURG, OHIO—W.VA.

Figure D-2.--Location and type of mining.

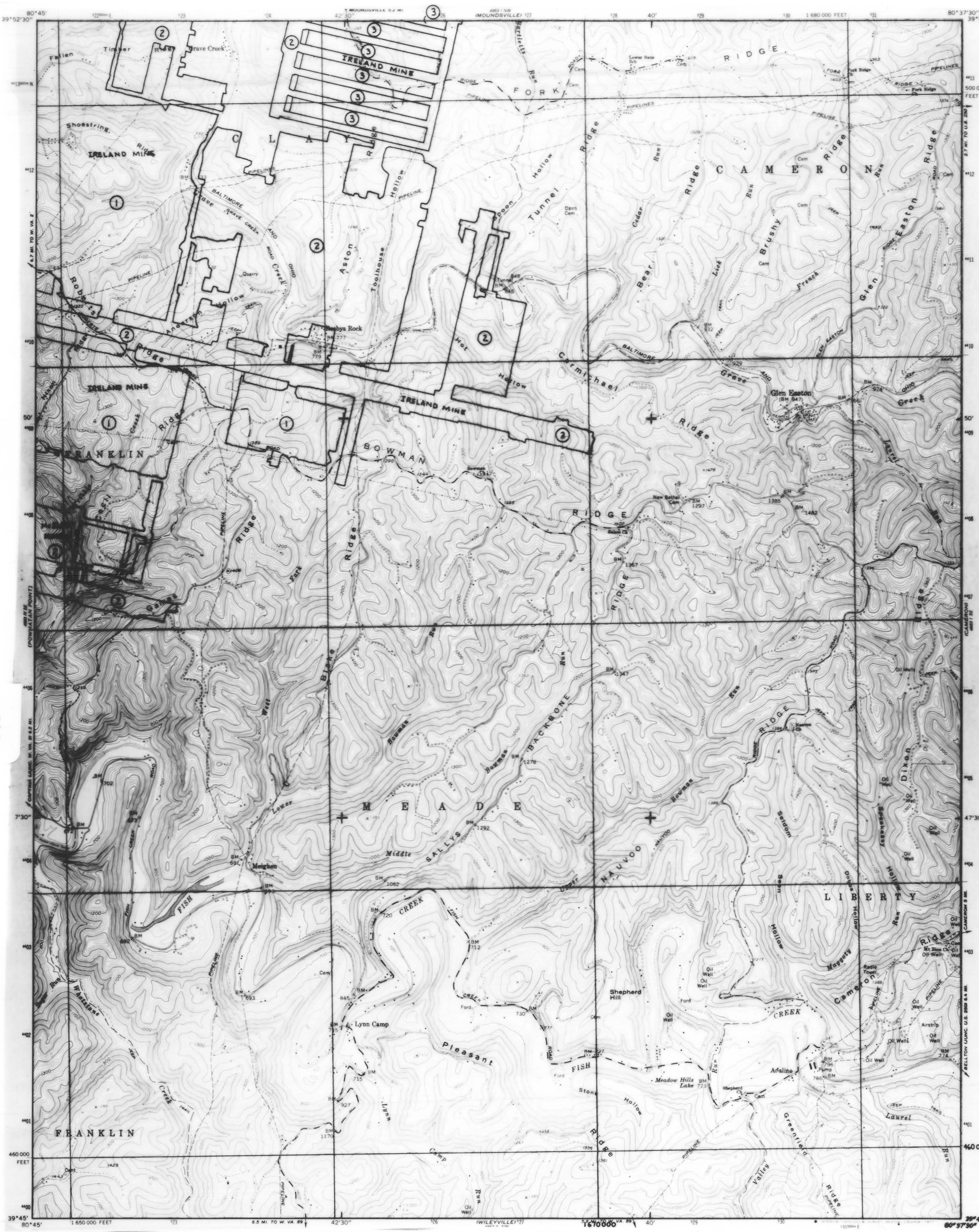
Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey

(2)

88-4006

(3)



Base map: U.S. Geological Survey 7.5 minute topographic quadrangle

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

(1) ABANDONED ROOM AND PILLAR MINING
(2) ACTIVE ROOM AND PILLAR MINING
(3) MINED OUT LONGWALL PANELS
(4) PROJECTED LONGWALL MINING

GLEN EASTON, W. VA.

Figure D-2.--Location and type of mining (Continued).

Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey

(3)

88-4006

(4)

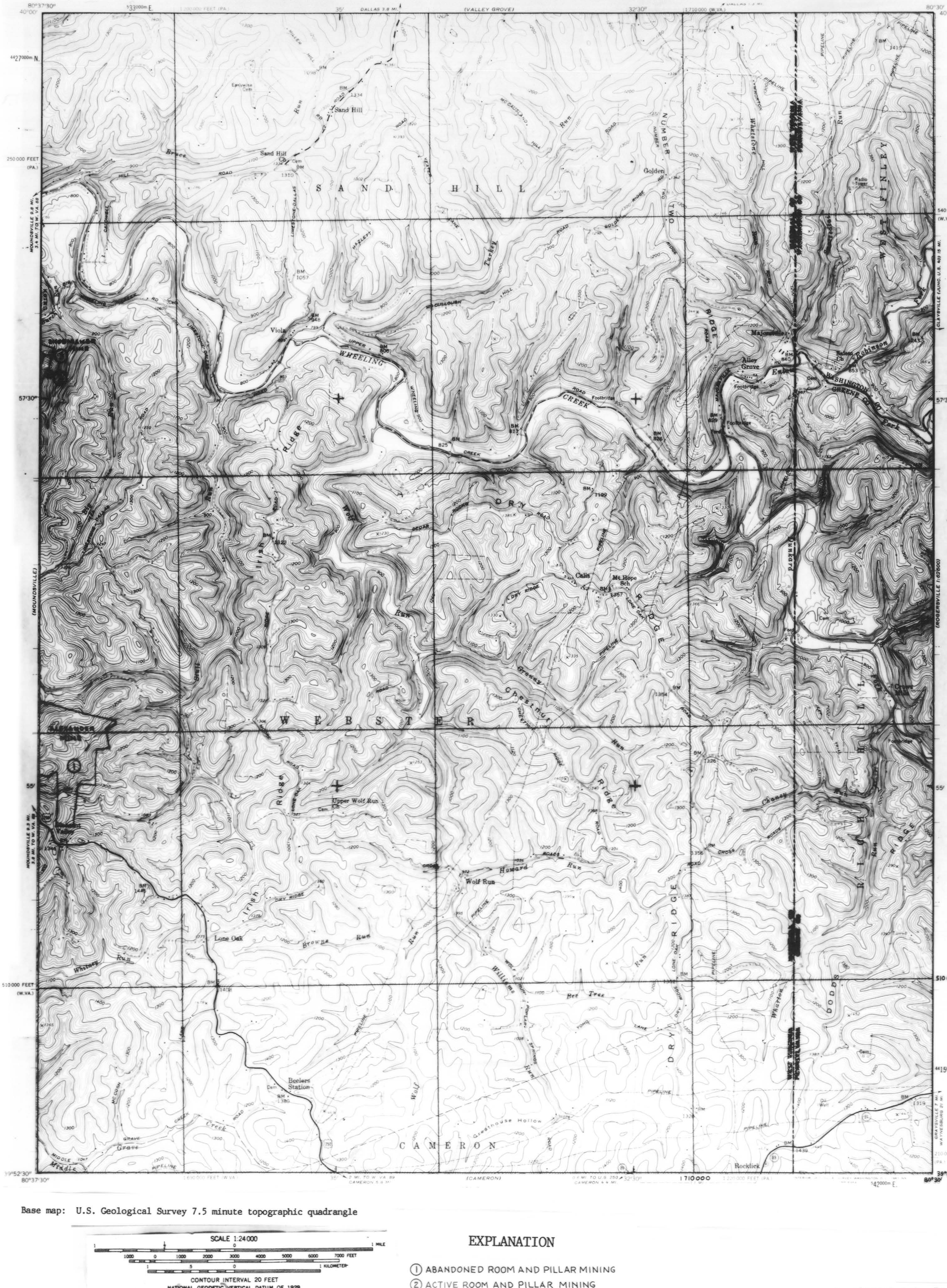


Figure D-2.--Location and type of mining (Continued).

Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey

(4)

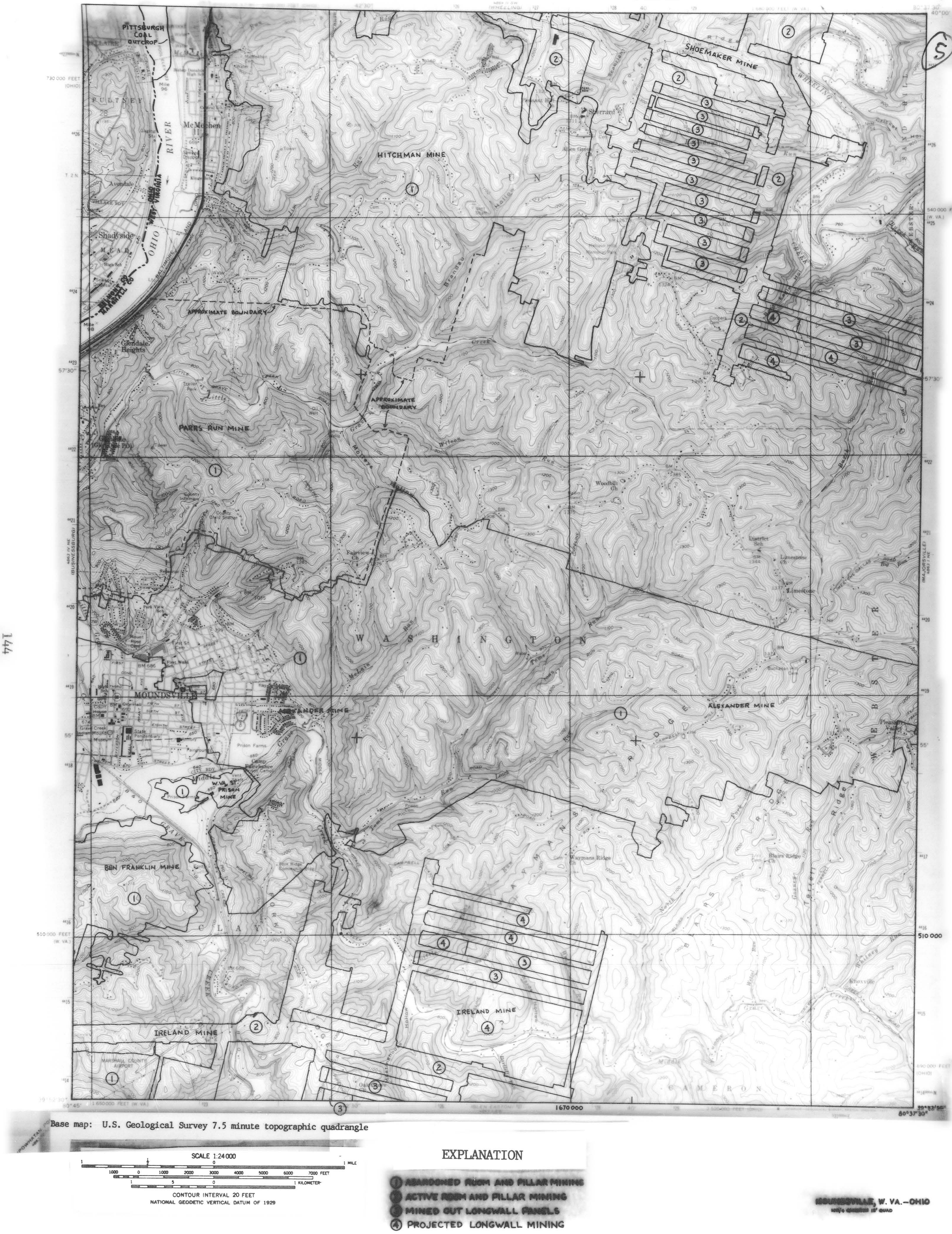


Figure D-2.--Location and type of mining (Continued).

Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey

88-4006

5

88-4006

Base map: U.S. Geological Survey 7.5 minute topographic quadrangle

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

1. ABANDONED ROOM AND PILLAR MINING
2. ACTIVE ROOM AND PILLAR MINING
3. MINED OUT LONGWALL PANELS
4. PROJECTED LONGWALL MINING

POWHATAN POINT, OHIO–W. VA.
SE/4 CLARINGTON 15' QUAD

Figure D-2.--Location and type of mining (Continued).

Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey

6

88-4006 (7)

Base map: U.S. Geological Survey 7.5 minute topographic quadrangle

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

1. ABANDONED ROOM AND PILLAR MINING
2. ACTIVE ROOM AND PILLAR MINING
3. MINED OUT LONGWALL PANELS
4. PROJECTED LONGWALL MINING

VALLEY GROVE, W. VA.—PA.
SE/4 WHEELING 15' QUAD

Figure D-2.--Location and type of mining. (Continued)

Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey

(7)

88-4006

Base map: U.S. Geological Survey 7.5 minute topographic quadrangle

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

(1) ABANDONED ROOM AND PILLAR MINING
(2) ACTIVE ROOM AND PILLAR MINING
(3) MINED OUT LONGWALL PANELS
(4) PROJECTED LONGWALL MINING

WHEELING, W. VA.–OHIO

Figure D-2.--Location and type of mining (Continued).

Underground mining as of January 1, 1984

Note: Mining maps were supplied by Consolidation Coal Company and the West Virginia Geological and Economic Survey