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RIVER BASIN BULLETIN 3

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WATER RESOURCES
OF THE
POTOMAC RIVER BASIN,
WEST VIRGINIA

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BY

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United States Geological Survey

Prepared by the
United States Geological Survey
in cooperation with the
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1972

I assume cooperator does not want to publish metric units in the report. However, a metric conversion table should be added to the report.

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~~Revised October 11, 1973~~

FACTORS FOR CONVERTING ENGLISH UNITS TO INTERNATIONAL SYSTEM (SI) UNITS

The following factors may be used to convert the English units published herein to the International System of Units (SI). ~~Subsequent reports will contain both the English and SI unit equivalents in the station manuscript descriptions until such time that all data will be published in SI units.~~

Multiply English units	By	To obtain SI units
	Length	
inches (in)	25.4	millimeters (mm)
	.0254	meters (m)
feet (ft)	.3048	meters (m)
yards (yd)	.9144	meters (m)
rods	5.0292	meters (m)
miles (mi)	1.609	kilometers (km)
	Area	
acres	4047	square meters (m^2)
	.4047	*hectares (ha)
	.4047	square hectometer (hm^2)
	.004047	square kilometers (km^2)
square miles (mi^2)	2.590	square kilometers (km^2)
	Volume	
gallons (gal)	3.785	**liters (l)
	3.785	cubic decimeters (dm^3)
	3.785×10^{-3}	cubic meters (m^3)
million gallons (10^6 gal)	3785	cubic meters (m^3)
	3.785×10^{-3}	cubic hectometers (hm^3)
cubic feet (ft^3)	28.32	cubic decimeters (dm^3)
	.02832	cubic meters (m^3)
cfs-day (ft^3/s-day)	2447	cubic meters (m^3)
	2.447×10^{-3}	cubic hectometers (hm^3)
acre-feet (acre-ft)	1233	cubic meters (m^3)
	1.233×10^{-3}	cubic hectometers (hm^3)
	1.233×10^{-6}	cubic kilometers (km^3)
	Flow	
cubic feet per second (ft^3/s)	28.32	liters per second (l/s)
	28.32	cubic decimeters per second (dm^3/s)
	.02832	cubic meters per second (m^3/s)
gallons per minute (gpm)	.06309	liters per second (l/s)
	.06309	cubic decimeters per second (dm^3/s)
	6.309×10^{-5}	cubic meters per second (m^3/s)
million gallons per day (mgd)	43.81	cubic decimeters per second (dm^3/s)
	.04381	cubic meters per second (m^3/s)
	Mass	
ton (short)	.9072	tonne (t)

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*The unit hectare is approved for use with the International System (SI) for a limited time. See NBS Special Bulletin 330, p.15, 1972 edition.

**The unit liter is accepted for use with the International System (SI). See NBS Special Bulletin 330, p. 13, 1972 edition.

RIVER BASIN BULLETIN 3

WATER RESOURCES OF THE POTOMAC RIVER BASIN, WEST VIRGINIA

By William A. Hobba, Jr., Eugene A. Friel, and James L. Chisholm

SUMMARY

This report describes the water resources of the Potomac River basin in West Virginia. This basin includes an area of 3,464 square miles or about 15 percent of the State. The present population is 125,500. Considerable future increases in population, with increases in recreational and industrial expansion and in the demand for water, are anticipated. Thus, a knowledge of the water resources is essential in proper planning for development.

~~Essentially~~ Virtually all water in the basin is derived from precipitation. Average annual precipitation is 38 inches per year; of this amount 25 inches is returned to the atmosphere by evapotranspiration, 8 inches becomes ground-water recharge, and 5 inches becomes direct overland runoff.

The hydrology of both surface water and ground water is related to geology. In numerous places perched streams are losing water to underlying cavernous limestone and fractured sandstone. In other places streams are gaining water that is discharged from adjacent aquifers. Ground water discharging to streams in the central part is derived mainly from springs in anticlinal structures of sandstone and limestone. Discharge to streams in the eastern part is derived mainly from springs on faults or other fractures in the carbonate rocks. Studies of streamflow at gaging stations indicate that from 60 to 85 percent of stream discharge in the 1969 water year was derived from ground-water sources.

Average annual streamflow is 0.9 cfsm (cubic feet per second per square mile) and ranges from 0.4 to 2.21 cfsm. Average 7-day low flows range from less than 0.03 cfsm to more than 0.15 cfsm.

Flood-frequency relations are presented in table form and were computed by using the Log-Pearson Type III distribution. Depending on location, streamflow storage for water supply would be replenished each year for continuous draft rates of from 19 to 34 percent of mean flow, with a 2 percent probability of failure. Values of flow duration and variability are presented in table ~~5~~ form. Surface-water impoundments decrease flood peaks and increase minimum flows. A study of the South Branch Potomac River from Petersburg to the mouth was made to determine travel time, the maximum concentration, and the duration of a contaminant at a given point when the streamflow is in the range of mean annual flow.

Water occurs in the folded and faulted crystalline rocks, sandstones, shales and siltstones, and carbonate rocks that underlie the basin. The carbonate rocks of Berkeley and Jefferson Counties are the best aquifers and may yield more than 600 gpm (gallons per minute) to individual wells tapping cavernous zones. The shale rocks of the central part are generally the poorest aquifers. Wells have been drilled 400 to 1,000 feet into shale without obtaining a usable quantity of water. A summary of the ground-water hydrology is given in plate 1 and table 1.

The chemical quality of both surface water and ground water is very poor to excellent, depending on location. In places, water from the shale contains as much as 7,900 mg/l (milligrams per liter) dissolved solids. In places water from the coal-bearing rocks contains concentrations of sulfate and iron in excess of 2,000 and 300 mg/l, respectively. The surface water of poor quality is commonly derived from ground water of poor quality, although in some streams (such as in the North and South Branches of the Potomac River and Opequon Creek) poor quality is due to pollutants.

Table 2 is a summary of facts about the Potomac River basin in West Virginia.

Plate 1

Ground-water hydrology of the Potomac River Basin, West Virginia

Table 1

Summary of Data Regarding Hydrologic Units and Ground Water

Table 2

Summary of Facts about the Potomac River Basin in West Virginia

INTRODUCTION

The study area lies in eastern West Virginia (fig. 1) and includes eight counties and what is commonly referred to as the "Eastern Panhandle". It is underlain by rocks of varied age, composition, and structure. The geologic names used throughout this report conform to those used by the West Virginia Geological Survey and are not necessarily the same as those used by the U. S. Geological Survey. Elevation of the land surface generally increases from east to west, and both the lowest and highest elevations in West Virginia are found in the basin (fig. 2). The lowest elevation (250 ft. above mean sea level) is at Harpers Ferry, at the junction of the Potomac and Shenandoah Rivers. The highest elevation (4,860 ft. above mean sea level) is at Spruce Knob, near Circleville in Pendleton County.

Consolidated rocks of four types underlie the basin: crystalline rocks; sandstones; shales and siltstones; and carbonate rocks. These rock types have been mapped as aquifer units (pl. 1) and are described in detail in table 1. This table summarizes data regarding the composition of the various aquifers, the quality of their water, and the yields of wells and springs tapping them.

Figure 1

Index Map of the Potomac River Basin in West Virginia

Figure 2

Relief Map and Cross Sections Showing Physiographic Provinces and General Rock Structure

Rock composition and structure are both related to topography. The shale and limestone are easily weathered and eroded and generally underlie valley areas. Sandstones are more resistant to weathering and erosion and, therefore, generally underlie ridge areas. This is apparent when comparing the geology (pl. 1) to the relief map (fig. 2). Crystalline rocks, underlying less than 1 percent of the basin, are also resistant to weathering and erosion and form the ridge at the extreme east edge of the basin. Rocks of the Valley and Ridge province form anticlines and synclines. Anticlines are beds of rock folded into an arch. Synclines are beds of rock folded into a trough ~~an inverted arch~~. Many anticlines composed of sandstone form ridges, and many synclines composed of shale form valleys. Some anticlines of easily weathered shale or limestone form valleys, and some synclines of resistant sandstones form ridges.

The Appalachian Plateau province is underlain by relatively flat-lying sandstone and shale. However, (strata) at depth may have been folded, folding ~~may be~~ more intensive. Here, too, the more resistant sandstone generally underlies ridges, and less resistant shale underlies slopes and valleys.

Strata at [illegible] folding [illegible]?

The major rivers are the North and South Branches of the Potomac, the Potomac, the Shenandoah, and the Cacapon (fig. 2). The upper reaches of the South Branch Potomac, the Shenandoah, and the Cacapon Rivers are fairly straight or gently meandering and generally flow in northeast-trending valleys along beds of weak, easily eroded rocks. At some places the rivers cross the ridges at right angles through water gaps in the more resistant rocks.

Purpose and Scope

This report presents basic information and interpretations regarding the occurrence, availability, and quality of the water resources of the Potomac River basin in West Virginia. The report is the result of one of a series of reconnaissances designed to evaluate the water resources of the river basins of West Virginia. The study was done by the U. S. Geological Survey, in cooperation with the West Virginia Department of Natural Resources Division of Water Resources and the West Virginia Geological and Economic Survey. The basin includes 3,464 square miles, or about 15 percent of West Virginia. ~~That~~ water resources are important to the basin and will play an important role in its future ~~goes almost without saying~~. Recreational and industrial development is anticipated because most of ~~it~~ the basin lies within a few hours driving time from Washington and Baltimore. As the area grows, knowledge of the water resources is ~~mandatory~~ needed if they are to be properly developed, managed, and protected.

Many of the basic data ~~in~~ for this report were obtained in the field by personnel of the U. S. Geological Survey between July 1968 and July 1971. and Plates 1, 2, and 3 show locations where most data were collected.

are published in a companion report (Friel, Hobba, and Chisholm, 1974).

WATER RESOURCES

Water in the Potomac River basin is mainly derived from precipitation, and most of West Virginia has abundant rainfall. Although that part of the State west of the Alleghenys has an average annual precipitation of 45 inches, the basin has an average precipitation of 38 inches annually. This difference is largely attributed to differences in elevation and storm patterns. Because most of the basin's water comes from precipitation, some knowledge of climate is essential to understanding its water resources.

The central part lies about 200 miles from the ocean. The basin lies on the eastern slopes of the Appalachians, and its climate is more continental than maritime. The area is influenced by prevailing westerly winds, which are frequently interrupted by surges of cool northerly and warm southerly air masses. These surges are accompanied by the passage of high and low pressure zones; associated with the latter are large-dimension storms, which are most common in the colder half of the year. Large storms are usually responsible for flooding the larger streams. In the warmer half of the year, the basin is affected by the showers and thunderstorms that occur in the broad current of air that tends to sweep northeastward from the Gulf of Mexico. Storms of this type often cause flash flooding in narrow valleys.

Figure 3 shows areal differences in average annual precipitation. me of the variations are dramatic; for example, from the mountains along e west edge of the basin to Petersburg, annual precipitation decreases 29 ches in an airline distance of only 15 miles. The vegetation also changes, espectively, in this distance from birch, spruce, and rhododendron to carlet oak, Virginia pine, and some prickly pear cactus. A marked rain hadow occurs east of the Alleghenys because westerly winds become warmer s they descend the east and leeward slopes of these mountains. The atmoshere is thereby capable of holding more moisture, and precipitation is orrespondingly reduced. Precipitation increases farther eastward, where opographic influences are more favorable and where the influence of the cean and coastal storms is more pronounced (U. S. Weather Bureau, 1960). eakened hurricanes traveling northeastward along the east side of the lleghenys occasionally cause heavy rainfall and flooding during late summer nd early autumn.

The extremes of monthly precipitation at Martinsburg during ~~the period~~ 1892 to 1969 ranged from ~~a minimum of~~ 0.07 inch~~es~~ in October 1963 to ~~a maximum of~~ 10.67 inches in May 1921. These extreme monthly values (and their ear of occurrence) along with the 1931-60 monthly normals are as follows:

Figure 3

Map Showing Average Annual Precipitation.

Month	Maximum (inches)	(Year)	Minimum (inches)	(Year)	Normal (1931-60) (inches)
January	5.49	(1937)	0.25	(1955)	2.63
February	4.90	(1897)	.25	(1901)	2.14
March	6.76	(1936)	.17	(1910)	3.26
April	8.62	(1918)	.74	(1946)	3.24
May	10.67	(1921)	.35	(1900)	3.81
June	7.54	(1896)	.88	(1966)	3.16
July	9.30	(1905)	.72	(1966)	3.58
August	10.00	(1911)	.57	(1962)	4.22
September	9.49	(1945)	.47	(1943)	3.06
October	10.38	(1942)	.07	(1963)	3.28
November	6.17	(1963)	.41	(1960)	2.53
December	5.25	(1901)	.19	(1955)	2.74

The variation, duration, and frequency of annual precipitation at Martinsburg are shown in Figure 4. The duration graph shows the percentage of total years in which a given value was equaled or exceeded, and the frequency graph shows the recurrence interval, in years, of a given annual value.

Drought is difficult to define. Hoyt's (1936) drought index, which is one of many definitions, states that a drought exists when annual precipitation is less than 85 percent of the mean. Using this criterion, droughts have occurred at Martinsburg during 15 percent of the years (1892 to 1969) (fig. 4). Annual precipitation as low as that of 1930 has a recurrence interval of at least 80 years. During the 17-year period ~~since~~ 1953-69, annual precipitation was below the 78-year mean in 14 of those years and was below the 85-percent drought index in 6 years. Perhaps the greatest economic impact of the entire 78-year period was from 1963 to 1966, when annual precipitation was below the 85-percent drought index for 4 consecutive years. The severity of a drought in some respects is determined by the amount of precipitation during the growing season; therefore, annual precipitation does not always reflect the severity of a drought.

Figure 4

Variation, Duration, and Frequency of Annual Precipitation at Martinsburg.

Tick Shows 85-percentile Value, the Drought Index of Hoyt (1936)

The hydrologic Cycle

Water moves continuously from the atmosphere to the earth and back to the atmosphere. This movement is termed the hydrologic cycle. Figure 5 depicts the hydrologic cycle in the basin and the approximate yearly amounts of water involved in each phase. It is emphasized that the amounts shown are averages for the entire basin. However, within the basin, variations may be wide from one locality to another.

Variations are caused not only by precipitation but also by temperature, wind, humidity, and length of growing season. These factors profoundly affect evaporation; data from the class-A type evaporation pan, as recorded by the U. S. Weather Bureau for the April-to-October period, show that for each 1,000-foot increase in altitude (with its decrease in temperature) evaporation decreased by about 1 inch (fig. 6). The growing season also becomes shorter with increasing altitude and decreasing temperature; thus, transpiration should generally decrease also. Therefore, more water is available to become overland runoff or ground-water discharge because of lesser evapotranspiration demands at higher elevations.

Figure 5

The Hydrologic Cycle in the Potomac River Basin in West Virginia

Figure 6

Average Evaporation from Class A Pans at Wardensville and Parsons

Potential evapotranspiration (Et) is the water loss under the othetical condition of no deficiency of water in the soil at any time use of the type and density of vegetation that would develop (Langbein Iseri, 1960). Monthly adjusted potential Et values for eight stations, computed by the Thornthwaite (1958) method, were furnished by Robert O. dfall, State Climatologist, and Walter H. Dickerson, Professor of Agricul- al Engineering, West Virginia University, and are shown in table 3. monthly potential Et in the valleys and at low elevations throughout basin exceeds precipitation from May through September on the average, t, at higher elevations and in areas of higher precipitation, it does not, is illustrated in figure 7. Theoretically, ground-water recharge should t occur in vegetated areas during the period when potential Et exceeds ecipitation. Therefore, ground-water storage should be steadily depleted Et demands and continuous seepage to streams.

Table 3

Adjusted Potential Evapotranspiration

Figure 7

Monthly Potential Evapotranspiration and

Precipitation at Petersburg and Bayard

The hydrologic cycle is in balance at all times. Therefore, total water input must equal total water output. Neglecting any interbasin underflow, water input is precipitation, and water output is total streamflow plus total water loss (fig. 5). Total streamflow is composed of overland runoff plus ground-water discharge to streams. Total water loss is the water that returns to the atmosphere by Et. Figure 8 shows the variations of total water loss as total precipitation minus total runoff during 1930-67 for 20 sub-basins. Because the values shown in figure 8 are average for the 38-year period, year-to-year change in ground-water storage may be neglected. The variation in water loss from one part of the basin to another is caused by precipitation differences and probably by interbasin transfer of ground water from one sub-basin to another.

The degree to which man's activities affect the hydrologic cycle is poorly understood. However, holding water in dams and ponds, pumping of wells, irrigation, and clear cutting of forests do affect the amounts of water passing through the various phases of the hydrologic cycle.

Figure 8

Average Annual ~~Precipitation, Runoff, and~~ Water Loss

Interrelationships Between Ground Water and Surface Water

There is a ~~an intimate~~ relationship between the ground-water and surface-water phases of the hydrologic cycle. The discharge of most streams is composed of a mixture of overland runoff and ground-water discharge that varies in time and place. During dry periods streamflow may be all ground-water discharge. During floods it may be all overland runoff. Overland runoff reaches streams quickly, and most of it is discharged from the basin within a few days. In contrast, ground-water discharge continues over a prolonged period and is greatest when the water table is highest, usually in the spring. It continues at a decreasing rate through summer and autumn, even when there is no ground-water recharge. Most of the large perennial streams discharge relatively large amounts of ground water annually. These streams are incised to a water table that generally slopes toward the stream and continuously feeds ground water to it. The smaller ephemeral streams of the upland part of the basin discharge only small amounts of ground water during dry summer and fall, when the water table drops beneath the bed of the stream and the stream goes dry. During such dry periods, a part of any overland runoff entering a stream may percolate to the water table through the stream bed and become ground water. This aspect of the interrelationship of ground water to surface water is further discussed and examples are cited in a following section, "Gaining and Losing Streams."

Geology and topography have a marked effect on the relationship of ground water to surface water. This effect is usually determined by permeability of the various rocks and the slope of the land surface. The four basic types of rock in the basin—crystalline, sandstones, shales and siltstones, and carbonates—generally have different hydraulic characteristics. The crystalline rocks and the shales and siltstones are the least permeable, and the sandstones and carbonate rocks are the most permeable. Hence, an area underlain by impermeable shale and siltstone would permit a large percentage of percipitation to become overland runoff. An area of equal size underlain by permeable, fractured, cavernous limestone receiving an equal amount of precipitation would permit most of the precipitation to become ground-water recharge. The greater amounts of ground-water recharge and storage are reflected in the high levels of base flow maintained in areas underlain by limestone. Topography affects ground-water recharge by causing greater runoff from steep slopes than from flat-lying areas underlain by rocks of similar permeability receiving similar amounts of precipitation.

The interrelated and variable influence of geology and topography on und-water recharge and discharge and streamflow are illustrated by the eamflow-duration curves shown in figure 9.

The slope of a flow-duration curve has a direct relation to ground-ter recharge and discharge. If little or no artificial surface storage present, a gently sloping flow-duration curve reflects the discharge of latively large quantities of ground water. A steeply sloping curve flects less discharge of ground water and indicates that the stream may flashy due to a great contribution from surface runoff. The lower part the curve reflects ground-water discharge almost entirely. The slopes f all the duration curves in the basin are rather flat compared with those n other areas of the State, indicating high ground-water storage and con-equent high base flows.

The South Branch Potomac River above Franklin and Opequon Creek above artinsburg are underlain by a highly permeable cavernous limestone. During eriods of precipitation direct storm runoff is reduced because much of the ater infiltrates the limestone and is stored there. Recharge to the lime-stone is greatest during the winter and spring. The stored water is gradually released throughout the rest of the year, resulting in high base flow during dry periods. Thus, the streamflow-duration curves for South Branch Potomac River at Franklin and Opequon Creek above Martinsburg have relatively flat slopes. The upper parts of the curves are low, and the lower parts of the curves are high.

Figure 9

Flow-Duration Curves of Selected Streams

in the Potomac River Basin

The Patterson Creek basin above Headsville and the Back Creek basin ve Jones Springs are genarally underlain by relatively impermeable shale l siltstone beds, which have a low capacity for ground-water storage. st precipitation runs off overland. Hence, there is little ground-water charge and, therefore, low base flows. The ~~stream~~flow-duration curves r these streams, thus, have relatively steep slopes. These streams are id to be "flashy" because they have a high variability of flow.

The North Branch Potomac River above Steyer, Maryland, is underlain by derately permeable sandstone and shale. Thus, moderately large amounts of ter infiltrate and become ground water. Although the slope of the middle rt of this curve is about the same as that for the areas underlain by mestone, the upper part of the curve indicates that the rocks of this area e not as effective as the limestones in taking on recharge, and the lower rt of the curve indicates that these rocks do not have as much stored ter to release as the limestones. The entire curve for this stream has e highest position on the graph because the annual precipitation in this ub-basin is the highest.

The low-flow frequency curves shown in figure 16 also illustrate the uence of geology on the low flow of streams. For example, the median y value (at the 2-year recurrence interval) for Opequon Creek is 0.17 (cubic feet per second) per square mile, as compared with 0.03 cfs per re mile for Back Creek. The difference between the two sets of curves mes even greater with longer recurrence intervals. The flatter slope higher position of the curves for Opequon Creek is another indication igher infiltration rate and storage capacity in this basin. The lowest flow each year, for at least the 7-consecutive-day periods, consists gely of ground-water discharge to the streams.

The variation in contribution to streamflow by ground-water discharge overland runoff in various sub-basins is discussed in more detail in a lowing section.

Gaining and Losing Streams

Streams, or parts of streams, may be classed as either gaining or osing. The flow of gaining streams is maintained or increased by the nflux of ground water. The flow of losing streams is depleted by leakage o an aquifer below the bed of the stream. Although losing streams are ore prevalent than generally thought, in the eastern United States the aining stream is the more common type.

Several large losing streams exist in the Potomac River basin. Probably Lost River is the best-known. Three miles west of Wardensville, at Route 55 and 259, the river goes underground (pl. 1). It probably drains into the fractured Oriskany Sandstone and cavernous limestone of the Helderberg Group to a point about 2 miles downstream, where it emerges as the Cacapon River. Surface flow takes place during periods when the level of water in the ground rises above the bottom of the stream channel and when flood flows in the river exceed percolation capacity of the stream bed.

Of the smaller losing streams, Smith Creek — from Zigler (4 miles outhwest of Franklin) to the South Branch — is the only one that has been tudied. The measured flows of Smith Creek upstream from Zigler ranged from as little as 0.1 cfs during periods of base flow to 18 cfs (table 4). During periods of low flow the stream disappears at or just below Zigler. During periods of high flow it generally disappears within 2 miles downstream from Zigler, but, during wet periods in the spring, it sometimes flows over the entire length from Zigler to the South Branch Potomac River.

Wells in the valley bottom at and downstream from Zigler show the water table to be as much as 200 feet lower than the land surface. Well 26-5-26 was drilled 80 feet deep in October 1967. At that time the water level in it was reported to be 30 feet below land surface. In June 1970 the well went dry and was drilled to a depth of 160 feet. The water level declined again. It was then drilled to 240 feet. At this depth the water level was measured on August 13, 1970, to be 194 feet below land surface. This decline in water level with well depth indicates an underground discharge zone or drain. The water level on January 21, 1971, was 172 below land surface, indicating recharge.

Table 4

Measured Discharge and Specific Conductance of Smith Creek at Zigler and near Franklin

It is difficult to determine the exact location and nature of the drain in the Smith Creek area. However, the lowest elevation of the water table beneath Smith Creek is about 1,850 feet above mean sea level. Thus, the water level is high enough that a hydraulic gradient probably could exist from beneath the creek south beneath Pickle Mountain along limestone caverns in the anticlinal structure to the South Branch Potomac River. Apparently, the water is not flowing in alluvium beneath and parallel to Smith Creek because the flow is less near the mouth, at Route 220, where it crosses over beds of shale, than it is at Zigler. These relatively impermeable shale beds overlie the sandstone and limestone and should force to the surface any large quantity of water moving beneath the creek. The water, apparently, is not discharging beneath the mountains to Friends Run, in the next east-west valley to the north, because that stream was dry over most of its lower 3 miles when observed during a base flow period in October 1970. In fact, the lack of perennial streams tributary to Friends Run suggests that the same underground drain is conducting water from beneath Friends Run southward beneath Smith Creek and discharging to the South Branch Potomac River.

Several other streams were found to be losing water at the time base-flow measurements were made in October 1969. (See base-flow section.) The amounts of the losses are shown in figure 11. The measurements show that losses take place not only on limestone formations but also on shale and sandstone formations. Losses on shale and sandstone are attributed to high rates of evapotranspiration and to underflow in the fractures along which the stream channel has developed.

There are probably many more losing streams in the study area. However, it is not always possible to detect these streams visually. However, much of the limestone favors the formation of caverns, which, in turn, may creata losing streams. Many structural features, including bedding surfaces, fractures, and some of the important joint sets, strike northeast. Underground drainage follows many of these features, regardless of the original direction of streamflow on the surface. Where streams lose water to areas underlain by shale and sandstone, underground flow is probably along fractures or faults beneath the stream channel, along which the stream channel has developed. Water-table contours indicate that underground drainage in Berkeley and Jefferson Counties (pl. 1-C) is controlled in part by faults. The nature of underground drainage for both high- and low-relief areas of the Valley and Ridge Province is further described in the hydrology section.

Streamflow Separation

As noted earlier, the relative amounts of overland runoff and ground-water discharge in streamflow vary with time and place. Continuous recording [illegible] instruments monitor the stage (~~which can~~ be converted ~~to~~ discharge) of major streams throughout the basin. The following procedure was used in estimating the daily proportion of overland runoff to ground-water discharge to streams in various streams throughout the study area.

Wyrick (written comm., 1972) describes a method of streamflow separation based on channel-method formulas discussed by Stallman (in Ferris and others, 1962, pp. 126-131). For Stallman's formulas to be applicable, the following assumptions are made:

1. The stream flows along a straight line of infinite length and fully penetrates the aquifer.
2. The aquifer is semi-infinite in extent (bounded on one side only by the stream).
3. The head in the stream changes abruptly in response to recharge at time equal 0 days.
4. The direction of ground-water flow is perpendicular to the stream.
5. The change in discharge from the aquifer is derived from changes in storage by drainage after abrupt recharge.

A type curve was plotted to represent the drain-function formulas. By
mparing records of daily stream discharge and daily precipitation, periods
streamflow record were selected for analysis beginning 1 day after abrupt
echarge by precipitation and followed by several days of no precipitation.
treamflow data for these periods were plotted on log-log paper against time,
n days, since recharge (fig. 10). The plotted points were matched to
he type curve by keeping the axes of both graphs parallel. Points on the
treamflow hydrograph matching the type curve were assumed to represent
round-water discharge. By projecting the type curve beneath the earlier
lots of stream discharge, the amount of ground-water discharge was
etermined back to the first day after recharge. The daily ground-water
ischarge was determined and tabulated for all periods of streamflow record
uited to this method of analysis. The ground-water discharge for inter-
vening days not suited to this method of analysis was estimated from a
similar period of record when similar ground-water levels and evapotranspira-
tion conditions prevailed. For a few periods, this method of estimating
could not be used, and discharges were estimated from known discharges and
ground-water levels. After ground-water discharge values were assigned to
all 365 days, the total was computed and expressed as a percent a of total
stream discharge.

Figure 10

Analysis of Streamflow of South Branch Potomac River at Franklin

The analyses of several streamflow records for 1969 showed that ground-
ater discharge ranged from about 60 percent of annual streamflow in areas
nderlain by shale and sandstone to 85 percent in areas underlain by carbonate
ocks. These results were compared with results obtained by ~~a~~ hydrograph-
eparation technique (Linsley and others, 1949). This technique produced
alues that were lower but generally within about 10 percent of the values
btained by the described method. As stated earlier, the lower parts of
low-duration curves give some indication as to ground-water-storage charac-
eristics in a basin. These flow-duration curves served as guidelines
hen assigning values for ground-water storage to various sub~~-~~basins, as did
ase-flow measurements (table 5) and the draft-storage curves (fig. 19).
he draft-storage curves show that sub~~-~~basins having large amounts of ground-
ater storage require less surface storage than those having small amounts
in order to supply a continuous draft of a given quantity.

The amount of ground-water-discharge to streams from each of several basins, as determined by the described method of streamflow separation, was converted to ground-water discharge per square mile and was mapped in plate 1-A on the basis of the underlying geology. Because 1969 was a year of little ground-water recharge, the ranges shown in plate 1-A have been adjusted slightly upward to approximate estimated values for an "average" year. The ranges in ground-water discharge per square mile shown in this plate indicate the approximate amounts of ground water that can be removed on an annual basis from the various aquifers under prevailing conditions without depleting (or mining) the supply.

Plate 1-A

Availability of Ground Water

DELETE

Base Flow

A stream is at base flow when all its water is derived from ground-water discharge. The base-flow characteristics of a stream are, therefore, determined largely by the ground-water environment. The amount of water and the rate at which it moves through aquifers to sustain the low flow in streams depends upon the amount of water in storage, the slope of the water table, and the permeability of the aquifer material. Storage is related to volume of interconnected openings in the rocks. Permeability is related to shape, size, and degree of interconnection of openings in the rocks. Storage and permeability are both normally low in shale and low to high in sandstone and carbonate rocks. Thus, the base flow of streams draining shale is commonly lower than that of streams draining sandstone and limestone.

The length of time it takes for a stream to reach base flow after precipitation depends upon numerous factors. Some of the most important are the amount of precipitation and evapotranspiration, and the geology. ie. [illegible]) In general, the greater the rainfall, the longer it takes streams to reach base flow. However, streams reach base flow in a relatively short period where rocks are permeable or evapotranspiration is high. During winter, ~~true~~ base flow may seldom be reached because of the effects of freezing and thawing on overland runoff and ground-water discharge.

"True" base flow may never be reached because [illegible]

[illegible]

In October of 1969, the base flow of 170 small streams and springs, each draining one type of rock, was measured and sampled for partial analysis. All flow measurements were made by a pygmy current meter or bucket and stop watch. The pH, hardness, and specific conductance were determined with portable field kits and are approximate. Chloride concentration was determined in the laboratory and is more accurate. Analyses and discharge measurements are shown in table 5, along with discharges for several other streams. All but two of the measurements shown were made between October 13 and 21, 1969. The last rain preceding this period was on October 8, when 0.34 ~~inches~~ of rain fell throughout the basin 5 days before measuring began. Ground-water levels during this period were near the lowest on record. (See section on "Storage and Water-Level Fluctuations".)

These base-flow measurements are significant in that they give some indication of the quantity of ground water being discharged to streams. Most of the streams measured drained a single geologic formation or aquifer during a period of base flow when ground-water levels were low and transpiration was minimal; therefore, the base-flow discharges should be indicative of minimum ~~ground~~-water yields from the various aquifers. These yields are shown in table 5 in ~~mgd/mi~~^{2} (million gallons per day per square mile) of aquifer. (During periods of greater transpiration, if rainfall and ground-water [illegible] and other influencing conditions remain unchanged, then base-flow discharges should be lessened by the amount lost through transpiration.)

When ground-water levels are low, I'd buy minimum water yield from aquifers. I would not buy minimum water yield from aquifers when transpiration was minimal. Please clarify. ✓ [illegible]

Table 5

Low-flow Measurements and Chemical Quality of Selected Streams and Springs

Care must be exercised in assigning significance to these data: First,[1] streams were selected that drained a single geologic formation. The flow of streams having larger drainage areas are probably more representative of the minimum yields of the formations they drain than the flow of smaller streams. Secondly, the shale is characteristically found in the valleys, and the more resistant sandstones and associated limestones are found on ridges. Streams in the ridge-forming formations may be small in drainage area, may not be incised to the water table, and are losing water instead of gaining it over parts or all of their courses. Streams in the valley formations may be larger in drainage area, incised to the water table, and gaining water over most of their courses. Therefore, the base-flow of valley streams is probably representative of the ground-water yields of the valley-forming aquifers, whereas the base flow of upland streams is generally not representative of the ground-water yields of ridge-forming aquifers. Thirdly, when measuring the drainage areas, it was assumed that ground-water and surface-water divides coincide. This may be true for most areas underlain by shale and some sandstone, but it is probably not true for many areas underlain by Oriskany Sandstone and carbonate rock. As mentioned above, streams flowing over these latter rocks are often losing rather than gaining; in other places the streams may be draining ground water from a greater area than indicated by the surface drainage area. Thus, yields of streams draining these aquifers may range from zero to greater than 0.800 mgd/mi^2 (when underground drainage is greater than the measured surface drainage area, the yield per square mile is excessively high). The true perennial yields of the various geologic formations probably lie between the extremes given in the table for each formation. What are probably more reliable estimates of areal yield, based on streamflow separation, recession hydrographs, flow-duration data, and low-flow data are given in plate 1-A.

The base flows of several streams were measured and sampled at or near the points where the streams flow from one formation to another. Figure 11 shows both losing and gaining segments of streams. Note in the graphs for Dillions and Mudlick Runs that both streams have lost water after flowing over Oriskany Sandstone. The fact that a small spring (site 61-A) discharges from the Oriskany Sandstone into Mudlick Run between the measuring points at sites 61 and 62 suggests that there is both a gain and loss over the sandstone.

These base-flow measurements also indicate that streamflow decreases in rock formations other than the limestones and the Oriskany Sandstone. Figure 11 shows that Rough Run loses 0.7 cfs as it flows over the Chemung Group. The local geology and topography suggest that the stream follows a local fracture zone, and the lost water may be flowing beneath the stream channel. Notice that the water quality at sites 132 and 133 is essentially the same. Apparently water quality did not change over this losing segment. However, between sites 133 and 134, streamflow increased slightly, and specific conductance also increased.

Figure 11

Changes in Quality and Quantity of Surface Water at Base Flow as Related to Changes in the Geology of the Stream Beds

In Howards Lick Run, which traverses the same geologic units, water quality changes between sites 69 and 72, as it gains a slight amount of water from the Chemung Group. Using specific-conductance and discharge values for sites 69 and 72 in October 1969, the approximate specific conductance of ground water discharging to the stream between sites 69 and 72 is computed by the following relationships:

$$C_1 Q_1 + C_2 Q_2 = C_3 (Q_1 + Q_2)$$

where Q_1 is the discharge of the stream at the upstream measuring site, Q_2 is the total ground-water discharge to the stream between the upper and lower measuring sites, $Q_1 + Q_2$ is the discharge of the mixture at the downstream measuring site, and the three C quantities represent the specific conductance for each of the three discharges (Hem, 1970, p. 273). The computed specific conductance was 220 micromhos, whereas the measured conductance for water discharging from a flowing well (25-4-9) near the stream between sites 69 and 72 was 290 micromhos in August 1969. The difference between the computed and measured values is generally attributable to changes in equilibrium conditions (temperature, pressure, aeration, etc.) that occur when ground water is discharged to the land surface. These changes cause some of the dissolved minerals to deposit in the stream bed, and specific conductance is, correspondingly, reduced.

SURFACE WATER

Source

Streamflow is derived either from direct overland runoff or from ~~ground-water~~ discharge from springs and seeps. Streamflow is influenced by natural basin and climatic characteristics as well as by the activities of man, some of which are analyzed in this section of the report.

Average Streamflow

The average flow of the Potomac River at Harpers Ferry is 5.4 billion gallons of water per day. This is equal to about 8,300 cfs (cubic feet per second) and represents an average runoff of 12 inches of water per year from the basin.

Streamflow during any given year may be greater or smaller than the average but seldom, if ever, exactly equals it. Average values of streamflow serve as a base to which other factors of streamflow may be related. The variation of annual discharge of Cacapon River near Great Cacapon (fig. 12) is typical of the streams in the basin. The extremes of annual discharges of the Cacapon River have ranged from 33 to 177 percent of the average ~~during~~ from 1924 to 1970. Although the average annual runoff of the Cacapon River is 11 inches, extremes in annual precipitation caused runoff totals of only 3.6 inches in 1969 and 19.5 inches in 1955. Some of the factors influencing precipitation runoff relations are: precipitation amount and intensity, land and channel slope, forest cover, stream density, geology, evapotranspiration, and activities of man.

Figure 12

Chronological Variation of Annual Runoff

of Cacapon River near Great Cacapon

The average annual runoff from the basin above Harpers Ferry is 0.9 s per square mile. Based on the period 1930 to 1967, yields from various rts of the basin range from 0.4 to 2.2 cfs per square mile (fig. 13). The lation of average annual discharge to drainage area is shown in figure 14.

Average discharge and years of record at stream-gaging stations are iven in table 6, and the years of record are presented graphically in able 7. Mean monthly discharges for the period of streamflow record at ach station are given in table 8.

Mean annual discharge (Qa) at ungaged sites may be estimated by a egression equation (Frye and Runner, 1970). The equation, developed by computer program, is in the form of:

$$Qa = 1.10\, A^{0.87}\, S^{0.15}\, St^{5.80}\, E^{0.42}\, F^{-0.14}\, P^{0.66}\, I^{-1.80}\, Si^{-0.42}$$

he drainage-basin characteristics are:

(A) is drainage area, in square miles.

(S) is main-channel slope, in feet per mile, determined from elevations at points 10 percent and 85 percent of the distance along the channel from the gaging station to the basin divide.

(St) is the area of lakes and ponds, in percentage of drainage area (plus 1 percent).

(E) is mean basin elevation, in thousands of feet above mean sea level.

(F) is forest area, in percentage of drainage area.

Figure 13

Map Showing Average Annual Runoff

Figure 14

Relation of Average Annual Discharge to Drainage Area

Table 6

Selected Data from Streamflow Records

Table 7

Availability of Streamflow Records

Table 8

Mean Monthly Discharge at Stream-gaging Stations

(P) is mean annual precipitation, in inches (minus 20).

(I) is precipitation intensity, in inches, expected in 24 hours once each 2 years.

(Si) is soils index, as determined from a soils-index map prepared by the Soil Conservation Service.

Estimates of Qa obtained by the equation have a standard error of estimate of 3.2 percent.

Use caution in estimating Qa for areas underlain by cavernous limestone where streambeds are dry during periods of each year.

Low-Flow Magnitude and Frequency

Magnitude and probable frequency of low flow data are necessary for economic design of systems that utilize surface water. With the rapidly increasing use of water and its increasing cost, cost-benefit analysis has become standard practice for design engineers. To compare advantages of alternate designs and to estimate the most economical solution, data on the frequencies of droughts and the storage requirements to maintain uninterrupted drafts are necessary.

Reduction of streamflow data into more usable table form by digital computers has made the determination of annual values of the lowest mean discharge of streams practicable for periods of various lengths. The tables of lowest mean discharge for each station give the lowest average discharge, in cubic feet per second, in each climatic year (April 1 to March 31) for periods of time consisting of 1, 3, 7, 14, 30, 60, 90, 120, and 183 consecutive days and for the climatic year.

These low-flow data show the extremes of low flow during the period of record and may be used to determine the dependable low flow yield of the stream at a stream-gaging station. Figure 15 shows the year-to-year variation of the lowest mean flow for 7- and 180- consecutive days for South Branch Potomac River at Franklin. Low-flow frequency curves of these data, such as those shown in figure 16, indicate the chances of (that) ~~a~~ flow being less than a specific amount ~~will occur~~. The curves also show how often flows will be less than ~~a stream may fail to provide~~ various average rates ~~of flow~~ under natural conditions and the amount of water available for use.

Figure 15

Annual Variation of Lowest Mean Flow for
South Branch Potomac River at Franklin

Figure 16

Low-flow Frequency Curves for the Back Creek and Opequon Creek

Low-flow frequency curves are constructed from streamflow data by ranking all the yearly discharge values for a specific consecutive-day period according to magnitude (rank), starting with the lowest discharge as number 1. The discharge values are plotted against the recurrence intervals, which are computed by the formula (N+1)/M, where N is the number of years used and M is the order number, as determined by the ranking. All points are plotted on log-probability paper, and a smooth curve is drawn through them. This curve, or family of curves (when more than 1 consecutive-day period is used), represents the lowest mean discharge for the indicated number of consecutive days for recurrence intervals, as picked from the curve. A family of nine curves showing the low-flow frequency for specified mean flows for each period is possible if all consecutive-day periods are used. It may be sufficient to draw only a few curves concentrated in one part of the family for a particular analysis (Miller and McCall, 1961).

As probability is the reciprocal of recurrence interval, the low-flow frequency curves indicate the probability of occurrence of annual minimum flows of various magnitudes. They are useful in determining storage requirements to maintain desired rates of flow for water supply during low-flow periods.

Low-flow frequency differs from flow duration in that the information is given as a chronological sequence of flows. For example, flow duration does not indicate whether the lowest 60 days of record were consecutive in one rare drought or were a few dry days nearly every year; in low-flow frequency, consecutive days are treated as a unit.

Although low flow for short periods of time is largely ground-water discharge to the stream, flows for longer periods, such as 120 and 183 consecutive days, contain direct contribution from rainfall and runoff. This contribution varies from tributary to tributary within the basin, as do the rates of infiltration.

The low-flow frequencies of 15 gaging stations were analyzed during this investigation. The stations have 12 or more years of record of daily discharge and are not affected by appreciable regulation or diversion. The base period for the study was April 1, 1930, to March 31, 1967. This 38-year period, the longest that was practical to use, includes the drought years of 1930, 1953, and 1963-66. The discharge figures obtained from this analysis are shown in table 9 and provide the data needed to construct the low-flow frequency curves for all 15 stations.

The magnitude and frequency of low flows (in runoff per sq mi) vary throughout the basin. This variation is caused mainly by differences in precipitation and ground-water storage, which, in this instance, are influenced by topography and geology. The stations chosen to show the differences in low-flow runoff are Back Creek near Jones Springs and Opequon Creek near Martinsburg (fig. 16).

Table 9

Magnitude and Frequency of Annual Low Flow at Stream-gaging Stations

Average 7-day Low Flow

The average of the lowest annual flows for 7 consecutive days in each year of record having a 2-year recurrence interval ($7Q_2$) is a convenient index for low flow. There is an even chance in any one year that the lowest 7-consecutive day flow will be greater (or less) than the $7Q_2$ value. On the average, this median value corresponds approximately to the 94 percent of flow duration for stations in the basin and may be considered to be the normal low flow.

The average 7-day low flow represents the discharge of ground water into the streams (base flow). Therefore, there is a relation between low flow and the water-bearing properties of the basin's rocks. The influence of the rocks' properties is obscured somewhat by the influences of precipitation and evapotranspiration. The greatest $7Q_2$ low-flow yields in the basin are 0.15 to 0.17 cfs per square mile in the eastern and southern parts, where permeable, cavernous limestone underlies the surface. However, zero or near-zero flows are found in areas underlain by cavernous limestone where the water travels underground through solution channels, leaving the streambeds dry during most of the drier periods of the year. In areas underlain by less permeable sandstone, siltstone, and shale, such as the Patterson Creek and Back Creek basins, low flows are on the order of 0.03 cfs per square mile, or less. The geographic variation of the 7-day low-flow values computed at streamgaging stations is shown in figure 17.

The median 7-day low-flow values along the South Branch Potomac River decrease downstream from 0.15 cfs per square mile at Franklin to 0.08 cfs per square mile near Springfield.

Figure 17

Map Showing Lowest Mean Flow for 7-consecutive Days Having a Recurrence Interval of 2 Years and 10 Years

Basin characteristics other than drainage-area size having a definite influence on 7-day low-flow values in the Potomac basin include geology, channel slope, forest cover, annual precipitation, and snowfall.

Numerous springs having unknown drainage areas are evident throughout the basin. As these springs eventually feed into streams, the contributing underground drainage area for a stream may not correspond to the surface drainage.

Flood Magnitude and Frequency

Flood inundation in the Potomac River basin in West Virginia does not cause a problem at present in most areas because the flood plains of most streams have been developed only for pasture or cropland. Heavy property damage from flash flooding has occurred in the past and probably will in the future in local areas. Knowledge of the magnitude and frequency of floods is necessary for future flood-plain zoning and for the design and location of highways and bridges. In practice, a flood of a certain magnitude is chosen to determine the design of a project or the type and degree of use of the flood plains. The design of dams and other structures, whose failure would result in major property damage or loss of life, is usually based on extreme floods rather than a flood of specific frequency. Other structures, such as bridges and highways, may be such that the inconvenience of occasional inundation or failure would not warrant the cost of construction to accomodate extremely large and rare floods. Certain land uses require immunity from flooding, whereas other uses permit occasional flooding. Therefore, the practical uses of flood-frequency analyses are: (1) Predicting the frequency of occurrence of a given flood discharge on the basis of past floods and (2) selecting the proper structural design and size to withstand a flood of a given magnitude.

The flood-frequency relations, as defined in this report, are based on the analyses of annual maximum floods that have occurred at stream-gaging stations before September 30, 1967.

Recurrence interval, as applied to floods, is the average number of years that will elapse between floods that equal or exceed a certain discharge. It is related inversely to the chance of a certain flood being equalled or exceeded in any year. Thus, a 25-year flood would have 1 chance in 25 of being equalled or exceeded in any year. This does not mean that a flood of a given recurrence interval will be equalled or exceeded only once during the 25 years—only on the average. It may be equalled or exceeded one or more times in any year or in successive years, or it may not be equalled or exceeded in a much longer period of time.

The time it takes for a flood peak to reach downstream points is greater from the headwater storms than for basinwide storms because of the travel ~~time of~~ the flood peak. ~~Simultaneous~~ contribution ~~of flow~~ throughout the basin from a basinwide storm ~~contributes to a flood~~ peak ~~of longer~~ duration ~~and an earlier maximum~~ than a flood peak from a headwater storm. A flood ~~peak is~~ generally spread over a longer period ~~of time for~~ large streams than for small streams. ~~Also a~~ flood peak will occur sooner on small streams,

The area of flood inundation is directly related to flood stage. A flood-stage-frequency curve for South Branch Potomac River at the gaging station 2½ miles west of Petersburg is shown in figure 18.

A convenient way of estimating the relation between floods and their frequency is by use of the station-frequency curve. Station flood frequencies for 17 stream-gaging stations based on the period of record at each station are given in table 10. These values were obtained by a computer program, using the Log-Pearson Type III distribution as the base method (United States Water Resources Council, 1967).

Figure 18

Frequency of Annual Flood Stages on

South Branch Potomac River near Petersburg

Table 10

Station Flood-frequency Relation

71

The Pearson Type III distribution is commonly fitted to the logarithms of flood magnitudes rather than to the magnitudes themselves (~~because it results in a smaller~~) skew. The skewness of this distribution varies. The Pearson Type III distribution, having zero skew (symmetrical distribution), is identical to the normal distribution (Riggs, 1968).

Flood-frequency information can be developed for points where streamflow records are not available by multiple-regression analysis. "This analysis produces a regression equation that can be used to compute the flow characteristics at any point on natural streams in West Virginia" (Frye and Runner, 1970). An estimate of the 50-year flood discharge, in cfs (Q_{50}), on any natural-flow stream in the Potomac River basin in West Virginia with a drainage area ~~over~~ more than 50 square miles can be obtained by the regression equation, $Q_{50} = 167 A^{0.88}$, where A is the size of drainage area. Fifty-year flood values obtained by this equation have a standard error of estimate of 30 percent.

spell out, re [illegible] number ✓

High-flow Frequency

There are certain problems in which flood volumes must be considered. These problems include reservoir design, where it is desirable to provide adequate flood-control storage (Dalrymple, 1960). The frequency of flood volume can be determined by using values of highest mean discharge for periods of various consecutive-day lengths, such as 1, 3, 7, 15, 30, 60, 90, 120, and 183 (~~consecutive days~~). Highest mean discharges are the highest average values during the specified consecutive-day periods for each water year. High-flow frequency values were obtained by computer program, using the Log-Pearson Type III distribution as the base method.

The reader is reminded that the values used are for calendar days. The maximum average discharge computed for 1 calendar day is usually lower than a maximum average discharge computed for a 24-hour period. The percentage difference in discharge between maximum daily values and maximum 24-hour values would be greater for small streams than for large ones.

High-flow frequency data for 17 stream-gaging stations are presented in table 11. These data are based on the period of record at each station; therefore, data for a given station may not represent the same time as that for another station.

Table 11

Magnitude and Frequency of Annual High Flow at Stream-gaging Stations

Water-Supply Storage Requirements

Most major streams have an average flow that is more than sufficient to meet the present and foreseeable future demands for surface water within the basin. However, during the low-flow season of late summer and fall, the unregulated flow of the streams may not be enough to meet these demands. When the demands for water become greater than minimum streamflow, artificial storage becomes necessary, so that water can be impounded during periods of high flow and used during periods of low flow. The frequency at which given amounts of storage are required provides a basis for obtaining an economical balance between the cost of providing storage and the loss caused by insufficient water supply.

The analysis of storage requirement for a specific project involves the consider~~ation~~ of factors, such as: (1) the amount and variability of streamflow, (2) the geology and topography at the reservoir site, (3) the time pattern of withdrawal, (4) the reduction of reservoir capacity by sedimentation, (5) the possible modification of the reservoir to provide for floodwater storage and recreation, and (6) the anticipated amount of evaporation from the reservoir.

To obtain net water yields in various areas, the increase in water loss by evaporation from the storage reservoirs must be determined. This increase in water loss is the difference between evaporation from a reservoir and the natural evapotranspiration from the same ground area with its normal vegetation (Lof and Hardison, 1966). Evaporation from reservoir surfaces is usually estimated from records of pan evaporation, which is a good index on an annual basis. At Wardensville, the difference between annual pan evaporation (36 inches) and estimated annual evapotranspiration (26 inches) is 10 inches per year. The loss of water from the reservoir by evaporation is offset to some extent by the gain due to precipitation on the reservoir (Riggs, 1966).

Storage may be classified as within-year or carry-over storage, according to the length of time required for its replenishment. For uniform draft rates less than the minimum annual mean flow, the required storage will usually be replenished each year. Such storage is within-year storage, and its amount is a function of the mean and within-year variability of flow. Draft rates greater than the minimum annual mean flow require storage larger than can be replaced annually. This carry-over storage may not be replaced for several years. Storage required for these high draft rates depends principally on the mean flow and the variability of annual mean flows.

Storage requirements depend on the chronological variation and magnitude of precipitation. A frequency curve of storages required shows the probability of failure but not the magnitude of the failure or its extent in time. The storage-requirement values given in this report (table 12) are based on streamflow records at individual stream-gaging stations for 15 locations. The computations were based mostly on natural flow conditions and neglect evaporation and seepage. Depending on location, these streams would replenish storage each year for continuous draft rates of from 19 to 34 percent of mean flow, with a 2 percent probability of failure. Continuous draft rates of 40 to 65 percent of mean flow, depending on location, would have a 20 percent probability of failure. Draft rates exceeding these values would require carry-over storage from year to year or for several years.

Table 12

Draft-storage-frequency Relations at Stream-gaging Stations

The method of analysis used here is based on within-year storages required to sustain selected continuous draft rates. Daily discharges from streamflow records and selected draft rates are furnished to the computer. The daily discharges are for each year of streamflow record, beginning April 1 and ending March 31. The program assumes a full reservoir on April 1 and provides the maximum deficiency (which is the storage required) and the deficiency, if any, from a full reservoir at the end of the year. On those days when the streamflow is greater than a selected draft rate, a positive storage value accrues. When the streamflow is less than the selected draft rate, a negative storage value accrues. The computer prints out the maximum storage requirement during each year for each of the selected draft rates. A set of draft-storage-frequency curves for each stream-gaging station can be prepered from these data. Figure 19 is an example. No curves are shown for draft rates greater than 134 cfs in figure 19 because the within-year storage was not replenished for one or more of the years during the period of record.

Table 12 gives the continuous draft rates, in cubic feet per second, ~~(cfs)~~ that can be sustained for various reservoir capacities, {in cfs-days per square mile}, and the percentage probability the reservoir would fail to sustain the draft rates. Assuming similar climatic conditions in the future, this information will give an indication of the amounts of water available with the provision of within-year artificial storage. For example, a continuous draft rate of 116 cfs (21 percent of the mean flow) on Cacapon River near Great Cacapon would require within-year storage of 20 cfs-days (39.6 acre-feet) per square mile of drainage area above the reservoir site. There would be a 2 percent probability (once in 50 years, on the average) that 116 cfs could not be maintained, and a draft rate greater than this amount would require carry-over storage.

Figure 19

Draft-storage-frequency Curves for

North Fork South Branch Potomac River at Cabins

Flow Duration

Flow-duration studies are used when considering streams for: (1) hydroelectric power, (2) general investigations of water supply, and (3) the dilution and disposal of wastes. Flow-duration data show the frequency of various rates of flow, irrespective of chronological sequence, throughout the entire flow range. They indicate the percentage of time, within a given period, during which any given rate of flow was equalled or exceeded. The analysis utilizes past data that will probably not be duplicated in the future. Nevertheless, if the record covers a representative span of meteorologic events over a long period, the data may be used to estimate the probability of a specified rate of flow. One concept of the flow-duration curve is that it is a means of representing in one curve the flow characteristics of a stream throughout the range of discharge. The curve provides a convenient means for studying the flow characteristics of streams and for comparing one basin with another.

One primary use of flow-duration data is to show and compare the variability of the flow of streams, as is done in the section describing the interrelationships between ground water and surface water. Variation in streamflow reflects variations in precipitation and differences in basin characteristics. Discharge of stored surface water or ground water,
[illegible] streamflow
~~artificial~~ or natural, serves to reduce the variability of flow.

Other than the artificial water, this sentence doesn't say exactly what it's meant to say.

Discharge of surface water or ground water from either artificial or natural storage reservoirs serves to reduce the variability of streamflow.

The slope of the duration curve is a quantitative measure of variability. Lane and Lei (1950) introduced an index of variability defined as the standard deviation of the logarithm of the stream discharge. On log-probability paper this index represents the fall (in tenths of a log cycle) of the duration curve in one standard deviation. To compute the index, first obtain values of discharge from the duration curve at 10-percent intervals from 5 percent to 95 percent of the time. Next, obtain the logarithms of these discharges and compute the mean logarithm. Compute the difference of each of the 10 logarithms from the mean and square the difference. Obtain the sum of the squares, divide by (19-1), and obtain the square root.

The variability indexes (based on daily discharge) from the duration curves were computed for 17 stations and are given in table 13. These values vary from basin to basin. They are a direct measure of the slope of the flow-duration curve. The highest values of variability indicate steeper slope of the curves and more "flashy" streamflow. The lower values of variability indicate higher (natural) storage capacity, resulting in higher sustained streamflow during dry periods. No attempt was made to adjust the values for the size of the drainage area. These indexes can be used as a tool to determine carry-over storage requirements for log-normal distribution of annual discharges, where more storage is required than can be replenished in any one year (C. H. Hardison, U. S. Geological Survey, oral communication, 1964).

The results of flow-duration analyses of 17 stations for the period of record at each station are shown in table 13. All the stations have at least 11 years of record and include the 1967 water year. The range of flow duration for all 17 stations in the basin fall within the shaded area shown in figure 20. There are only minor differences in the slopes of the duration curves for the various streams in the basin, as indicated by the variability indexes. The major differences are in curve positions, which indicate volume of flow per unit area.

Table 13

Flow Duration at Stream-gaging Stations

Figure 20

Range of Flow Duration

Effects of Impoundments on Flow Duration

There are 20 flood-retarding structures in the Patterson Creek basin, upstream from the stream-gaging station near Headsville, which were constructed between 1963 and 1970 by the Soil Conservation Service (pl. 2). These structures retard flood waters from 45 percent (97 square miles) of the drainage area above the stream-gaging station and have a total temporary floodwater-storage capacity of about 16,700 acre-feet (table 14). The flow-duration curves shown in figure 21 indicate a change in flow duration caused by these structures. The curve for the 1970 water year shows a decrease in high-water discharge, even though the monthly average for the wet part of the year (January through April) was slightly above normal. The curve shows an increase in minimum flow, even though the monthly averages were below normal during the dry part of the year. The structures have a total minimum pool volume of about 1,300 acre-feet. The increase in minimum flow was conceivably due to leakage and seepage from the minimum pool volume. The lower mean flow for the 1970 water year (about 18 percent below average, as indicated by the middle part of the curve in figure 21) was due to below-normal precipitation because the dams should not appreciably affect the average flow.

Figure 21

Flow-duration Differences of

Patterson Creek near Headsville

Table 14

Selected Data on Floodwater Retarding Structures

Time of Travel

Time of travel refers to the movement of water or waterborne materials from point to point in a stream for steady or gradually varied flow conditions. The use of fluorescent dyes and tracing techniques provides a means of measuring the time-of-travel and dispersion characteristics of the flow in streams. Dye tracing simply means that a dye is injected at some location along a stream and detected at other locations downstream.

In recent years attention has been focused on the growing problems associated with using streams to dilute and carry away wastes and contaminants. The mixing and rates of movement of the wastes and contaminants in streams are of major concern.

A study was made to provide a guide for predicting the time-of-travel and concentration attenuation of water-soluble materials in the South Branch Potomac River from Petersburg to the mouth. This was done by introducing a fluorescent dye known as "Rhodamine B" into the river and monitoring the dye cloud by sampling at selected points along the river (fig. 22). Graphs developed from data collected during the study can be used to predict the travel time, the maximum concentration, and the duration of a contaminant at a given point when the streamflow is in the range of the mean annual discharge.

Figure 22

Map Showing Locations of Time-of-travel Sampling Sites

For purposes of this study, the 69-mile reach of the river was divided into two subreaches. Dye was injected simultaneously at the upstream end of each subreach to shorten the overall sampling time required. The flow was not obstructed by impoundments and was sufficient to lessen the effects of local pools and riffles. The study was made on November 18-20, 1970, when the reach was relatively free of suspended sediment and algae. A profile of the South Branch Potomac River is shown in figure 23.

The upstream subreach was 37.2 miles in length, with an average fall of 7.6 feet per mile. Twenty-nine and six-tenths pounds of 40-percent solution Rhodamine B dye was injected instantaneously at site one, 250 feet upstream from U. S. Highway 220 bridge at Petersburg. Water samples were collected periodically at sites 2 through 7.

The downstream subreach was 30.1 miles in length, with an average fall of 3.9 feet per mile. Fifty pounds of 40 percent solution Rhodamine B dye was injected instantaneously at site 7 at the B. & O. Railroad bridge, about a mile downstream from Romney. Water samples were collected periodically at sites 8 through 11.

Discharges at the U. S. Geological Survey stream gages near Petersburg, Moorefield, and Springfield were computed from recorded stages and stage-discharge relations. The discharges at intermediate sites were prorated on the basis of time and drainage area. The discharges at the three stream-gaging stations were approximately at the 32-percent flow-duration point and were about equal to the mean annual flow.

A fluorometer, calibrated with standard solutions of known dye concentrations, was used to determine the dye concentration in each water sample. The relations of observed concentrations to elapsed time since injection are illustrated in figures 24 and 25.

Figure 23

Profile of South Branch Potomac River

Figure 24

Observed Time-concentration Curves for

South Branch Potomac River between Petersburg and Romney

Figure 25

Observed Time-concentration Curves for

South Branch Potomac River between Romney and the Mouth

Due to various physical, chemical, and biological processes, part of the tracer dye is always lost. The observed concentrations are always less than would be expected from a conservative solute. A conservative solute is a solute which, although it becomes diluted and dispersed as it moves downstream, has no loss in total volume. The observed dye concentrations were adjusted upward to reflect a percentage recovery (PR) of 100 percent of the dye and, hence, would represent the concentration of a conservative solute, by the equation

$$PR = \frac{\text{Amount of dye recovered}}{\text{Amount of dye injected}} X\ 100$$

or

$$PR = 2.25 X\ 10^7 \frac{Q\ Ac}{Wd\ Cs}$$

Cubic [illegible] second, spell out

where Q is maximum discharge in the subreach, in cfs; Ac is the mean area of the time-concentration (TC) curve, in micrograms per liter-hours; Cs is the manufacturer's stock solution, in micrograms per liter (40 percent = 40 X 10^7); and Wd is the pounds of dye injected, having a concentration Cs.

The use of conservative concentrations in reporting time-of-travel results avoids the problems of variable dye losses due to type of dye, time, and space. Conservative concentration (C_c) is the observed concentration increased to that of a conservative solute; it can be computed by the equation

$$C_c = \frac{C_{obs} X\ 100}{PR}$$

where C_{obs} is observed concentration, in micrograms per liter (or parts per billion).

The utility of time-of-travel data is enhanced if reported in terms of unit concentration. Unit concentration is the concentration of a conservative contaminant resulting when 1 pound is injected into 1 cfs of flow, assumed to be existing throughout the reach. Essentially, unit concentration removes the diluting effect of increasing discharge at downstream points. Unit concentration (C_u) may be computed by the equation

$$C_u = C_r \times Q = \frac{\text{Micrograms per liter} \times \text{cfs}}{\text{Pounds of dye}}$$

where

$$C_r = \frac{C_c}{W}.$$

C_r is the relative concentration or the conservative concentration that would result from injection of 1 pound of contaminant, and W is pounds of pure dye (100 percent concentration).

The time-concentration curves were used to compute unit concentration for each sampling site. The unit concentrations corresponding to the peaks were plotted versus lapsed time, resulting in the peak-concentration-attenuation curve shown in figure 26. The curve presents a convenient method of estimating a maximum peak concentration of a conservative solute. Depending on the loss characteristics of the particular solute, the observed maximum concentration should always be less than that of a conservative solute. Results of the time-of-travel computations are summarized in table 15.

The times-of-travel relations of cumulative lapsed time to distance for the leading edge of the dye cloud, the peak concentration, and the trailing edge (at 5 percent of peak concentration) are illustrated in figure 27.

Figure 26

Peak-concentration-attenuation Curve

Figure 27

Traveltime-distance Relation on South Branch Potomac River

Table 15

Summary of Time-of-travel Computations

Dispersion studies have shown that each stream and reach of stream has unique dispersion characteristics. Even in the same reach, the rate of dispersion varies with discharge, as different processes and physical factors become more, or less, dominant.

Attentuation of peak concentration varies with travel time, which is dependent on discharge. However, the time-of-travel and peak concentration attenuation do not vary in the same ratio as the discharge. For example, if the discharge were halved, the peak concentration at a given point downstream would be somewhat less than double. The time-of-travel could be anywhere from slightly longer to many times longer. Local pools and riffles in a stream greatly increase the lapse time between the leading edge, peak concentration, and trailing edge of the dye at low discharges.

The time-of-travel and dilution of materials not completely soluble in water are beyond the scope of this report. Large and rapid changes in the discharge could cause significant differences in the traveltimes and dispersion characteristics. These results do not apply to the velocity of a flow wave, which normally moves faster than the average velocity of the stream.

The results obtained from this study are valid only for the discharges and other conditions prevailing during the study. At least two additional studies at approximately 70 and 95 percent flow-durations would allow interpolation of traveltimes for various discharges. It would also provide greater insight into the dispersion characteristics of the stream and greatly enhance the usefulness of the data.

GROUND WATER

Source

Precipitation is the ultimate source of all water in the study area (fig. 5). Although precipitation is intermittent, ground water is continually moving from storage in the rocks to streams and, in places, from the streams to the ground.

In addition to natural recharge from precipitation and streams, man sometimes artificially recharges aquifers. Wells are used for artificial recharge ~~of this type~~ in the carbonate rocks of the easternmost two counties to drain low areas of excess overland runoff. Man-made lakes also recharge aquifers by seepage (fig. 37). Septic-tank effluent is another source of artificial recharge.

The only ground water in the basin that possibly was not derived from precipitation in the recent geologic past is connate water encountered in deep gas wells. Connate water is sea water that was trapped in sediments when the rocks were deposited millions of years ago. As the rocks are eroded and fresh ground water circulates through the rocks, this old sea water is flushed and again enters the hydrologic cycle.

Hydrology

Water is found in practically all rock formations in the study area. However, the quantity of water contained largely depends on the kind, size, and degree of interconnection of the openings in the rock. The rocks have openings or pore space that are classified as primary or secondary, according to how or when they were formed. Primary openings are intergranular pore spaces that have existed since sediment deposition. Secondary openings are joints, fractures, faults, caverns, or intergranular porosity formed since consolidation of the original sediment.

Alluvial and colluvial deposits are the main fresh-water aquifers in the study area having primary (intergranular) porosity. Most of the intergranular porosity in consolidated aquifers is probably secondary, ~~porosity~~ formed by the solution of cement in by ground water. However, ~~it is possible that~~ some intergranular porosity is primary, for example, in the Oriskany Sandstone. The Oriskany is known for the gas it produces, and, perhaps, cementation never took place in pores occupied by gas (Thomas Arkle, Jr., West Virginia Geological Survey, oral communication, 1970). Also, ~~the~~ deep connate water ~~mentioned previously~~ was probably trapped in primary openings of the sediments, as they were deposited millions of years ago. As the salt water is flushed, these openings can be occupied by fresh ground water.

It is in the secondary openings of aquifers that most fresh ~~ground~~ water is found. Nearly all ~~of~~ the secondary openings are the ~~direct or indirect~~ result of rock movement or solution since deposition and consolidation. The effect each type of secondary opening has on the hydrology depends upon the type of rock and on its location with respect to rock folding and topography. The nature of secondary openings and their effect should be apparent in the following discussion of the hydrology of the various parts of the basin.

High-relief Areas of the Valley and Ridge Province

Anticlinal ridges

Most of the central and western part of the Potomac Basin is underlain by intensely folded rocks, which form a series of northeast-trending ridges and valleys (fig. 2). Many of the ridges are underlain by sandstone and limestone folded into arches, or anticlines; the valleys and some ridges are underlain by shale and siltstone folded into inverted arches, or synclines. The anticlinal ridges underlain by Oriskany Sandstone are of particular interest because they are recharge areas, which are also generally more permeable than the shale valleys.

Springs.--Springs yield clues to the local and regional hydrology in the high relief areas. Major springs occur mainly: (1) in water gaps through anticlinal ridges, (2) at the noses of plunging anticlinal ridges, (3) at the bases of sandstone ridges, and (4) on the upper slopes of the ridges.

Most of the large springs are in gaps eroded through ridges capped by the Oriskany Sandstone and underlain by limestones of the Helderberg Group and Tonoloway Formation (Hydrologic Unit 5, see table 1). Many of these springs are located on nearly vertical fractures, or on bedding-plane fractures, which tend to parallel the anticlinal axis. These fractures apparently formed as a result of rock folding or rock expansion brought about by the removal of the weight of the overlying bedrock by erosion, or a combination of the two.

One of these fracture planes is visible in the photograph of the limestone (Helderberg Group) quarry in Mechanicsburg Gap (fig. 28). The southeast wall of the quarry on the right side of the photograph lies along a nearly vertical fracture plane. Part of this fracture plane can be seen in the rocks near the road in the foreground. Directly across the road from the quarry and nearly in line with the fracture plane is a large spring (23-4-9). This spring yields 150 to 1,000 gpm, depending on the time of the year, and it apparently drains parts of the ridge on either side of the gap. Some gap springs discharge along steeply dipping bedding planes. Solution along these fractures and bedding planes, exposed in various gaps, in limestone quarries, and in one underground mine, has formed large caverns. Although no caverns are apparent in the photograph of the limestone (Wills Creek Formation) quarry in (B) of figure 28, the photograph illustrates the discharge of ground water along the nearly vertical bedding planes and some nearly horizontal release fractures between 20 and 30 feet from the top of the quarry. Note the lack of ground-water discharge from the thickbedded unit in the center of the photograph. It is easy to visualize that if a well were to be drilled into a vertical impermeable bed, such as this, no water would be obtained: (1) until an occasional water-bearing fracture was encountered in the impermeable unit or (2) until the well completely penetrated the impermeable unit to obtain water from the more permeable adjacent rocks.

Figure 28

Photographs of Limestone Quarries a (A) Mechanicsburg Gap near Romney, (B) a gap near New Creek, and (C) a gap near Baker

Figure 28-C is a photograph of another limestone (Helderberg Group) quarry in a gap on the west limb of an anticlinal ridge. A mine opening can be seen at the right edge of the photograph. Near the center of the photograph is a small amount of talus. Before quarrying began about 30 years ago, a spring reportedly discharged near the base of the talus. Directly behind the talus a large cavern was recently encountered while mining. The cavern, which developed in the nearly vertical beds, has a 50-foot-high ceiling in one place and extends for 300 feet or more along the strike of the rocks. It is reported that during or shortly after a heavy rainfall on the ridge above the mine, in 1969, water discharged from the cave and flooded the mine. This rapid response to rainfall suggests that this cavern is directly connected to a large sinkhole on the ridge about 2 miles from the mine. There is almost no leakage through the roof or walls of the mine. The floor of the mine generally slopes downward, and the lowest part of the mine, 500 to 600 feet from the entrance, is flooded with 1 to 2 feet of water. This part of the mine is near river level, and the water level in the mine reportedly rises and falls with the stage of Lost River, which passes within about 200 feet of the mine entrance.

Not all springs in gaps discharge at land surface. Several springs discharge beneath the South Branch Potomac River in the gap through Mill Creek Mountain, 3½ miles north of Romney. Spring discharge was discovered in this gap while making a time-of-travel study with red Rhodamine B dye. As the reddish-colored river water passed through the gap, several springs in the river remained clear because of the upwelling of ground water from submerged springs. Local residents report that cold spots are encountered in the river here and at other locations in the gap while swimming.

In 1971 the village of Springfield developed a small spring (23-1-31) a gap east of Springfield for a public water supply. The orifice of the pring was about 1 foot above the level of the stream in the gap. A pit -feet square was dug in limy sandstone bedrock directly across the stream rom the spring for the construction of a reservoir. At a depth of about 0 feet, a large volume of water entered from the bottom of the pit. The tatic water level in the pit stood about 1 foot above the creek level, and umping at 140 to 150 gpm lowered the water level about 7 feet, or to ithin about a foot of the bottom. This situation is comparable to the ne described above for South Branch Potomac River in the gap through Mill Creek Mountain. The only difference is that at Mill Creek Mountain Gap most of the ~~ground~~ water is being discharged beneath the river's surface, whereas near Springfield most of the water discharges at the spring above the level of the stream.

Springs at the noses of plunging anticlines are apparently supplied with water through the same fractures and solution openings that supply water to springs in gaps. The only difference is that the tilt or plunge of the anticline may help direct water along the fractured cavernous zone and bedding planes, which trend with the axis of the ridge, to the nose of the anticline, where the sandstone plunges beneath relatively impermeable shale of the Marcellus Fomration. The shale cannot transmit all the water moving through the more permeable sandstone and limestone of the anticline, and this water discharges to the surface at a spring. Springs of this type are commonly found at or near the larger streams, and sometimes form headwaters of [illegible] perennial streams. Three such springs near Wardensville, are shown in figure 29 and plate 1-D. The figure also shows the probable direction of ground-water movement and the lowering effect of the drainage to the springs on the water table beneath the ridges. One spring (25-2-3) is located on Trout Run. Its yield ranges from about 5,000 to 15,000 gpm. A second spring (25-2-8), just east of Wardensville is used as a public supply by Wardensville. It yields about 65 gpm. The third spring (25-2-4) is located about 2 miles northwest of Wardensville. Its yield ranges between about 150 and 400 gpm. Other springs of this type are also located at the nose of plunging anticlines formed by hydrologic Unit 6.

Figure 29

Diagram Showing the General Hydrology of a High-relief Area near Wardensville

Plate 1(D)

Diagram Showing the General Hydrology of a High-relief Area near Wardensville

DEleTE

Over a long period of time, ground-water recharge and discharge are approximately equal. If it is assumed that, on an average, approximately 9 inches of precipitation, or 150 million gallons per year per square mile, recharges the sandstone-limestone ridges, then, by knowing the average annual discharge at a spring, it is possible to calculate the approximate area of recharge for the spring. Provided there are no other significant areas of discharge from the ridge, the computed recharge area can be used to approximate the surface boundaries of the recharge area. By knowing the approximate boundaries of the recharge area, it could be protected from contamination or recharged artificially.

The above method of computing recharge area may be sufficiently accurate for determining the recharge area for springs discharging at the noses of anticlines; however, gap springs may be recharged from one or both sides of the gap. Thus, water-level data may be necessary to determine the recharge area more accurately.

Wells and caves.--Water-level data from wells in anticlinal ridges suggest that extensive areas are drained by springs in gaps or at the nose of anticlines. The block diagram in figure 29 shows the low water level in well 25-2-37. Ground water is apparently being drained from the area of the well southwestward along the anticline to discharge in the gap at the Cacapon River.

[illegible]
wells and 1 to 3 feet (fig. 42) in [illegible]

The cross-section in plate 1-E also shows low water levels in deep wells tapping ridges underlain by Units 5 and 6 (table 1) near Capon Bridge. Fluctuations of the water level measured in well 23-3-12 on Schaffnaker Mountain (pl. 1-E and fig. 32) indicate recharge. Discharge is also occurring beneath these ridges in order to have these depressions in the water table. ~~Normally,~~ ground-water fluctuations on ridges are on the order of tens of feet (fig. 32), whereas, fluctuations in most valley wells are on the order of 1 to 3 feet (fig. 42). The small annual fluctuations observed in well 23-3-12 in conjunction with the fact that ground-water recharge is high (inferred from the lack of observed overland runoff) suggest that ground-water storage is large and that the well is tapping an area near the base level of underground drainage.

A railroad tunnel near Short Gap, West Virginia, also gives some clues to the hydrology of ridges underlain by Units 5 and 6. The tunnel passes east-west through a ridge formed by limestone, sandstone, and shale of Units 5, 6, and 7, respectively (fig. 33). The tunnel is approximately 30 feet in diameter and is essentially a horizontal well. The measured flow leaving the west end is about 300 gpm. The tunnel is about 4,160 feet long; therefore, the yield is only 0.072 gpm per foot of length. This low yield can be explained by the shape of the water table. The approximate water table shown in figure 33 was drawn on the basis of observed wet and dry parts of the tunnel. Its slope indicates that discharge is occurring in the ridge beneath the tunnel near the contact of the Helderberg Group with the Oriskany Sandstone. The shape of the water table indicates that ground water is discharging parallel to the bedding beneath the ridge.

Plate 1(E)

~~Typical~~ East-west Cross Section through the Central Part of the Study Area Showing Wells and the Approximate Geology, Structure, and Water Table

DELETE

Figure 32

Water Levels in Wells 23-7-18 and 23-2-12,

Precipitation at Romney, and Chloride Content in Water from Well 23-7-18

Figure 33

Cross Section of Knobley Mountain near Short Gap

Showing Railroad Tunnel, Sampling Sites,

and Probable Water Table

Field observations and data presented by Davies (1958) indicate that numerous caverns occur at or near the crests of anticlinal ridges or on the limbs of anticlines along bedding planes. Dry caves may be found in various gaps at different elevations, indicating that ground water has drained along these fracture zones and bedding planes in earlier geologic time. Presently ground water is following some of the same fractures, caverns~~,~~ and bedding planes. However, ground water is now discharged at a lower level because erosion and solution have lowered both the level of underground channels and the levels of local streams to which the springs discharge.

The development of caverns beneath these ridges may be largely restricted to specific rock layers. A tabulation of the caverns given by Davies, as they occur in the different limestone rocks of the high-relief areas, show 52 caves in the Helderberg Group and 27 in the underlying Tonoloway Limestone and Wills Creek Formation. The Helderberg Group is reported to be a purer limestone than the Tonoloway or Wills Creek Formations (Reger, 1924, p. 662, 669, 672), and it is mined in many places in the basin. The fact that nearly twice as many caves are known to exist in the Helderberg Group as in the Tonoloway and Wills Creek Formations supports the concept of cavity development described by Rauch and White (1970, p. 1191). They report, for geologically similar carbonate rocks in Pennsylvania, that "cavity development is enhanced by purity of the bulk rocks, small grain size (micrite), and possibly by silty streaks. Cavity development is inhibited by high concentration of SiO_2, Al_2O_3, dolomite, sparite, and impurities, or by very low dolomite concentrations."

Some springs are found on the lower slopes of anticlinal ridges at or below the contact of the Marcellus Formation with the Oriskany Sandstone. These springs are probably on joints or fractures normal to the strike of the bedrock of the ridges. Figure 34 shows the characteristic "X" shaped joints in the Oriskany Sandstone. Springs commonly occur on the lower valley wall at joints in the Marcellus, which coincide with water-bearing joints in the underlying Oriskany. Water recharging these springs enters through joints in the Oriskany on the slopes of the ridge and percolates downward along open joints and bedding planes to connecting joints in the overlying Marcellus shale, which carry the water to a surface spring. Occassionally, the water discharges directly to the surface from joints in the Oriskany. Springs of this type discharging through shale commonly yield from 5 to 50 gpm. However, one exceptional spring (25-4-10) near Romney was estimated to yield 90 gpm. A group of small springs (25-2-9) near Wardensville yields 740 gpm of water, which is derived directly from the Oriskany (fig. 29). On the flank of at least one anticlinal ridge, where the Oriskany Sandstone and Helderberg Group have been removed by erosion, two springs (24-1-1 and 22-3-10) discharge from the base of the hill directly from the Tonoloway and Wills Creek Formations. Each is estimated to yield over 1,000 gpm.

Springs of another type are found higher on the flanks of anticlinal ridges. They are small springs or seeps discharging from perched water tables in weathered residium overlying hard, less permeable layers of sandstone. Springs of this type commonly yield 1 to 5 gpm. Some are perennial and others go dry in the summer and fall.

Figure 34

Photograph of Jointing in Oriskany Sandstone

Still another type of spring is found on many of the anticlinal ridges in places where the sandstone is folded into small synclinal structures. These structures generally contain weathered shale or chert and are relatively impermeable. Thus, they supply relatively small quantities of water to wells and springs.

An investigation was made on one syncline near the top of Cooper Mountain, in Hampshire County just west of Capon Bridge. Water levels in wells on Cooper Mountain indicated that the water table was very low in the Oriskany Sandstone but high in the syncline (pl. 1-E). A test well (23-7-31) drilled in June 1971 near the axis of the syncline revealed that the syncline contained a brown and white silty and in part sandy clay. Measurements of the static water level, or head, after the well was completed to different depths showed that the water level declined, indicating greater head near the top of the well than at the bottom. Because water moves from high head to low head, the general direction of water movement in the vicinity of the well is downward. The fact that a nearby domestic well (23-7-18) flows during wet periods in the spring indicates that flow is upward during this time of year and that recharge is entering the synclinal clay at depth from the adjacent layers of the Oriskany Sandstone. Short-term rises in the water level in the test well (23-7-31) in response to rainfall suggests that recharge is taking place at depth through the sandstone. However, during dry periods this "water-logged" syncline is surrounded by "dry" Oriskany Sandstone, and perched water from the syncline gradually drains into the underlying sandstone. Thus, large annual water-level fluctuations are observed in the syncline. Annual fluctuation of water level in the domestic well (23-7-18) is about 30 feet.

Springs discharge from some of these synclines where gulleys have been eroded into the ridges and intersect the water table in the synclines. One such spring (23-7-13) is on Cooper Mountain near the test well. The flow of the spring ranges from 2 gpm in the summer to about 20 gpm in the spring. The yield of such springs is probably greatest when they are near the axis of the syncline and near the contact of the clay and sandstone, where horizontal permeability may increase. Spring 23-4-13, near Romney, is probably near such a contact, and its yield ranges from about 5 to 90 gpm.

Synclinal ridges and other areas

Nearly all the several synclinal ridges in the high-relief area are underlain by Hydrologic Unit 8. Because these rocks are not very permeable, the water table generally parallels the land surface (pl. 1-E) and lies less than 100 feet below it, even at the tops of ridges. For example, well 26-3-5 is at the very crest of the Shenandoah Mountains, and the water table is only 34 feet below land surface. However, the water table may be as deep as 200 feet, where there is underground drainage along permeable zones.

Ground water moves from the ridges to the valleys, where it discharges to streams and springs. Most large springs discharge along major fractures and along streams incised on or near synclinal axes. For example, see spring 23-6-2. Artesian conditions probably exist beneath Meadow Run downstream from this spring. The rocks on either side of the stream dip toward the stream, and, thus, ground water tends to be funneled along open bedding planes toward the stream.

Faults and fractures generally form the most permeable openings in ese rocks, and streams overlying them may be losing streams. An example s shown in figure 11. Observation well 19-4-8 is near a fault, and, lthough the well is within about 50 feet of a small perennial stream, the ater level in the well is about 60 feet below the level of the stream.

The hydrology of the remainder of the Valley and Ridge Province is uch the same as described here, but in the less permeable shale the faults nd other fractures have less effect on the ground-water regimen.

Low-relief Areas of the Valley and Ridge Province

Much of the two easternmost counties is underlain by folded and faulted carbonate rocks and shale. Because these rocks are easily eroded, a wide valley (commonly called the "Great Valley") of low relief has formed on them. The hydrology of this area is somewhat different than that of the high-relief areas because of low relief, different rock composition, and the presence of numerous faults.

Springs

Many springs discharge from these carbonate rocks. In fact, Bieber (1961, p. 23-24) reports that the combined discharge of 112 inventoried springs in Berkeley and Jefferson Counties is more than 100 mgd (million gallons per day) except during weather extremes.

Twenty-five of the 112 springs were measured or estimated to discharge over 1,000 gpm each. Of these, 16 are on or near mapped faults. Apparently the faults ~~are~~ constitute permeable zones that act as drains, collecting water along their length from tributary faults, fractures, lineaments, sinkholes, and solution channels. Ground water entering a fault zone moves downgradient along or near the fault to the point of discharge at a spring. The springs usually discharge near a stream or form the headwaters of a stream. The water-table map (pl. 1-C) was constructed from water-level data from wells and from spring elevations. The path of ground-water movement and the area supplying water to these springs can be inferred from it. The direction of ground-water movement can also be inferred from the movement of polluted ground water. In three incidents (pl. 1-C , see section on "Ground Water Quality" for details on these incidents) the direction of ground-water movement indicated by pollution movement was generally the same as the direction of ground-water movement indicated by the water-table contours.

Wells and caves

It can be seen from the slope of the water table in plate 1-C that Harland Spring (20-2-46) is probably deriving most of its water from the quadrant lying southwest of the spring. A lineament that trends to the northeast through Harland Spring approximately follows the dashed line that represents the boundary between magisterial districts 20-1 and 20-2. It is probably along this lineament that much of the water moves to the spring. The lineament may represent a continuation of the fault that passes near spring 20-1-85. A study of the lineament was made 0.8 miles south of Harland Spring. A survey was first made by hand-held fluxgate magnetometer. The magnetometer was read every 25 feet or less along three east-west lines, which were about 900 feet long and ran approximately normal to the strike of the rocks. Each reading of the magnetometer was made with the operator facing north, and readings were made at a base station at least every half hour, so that changes in magnetic background could be detected and subtracted from the observed readings. Higher, or more positive, readings were generally obtained for the valleys traversed, and more negative readings were obtained over the hilly areas or where bedrock cropped out. Three test wells were then drilled to determine the nature of the geology beneath the areas where positive and negative readings were obtained. Well 20-2-52 was drilled at a point on line two, where one of the greatest positive anomalies was observed. The top of bedrock was 8 feet below land surface at this site, and, after drilling about 2 feet, there was only partial return of the drill water being pumped into the hole. Between depths of 27 and 42 feet, three cavernous openings were penetrated. Total depth of this hole was 56 feet, and water was encountered at about 55 feet. Well 20-2-53 was drilled at a point on line one, where a negative anomaly was observed. The top of bedrock was 1 foot below land surface, and, after drilling to about 16 feet, there was no return of drill water. No caverns were encountered; however, a 1-foot-thick clay layer, penetrated at about 30 feet, may have been a clay-filled solution opening.

A third well (20-2-54) was drilled at a point on line one, where another positive anomaly was observed. The top of bedrock was at 16 feet, and there was no return of the drill water from a depth of 17 feet to the bottom of the hole at 44 feet. The water table is about 41 feet below land surface in this well, or about 24 feet higher than the water level in well 20-2-52. This suggests that 20-2-52 is in a discharge zone, probably the one carrying a part of the water that discharges at Harland spring.

It is probable that most fault zones or lineaments, such as those conducting water to Harland spring, are cavernous. However, as indicated in an earlier section, the development of caves may be restricted to specific types or layers of rock. This is also suggested by the similar chemical composition of water from four large springs on faults. (See section on Ground Water Quality.) Data presented by Davies (1968) show that there are nine known caverns developed in the Chambersburg Limestone, seven in the Beekmantown Group, and six in the Conococheague Limestone. Many of these caverns are developed along joints.

Appalachian Plateau Section

The Appalachian Plateau province (fig. 2) is distinctly different from the rest of the basin with regard to climate, geology, and hydrology. Much of this part of the basin lies at altitudes between 2,500 and 4,860 feet, which is the highest point in West Virginia (Spruce Knob in Pendleton County). Because it lies at a high elevation, it generally receives more precipitation and has cooler temperatures and a shorter growing season. Its rock strata are relatively younger and flat-lying and also contain beds of coal.

The geology is the key to understanding the hydrology. The rock in this area may be described as being multiple layers of slightly tilted strata of varying thickness, permeability, and porosity. The strike is to the northeast, and the dip is generally less than 10° to the east or west. However, at depth, dip may be greater and folding more intense. The more resistant sandstone generally underlies the ridges, and the less resistant shale, coal, and limestone underlie the slopes and valleys. Most of the same types of rocks underlie much of the Monongahela River basin, and the following description of the hydrologic character of these rocks has been largely taken from a report on the Monongahela River basin (Friel and others, 1967).

In general, shallow ground water in the basin moves slowly from topographically high intake areas to nearby valleys, where it is discharged as seeps and springs or discharged directly to stream channels. Variations in permeability and structural attitude of the rocks may control or alter the pattern of movement. Where the rocks are relatively flat lying, deeper ground water may move laterally without being influenced by the topography and shallow hydrologic conditions. The velocity of ground-water flow in most of the rocks is usually low, ranging perhaps from a few inches to several hundred feet per year. The velocity is controlled primarily by the hydraulic gradient and by the ability of the rocks to transmit water (hydraulic conductivity).

The sedimentary rocks form a series of complicated aquifer systems, each composed of several hydraulically connected beds. The degree of hydraulic connection ranges from direct contact with free hydraulic connection to very little connection through poorly permeable intervening strata.

Beds of sandstone are generally the best aquifers, although, locally, limestone can be an excellent aquifer. Fractures and intergranular openings in the sandstones facilitate storage and movement of water. Shale is usually fractured also, but, except under unusual local conditions of extremely dense and interconnected fracturing, shale does not permit rapid transmission of large quantities of water.

Springs and seeps discharge throughout the basin, usually on hillsides, near the edges of valleys, and along streams. Springs usually issue from fractures in the sandstone and shale, the water being diverted to the surface by rocks of relatively low permeability beneath the fractured zone. Most of the springs issuing from sandstone and shale yield only a few gallons per minute but are adequate for domestic or farm requirements. The larger springs, yielding several hundred to several thousand gallons per minute, generally flow from solution channels in limestone. These water-filled channels are formed in the limestone mostly by the enlargement of joints and fractures by the chemical and abrasive action of water.

Past and present deep and surface mining operations affect the groundwater hydrology of this part of the basin, some places more than in others. Most of the deep coal mining has been along the North Branch Potomac River and near the mouths of major tributaries to the North Branch. Deep mining has partly drained aquifers in other parts of West Virginia, and the lowering of the water level 90 feet in an observation well is illustrated by Friel and others (1967, p. 99). There are only three mines for which the groundwater drainage has been measured in the study area. Although all three mines are near the top of the same hill, their combined discharge was about 140 gpm in March of 1950.

Base-flow measurements (table 5) and water-budget analyses (fig. 8) suggest that underground drainage may be occurring beneath a part of Abram Creek basin. The measurements indicate that some streams near Emorysville have a lower runoff per square mile than other streams in the same vicinity. This lower runoff may be due to mine drainage beneath this area to Deep Run, which lies to the north. Although deep mines exist in the south side of Deep Run, their extent is unknown. However, the rocks in this area generally slope toward Deep Run, and drainage from the mines would probably enter the Run.

Storage and Water-Level Fluctuations

Natural

One way to monitor the relative volume of water in the ground-water phase of the hydrologic cycle is to measure water levels in wells on a continuous or periodic basis. Graphs of water-level fluctuations are useful in that they show when and relatively how much ground-water recharge takes place. As the period of record becomes longer, they are useful in showing cyclical variations and long-term trends in ground-water storage.

Records for some observation wells in West Virginia show that over the past 30 years ground-water levels have neither [illegible] (increased or decreased) ?

(Friel and others, 1967, p. 95). This means that ground-water storage in these most areas is about the same today as it was years ago. For example, the hydrograph of well 20-5-7 in figure 35 shows annual and multi-year cyclical variations; although the minimum water levels show a slight downward trend, the maximum water levels have not changed essentially for 13½ years.

[illegible] or, better, why is
not changed to most [illegible]
the spread of [illegible]

Figure 35 also shows that the time of year in which precipitation occurs is critical to ground-water recharge. Consider the period from 1959 to 1966. The graph shows 33.19 inches of precipitation in 1959, causing a peak water level of 44 feet below land surface. In 1964, which had even less precipitation (29.96 in.), the peak water level was 32 feet, the second highest on record and approximately equal to the maximum water level of 31.5 feet in 1961, when precipitation was 38.77 inches. The height of the water table is not directly proportional to precipitation because much of the precipitation is evaporated or transpired by plants and never reaches the water table when the bulk of annual precipitation occurs in summer (as in 1959). If the bulk of annual precipitation occurs in the fall, winter, or spring (as in 1964), when vegetation is dormant, it has the opportunity to infiltrate to the water table if the ground is unfrozen. Note also that 1969 had 27.75 inches of precipitation. Although this is only 2 inches less than in 1964, most of the precipitation occurred in the summer, and record lowest maximum and minimum water levels were recorded.

Figure 35

Hydrograph of Water-level Fluctuations in

Well 20-5-7 and Precipitation at Martinsburg

Figure 35 also shows what appears to be multi-year cyclical trends. lowest annual water level declined from 53 feet in 1957 to 60.5 feet in). The lowest annual level rose to 52 feet at the end of 1960 and gradually reased to [illegible] a ~~maximum low of~~ about 65 feet in 1969. These long-term fluctions probably reflect the cumulative effect of several deficits in ual ground-water recharge.

Figure 36 shows hydrographs for a deep artesian and a shallow waterle well. The wells are about 5 feet apart, and the hydrographs exhibit variations typical of most wells in the basin. Although the water-levels spond similarly to recharge, the water level in the dug shallow water-table well has a greater nge of fluctuation than that ~~the water level~~ in the deep artesian well.

A possible explanation is that the water-table aquifer was receiving greater amount of recharge. Perhaps this recharge came from the upward scharge of water from the artesian system as well as from downward rcolation of precipitation.

Figure 36

Water-level Fluctuations in a Deep Artesian Well Compared to Water-level Fluctuations in an Adjacent Shallow Water-table Well and Precipitation at Moorefield e

's affect

Man's activities can also affect ground-water levels. The hydrograph well 22-3-21 (fig. 37), within 150 feet of a dam, shows that in 1968, :ore the dam impounded water, the lowest water level in the well was out 30 feet. Impoundment began in April of 1969. Since that time, water- vel fluctuations of lees than 1 foot have generally been maintained by e dam. The lowest water level in the well was only 25 feet in 1969 a year of extremely low ground water recharge) and about 24 feet in 1970. ee figure 35.)

Railroad tunnels also affect ground-water levels. There are six own tunnels in the study area located near Ridgeley and Paw Paw. They nerally penetrate lobes of land lying between meanders of the Potomac iver. The tunnels are much like deep coal mines in that they drain ground ater, which lowers the water table. One of the tunnels was studied and s further discussed in the "Availability" section.

Figure 37

Water Levels of Wells 22-3-21 and 23-1-23, Precipitation at Romney and Approximate Water Level Fluctuations in Reservoir near Well 22-3-21

During the construction of Interstate Highway 81 near Bunker Hill, sting near the intersection of Route 81 and Sylvan Run, reportedly sed Sylvan Run to go dry from Route 81 to a point 1.4 miles to the t. The site of the blasting was 1.2 miles southwest of Le Fevre ing (20-6-52), which is used as a source of water by the Berkeley County lic Service District. The superintendent at the water plant has observed at rainstorms south of the spring make the spring water cloudy. Since asting for Route 81, he has observed that the water becomes cloudy sooner ter a storm than it did before. The water-table map in plate 1-C and e hydrologic map in plate 1 indicate that the recharge area for the spring es to the west-southwest. Sylvan Run is perched above the water table, t blasting apparently opened fractures beneath the Run, and now a part d sometimes all the water in the stream goes underground. Six hundred unds of salt flushed into a sinkhole near the stream showed that water om this area emerges at Le Fevre Spring.

Although we have no hydrographs to illustrate it, undoubtedly there re places in the western part of the basin where the water table has been wered by drainage or pumpage from active or abandoned deep and strip oal mines. The hydrograph for an observation well at Masontown, in earby Preston County, indicates that the water level in the well declined bout 90 feet in 1 year because of deep mining in the area (Friel and others, 967, p. 99).

Availability

Ground water is generally available throughout the basin; however, the
ity available varies from one aquifer to another and from one place
other within a given aquifer. The largest ~~ground-water~~ supplies are
able from sandstone and carbonate-rock aquifers containing secondary
ngs, such as faults, lineaments, joints, or solution cavities within
zone of saturation. Figure 38 and 39 illustrate areas ~~to develop~~ moderate
rge supplies of ground water in high-and low-relief areas. The least
r is available from shale and siltstone aquifers containing almost no
ndary openings. Although nearly all rocks contain fewer secondary
ings with increased depth below land surface, the decrease is more marked
hale. Shale is more plastic than sandstone or carbonate rocks, and,
epth, the weight of the overlying rock squeezes openings shut. The lack
econdary openings dramatically affects the yield of deep wells. Some
s (23-4-19, 24-2-5) have been drilled in shale to depths of about 900 feet
out obtaining a usable quantity of water. In contrast, a gas well (23-1-22)
trating limestone at a depth of about 10,600 feet produced about 16 gpm.

Table 1 summarizes the ground-water availability for the hydrologic
ts in the basin. Plate 1-A shows the range of ~~ground-water~~ yields that
be expected from wells ~~and from~~ the various areas of the Potomac-River
in. The ranges of areal yield shown on the map are based on ground-water
off values obtained from streamflow analysis described in the section on
eamflow separation. Because the streamflows analyzed were for the 1969
er year, when ground-water recharge was below average, the ranges shown
the map have been adjusted upward to approximate values for an "average"
ar.

Sounds [illegible] "thing" [illegible]

otherwise, [illegible] elsewhere,

Figure 38

where

Places (to Obtain) Relatively Large Quantities

of Good Quality Ground Water may be obtained

To be colored? [illegible]

Figure 39

Places to Develop Moderate to Large Ground-water Supplies in Areas Underlain by Carbonate Rocks

See map
p136.

[illegible]

The areal yields given in plate 1-A indicate the amount of ground-
er that annually discharges from each square mile of aquifer as stream-
. These figures also roughly indicate the quantity of water that
ld be pumped from each square mile of aquifer without dewatering the
ifer under prevailing conditions.

Aquifer Characteristics

In addition to knowing the probable yields of individual wells and the
per square mile, it is important to know the approximate hydraulic
icients of the various aquifers. By knowing the transmissivity and
ge coefficient, it is possible to predict drawdown of water levels at
ous distances from a pumped well for various pumping rates and durations.
data are useful when spacing wells, so that drawdown created by pumping
not result in significant well interference.

One means of determining transmissivity and storage coefficient is the
fer test. This normally involves pumping a well at a constant rate while
uring the drawdown created in a nearby observation well. By analyzing
drawdown data in accordance with methods described by Ferris and others
62), values of transmissivity and storage coefficient can be obtained.
erous aquifer tests were made at the sites of wells in Allegany and
hington Counties in Maryland (Slaughter and Darling, 1962). These
nties lie adjacent to the northern border of the study area and are
derlain by the same geologic formations. Thus, the hydrologic coeffi-
ents determined from these aquifer tests (table 16) should be applicable
the Potomac River basin in West Virginia. [illegible]

Although (no aquifers pumping ~~tests were made~~) in the study area, a
w aquifers were evaluated by a channel method described by R. W. Stall-
an (Ferris and others, 1962, pp. 130-132) for analyzing aquifers under
teady-state flow conditions with uniform recharge.

Table 16

Ranges of Transmissivity and Storage Coefficients

or Allagany and Washington Counties, Md. (Slaughter and Darling, 1962)

The method assumes:

(1) The existence of an aquifer bounded on two sides by parallel streams of infinite length, which fully penetrate the aquifer.

(2) The aquifer is homogeneous and isotropic and is recharged at a rate constant with respect to time and space.

(3) Flow is one dimensional, and a ground-water divide is located midway between the streams.

By using estimated and measured base flow of segments of several streams nearby measurements of ground-water level, it was possible to calculate ues for recharge and transmissivity for three geologic formations ble 17). These values of transmissivity compare favorably with the values en for the same geologic formations in table 16.

Table 18 shows ranges of hydraulic conductivity determined by the U. S. il Conservation Service for drill holes penetrating approximately the per 50 to 75 feet of rock in hydrologic units 7 and 5. The conductivities re generally determined for 5-to 10-foot segments of drill hole sealed ove and below by packers. Water was then pumped into the section of hole a constant head, and the loss of water into the section of hole recorded. e quantity of water lost per unit time at constant head was used to lculate conductivity, in feet per day.

Table 17

Values for Transmissivity and Recharge Based on Measured and Estimated Streamflow and Ground-water Level Measurements

Table 18

Ranges of Field Hydraulic Conductivity (K) of about the top 50 Feet of Bedrock, as Determined by the U. S. Soil Conservation Service

The upper range of conductivity given in the table is often high and be misleading. For example, most of the hydraulic-conductivity data n in table 18 are for drill holes 50 to 75 feet deep on the slopes of leys near small streams. The data for many wells indicate relatively n hydraulic conductivity in the upper 25-35 feet of hole. However, the er table often lies below or toward the bottom of this permeable zone ept in valley areas. The table below shows the change of hydraulic ductivity with depth in well 26-6-39:

Depth Interval (feet below land surface)	Hydraulic Conductivity (K) (ft/day)	Transmissivity (T) (ft^2/day)
5 - 10	16.0	
10 - 15	----	
15 - 20	8.49	
20 - 25	7.67	
25 - 30	.09	
30 - 35	2.03	
35 - 40	.22	
40 - 45	.09	12.9
45 - 50	.09	
50 - 67	.04	

The water level in this well is 32 feet below land surface. If this re a water-supply well, most of the pumped water would move to the well rough the zone of lower hydraulic conductivity. Using an average conductivity of 0.35 ft/day, the transmissivity of the saturated zone is calculated o be 12.9 ft^2/day (T = K x aquifer thickness). Wells tapping rocks of his transmissivity are often drilled deep, so that water drains from the ore permeable upper zone into the well and is stored between periods of umping.

Hydraulic conductivity typically decreases with depth in all types of ocks. Although there are occasionally permeable zones at depths of 200-300 eet in shale, beyond this depth conductivity is small. In limestone and andstone, conductivity decreases with depth, but permeable zones bearing alt water have been found at depths of over 10,000 feet. For example, one as well (23-1-22) is reported (F. H. Jacobeen, Jr, Washington Gas Company, ral communication, 1971), to have flowed 16 gpm of salt water under an rtesian head of about 200 feet from a permeable zone in the Beekmantown ormation at a depth between 10,496 and 10,631 feet. However, this is nusual. Most gas wells encounter very little water below a depth of bout 1,000 feet. Well 25-3-40 yielded only one-fourth gallon per hour at depth between 1,141 and 1,159 feet. Seldom do water-bearing zones at epth produce more than 1 or 2 gpm.

Quarries and Mines as Sources of Ground Water

The hydraulic conductivity or storage capacity of aquifers has been ged locally by quarries or open-pit mines and deep mines in limestone coal deposits. Some of these mines drain water from aquifers, but a others, abandoned, become filled with water and increase the hydrau- conductivity and storage capacity of the rocks. When quarries and es are hydraulically connected to water-bearing zones of high hydraulic ductivity they are likely sources of large quantities of water. Some ndoned limestone quarries in Berkeley County have been developed for lic water supplies near Bunker Hill by the Berkeley County Public Service trict and near Martinsburg by the Opequon Public Service District. These rries are, in effect, large dug wells that extend a considerable distance low the water table.

The quarry developed by the Opequon Public Service District near rtinsburg illustrates the quantity of ground water made available. is quarry is excavated in the Stones River Group of rocks (Unit 2) about 4 les north of the center of Martinsburg. Five pits have been dug along e strike of the rocks. The Opequon Public Service District pumps water om the third quarry from the north, which is approximately 200 x 1,500 x 0 feet deep. It is connected to the next quarry, 120 feet to the north, a 20 x 20-foot tunnel below the water surface. This latter quarry is out 250 x 1,700 x 150 feet deep.

Since pumping began in 1962, average monthly water use has increased om about 2 million gallons to 5.5 million in 1970 (fig. 40-B). Only a v water-level data are available for the Opequon quarry and some of the jacent quarries. However, nearly complete pumpage data are available r the Opequon quarry. Figure 40 was prepared from these records in an tempt to predict the maximum sustained yield of the quarry. Figure 40-A ows the water levels in the Opequon quarry, as recorded by consulting gineers employed by the Opequon Public Service District and by Hydro-Space esearch Corporation employees who use the quarry adjacent to and north of he Opequon quarry for underwater testing of instruments. The line is rawn to represent the average annual lowest water level in the quarry over he period of record. The highest water mark on the quarry wall indicates hat the static level before pumping began was at about 415 feet elevation r about 40 feet below land surface. Water-level measurements indicate that the water level in the quarry had stabilized at about 8 feet of drawdown in 1967, at an average pumping rate of 70,000 gallons per day. In June 1968 a large industry went into operation, and pumpage increased to about 180,000 gallons per day. This additional pumpage caused a decline in the water level that continued until October 1969. The lowest annual water level in 13 years of record, recorded at well 20-5-7 in Martinsburg (fig. 35) in 1969, reflects decreased ground-water recharge in the fall and winter of 1968 and spring of 1969. The lowest water level in the well in 1969 was about 5 feet below water-level lows recorded in 1959 and 1966. Thus, in drawing the line on graph A, it was considered that, if 1969 had been a "normal" year, the annual lowest water level would have been at least 5 feet higher then shown on the graph. In extending the line into 1970, it was assumed that the annual lowest water level in 1970 would occur in October and would be at 395 feet elevation, or slightly higher than the lowest annual water level for 1969. This is probably a reasonable estimate of water level because 1970 had a normal amount of recharge, as shown in figure 35, and pumpage from the quarry was somewhat reduced from that of 1969 (fig. 40-B).

Figure 40

Approximate Lowest Water Level in Opequon Quarry, Average Daily Pumpage from the Quarry, and Relation of Water Level in the Quarry to Pumpage

Graph B shows annual average daily pumpage from the quarry during 70. Pumpage generally increased from 1963 to 1967, but from 1968 to withdrawal increased more sharply because of use by new industry.

In graph C the trend of the two average lines in graph A and B are ed against each other. Based on pumpage, future water levels in the ry can be estimated from this graph. Because the original depth of r was about 115 feet, maximum drawdown probably should not exceed 80 because 90 percent of the maximum yield is being obtained (Edward E. son, Inc. 1966, p. 107) at 80 feet of drawdown (67 percent of maximum down). The dashed line on graph C indicates that, with 80 feet of down, pumpage would be approximately 730,000 gallons per day. However, use water-table conditions exist at the quarry, the relationship between age and drawdown would approximate a straight line only for the first 40 t of drawdown. After that, yield per foot of drawdown would decrease as rocks surrounding the quarry were dewatered. The solid line indicates t the yield at 80 feet of drawdown may be more or less than the 650,000 lons indicated on the graph because of (1) annual fluctuations in the er-table and (2) error in drawing the line representing the average annual est water level in graph A.

The superintendent of the Opequon Public Service District was employed he quarry before its shutdown in 1949. He reports that a 25-horsepower trifugal pump, which normally operated continuously at about two-thirds imum discharge against a head of 160 feet, kept the quarry dry before ing operations ceased. However, three additional 30-horsepower pumps e with a 4-inch discharge line and two with 6-inch discharge lines) were rated for 5 or 6 days after rainy periods to keep the quarry dry. The 25-sepower pump, if 70 percent efficient, should be capable of pumping 450 m against a head of 160 feet. If operating at two-thirds capacity, it uld have been pumping about 300 gpm. Estimating that total annual pumpage om the other three pumps would average 100 to 200 gpm, the total yield of e quarry at maximum drawdown would be 400 to 500 gpm, or 600,000 to 700,000 d. This agrees fairly closely with the estimate obtained from graph C.

Abandoned deep coal and limestone mines that are filled with water can lso supply large volumes of water. An abandoned limestone mine about 2 iles south of the center of Martinsburg is the only mine in the basin known o have been developed as a source of ground water. The volume of rock emoved from the mine is unknown, but mining has taken place on several ifferent levels, and the bottom of the mine is about 650 feet below land urface. In 1968, Capitol Cement Company drilled an 18-inch well to a depth f 565 feet, where it intersected an 80-foot-high room in the abandoned ine. An average of 0.75 mdg is pumped from this well to supplement an equal amount of recycled water, which is pumped from an old quarry. The city of Martinsburg also drilled a well that taps these underground mine workings; it serves as an auxilliary source of water for the city.

One coal company pumps water from a deep mine through a well (24-1-38) r Henry. The water is pumped out in order to lower the water level, so t coal can be mined and air properly circulated in active workings at llower depths. Water is pumped at a rate of about 2,000 gpm 4 or 5 days week, or 210 to 260 days per year. Using these values of time and pumpage, nputed values of annual daily pumpage range from 1.6 to 2.0 mgd.

Slaughter (in Slaughter and Darling, 1962, p. 130) reports that the ffman drainage tunnel was constructed to drain coal-bearing rocks in nearby ryland that are similar to those in the study area. The tunnel penetrated rata from the upper part of the Monongahela Group to the middle of the nemaugh Group. It had a total length of 10,646 feet and approximately 2,600 et of auxiliary tunnels and 26,700 feet of connecting drainage ditch. The nnel drained about 14 square miles, and its mean flow in 1958 and 1959 s 9,170 gpm or about 0.94 mgd per square mile. However, as much as 50 per-nt of this water may be derived from streams that are losing water to the ine.

It is apparent from these two examples that large quantities of water re available from mines and tunnels in coal-bearing rock. However, the ater is generally acidic and contains excessive concentrations of iron nd sulfate or other constituents ~~(see analyses for 24-1-38 in table 22),~~ nd must be treated before being suitable for most uses.

Some abandoned strip mines are also located in the Appalachian Plateau art of the basin. When ground water fills such mines, they may also supply large quantities of water. Here, also, the water is generally acidic and may be high in iron and sulfate. Thus, treatment may be necessary before using the water for most purposes.

Problems

Problems concerning ground-water quantity generally arise because
;ood aquifers are unevenly distributed throughout the area, (2) water-
ing openings are unevenly distributed within each aquifer, (3) physical
acteristics of some aquifers make well construction difficult, and
in places deep water tables make both well construction and pumping
icult and costly.

Shale is generally the poorest aquifer in the basin, and generally
rlies the valley areas, where much of the population is concentrated.
efore, low well yield is a common problem where demand is greatest.
example, three wells completed in shale about 4 miles west of Romney
200, 400 (23-5-8), and 960 (23-4-15) feet deep but encountered no
r. A fourth well (23-5-7) in the same vicinity, about 125 feet deep,
duced about 3 gpm. Another well (24-2-17) located in shale near Petersburg
800 feet deep and was also, reportedly, dry.

Some wells tapping good aquifers yield less than expected. For example,
onate rocks are the best aquifers in the area; however, some wells
ring locally impermeable zones yield less than 5 gpm. Other wells tapping
same rocks but penetrating larger water-bearing joints, faults, fracture
es or cavities may yield over 500 gpm. Often associated with the high
ld is turbidity. The turbidity may be caused by turbid recharging water
turbulent flow created in the aquifer or well by high rates of pumping.
turbulent flow picks up sediment in fractures and caverns and carries
into the well. The turbidity problem can sometimes be reduced or elimi-
ed by installing screened gravel-packed wells, by reducing pumping rates,
both. In areas underlain by limestone there have been instances in which
pumping of wells has caused sinkholes to develop. Sediment from the
khholes, in turn, may produce more turbidity. Two sinkholes developed
thin 200 feet of well 20-5-61 in Berkeley County, as it was pumped at
out 250 gpm (Guy Reynolds, Corning Glass Co., oral communication, 1970).
nearby Maryland, sinkhole development is also reported (Slaughter and
rling, 1962, p. 60) at a disposal site for water pumped from a well during ?
esting
mping. In both instances sinkhole development may have been partly caused
soil saturation and loading caused by discharging the pumped water to
e land surface. However, lowering the water level by pumping was probably
e major factor contributing to the development of the sinkhole. Lowering
e water table removes buoyant support of residual clay roofs of cavities
bedrock. Thus, the roofs are prone to collapse (Newton and Hyde, 1971,
. 17).

Wells tapping the Oriskany Sandstone usually produce water, but ionally the rocks are tightly cemented and contain few joints and tures, and, thus, wells may yield only 1 to 5 gpm. In many places the stone is well jointed and (or) poorly cementad, so that it is friable, although it may yield ample water to wells, flowing sand or caving and rocks can be a problem when drilling. Unless such wells are erly cased, screened, and developed, flowing sand can also be a lem later when the well is pumped.

Caving sand and rocks are commonly associated with wells drilled in ges underlain by Oriskany Sandstone. Permeable zones of ground-water nage, found beneath many of these ridges, create low water tables. e, when wells are drilled on these ridges, construction may be difficult costly because of the physical character of the rock, and pumping may be costly because of the extreme depth to the water table.

WATER QUALITY

The chemical quality of water in the Potomac River basin ranges from y poor to excellent and depends upon the history of the water before time of sampling. Most of the chemical analyses given in this report e made by U. S. Geological Survey personnel on samples collected ween 1968 and 1971.

In considering the development of water resources, quality as well quantity is important because most water uses have limiting water-quality teria. Table 19 shows the source and significance of dissolved minerals water, and table 20 gives recommended maximum concentrations recommended by the U.S. Public Health Service (1962) of major mical constituents in water for industrial, domestic, and agricultural es.

As water moves through some phases of the hydrologic cycle, it dissolves terials it contacts. Even atmospheric water contains dissolved material om gas, dust, smoke, or other particulate matter. However, the dissolved-lids content of two samples of precipitation collected near Romney, was tremely small—less than 5 mg/l. Precipitation downwind from industrial itas probably contains greater amounts of dissolved solids.

The mineral matter water dissolves depends principally upon the olubility of the mineral, the surface area and contact time between the ineral and water, and the physical and chemical characteristics of the ater. Because ground water is in intimate contact with rock minerals for elatively long periods, it is usually more highly mineralized than runoff.

Table 19

Source or Cause and Significance of Dissolved Mineral Constituents and Properties of Water

Table 20

Recommended Maximum Concentrations, in Milligrams per Liter, of Major Chemical Constituents of Water for Industrial, Domestic, and Agricultural Uses

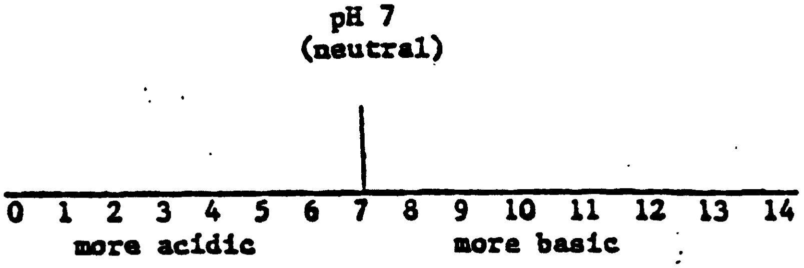
tream water is usually a mixture of overland runoff and ground-
discharge. However, the flow in a stream may be sustained solely by
r source at times. During floods, most water in streams is composed
erland runoff, and the dissolved-solids ~~content~~ concentration is usually much lower
during low-flow periods, when stream flow is sustained by ground-water
arge.

In describing the quality of the waters of the Potomac River basin,
as been made of the chemical, physical, and biological parameters
ded in table~~s~~ 19 ~~and 22~~, as defined below.

Temperature.—Observations are made at the time of sample collection.
ermograph installations, automatic equipment measures and records
ratures hourly.

Specific conductance.—Water containing dissolved minerals, salts,
ome mineral acids and bases, conducts an electrical current. Dissolved-
ds content is related to the conductivity of the water. A measurement
pecific conductance, therefore, permits an estimate of the dissolved-
ds content of a sample of water.

Hydrogen ion concentration - pH.—Acids have a pH less than seven, and
lis (or bases) have a pH more than seven, as illustrated below:



It is difficult to express exactly what pH means in terms of water use. : with a range of pH over several units may often be suitable for some oses, but for others the pH may be so critical as to allow only a 0.2 - pH unit variation. Rainwater and Thatcher (U. S. Geological Survey, , p. 237) state that "the pH of potable water is not pathologically ificant." The Federal Water Pollution Control Administration (now ronmental Protection Agency) recommends a "permissible criterion" .0 to 8.5 for public water supplies derived from surface-water sources 6.0 to 9.0 for the fresh water aquatic life environment (U. S. Department nterior, 1968).

Aside from physiological concerns, knowledge of pH is necessary when tening and purifying water by excess lime and in selecting proper gulents for water purification. When pH, calcium, and alkalinity are wn, it is possible to evaluate the "corrosive potential" of water ylis, 1935).

Hardness.—Water is characterized as being soft or hard according its reaction with soap. The greater the amount of soap required to duce sudsing, the greater the hardness. For convenience, degrees of rdness are usually expressed by the U.S. Geological Survey according to the following arbitrary ranges:

0 - 60 mg/1 - Soft

61 - 120 mg/1 - Moderately hard

121 - 180 mg/1 - Hard

more than 180 mg/1 - Very hard

[illegible] and [illegible]

Hardness is caused by calcium and magnesium ions. The calcium and esium in solution that is chemically equivalent to bicarbonate is ally called "carbonate hardness" and can be removed by boiling. The forces the carbon dioxide from the water, causing the formation of luble carbonates, which subsequently precipitate as boiler or kettle e. The hardness in excess of carbonate hardness is "permanent" or carbonate" and is usually attributed to the sulfates or chlorides of ium and magnesium. The chlorides are highly corrosive when the water mes heated.

Softening water for home use is much more common today than it was w years ago. Softening units for the home are readily available and yield a saving sufficient to cover costs, while providing the conven- ces of soft water. Hard water costs are often unnoticed by the consumer, the expense is real and continuing. For example, by considering increased mbing and fuel bills due to scale in hot water systems, additional soap sumed, and decreased life of clothing and other fabrics, it has been imated that, for a family of four, moderately hard water (61 - 120 mg/1) cost $44 annually (Steel, 1960, p. 313). The loss or cost to industrial commercial water users may be proportionally greater and may be an portant consideration in locating plants and other facilities.

Iron.—Iron, due to its nearly universal occurrence, is likely to be nd in most water. It is present in practically all soil, sand, and rock. n water containing dissolved iron, as ferrous bicarbonate, is exposed to , oxidation yields ferric hydroxide, which is insoluble and drops out of ution as a red-brown precipitate. Its formation can often be noticed rtly after some well water first comes in contact with air.

Iron degrades water by imparting a metallic taste, staining fixtures, l discoloring clothing and other fabrics washed in it. A major problem ated by iron in a water supply is that it incrusts and blocks distribu- n pipes.

Iron is essential to the nutritional requirements of the body. The miting amount of 0.3 mg/l, as recommended by the U. S. Public Health rvice, "is not likely to have any toxicological significance" (U. S. blic Health Service, 1962).

Dissolved Oxygen.—Dissolved oxygen (DO) is a desirable constituent rmally found in surface water in varying amounts, dependent mainly upon mospheric pressure and water temperature. At normal temperatures and mospheric pressures, the DO concentration of natural water ranges proximately from 7.5 - 13.0 mg/l.

In evaluating stream "health", dissolved oxygen is an excellent indica- r of the status of the biochemical balances essential to stream self- rification.

Certain minimum concentrations of dissolved oxygen are necessary ustaining desirable biota of a stream. Trout require a DO concentration t least 6.0 mg/l; other species may tolerate lower dissolved-oxygen entrations for short periods of time (U. S. Department of Interior, 1968).

Biochemical Oxygen Demand.—Dissolved oxygen is chiefly responsible natural purification of streams by oxidization of organic wastes and er but possibly significant amounts of inorganic contaminants. The am's natural content of oxygen is used up in this process, and a ure of the oxygen depletion provides a means of assessing the degree effect of pollution entering a stream. The biochemical oxygen demand) is a test that measures the amount of oxygen required for stabiliza- of organic wastes in a stream. The BOD of a sample is measured by difference between its initial DO concentration and the DO concentration sealed sample at the end of a 5-day incubation period.

The purity of river wastes has been defined by Taylor (1958), ording to the biochemical oxygen demand expressed in milligrams per er BOD, as follows:

Classification		BOD
Very clean rivers	—	1 mg/l
Clean rivers	—	2 mg/l
Fairly clean rivers	—	3 mg/l
Rivers of doubtful purity	—	5 mg/l
Polluted rivers	—	10 mg/l

Ground Water

The quality of ground water varies widely from aquifer to aquifer within individual aquifers with time and place because of local varia- ns in mineral composition of the aquifer, ground-water flow paths, and meabilities. Some general statements regarding ground-water quality in basin can be made based on these considerations: Ground water beneath ridges in the basin has a lower concentration of dissolved minerals, n that beneath valleys because the ridges are mainly recharge areas and valleys are mainly discharge areas. Thus, a well on a ridge usually tains relatively "young" and pure ground water near the start of its w path. A well in a valley usually obtains relatively "old" and impure ound water near the end of its flow path (fig. 29). Another reason for is difference is that the valleys are commonly underlain by low permeability ale. Water moves through shale slowly, and it dissolves a large amount mineral matter. Some anticlinal ridges are commonly capped by relatively soluble and permeable Oriskany Sandstone underlain by cavernous limestone. though the limestone is soluble, in water it is locally extremely per- able, and water moves rapidly through it. Thus, neither type of rock ntributes heavily to dissolved minerals in the ground water.

Some synclinal ridges are capped by other sandstone beds and underlain
ale and sandstone. These are less permeable than the anticlinal ridges,
ater moves more slowly through them. However, approximately the same
ntration of dissolved minerals may be contained in water from shallow
s because of the lack of soluble minerals in the rocks that characteris-
lly underlie these ridges. A greater concentration of dissolved minerals
be contained in water from greater depths because slower water movement
its more time for solution.

Ground water becomes more highly mineralized with depth beneath both
es and valleys. With increased depth beneath ridges, length of flow
s and times of contact with the rocks increase and permeability decreases;
, dissolved-minerals content of the ground water increases. With
eased depth beneath most valleys, the length of flow paths and time of
act with the rocks decreases (but they are still longer than beneath
ridges), but permeability also decreases. This decreased permeability
its only very slow ground-water circulation at depth. Thus, highly
ralized water may be expected.

Trapped sea water (connate water) may also contribute to the salinity
ater at depth. Records for one gas well (23-1-22) in Hampshire County
cates that saline water having a chloride concentration of about 13,000
was encountered between 10,496 and 10,631 feet. This is approaching
chloride concentration of sea water, which is 18,981 mg/1 (Rankama and
ma, 1950).

Drillers' records of deep gas wells drilled in the study area indicate "fresh" water extends to a maximum depth of about 2,000 feet. However, drillers' definition of "fresh" water is unknown. Three inventoried sampled wells (23-5-13, 22-6-5, and 22-4-12) were from 392 to 640 feet and yielded water containing from 400 to about 3,500 mg/l chloride. areas where ground water less than 500 feet deep is too saline for use domestic water supplies are shown as areas of high chloride or sulfate plate 1-B.

Temperature

The temperature of ground water in the basin is almost always within gree or so of the average annual air temperature. But, just as the age annual air temperature varies throughout parts of the basin, so ground-water temperature. For example, the average annual air tempera- in the Allegheny Mountain section is 47.0° F, and ground-water tempera- is 9° C (48° F). Average annual air temperature near Romney is 52.5° F, ground-water temperature is 13° C (55° F). The constant temperature of round water was demonstrated by a thermograph from a recorder placed in old Romney town spring (23-4-9) just west of Romney. The temperature rd spans the period July 22, 1969, to April 20, 1970. The temperature ined from a high of 13.5° C in the fall of 1969 to a low of 13.0° C in ll of 1970.

Although the temperature of most fresh ground water lies between 9° 13° C, both unusually warm and cold ground water is found in the basin. warm water is probably moving upward from depth. For example, the perature of water from warm springs at Berkeley Springs ranges from 19° 23° C (66° to 73° F). The water temperature measured in two deep gas ls (26-4-9 and 23-1-22) increases an average of 6.8° C (12.2° F) per 1,000 t of depth. If the gradient is about the same throughout the basin and is assumed that the ground-water temperature at land surface is 11.1° C ° F), it would suggest that water discharging at the warm springs mperature = 23° C, or 73° F) at Berkeley Springs is moving upward from epth of 1,750 feet or more. The chemical quality of the water and a lack known geologic agents by which the water could be warmed, suggest that ating is due to the increase of rock temperature at depth.

Unusually cold water is obtained from a small spring at the base of Mountain. The temperature of water from this spring was measured to be ° C (49.5° F) in late August of 1969. This temperature is one that may expected at the higher elevations in the western part of the basin. ever, the elevation of the spring is about the same as the elevation of ney, where water temperature is usually 12° to 13° C. The ridge upslope m the spring is composed of large angular fragments of Oriskany Sandstone us and largely barren of vegetation. It is reported that ice is preserved tween these rock fragments and boulders until about July each year. At time the spring was sampled, air emerging from the rocks at the base the mountain near the spring had an air-conditioning effect. A logical planation of this phenomenon may be that in most parts of the basin frost netrates the ground to depths less than 3 feet. Perhaps frost penetrates cks of this ridge more than 3 feet. The greater thickness of cooled rock y be enough to lower the temperature of shallow ground water.

The temperature of shallow ground water can also be changed by rapid charge of cold or warm surface water to permeable aquifers. Such recharge metimes occurs in areas underlain by cavernous limestone, where surface ter may be channeled directly into the ground. Similarly, the temperature water in alluvial aquifers adjacent to streams may fluctuate in response the temperature of water in the stream, particularly if (1) the stream a losing one, (2) pumping from the aquifer induces infiltration from the tream to the aquifer, and (3) flooding surface water creates a hydraulic radient from the stream to the aquifer.

When ground water is exposed to the atmosphere in open pits or quarries, temperature is affected. Figure 41 shows how water temperature in a water-filled limestone quarry 4 miles north of Martinsburg fluctuates average monthly air temperature and water depth. Large temperature ctuations are observed at the surface, but only minor fluctuations observed 100 feet below the surface. Notice that the highest temperature 100 feet is 43° F. This is colder than most ground water and the average ual air temperature in the vicinity of the quarry. The lower temperature be caused by cold water that sinks to the bottom of the quarry in winter spring as surface ice and snow melts.

Figure 41

Water Temperature at Various Depths in the Martinsburg Quarry near Martinsburg and Average Monthly Air Temperature at Martinsburg Airport

Specific Conductance and Dissolved Solids

Owners of domestic wells may be annoyed by changes in the quality of
ir well water, such as increases in hardness and hydrogen sulfide content.
se increases often occur in late summer and fall in wells tapping shale
valley areas. The probable explanation is that in the summer and fall,
n the water table is near its lowest level, the greatest part of the
ped water is derived from deep flowing, highly mineralized water. At
es of the year when the water table is higher, the greater part is
rived from less mineralized local recharge. Figure 42 illustrates the
lical variation in specific conductance of water from well 26-2-14.

Some well owners report a correlation between precipitation and hydro-
n sulfide (H_2S) odor in their water. A possible explanation is that
ring times of recharge, percolating ground water flushes oxidized minerals
om the unsaturated zone into the water table. Because less than 1 mg/l
H_2S will create a strong, objectionable odor, bacterial action plus
ly a slight increase in flushing action of sulfide minerals could cause
e odor (Hem, 1970, p. 168-170).

Figure 42

Graph Showing Water Level and Specific Conductance of Water in Well 26-2-14, and Precipitation Recorded at Franklin

Figure 43

Dissolved Solids Versus Specific Conductance of Ground Water

The specific conductance of water from most of the observation wells led have trends comparable to that of well 25-2-14. However, the ific conductance of water from carbonate rocks does not always ow the same cyclical pattern as water from other rocks, perhaps because uctivity is related to recharge, and carbonate rocks are often not arged in the same cyclical pattern as other rocks. Carbonate rocks ain cavernous openings, which permit recharge any time of year when cipitation is adequate. Other rocks generally permit recharge only in fall, winter, or spring, when evapotranspiration rates are low, soil-sture requirements are satisfied, and water availability is high.

Another exception to the cyclical pattern is shown by the specific
ctance of water from well 23-5-17 (fig. 44). Over short periods of
, the specific conductance of water from this well seems to respond
echarge, similarly to that of well 25-2-14. However, over the period
ecord, the conductivity (thus, dissolved solids)/ seems to be decreasing.
gradual decrease is probably related to decreasing solution-activity
shale borrow pit and fill nearby. In July 1967, the Highway Depart-
opened a borrow pit about 300 feet long and 50 feet or more wide just
th of the highway and about 100 feet upslope from the well. Some shale
ved from the pit was deposited as fill on the south edge of the highway
ediately upslope from and adjacent to the observation well. The borrow
has been inactive since 1967 or 1968, but the pit, fill, and slumping
arently caused an increase in the exposure of fresh unweathered shale
a corresponding increase in dissolved minerals in the local ground
er. Because no additional fresh shale is now being exposed, the removal
minerals by percolating water is gradually decreasing as the shale
thers.

Figure 44

Water Level and Specific Conductance of Water in Well 23-5-17 and Precipitation at Romney

Pollution and Other Water-Quality Problems

Chemical and bacterial pollution is a water-quality problem in some s of the study area. Although its extent is largely unknown, it is ably most widespread in the carbonate rocks of the two easternmost ties. Pollution of in water in of ~~the~~ carbonate rocks has been reported r Inwood. When waste water from a fruit-processing plant was ponded on land surface about a mile north of Inwood, leakage from the pond polluted water that discharged at a spring 3½ miles south of the pond near ker Hill. When the pond was relocated about a mile to the east, pollution the spring reportedly ceased. Plate 1-C lends credence to this report. it indicates a high in the water table north of Inwood, and the 500-foot tour shows that the water table slopes from the Inwood area to the spring. und water is probably flowing toward the south along a permeable fault ne, which lies on the west side of the shale formation that passes rough the area (pl. 1-C).

Plate 1-B shows areas where chemical analyses indicate ground water ntains greater than 45 mg/l nitrate. Nitrate is generally considered be an indicator of pollution from fertilizers and human or animal waste oducts. However, some nitrate may be derived from the solution of lime-one minerals or from biological processes in the soil. Nitrate concentra-on in water in excess of 45 mg/l is harmful to infants (table 19) (U. S. blic Health Service, 1962, p. 47-50). Monthly analyses by Corning Glass mpany of water samples from two wells (20-5-61, 62) tapping limestone reveal at nitrate content ranged from 25 mg/l to 100 mg/l from March 1967 to y 1970.

Water samples collected from several wells and springs near Charles
by the State Health Department suggest a relation between high precipi-
ion and high bacteria concentration in ground water. A high bacteria
tent in the water of one well was later determined by a salt-tracer study
be coming from overland runoff entering a nearby highway drainage well.
h bacterial content in water from the other wells and springs in the
a may have been coming in part from water entering the drainage well,
possibly by recharge at other points.

Other drainage wells along highways in Berkeley County permit contaminants
enter the limestone. Salt, oil, gas, and possibly other contaminants are
ing flushed into these wells by runoff from highways. These aquifers
uld become extensively polluted, for example, if a truck carrying chemicals
uld spill its load within the area drained by wells. Once a contaminant
aches the water table, it may be flushed downgradient by natural ground-
ter movement, thus spreading the contaminant. Because ground-water
vement is generally slow, it could take years for the contaminant to
flushed from the aquifer.

One well about half a mile southeast of Leetown is reported to have
n contaminated by gasoline from a leaking gasoline-storage tank about
f a mile southeast of the well. After the tank was repaired, contamina-
n reportedly ceased at the well. Plate 1-C shows that the water table
pes to the northwest in this area. Contamination of this type may render
und water nonpotable, and it may also constitute a hazard to life and
perty, if explosive gaseous mixtures are formed in well bores or struc-
es housing wells. Gasoline was found in a well tapping limestone in
nsylvania after the well had exploded (Gold and others, 1970), excavating
rater 20 feet in diameter and more than 9 feet deep. The explosion
olished a concrete pump house, and flying rock and debris caused con-
lerable damage to buildings within 180 feet of the well. After the
plosion, it was determined that a buried gasoline storage tank 150 feet
om the well was leaking. Calculations showed that as little as 2.5
llons of gasoline could supply the gasoline vapor required to produce
explosion capable of this amount of damage.

Another potential source of chemical contamination of ground water e pesticides used on orchard and farm lands. Although analyses to date veal no significant pesticide contamination (table 21), the analyses epresent the content of the water at only one time and place. In limestone reas, especially in Berkeley and Jefferson Counties, where in 1967 6,500 acres was in orchard and 98,000 acres in tilled farmland (U. S. Dept. f Agriculture, 1970), some ground water may become contaminated. Pesticides end to be retained and concentrated in soil and plants. Thus, in areas nderlain by cavernous limestone and overlain by tilled soil, pesticides nd other contaminants may be flushed to the water table by overland runoff.

As the foregoing statements indicate, the highest incidence of contamiation is in the carbonate aquifers because of solution cavities and sinkholes, through which water can enter without being filtered through the soil mantle. However, contamination is by no means restricted to them. High chloride in water from some wells tapping shale and sandstone near septic tanks and barn yards suggests that the water is polluted. However, sparse population in parts of the basin underlain by shale and sandstone prevents pollution from being a major problem.

Table 21

Pesticide Analyses of [illegible] Ground Water

[illegible] water?

Changes in chemical quality can take place in water from a well tapping or more aquifers of varying permeabilities and yielding water of ferent quality. The following analyses are for samples collected from h a well (19-2-11) in 1969.

ple	Total Hard-ness	Ca	Mg	SO_4	Cl	pH	Fe	Mn	Remarks
1	169.4	53.7	8.4	98.4	1.5	6.0	0.4	0.01	Pumping continuously 50 gpm.
2	372.1	120.9	16.4	214	2.5	6.65	1.2	0.33	Pumping at required daily volume (18 gpm). Sample taken after 48 hour shutdown.
3	151.2	49.2	6.6	77.8	1.5	6.2	0.4	0.22	Pumping continuously 18 gpm.
4	467.2	149.1	20.3	256.8	3.5	6.7	5.6	0.67	Pumping at required daily volume (18 gpm). Sample taken after 62 hour shutdown.

The well penetrates 430 feet of Marcellus Shale and 35 feet of Oriskany ndstone. The shale is relatively impermeable and yields water high in ssolved solids. (See table 1.) The sandstone is more permeable than the ale and yields water low in dissolved solids. Analyses for samples one d three show that, while pumping continuously, most of the water (low ineralization) was coming from the more productive sandstone. During eriods of shutdown, water (high mineralization) has entered the well from he less productive shale. Thus, analyses for samples two and four repre- ent different mixtures of water from the sandstone and shale aquifers.

Water from wells tapping limestone aquifers and clayey formations is equently turbid. ~~Some newly drilled wells tapping nearly any formation ald turbid water.~~ In limestone aquifers, turbidity may be caused by pid entrance of surface water through sinkholes, which, in turn, disturbs e sediment on the bottom of cave streams. Some surface water is turbid fore entering a sinkhole. Turbidity is reportedly caused by a well that ains surface water from a low area along a road near Charles Town. About 2 urs after runoff enters the drainage well, sediment is reportedly pumped om a domestic well 300 feet away. A test made by the U. S. Geological rvey showed that when 200 pounds of salt (NaCl) was flushed with 1,000 llons of water down the drainage well, chloride concentration began to ncrease at the domestic well in about 2 hours and reached a peak concenration in less than 5 hours. Other drainage wells exist, but the extent f problems created by them is unknown.

Some wells tap formations containing clay layers adjacent to relatively ermeable openings. As pumping lowers the water levels in these wells, ater enters through the permeable openings at increased veolcities. When ntrance velocities become turbulent, clay and other fine particles are icked up by the water.

In wells tapping nearly all formations, turbidity may be a problem or a time after the well is constructed. This turbidity is caused by the emoval of fine drill cuttings from the well bore and clay from pore and racture space adjacent to the well bore.

Classification

It is apparent from the preceding discussion and plate 1-B ~~table 22~~ that ground-
er quality varies widely throughout the study area. An attempt to
ssify the ground waters of the basin was made by use of a trilinear
gram suggested by Piper (Hem, 1970, p. 268), (fig. 45). In using this
gram, the concentration of each major cation and anion is expressed as
ercentage of the total milliequivalents per liter, or epm (equivalents
million), in each sample. The major cations are usually calcium (Ca),
gnesium (Mg), sodium (Na), and potassium (K). Major anions are usually
carbonate (HCO_3), carbonate (CO_3), chloride (Cl), and sulfate (SO_4).
her constituents, such as nitrate (NO_3), fluoride (F), iron (Fe), manga-
se (Mn), free silica (SiO_2), and others are usually present in minor amounts
naturally occurring waters. The percentages of cations and anions in
each sample is then plotted as a single point on each of the two triangles
the lower left and right parts of the diagram. These two points, in turn,
e used to determine a single point in the plotting field, which lies
tween the two triangles. If, for example, most of the points describing
e composition of water from a particular formation fall near the upper
int of the plotting field, then the water may be classified as a calcium
gnesium sulfate or chloride water.

Delete

~~Table 22~~

~~Chemical Analyses of Ground Water in the Potomac River Basin in West Virginia~~

Figure 45

Diagram Showing Relative Chemical Content of Ground Water from Various Sources

From [illegible] (1974)

By plotting the chemical data presented in table 22 in this fashion, ne relationships of water composition to geology are apparent. Figure 45 ows that water from all the carbonate rocks (Units 2, 5, and 9) and from e Oriskany Sandstone (Unit 6) is of the same general composition. That , the percentage of each constituent or group of constituents represented the area shown in the plotting field is approximately the same. However, e concentrations are usually much higher in water from the limestone of it 2 than they are in water from sandstone of Unit 6 and the limestone Unit 5. Perhaps this difference can be explained by the relative lubilities of the minerals in the various units and may also be related topographic differences in the areas underlain by the units. Unit 2 argely underlies the low-relief area of the eastern part of the basin; Units and 6 largely underlie ridges of the high-relief area in the central part f the basin. Because of low relief and low hydraulic gradients, it is ikely that ground-water movement is slower in Unit 2 than it is in Units 5 nd 6. Thus, water is in contact with Unit 2 longer than it is with Units 5 nd 6 and is able to dissolve more minerals from the rocks.

Note that the composition of seven samples of water collected at
ferent times from four of the large springs (20-1-85, 20-5-58, 20-6-52,
21-2-43; all yield ~~over~~ more than 1,000 gpm) discharging from the carbonate rocks
Jnit 2 in Jefferson and Berkeley Counties is represented by a small area
the plotting field in figure 45. This suggests that water discharging
n these springs is derived from the same aquifer or combination of aquifers.
s is of interest because these springs probably discharge water that
lows faults or fault zones (pl. 1-C). Although the faults cut across
ferent rock formations or form the contact between two different rock
mations, the composition of the water varies but little. This suggests
at the solution openings supplying most of the water to the springs have
eferentially developed along particular types of rock cut by the faults
fault zones.

The plotting field shows that some water from the Tonoloway and Wills
ek Formations in Unit 5 has a higher percentage of sulfate than water
a the other carbonate rocks. High sulfate may be expected in water from
se rocks because of the presence of anhydrite ($CaSO_4$); Martens (1939, p.
38) reports that deep gas wells tapping rocks of Unit 5 west of the study
a penetrated much dolomite and anhydrite, and one gas well ~~in~~ Doddridge
nty penetrated about 50 feet of salt (NaCl). Both anhydrite and salt are
;hly soluble, and, in parts of the Potomac basin where Unit 5 is at or
ar land surface, much anhydrite and salt has been removed by circulating
ound water. Where Unit 5 is deeply buried, most of these minerals
obably [illegible] ~~remain because of less~~ circulation of ground water.)

The diagram shows that the composition of water from wells tapping
rbonate aquifers varies more than that from large springs [illegible] ~~tapping~~ the
me aquifers. If ground-water quality is related to solubility of minerals
the aquifer, the time of contact with the rocks, and the area of contact
r unit volume of water, than it can be inferred that the water discharged
the sampled springs passes along flow paths of similar length through
ocks of similar mineralogy containing permeable openings of similar size.
ne composition of water from the sampled wells probably varies as it does
ecause the water passes along flow paths of different length through rocks
f differ~~ing~~ent minerology containing permeable openings of differ~~ing~~ent sizes.
nother possible source of variation may be an influx of surface water to
ome wells.

The composition of water from Unit 4 is represented in the diagram by orizontal band in the plotting field. The content of the water generally ges from high calcium bicarbonate to relatively high sodium chloride ter from one well is extremely high in sodium bicarbonate and was neglected drawing the band shown.). Because about half the rock formations con- ituting this Unit are of Silurian age—a time when most salt deposits were rmed—the high salt content of water from some wells may indicate areas ere the salt deposits have not been completely flushed from the rocks. ch areas as these may be tapped by wells 22-1-4, 22-3-7, and 22-3-8 ~~(table 7~~.

A band showing the composition of water discharging from Warm Springs 9-1-1) at Berkeley Springs lies between the bands shown for the carbonate ocks and Unit 4. The spring water varies from a composition similar to ter from the carbonate rocks to one where the percentage of chloride and lfate is higher than in Units 4 or 5. One of the samples from this spring lso has an unusually high concentration of chloride (42 mg/1). The fact hat the water from the spring is unusually warm (66-73° F) and at times nusually high in chloride suggests that it comes from considerable depth. ossibly, the water is a mixture of cool calcium bicarbonate water from ear-surface sandstone and carbonate rocks and warm sodium chloride water rom deep aquifers. Because Unit 4 is the only aquifer beneath the spring hat has water similar in quality to the spring water, it seems likely that t least a part of the spring water is derived from Unit 4.

The area shown on the diagram (fig. 45) representing the composition water from the Hampshire Formation and Chemung Group shows that water om both ~~formations~~ is similar. This similarity reflects a similarity the bulk mineral composition (Martens, 1939, p. 22-23) of the formations. wever, some differences in mineral composition contribute to differences the quality of the ground water. The Hampshire Formation has much hema- te cement, whereas the Chemung Group has little, but the Chemung contains nsiderably more pyrite (FeS) and organic materials than the Hampshire. The composition of the pyrite and sulfur in the Chemung probably forms locally gh concentrations of iron and sulfate, which are common in water from this rmation but uncommon in water from the Hampshire.

The composition of water from Unit 7 varies more than the composition f water from any other hydrologic unit in the basin. As shown in figure 45, ome of the water has a composition similar to that of water from the car- onate rocks, but most of the samples are higher in sulfate and chloride. hree samples of water from just south of Moorefield contain high concentra- ions of magnesium and sulfate. Analyses of water from five other wells apping Unit 7 plot erratically on the diagram, which probably reflects he diversity of mineral composition of the rocks and, possibly, the influ- nce of saline water moving upward from depth. The areas known to be influenced by saline water are the synclinal valleys of Patterson Creek nd Mill Creek, which lie west of Mill Creek Mountain (pl. 1-B). These areas re underlain by a thick shale, and the water from some wells is soft and igh in chloride (fig. 45A). The deeper wells generally have water of igher chloride content. For example, well 22-4-8 is only 170 feet deep and ields water having a chloride concentration of 312 mg/l. Another well (22-6-5) in the same general vicinity is reported to be 530 feet deep and to yield water having a chloride concentration of about 3,700 mg/l (table 22).

Figure 45A

Diagram Showing the Zones of Fresh and Salty Ground Water in the Synclinal Beds of Shale and Siltstone Beneath Patterson Creek and ll Creek Valleys. Well A Yields Fresh Water and Well B Yields Salty Water.

It is apparent that there are two different types of ground water in e synclinal valleys, when analyses of water from streams at base flow shallow wells are compared to analyses of water from deeper wells ;. 45A). Water of one type is found near the surface in the zone of ive ground-water circulation. Water from this zone is acidic and hard. other is found in the deeper zone of slow ground-water circulation. er from this zone is alkaline, soft, and high in chloride. A probable lanation for the difference ~~in quality of~~ water is that the salt has n flushed from the upper zone by active circulation of ground water. harge entering this zone from the surface is acidic and able to dissolve bonate minerals, where present, from the rocks. Thus, the water becomes d. The water moving upward to the land surface from depth flushes salt m the intervening rocks. Thus, the water is high in chloride, and, ause it is alkaline, it is unable to dissolve carbonate minerals and is erally soft.

Unit 7 underlies most of the larger streams in the basin; therefore, it so underlies most alluvial aquifers. Because the alluvium has been partly rived from and overlies Unit 7, the composition of water from the alluvium generally similar to that from Unit 7. It seems likely that in places ere alluvium is underlain by other units, the water's quality will be milar to that of water from the underlying units.

The composition of water from Unit 10 generally falls within the large eas shown for water from Units 3 and 7 on the diagram.

Surface Water

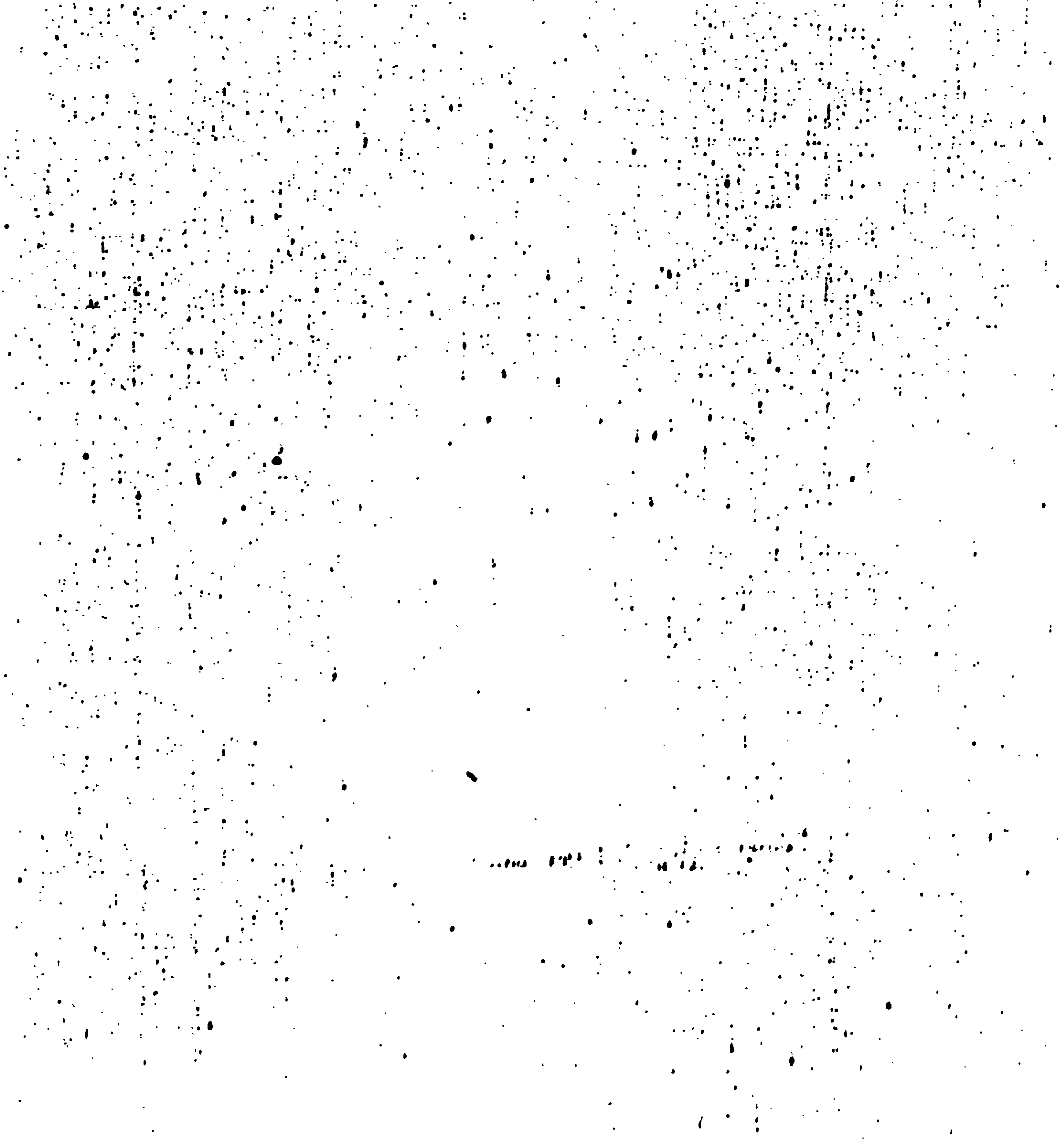
The quality of surface water in the Potomac basin varies greatly
stream to stream and within a given stream. Many factors, both man-
and natural, determine the water quality.

Water quality in streams ranges from poor to excellent. Waters of
ferson and Berkeley Counties are highly mineralized and contrast sharply
those
n the dilute tributaries of the Cacapon River. Hardness ranges from
ft" to "very hard", and iron is usually found in trace amounts but
en in quantities sufficient to restrict water use.

Under natural conditions, most streams contain water of the calcium
arbonate type; a few tend toward rather high sulfate and chloride;
fate concentration is generally higher than that of chloride. Water
m some streams is difficult to classify because of changes in the pro-
with changes in streamflow.
tions of major ions ~~when discharge changes greatly~~. North River and Lost
er, the main headwaters of the Cacapon River, are high in bicarbonate
moderately low to base flow. At high flow the North River has increased
fate concentration (fig. 46), which may be due to the "washing" of
thered pyritic materials by runoff. As a result, the Cacapon River
[illegible]
~~etimes has~~ water moderately high in sulfate. The Shenandoah River varies
m a calcium bicarbonate type at high flow to calcium sulfate chloride
e at base flow.

Figure 46

Changes in Proportion of Major Ions with Changes in Flow



The major water-quality problems in the Potomac basin are the result of coal mining and inadequate treatment of wastes released to streams.

Acid mine drainage has resulted in severe deterioration of the water quality of a 30-mile stretch of the North Branch from Kitzmiller to near Pinto. The basins of Stony River and Abram Creek are also subjected to acid mine drainage, and, as a result, many of the tributary streams are highly acid, and a few have iron concentrations as great as 600 mg/l. For example, Little Buffalo Creek normally has a pH of 6.6 and an iron concentration of less than 1.0 mg/l upstream from a coal-mining operation; downstream from the ~~coal-mining~~ operation, the pH is often as low as 3.3, and the iron concentration ~~content~~ is 300 mg/l.

Industrial development is extensive along the North Branch of the Potomac, and concentrated industrial wastes are discharged to the river. A long stretch of the North Branch is unfit for recreation or water supply, and the dissolved-oxygen content is not adequate to support a balanced fish population.

Municipalities discharge inadequately treated sewage into the streams of the Potomac basin. The water quality of many of the receiving streams has been degraded severely. Opequon Creek, for example, frequently has 3.0 mg/l or less dissolved oxygen and high coliform counts. The South Branch of the Potomac between Moorefield and Sector also receives inadequately treated municipal and industrial wastes. Foul odors are often detected along this stretch of the South Branch.

Chemical analyses of surface waters of the basin show that surface-water lity varies areally and can be regionalized, in order of increasing eral concentration, as follows:

1. Cacapon River and its major tributaries
2. South Branch Potomac and its major tributaries
3. Abram Creek and Stony River
4. Small streams in Jefferson and Berkeley counties

le 23 shows a "typical" analysis based on median values of each measured rameter for each group of streams.

During the study period, water analyses were made at several stream tes by U. S. Geological Survey personnel. Table 24 shows the median, ximum, and minimum values of these analyses.

The West Virginia Department of Natural Resources routinely collects d analyzes samples for chemical and biological parameters. Table 25 shows e median, maximum, and minimum values of selected parameters analyzed ring the study period.

Table 23

"Typical" Analyses Reconstructed from Median Values Obtained from 1960 to 1970

Table 24

Chemical Analyses of Selected Streams — Madian, Maximum, and Minimum Values

Table 25

Chemical Analyses of Selected Streams -
Median, Maximum, and Minimum Values

(Data Furnished by West Virginia Department of Natural Resources)

Temperature

~~Surface-water~~ temperatures of the Potomac River basin streams range 0° C to 31° C (88° F). The daily temperature range of larger streams ormally small, whereas that of smaller streams is larger and closely ted to range of air temperature.

Figure 47 shows the water-temperature relationship between South ch Potomac at Franklin and South Branch Potomac at Petersburg. The r at Petersburg is 37 miles downstream from Franklin and is usually a degrees warmer than that at Franklin. During the winter, water tempera- at both stations approach freezing. This is usual for larger streams the basin, particularly those fed by springs.

Figure 48 shows the daily maximum and minimum water temperatures of ny River near Mount Storm. At this station, Stony River has a relatively ll drainage area (48 sq mi) and would normally be expected to have a ater daily fluctuation in temperature than observed. However, its perature is affected by impoundment in the Stony River Reservoir 14 miles tream.

Temperature affects solubility of dissolved gases and solids, viscosity, density. Increases in water temperature cause increases in the ability the water to hold dissolved solids, but cause decreases in viscosity, nsity, and dissolved gas content of the water.

Table 26

Effect of Temperature on Properties of Water

Delete

Figure 47

Once Daily Water Temperature for the First and Fifteenth
day of Each Month for South Branch Potomac River
at Franklin and Petersburg

Delete

Figure 48

Maximum and Minimum Daily Water Temperature for the First and Fifteenth of Each Month for Stony River near Mount Storm

delete

Specific Conductance and Dissolved Solids

The ratio of dissolved solids to specific conductance of streams ranges from 0.55 to 0.63 (fig 49).

Most streams in the study area have a dissolved solids to specific uctance ratio of 0.63. Opequon Creek and the Shenandoah River have a solved solids to specific conductance ratio 0.55 (fig. 49). Table 27 ws the frequency of specific conductance for selected streams.

Specific-conductance values of most surface waters are related to h cultural and natural factors. For example, coal mining in the north- tern part of the basin has exposed large quantities of pyrite (iron fide) to weathering by water and air. Sulfuric acid, a byproduct of s weathering, dissolves other minerals, which are added to the dissolved- lids load in overland runoff. The increased dissolved-solids load is flected in high specific-conductance values for Stony River, North Branch tomac, and Abram Creek. The North Branch Potomac at Luke, Maryland, equently has specific-conductance values of 250 micromhos.

Towns and industries discharge liquid wastes that contain chloride d nitrate. These are not removed by the sewage-treatment methods generally ed throughout the basin. Opequon Creek, immediately downstream from a wage outfall, has nitrate in concentrations four times those found in the ream 2 miles upstream.

The mineral content of geologic formations plays an important role in e quantity and type of dissolved solids in streams. Limestone and dolomite derlie the valleys between the Shenandoah River and Back Creek. As water ntacts these materials, some carbonate and sulfate minerals are dissolved d added to the streams or to ground water. Opequon Creek has sulfate ncentrations that often exceed 40 mg/l and specific-conductance values that sually exceed 400 micromhos.

Figure 49

Ratio of Dissolved Solids to Specific Conductance of Streams

Table 27

Frequency of Specific Conductance of Selected Streams in the Potomac River Basin

Just east of the Shenandoah River is a narrow band of relatively
uble quartzitic rock. Water discharging from this rock contributes
e to the dissolved-solids content of local streams and may, in fact,
e the dissolved minerals in the Shenandoah River.

Ground water entering Patterson Creek and South Branch Potomac River
Moorefield contains high concentrations of iron and sulfate. Figure 50
strates the control ground-water discharge has on dissolved solids in
r of the South Branch Potomac at Franklin. At this site there is a
tively large volume of ground water of fairly uniform dissolved-solids
ent mixing with overland runoff. The result is that specific conductance
es only slightly. This contrasts markedly with the South Branch Potomac
Springfield, where relatively larger volumes of overland runoff, having
able dissolved-solids concentration ~~content~~, controls water quality more than dis-
ging ground water, and where the effects of culture sometimes mask
ral water quality.

Figure 50

Duration Curves of Specific Conductance of South Branch Potomac River at Franklin and near Springfield

Hydrogen Ion Concentration (pH)

The pH of water in the Potomac River basin ranges from 3.3 to 9.0, about 90 percent of the basin yields water with a pH of 6.5 - 8.2, "acceptable" range. This is true for the waters of the South Fork he Potomac, Cacapon, and Little Cacapon and all the major tributary ams in Jefferson, Berkeley, and Morgan Counties.

Streams in the Stony River and Abram Creek basins have pH values that ~~rast-with~~ e lower than those of streams in the rest of the study area. Stony River, 1115 largest North Branch tributary, is the site of two large private impounds. A few miles east is Abram Creek, which flows parallel to Stony er (fig. 51). These streams and many of their tributaries receive acid inage from mines. Median pH values for the region are about 5.0; the pH ~~led to~~ l not exceed 5.5 at Abram Creek at Oakmont, where samples were taken ut every 2 months from May 1969 to March 1971. According to a report the West Virginia Department of Natural Resources (1969), "pollution . . . destroyed any fishery present in Abram Creek" and Stony River generally s no fishable population." The North Branch of the Potomac also receives d-mine drainage and, consequently, its fish production has been reduced.

The acidic waters in the North Branch become neutral or slightly caline by the time the water reaches Keyser. This increase in pH is due t only to the buffering effects of calcium bicarbonate water entering the in stem from runoff and ground-water discharge but also to the discharge waste water from water-treatment plants.

Figure 51

Iron Concentration of Surface Water at Low Flow

In summary, the pH of most stream water in the basin is within a range satisfies criteria for public water supplies, recreational facilities, aquatic habitats. But there is a small area in the western part of the n where pH values are extremely low and are directly related to acid drainage.

Hardness

During October 1969, when streams were at low flow, water hardness ietermined at 136 stream sites and 37 spring sites. Water from two- ds of the springs ranged from hard to very hard, as did the water from st half the stream sites sampled. Water from approximately one-third he basin had a hardness of less than 60 mg/l (fig. 52). Water from the inder of the basin was generally hard, ~~reaching~~ having a maximum of 932 mg/l. hardest water was found in an area underlain by limestone, a few miles h of Martinsburg. The North Fork of the South Branch and mainstem of Potomac yield water with hardness greater than 200 mg/l. The ranges ardness found in water from both springs and streams at low flow are n in table 28.

At moderate flows Patterson and Opequon Creeks have the hardest water. er of the Cacapon River and reaches of the South Branch of the Potomac nstream from Moorefield also ranges from hard to very hard. Table 29 ws water hardness for some of the large streams of the basin.

le 28.—Ranges of water-hardness of streams and springs sampled during period of low flow. ~~Number of streams and springs in the Potomac River basin having water-hardness as shown at low flow.~~

	Soft (0-60 mg/l)	Moderately Hard (61-120 mg/l)	Hard (121-180 mg/l)	Very Hard (180 mg/l or more)
of Stream~~s~~ sampled	49	30	24	33
of Spring~~s~~ sampled	7	6	15	9

Figure 52

Hardness of Surface Water at Low Flow

Table 29

Hardness of Surface Water, July 1967 to December 1969

(Data from West Virginia Department of Natural Resources)

Iron

During the October 1969 low-flow period, samples from 169 springs and 11 streams were analyzed for iron content; 21 samples had concentrations 0.3 mg/l or more iron, and a few had no iron (fig. 51). An iron concention of 300 mg/l was found in Elk Run at Henry and Little Creek near marck. The high concentration is a result of coal mining in the area. Stony Creek-Abram Creek drainage area generally has an iron concentration ging from 0.5 mg/l to 5.0 mg/l. Along the North River from Loom to rgent, values of 0.3 to 0.5 mg/l are common. Water from the remaining reams contained about 0.1 mg/l dissolved iron.

Monthly sampling of some larger streams reveals iron concentrations nging from trace amounts to 10.0 mg/l. Opequon Creek near Terico Heights casionally contains 5.5 mg/l iron, but it is usually less than 0.1 mg/l. the Potomac River at Paw Paw iron concentrations reach 9.0 mg/l, but lues of 0.2 - 0.5 mg/l are much more common. In the North Branch at nto, Maryland, iron concentration reaches a maximum of 3.9 mg/l, but e median value of 24 samples is 0.9 mg/l.

Dissolved Oxygen

Generally, DO (dissolved-oxygen concentrations) in surface waters of
basin represent from moderately high to very high percentage oxygen
ration. About two samples per month were taken at 18 stations during
study period. Most of the samples, except those from the North Branch
he Potomac, had DO concentrations that represented greater than 88
ent saturation and were often greater than 100 percent (super-satura-
). At various points throughout the basin, oxygen-consuming domestic
industrial wastes are discharged into streams. Immediately downstream
these points, the DO content is generally severely depressed, but it
nally recovers to saturation after the stream flows a few miles, and nuisances are not
ted.

Exceptions are Opequon Creek and the North Branch of the Potomac.
quon Creek receives large amounts of domestic wastes, as indicated by
ermittent high bacteria counts (coliform) and elevated BOD (biochemical
gen demands). Of 48 samples, 2 had a DO concentration of less than 6.0
'1, and 42 had 8.0 mg/l or greater. Sharp fluctuations in DO can be
trimental to higher forms of aquatic life, particularly when minimum DO
nges from 5.0 - 5.5 mg/l, as it does in Opequon Creek.

The water quality of North Branch of the Potomac is degraded by indus-
ial and municipal effluent (fig. 53). Approximately a 40-mile reach
this stream (from near Bloomington, Md. to a few miles downstream from
berland, Md.) has a low dissolved-oxygen concentration, which ranges from
percent to 50 percent saturation, and a high biochemical oxygen demand.
ter quality in this reach is further degraded by acid waters from the
al mining areas of Stony River and Abram Creek. Dissolved-oxygen concen-
ations along this reach of the North Branch are frequently as low as 3.0
/l. Eighteen of 24 samples collected during June, July, and August 1969
d DO concentrations of less than 6.0 mg/l, and 12 had less than 5.0 mg/l.
e minimum DO of 2.0 mg/l was recorded at mile 313.5 near Cresaptown at a
ite immediately downstream from an industrial waste discharge point. During
his period, only one value greater than 6.0 mg/l was recorded in this reach
f the river.

Figure 53

Dissolved Oxygen-Biochemical Oxygen Demand Relationships

on North Branch Potomac River

Biochemical Oxygen Demand

Opequon Creek near Terico Heights has BOD (biochemical oxygen demand) es ranging from less than 1.0 mg/1 to more than 5.6 mg/1. Twenty- n percent of the water samples from Opequon Creek had a BOD value of to 5.7 mg/1.

Values of BOD for the South Branch of the Potomac River are mostly in the ge of "very clean" to "fairly clean". For example, from July 1967 to ember 1969/ only three of the 24 samples taken from the South Branch nstream from Franklin had a BOD values slightly greater than 2.0 mg/1.

The North Fork of the South Branch at Judy Gap is normally low in gen-consuming substances, but on July 25, 1967, an unusually high BOD ue of 6.8 mg/1 was recorded. On the same date, a coliform bacteria nt of 33,000 colonies per 100 ml was reported.

The highest BOD values in the basin are found in the water along a mile reach of the North Branch of the Potomac. Water in this segment the Potomac frequently has high BOD values and depressed DO content g. 53). From mile 337.5 downstream to mile 313.5, BOD fluctuates lely over a range of 9.0 - 43 mg/1. Of 24 samples taken from this reach ring June, July, and August 1969, 14 had BOD values greater than 20 mg/1.

Dissolved Oxygen-Biochemical Oxygen Demand Relationship for a Selected Stretch of the North Branch of the Potomac

A close relationship normally exists between DO and BOD. When one is h, the other is low. For example, when BOD is high it may remove oxygen m the stream faster than it can be replenished by the atmosphere. Thus, concentration decreases. This situation is often referred to as the .ssolved-oxygen sag". As the water flows downstream, the oxygen content ntually returns to normal (saturation) because of reaeration inflow of ner water or bio-degradation of the organic waste.

BOD, oxygen sag, and reaeration may be demonstrated by observing the -BOD relationships on the North Branch Potomac River from mile 338.2 to le 277, as shown in figure 53. The graph shows BOD and DO changes at rious points on the stream, as related to discharges of organic wastes.

Upstream from mile 338.2, DO is 9.0 mg/1, and BOD is relatively low .0 mg/1). Both factors indicate relatively clean watar. Immediately wnstream from mile 338.2, DO and BOD quickly respond to an effluent of ganic waste. BOD increases to 22 mg/1, and DO decreases to 5.0 mg/1 2 percent saturation). About 7 miles downstream, additional organic waste scharges into the stream. Dissolved oxygen "reserves" being exhausted, D and DO respond by rising to 24 mg/1 and declining to 4.0 mg/1, respect-ely. In this condition, the stream is unable to sustain desirable biota, d its capacity for neutralizing organic wastes is negated. From mile 326 314, DO rises to 5 mg/1 and BOD declines to 8.0 mg/1.

Immediately downstream from mile 314 the stream receives a concentrated ganic-waste effluent, and BOD reaches a high of 42 mg/l. DO reaches a low 2.5 mg/l (29 percent saturation). Reaeration and the addition of cleaner ter from the South Branch and other tributaries cause BOD and DO to turn to "normal" by the time mile 277 is reached. (Data are incomplete om mile 312.5 to mile 277.)

Table 30 shows the median, maximum, and minimum values of several rameters observed on the North Branch during June, July, and August 1969.

Table 30

Chemical Analyses for the North Branch Potomac River (from mile 338.2 to mile 277)

Problems and Treatment Methods

From the foregoing discussion, it may be concluded that natural water
ity is often unsatisfactory in much of the river basin. The unsatis-
ory quality and variability of the chemical charactar of ground water
surface water largely reflects the mineral content of the formations
quifers with which the water comes in contact. Water from carbonate
fers is almost always very hard, occasionally contains iron, and is
eptable to pollution from surface sources. Water from shale almost
ys contains objectionable amounts of iron, is usually hard, and may
tain excessive chloride or sulfate. Water from sandstone is commonly
t and acidic. Water from the coal-bearing rocks is commonly soft,
dic, and high in iron.

Most of the people in the basin live in valley or lowland areas, which
usually underlain by shale or limestone. Rocks of this type commonly
ld water containing exceseive dissolved solids for satisfactory domestic
. Although water in the streams of these valley areas generally contains
s dissolved solids than ground water, certain chemical constituents may
excessively high in both surface water and ground water.

The areal distribution of some water-quality problems can be seen in
ate 1-B. The general causes for the dissolved constituents are summarized
table 19, and some methods of treatment to remove objectionable consti-
ents are given in table 31.

Table 31

Selected Ways of Removing or Reducing Chemical Constituents That Exceed Recommended Maximum Concentrations

PRESENT USE AND FUTURE DEVELOPMENT

Although the 1970 census shows a decrease in population of West inia, the population of the Eastern Panhandle remained about the same t was in 1960. However, the population is expected to increase in the future because of the growing popularity of the Panhandle as a recrea- area. With the completion of "Corridor H" highway, the area will be more accessible to industry and people from more densely populated as to the east.

As the population and economy of the area expand, more water will be ied. Much of this water will probably come from ground-water sources. e wells will be needed to supply water for rural residences. Also, as population of shale valley areas becomes great enough to justify ablishment of public water systems, other large springs or wells at bases of sandstone and limestone ridges will be developed. Berkeley Jefferson Counties will need more water than other counties if they ome even more industrialized and populated. Nearly all municipalities industries in these two counties use ground-water supplies, largely ause the area is underlain by limestone aquifers, and copious supplies available from springs, abandoned limestone quarries, and wells. In future, it may become necessary to develop other springs or to tap meable fracture traces or fault zones with wells of high yield in order supply enough water.

Problems of waste disposal and ground-water pollution will be
sociated with increased population and industrial development. Careful
udy and planning will be needed to determine directions of ground-water
vement and, thus, safe areas for sewage and waste disposal, ground-water
velopment, and perhaps ground-water recharge, particularly in areas
derlain by carbonate rocks. In areas underlain by shale and sandstone,
velopment poses somewhat less of a problem with respect to ground-water
llution because the ridges are generally recharge areas and the valleys
e generally (but not always) discharge areas. Thus, contamination of
st of the ground water can be avoided simply by keeping potential con-
minants off the ridges.

Gross water-use figures are given in table 2, and detailed water use
igures are given in table 32 for specific public and industrial systems.
he figures indicate that municipal and domestic supplies are largely
erived from ground-water sources and that industrial supplies are largely
erived from surface-water sources in the basin.

Some of the larger villages use surface water because they are underlain
y shale aquifers that furnish water of a poor quality for domestic con-
umption. Most of the recent water systems developed for small areas
tilize water discharged from large springs at the bases of sandstone and
limestone ridges.

Table 32

Public and Some Industrial Water-supply Systems in the Potomac River Basin in West Virginia

Although no figures are available for recreational use of water, it is coming increasingly important. The Soil Conservation Service plans to ild dams in addition to the ones shown in plate 2. Some of these will used for water-related recreation, as will a large dam under construction the U. S. Army Corps of Engineers on the North Branch Potomac River at oomington and another planned for the South Branch Potomac River near tersburg.

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Table ~~2~~1.—Summary of data ~~for~~ regarding hydrologic units and ground water

Geologic systems		Rock units	Range of thickness (feet)	Main rock type	Hydrologic unit	Description	Well depths (feet)	Well yields (gpm)	Water-quality parameters			Specific conductance (micro mhos)		Remarks
									Iron (mg/l)	Chloride (mg/l)	Hardness (mg/l)			
QUATERNARY	Holocene	Alluvium	0-35		11	Unconsolidated stream deposits are mainly of silt and clay containing lenses of sand and gravel. Significant saturated thicknesses of alluvium are usually found only near major streams. Many alluvium deposits are on terraces and are unsaturated.	4-35	0-40	<0.1-3.0	2.0-72	<51-290	100-760	Range	Water quality is often similar to that found in formations underlying the alluvium. Shallow water tables in alluvium are susceptable to pollution. One large diameter well at Petersburg yields about 450 gpm.
									0.4	<8	<136	280	Median	
PENNSYLVANIAN	Upper	Monongahela Group	0-180	▤	10	Analysis of drill logs by Overbeck (1954, p. 50-51) for drill holes penetrating these formations in Garrett County, Maryland, indicate that 20 to 35 percent of the Conemaugh Group is sandstone (including siltstone), about 50 percent of the Allegheny Formation is sandstone, and 55 to 70 percent of the Pottsville Group is sandstone. The sandstone content of the Monongahela Group is thought to be similar to that of the Conemaugh. The remaining percentages of each formation are shale, clay, some limestone, and coal. Most of the coal beds are located in the Conemaugh and Allegheny Formations. Occasional thin beds of limestone (less than 5 feet thick) occur in all of the formations above the Pottsville. Beds of clay are often found at the base of coal deposits. The Mauch Chunk, the lowermost group in this hydrologic unit, consists of thin-bedded sandstones, siltstones, and non-calcareous red or green shales.	12-325	2-250	0.1->5	<8-56	<17-200	<50-1010	Range	Average yield of wells is about 13 gpm in the Monongahela Group; the average yield gradually increases downward and is about 45 gpm in the Pottsville Group. The Mauch Chunk Group generally yields less than 5 gpm to wells (Friel, E. A. and others, 1967, p. 80-81). Water from all formations is generally acidic. Soft water is usually obtained from the Pottsville formation and most springs. Highest iron concentrations are generally found in formations of the Allegheny and Pottsville. The Monongahela Group underlies only a very small part of the study area.
		Conemaugh Group	780-840	▤			60	<30	0.5	<8	110	200	Median	
	Middle	Allegheny Formation	150-200	▤										
	Lower	Pottsville Group	350-450	▤										
MISSISSIPPIAN	Upper	Mauch Chunk Group	500-800	▤										
	Upper	Greenbrier Group	100-[illegible]	▦	9	The Greenbrier Group is mainly limestone; however, approximately the upper 100 feet is usually a reddish calcareous shale. The bottom half is sometimes sandy and separated from the top half by a 5- to 7-foot thickness of bluish, sometimes cherty, limestone. The basal 300 feet is mostly blue, gray, or reddish limestone. The uppermost part of this basal section often contains shale layers or partings and is thin-bedded. With depth, the shale beds diminish, and the limestone beds become more massive. This limestone is thickest and relatively pure in Pendleton County but decreases in thickness and is thought to become more sandy in the northern part of the basin. Because of its low resistance to weathering, poor exposures of Unit 9 are common, and it characteristically forms benches of relatively rich soil.			<0.1	1.3-6	<160-200	340-390	Range	No wells were inventoried that tap this unit. However, springs yield from 50 to 2000 gpm. Friel and others (1967, p. 81) report wells as deep as 310 feet yielding 5 to 100 gpm and averaging 45 gpm. Overbeck (Amsden and others, 1954, p. 138) reports that in nearby Maryland wells are as deep as 200 feet, yielding 1 to 20 gpm, and average 14 gpm. The chemical data shown here are for baseflow surface water samples (Table 3). Thus, dissolved minerals in ground water may be slightly higher. *Dye studies in Pocahontas County, West Virginia indicate cavernous drainage through this unit beneath several ridges (Davies, W. E., 1965 Supplement, p. 1-2). Similar cavernous drainage may occur in western Pendleton County.*
									<0.1	<6	180	365	Median	

Table 1.—Summary of data for hydrologic units.-Cont.

Geologic systems		Rock units	Range of thickness (feet)	Main rock type	Hydrologic unit	Description	Well depths (feet)	Well yields (gpm)	Water-quality parameters			Specific conductance (micro mhos)		Remarks
									Iron (mg/l)	Chloride (mg/l)	Hardness (mg/l)			
MISSISSIPPIAN	Lower	Pocono Group	200-600		8	These three formations are relatively easily identified in the field on the basis of color and lithology. The Pocono Group is a gray relatively thin formation composed mainly of hard massive sandstone with some shale beds. The underlying Catskill Formation is maroon to reddish brown at weathered outcrops and forms a red soil which especially stands out when wet. The upper 300-400 feet of this formation is siltstone and shale. The lower part is nearly all fine-grained, well-cemented hard, massive sandstone with some shale. The Chemung is nearly always a rusty yellowish-brown in color. Approximately the top half of the formation is thin-bedded, hard, blocky sandstone. The bottom half is principally thin-bedded, siltstone and shale with a massive sandstone member present at its base in the easternmost areas. It should be noted here that both the Pocono and Chemung Groups occasionally contain thin red beds near the contact with the Hampshire. Likewise, the Hampshire Formation sometimes contains some gray or brown beds. Where this happens, bedding thickness is a good indicator as to the geologic contact between the Hampshire and the adjacent groups.	18-640	1-75	<0.1-30	1-80	34-156	58-390	Range	The Hampshire Formation generally yields the least amount of water, and the Chemung generally yields the most ~~amount of water~~. However, water from the Chemung very often contains objectionable amounts of iron, whereas water from the Hampshire and Pocono seldom does.
							130	10	0.4	<8	85	250	Median	
DEVONIAN	Upper	Hampshire Formation (CATSKILL FACIES)	1200-3000											
		Chemung Group	1200-3500											
		Brallier Formation (includes Harrell Shale)	1500-2300		7	The Brallier Formation is a greenish-gray shale, siltstone, and sandstone. The sandstones in this formation are 2 to 6 inches thick and are characteristically flaggy. Sandstone and siltstone may comprise about 35 percent of the formation. The lower 50 to 400 feet of this formation (actually the Harrell Shale) is black shale which lacks bedded sandstone or flags. Below, lie the brownish sandy shales of the Mahantango Formation. Occasional sandstone beds are contained but are seldom flaggy. These rocks weather to a chocolate brown or brownish buff and develop red to brown loam soil. Toward the base of this formation, some beds or lenses of calcareous shale occur. Many concretions are normally found near the contact with the underlying black Marcellus Formation. The Marcellus is a black carbonaceous, clayey, fissile shale which contains considerable pyrite and minor amounts of siltstone. Perhaps 50 to 150 feet from the base of this formation is one or two beds of limestone each having a thickness of about 20 to 40 feet (Reger, D. B., 1924, p. 320). Large limestone concretions sometimes occur near the base of this formation as well as an unusual thin bed of rock commonly referred to as the "brown break" or bentonite by drillers and is an excellent marker bed when present.	5-962	0-75	0.1->6	2-1270	15-6370	75-1000	Range	The Brallier Formation generally yields less water than the other formations in this hydrologic unit. Water from the Brallier Formation is also generally lower in iron, hardness, and total dissolved solids than the Marcellus and Mahantango Formations. Water from the Marcellus generally has the highest concentrations of iron.
							75	8	>1	<8	170	480	Median	
	Middle	Mahantango Formation	300-1000											
		Marcellus Formation	500-900											
	Lower	Needmore Shale												

The Needmore shale lies beneath the bentonite and is a dark gray or green shale that grades westward into chert and limestone

Table 1.—Summary of data for hydrologic units.-Cont.

Geologic systems		Rock units	Range of thickness (feet)	Main rock type	Hydrologic unit	Description	Well depths (feet)	Well yields (gpm)	Water-quality parameters: Iron (mg/l)	Water-quality parameters: Chloride (mg/l)	Water-quality parameters: Hardness (mg/l)	Specific conductance (micro mhos)		Remarks
DEVONIAN	Lower	Oriskany Sandstone	100-500		6	This unit is mainly comprised of sandstone sandwiched between two layers of generally soft calcareous chert. The upper chert layer ranges in thickness from zero to 100 feet and in some exposures is a highly weathered brown sandy layer containing small blocks of chert. The Oriskany Sandstone is a medium- to thick-bedded brown-to-white sandstone. In some places the rocks contain very hard silica cement; in other places they contain softer carbonate cement; in still other places they are friable and completely devoid of cement. The lower dark chert layer (Shriver Chert) ranges in thickness from near zero in Morgan County to 312 feet in Pendleton County. It weathers much the same as the upper chert layer. This hydrologic unit commonly caps or forms the slopes of anticlinal ridges.	10-552	1-150	0.1-1.0	<8-85	<17-476	<50-870	Range	For best yields, wells tapping this unit should be located low on the flanks of anticlinal ridges or at gaps in these ridges. One dug well 10 feet deep located in such a gap produces over 150 gpm. Springs yielding from 1 to 15,000 gpm are found in this unit usually in gaps or at the nose of plunging anticlines and sometimes along the flanks of ridges.
							100	15	<0.2	<8	<83	140	Median	
		Shriver Chert												
		Helderberg Group	300-600		5	The upper part of the Helderberg Group consists of thin-bedded light-colored cherty limestone. The middle part is shaly and thin-bedded. The bottom part is massive-bedded relatively pure limestone that is commonly mined for road-building purposes. The underlying gray, flaggy, thin beds of the Tonoloway Formation contain some silica and dolomite and grade downward into the hard flaggy limestone and calcareous shales of the Wills Creek Shale. The basal 25-100 feet consists of red or green sandy shales and one very fine-grained hard sandstone bed which ranges in thickness from 5 to 50 feet. is the [illegible] sandstone which	13-420	2-200	0.01-6.5	1.1-43	6-390	75-670	Range	The Helderberg Group generally yields more water than other formations in this unit. Water is almost always alkaline. Water occasionally contains slightly objectionable concentrations of iron when derived from the shale ~~Cayuga Group.~~ formations. Springs yielding from 5 to 6000 gpm are found in this unit usually in water gaps. This unit probably stores much of the water discharged to large springs in the overlying Oriskany Sandstone. fault
SILURIAN	Upper	Tonoloway Formation	200-400				100	20	<0.1	<8	<200	410	Median	
		Wills Creek Formation	200-400											
		Williamsport Sandstone	60-100											
	Middle	McKenzie Formation	150-400		4	The McKenzie Formation is a bluish-gray wavy-bedded flaggy limestone and limey shale that forms the upper part of this hydrologic unit. The adjacent Clinton Group is predominately red shale with thin beds of sandstone and occasional limestone lenses or layers. The underlying thick-bedded Tuscarora Sandstone varies in color from gray to pink and is extremely hard and resistant to weathering. In parts of Pendleton County vertical beds of Tuscarora sandstone form spectacular walls or sheets of rock. The red beds of the Juniata Formation consist of thin-bedded blocky sandstone and shale. Sometimes this formation is underlain by thick-bedded gray Oswego Sandstone.	32-265	0-40	<0.1-5	1.1-<8	6-258	<50-475	Range	No wells were inventoried tapping the Oswego and Juniata Formations, and only 2 wells were inventoried tapping the Tuscarora Sandstone. Thus, these data largely represent the McKenzie Formation. The other formations in this unit probably yield less water but of better quality than that from the McKenzie Formation.
							100	8	0.3	<8	<100	200	Median	
		Clinton Group	300-600											
	Lower	Tuscarora Sandstone	50-300											
ORDOVICIAN	Upper	Juniata Formation	500-1000											
		Oswego Formation	100-200											

The state map is exactly as this is here.
Also our already published Pl. 1 is the same as it is here.

Table 1.—Summary of data for hydrologic units.-Cont.

Geologic systems		Rock units	Range of thickness (feet)	Main rock type	Hydro-logic unit	Description	Well depths (feet)	Well yields (gpm)	Water-quality parameters			Specific conductance (micro mhos)		Remarks
									Iron (mg/l)	Chloride (mg/l)	Hardness (mg/l)			
ORDOVICIAN	Upper	Martinsburg Formation	1500-2300		3	The upper part of this unit largely consists of blocky sandy shale with interbedded sandstone. Downward, the rocks grade into thin-bedded shale, and near the base of the unit are generally calcareous with some lenses and beds of limestone. However, the unit seldom contains limestone in Hardy County. In Berkley and Jefferson Counties, the shale is crumpled and folded and is mined in places for use in the manufacture of bricks.	28-175	2-50	0.1-10	1-121	111-540	234-1020	Range	Highest producing wells are believed to tap areas where permeability has been increased by crumpling and breaking of the rock or removal of calcareous cement or beds by solution.
							65	20	2	15	250	350	Median	
	Middle	Trenton and Black River Groups	400-500		2	The Trenton-Black River Group is shaly near its contact with the Martinsburg Formation. Downward, it grades into a hard, thin-bedded, blue-black limestone that is flaggy or cobbly in weathered outcrops. The upper part of the underlying St. Paul Group consists of thin-bedded quite pure limestone that becomes more massive and higher in silica and magnesium toward its base. The Beekmantown Group contains abundant chert in its upper horizon. The remainder of the group consists of occasional beds of very pure limestone and beds of dolomite and limestone which are often high in silica, especially near the base. The high silica content continues into the underlying Conococheague Formation. Although this formation is largely limestone, it contains some banded sandstone near the top, minor amounts of dolomite and characteristically contains beds of oolite throughout. The Elbrook Formation is mainly thin-bedded limestone and calcareous shales. However, massive beds of dolomite occur near the center of the formation, and chert is abundant throughout. The adjacent Waynesboro Formation is a mass of silicious limestone, sandstone, sandy shale and some dolomite. However, some very pure limestone beds do occur and are locally mined. The upper beds of the Tomstown Dolomite are massive, banded, hard limestone and dolomites. Lower in the formation are massive beds of siliceous dolomite with thin beds of relatively pure limestones. Considerable amounts of shale occur near the base of the formation.	11-705	1-630	0.1-0.7	3-24	216-636	500-840	Range	The largest supplies of water are usually obtained from wells tapping the Beekmantown Group in the eastern part of the basin. Discharges of 1000 to 5000 gpm occur from 25 springs in this unit. About 2/3 of these springs are on faults. (Some smaller springs are also on faults.) The water is polluted in places where drainage wells or solution openings permit surface drainage or waste water to discharge directly to the water table. The Trenton-Black River Group, Beekmantown Group, and Conococheague Limestone are probably more cavernous than the other rocks in this unit.
		St. Paul Group	500-800				150	35	<0.2	8	290	540	Median	
	Lower	Beekmantown Group	2000-2500											
CAMBRIAN	Upper	Conococheague Formation	1500-1800											
	Middle	Elbrook Formation	2200-2500											
		Waynesboro Formation	1500-1600											
		Tomstown Dolomite	1000											
	Lower	Antietam Formation	500		1	The Antietam Formation is generally a thick-bedded, hard quartzite and sandstone that is calcareous in places and weathers to form sandy soils. The adjacent Harpers Formation is an intensely folded and uniform sandy shale. The underlying Weverton-Loudoun Formation is mainly quartzite that varies in texture from a fine-grained to a moderately-coarse conglomerate. Its color varies from nearly white to purplish black and in some places resembles dark-gray granular granite. The basal part of this unit is formed from greenish-gray rocks of the Catoctin Formation which is largely schist.	18-212	1-45	<0.1	<5	<100	<212	Range	No wells tapping the Catoctin Formation were inventoried. However, small to moderate supplies of water are available from other formations in this unit.
		Harpers Formation	1200				150	7					Median	
		Weverton-Loudoun Formation	300-600											
PRECAMBRIAN		Catoctin Formation												

Table ~~1~~ 2.--Summary of facts about the Potomac River basin in West

Drainage area in W. Va.--3,464 square miles or 15% of West Virginia.

Population--125,495 in 1970 (1960 population - 120,596).

Climate--Average annual precipitation - 38 inches (see figure 3).
Annual temperature - varies from 54°F in lowlying valleys in the central and eastern part of the basin to 47°F in the high mountains along the western edge of the basin.
Annual snowfall - varies from about 24 inches in lowlying valleys to over 80 inches in the higher elevations along the western edge of the basin.
Annual growing season - varies from 180 days in valleys to 110 days in mountains.

Topography--Generally a series of northeast-trending mountains and narrow valleys bordered by broad valleys on the east and a high plateau on the west. Elevations range from 250 to 4,860 ft.

Geology--The extreme eastern part of the basin is underlain by crystalline rocks of Precambrian age. The extreme western part of the basin is underlain by flat-lying sandstone rocks of Pennsylvanian age. In between these extremes are highly folded sandstone, shale, and limestone rocks of intermediate age.

River discharge at Shepherdstown, W. Va.:
Minimum--282 cfs, August 1, 1966
Maximum--335,000 cfs, March 19, 1936.

Number of flood-retarding dams in Potomac River basin--64 (37 more are presently proposed).

Industries--Coal and limestone mining, farming, pulpwood, manufacturing, and canning.

Surface water	Use		Problems
	Domestic	(Unknown)	Turbidity and high temperatures
	Municipal	1.40 mgd	
	* Industrial (self supplied)	10.8 mgd	
Ground water	Use		Problems
	Domestic	2.5 mgd	Inadequate supplies mainly from shale formations. Poor quality water mainly from shale and coal-bearing formations.
	Municipal	5.5 mgd	
	* Industrial (self supplied)	5.5 mgd	
Total		25.7 mgd	

Federally owned forest--Approximately 172,500 acres (7.9% of basin)
State owned forest--Approximately 46,383 acres (2.1% of basin)

Largest city--Martinsburg (14,626 population)

Land use, 1967 inventory--Cropland 11.5%, Pasture 14.9%, Forest 61.7%, Orchards, vineyards, bush fruit 1.1%, Other 10.8%.

* Self supplied by industry

Table ~~Adjusted~~ potential evapotranspiration

~~Adjusted~~ potential evapotranspiration, in inches

Month	Bayard	Franklin	Kearneysville	Martinsburg	Petersburg	Piedmont	Romney	Wardensville
January	0.00	0.04	0.05	0.02	0.07	0.01	0.02	0.01
February	.00	.14	.10	.06	.16	.03	.11	.04
March	.31	.63	.66	.58	.70	.56	.68	.58
April	1.62	1.94	1.94	1.88	2.08	1.87	1.90	1.80
May	3.11	3.49	3.65	3.64	3.61	3.52	3.50	3.46
June	4.25	4.57	5.06	5.14	4.92	4.82	4.93	4.73
July	4.76	5.26	5.87	6.02	5.63	5.58	5.63	5.47
August	4.23	4.75	5.19	5.28	5.02	5.00	5.10	4.86
September	2.96	3.31	3.57	3.56	3.49	3.46	3.50	3.36
October	1.65	1.98	1.97	1.93	2.03	1.95	2.03	1.88
November	.51	.73	.74	.66	.73	.65	.70	.68
December	.00	.05	.10	.07	.13	.03	.06	.03
Annual	23.40	26.89	28.90	28.84	28.57	27.48	28.16	26.90

Data furnished by Robert O. Weedfall, State Climatologist, and Walter Dickerson, Professor, Agricultural Engineering, West Virginia University.

Table 4.--Measured discharge and specific conductance of Smith Creek at Zigler and near Franklin.

Date	Smith Creek at Zigler, W. Va.		Smith Cr. Nr. Franklin, W. Va.		Remarks
	Discharge (cfs)	Conductance (micro mhos)	Discharge (cfs)	Conductance (micro mhos)	
5-7-68	7.55	480	0.4	180	
6-4-68				60	
6-5-68	20.0	80			
6-20-68	7.4	55	0.2	170	
8-1-68	1.2	75	0.04	435	
9-16-68	0.12	105	0		
11-5-68	0.59	110	0		
12-19-68	3.0	55	0		
1-23-69	3.3	60	0(frozen)		
3-7-69	5.8	55	0		
4-29-69	17.5	295			
6-2-69	5.4	60			
1-21-71	10(est.)	70	0.5(est.)		Stream dry 2½ mi. downstream from Zigler
6-24-71	16.41		5.02		

Table 5.--Low-flow measurements and field chemical analyses of selected streams and springs.

Site or spring number	Station	Drainage area (square miles)	Date (October 1969)	Discharge (cfs)	Discharge (MGD per square mile)	Iron (mg/l)	Chloride (mg/l)[1]	Total hardness (mg/l)[2]	Specific conductance (micromhos at 25°C)	pH	Water temperature (°C)	Geology[3]
1	Abram Creek Trib. nr. Oakmont	1.51	13	0.029	0.012	0.0	7.7	51	115	5.8	13.3	Pc
2	Maple Run nr. Emoryville	1.50	13	.069	.028	.9	5.8	26	<50	6.6	19.0	Pc
3	Emory Run nr. Emoryville	3.28	13	.389	.078	.6	32.8	205	640	<4.0	12.0	Pc
81	Elk Run at Henry	3.76	14	.628	.110	5.0	50.0	---	6800	<4.0	12.5	Pc
83	Red Oak Creek at Wilson	3.06	14	.902	.188	.3	1.3	17	< 50	6.9	11.8	Pc
84	Difficult Creek nr. Gormania	6.6°	14	1.75	.168	.2	1.9	17	< 50	6.8	11.5	Pc
85	Mill Run nr. Mt. Storm	5.01	14	1.43	.188	1.0	7.7	205	420	6.2	11.5	Pc
86	Johnnycake Run nr. Mt. Storm	4.12	14	.758	.117	.1	24.5	51	118	7.0	11.8	Pc
4	Piney Swamp Run nr. Piedmont	.74	14	.120	.105	1.0	16.7	17	63	5.8	12.2	Pa
87	Little Creek nr. Bismarck	.68	15	.366	.162	5.0	32.0	---	2420	5.0	5.3	Pa
104	Roaring Creek nr. Onego	7.67	13	3.12	.155	.1	9.0	34	51	7.0	14.0	Mmc
107	Laurel Run nr. Simoda	.12	14	.058	.310	.1	1.3	42	90	7.0	17.5	Mmc
26-1-11	Spring on Roaring Cr. nr. Onego	—	13	2.13	---	.1	3.2	34	65	7.0	13.5	Mmc
26-1-12	Spring on Long Rn. nr. Onego	—	13	1.39	---	.1	.1	17	51	6.8	12.5	Mmc
105	Tanyard Run nr. Riverton	.12	14	.010	.054	.1	5.8	162	340	7.6	13.0	Mg
106	Unnamed Run nr. Riverton	.18	14	.015	.054	.1	2.6	162	340	7.9	14.0	Mg
108	Back Run nr. Cherry Grove	.85	14	.005	.004	.1	1.3	204	390	8.0	11.0	Mg
80	North River Trib. nr. Rio	1.68	21	.052	.020	.1	3.9	17	<50	6.0	11.1	Mp
110	Laurel Run Trib. at Simoda	.16	14	.002	.008	.1	3.9	8	<50	5.8	12.0	Mp
26-1-13	Spring on Roaring Cr. nr. Onego	—	13	.390	—	.1	5.8	34	85	7.5	14.0	Mp
111	Briery Gap Rn. Trib. at Simoda	.31	14	0	0	—	—	—	—	---	---	Mp
26-1-14	Spring on Roaring Cr. at Onego	—	13	3.79	—	.1	1.3	34	95	7.2	13.0	Mp
194	Rockwell Run nr. Paw Paw	.43	13	0	0	—	—	---	—	---	---	Mp
34	N. Fk. Little Cacapon R. nr. Shanks	10.46	16	.221	.014	.1	11.1	51	135	6.6	11.6	Dhs
35	Three Churches Rn. nr. Three Churches	3.52	14	.030	.006	.2	21.8	68	170	7.0	14.5	Dhs
43	Pine Draft Rn. nr. Pleasantdale	2.13	16	.006	.002	—	25.8	51	285	6.3	11.5	Dhs
44	Gibbons Run nr. North River Mills	6.38	17	.063	.006	.2	9.0	51	145	6.5	11.5	Dhs
45	Maple Run nr. North River Mills	7.03	17	.079	.007	.1	13.5	68	180	7.0	9.8	Dhs
47	Critton Run nr. Largent	7.98	17	.090	.007	.2	21.2	51	165	6.5	11.5	Dhs
67	Skaggs Run at Inkerman	8.04	21	.238	.020	.1	14.2	51	145	7.0	12.5	Dhs
69	Howards Lick Rn. nr. Mathias	6.84	20	.111	.010	.1	14.8	51	135	7.0	13.8	Dhs
70	Wetzel Hollow nr. Mathias	8.29	20	.173	.014	.1	1.3	34	95	7.0	11.6	Dhs
25-4-15	Lee Sulfur Spring at Lost River State Park	—	20	.002	—	.1	5.8	51	340	8.5	10.0	Dhs
163	Unnamed Run nr. Johnstown	.43	15	0	0	—	—	—	—	---	---	Dhs
103	Seneca Creek nr. Onego	23.18	13	3.95	.110	.1	3.9	51	88	7.2	13.5	Dhs
109	Teter Camp Rn. nr. Cherry Grove	4.82	14	.648	.084	.1	9.6	34	90	7.0	11.0	Dhs
132	Rough Rn. nr. Ft. Seybert	3.64	16	.770	.130	.1	2.6	17	<50	6.5	9.5	Dhs
211	Unnamed Rn. nr. Stotlers Crossroads	.52	14	.001	.001	.1	6.4	34	79	5.5	13.5	Dhs
213	Unnamed Rn. nr. Stotlers Crossroads	.40	14	Trace	---	.1	5.8	68	142	7.0	13.9	Dhs
214	Mountain Rn. Trib. nr. Johnson's Mill	.62	13	.012	.012	.1	10.3	34	105	7.0	16.0	Dhs
71	Sperry Run Trib. nr. Rio	1.96	20	.033	.011	.1	10.3	51	135	7.0	17.0	Dch
72	Howards Lick Rn. nr. Mathias	8.60	20	.124	.009	.1	12.2	51	142	8.0	14.0	Dch
28	Broad Run nr. Grace	3.37	14	.011	.002	.2	6.4	51	155	7.0	14.0	Dch
40	Bearwallow Creek nr. Augusta	5.05	16	.056	.007	0	18.7	51	200	7.5	14.5	Dch
41	Bell Hollow nr. Augusta	4.74	16	.148	.020	.1	18.7	51	150	6.8	17.2	Dch
42	S. Fk. Little Cacapon R. nr. Augusta	7.93	16	.116	.010	.1	7.7	51	138	7.0	14.2	Dch
18	Wild Meadow Run nr. Burlington	2.53	15	0	0	—	—	—	—	—	---	Dch
22	Mikes Run Trib. nr. Antioch	1.05	15	1.71	1.05	1.0	6.4	137	210	6.0	18.0	Dch
193	Potomac R. Trib. nr. Doe Gully	.11	13	0	0	—	---	---	---	---	---	Dch
200	Unnamed Run nr. Stotlers Crossroads	.46	14	0	0	—	---	---	---	---	---	Dch
204	Dry Run nr. Berkeley Springs	1.32	13	.012	.006	.4	10.3	51	126	6.0	18.5	Dch
205	Swim Hollow nr. Berkeley Springs	.92	13	.007	.005	.4	9.6	51	125	6.0	20.0	Dch
209	Iden Run nr. Stotlers Crossroads	.69	14	Trace	---	.1	26.4	51	103	7.0	14.0	Dch
221	Sleepy Cr. Trib. nr. Stotlers Crossroads	.60	14	.004	.004	.2	2.6	68	157	7.0	15.0	Dch
133	Rough Run nr. Ft. Seybert	4.84	16	.014	.002	.1	2.6	17	<50	6.0	12.0	Dch
24	Broad Hollow nr. Green Spring	1.79	14	.012	.004	.1	5.2	51	135	6.5	15.5	Db
25	Round Bottom Hollow nr. Green Spring	2.03	14	.001	.0003	.1	7.1	51	105	6.5	15.0	Db
58	Mill Branch Trib. nr. Capon Bridge	.63	16	0	0	—	---	---	---	---	---	Db
66	Durgon Creek nr. Durgon	1.79	17	.018	.006	.1	6.4	76	210	7.9	19.0	Db
73	Howards Lick Run at Mathias	9.30	20	.125	.009	.1	12.2	51	122	7.5	16.2	Db
92	Thorn Run at Forman	2.71	15	.057	.014	0	12.9	68	190	6.4	12.2	Db
21	Staggs Run nr. Headsville	3.60	13	.030	.005	---	18.7	---	---	---	---	Db
93	Patterson Creek nr. Lahmansville	1.95	15	Trace	---	.8	2.6	68	190	6.2	12.8	Db
134	Rough Run nr. Ft. Seybert	5.15	16	.220	.028	.1	4.5	26	58	6.0	12.5	Db
197-A	Sleepy Cr. Trib. nr. Stotlers Crossroads	.61	14	Trace	---	.2	23.8	68	198	7.0	16.5	Db
198	Unnamed Run nr. Smith Crossroads	.53	14	0	0	---	---	---	---	---	---	Db
206	Sleepy Cr. Trib. nr. Ridersville	1.98	13	.028	.009	.1	5.2	68	165	7.0	16.0	Db
206-A	Unnamed Run nr. Ridersville	.66	13	.014	.014	.1	18.7	68	190	7.0	16.0	Db
218	Unnamed Run nr. Sleepy Creek	.43	14	0	0	.2	4.5	51	105	6.0	14.5	Db
219	Sleepy Cr. Trib. nr. New Hope	.48	13	.002	.003	.1	—	34	103	7.0	15.6	Db
220	Sleepy Cr. Trib. nr. Johnson's Mill	.42	13	0	0	.1	12.2	51	102	6.5	17.5	Db
95	Robinson Run Trib. nr. Cabins	1.92	15	.067	.023	.2	5.1	137	280	7.5	12.8	Dmt
96	Hoglan Run nr. Cabins	3.33	15	.075	.015	.3	5.2	205	430	7.5	13.9	Dmt
164	Back Creek Trib. nr. Allensville	2.71	15	.013	.003	.1	5.2	68	159	6.5	13.0	Dmt
165	Whites Run Trib. nr. Johnstown	.02	15	0	0	—	---	---	---	---	---	Dmt
167	Back Creek Trib. nr. Glengary	.83	14	0	0	.1	---	68	195	6.0	14.3	Dmt
168	Back Creek Trib. nr. Shanghai	1.34	15	.013	.006	.1	6.4	68	158	7.0	12.0	Dmt
169	Back Creek Trib. nr. Shanghai	.95	15	0	0	---	---	---	---	---	---	Dmt
170	Back Creek Trib. nr. Hedgesville	.43	15	.005	.008	.1	12.2	85	185	6.0	14.0	Dmt

Table 5.--Low-flow measurements and field chemical analyses of selected streams and springs.-Cont.

Site or spring number (See Pl. 2)	Station	Drainage area (square miles)	Date (October 1969)	Discharge (cfs)	Discharge (MGD per square mile)	Iron (mg/l)	Chloride (mg/l)1/	Total hardness(mg/l)2/	Specific conductance (micromhos at 25°C)	pH	Water temperature (°C)	Geology
195	Warm Spring Run nr. Berkeley Springs	1.17	14	0.013	0.007	0.1	64.4	170	500	7.0	15.5	Dmt
196	Rock Gap Rn. Trib. nr. Rock Gap	.94	14	.004	.003	.2	51.5	119	328	7.0	13.2	Dmt
199	Unnamed Run nr. Smith Crossroads	.74	14	.013	.012	.1	18.0	68	208	7.0	14.0	Dmt
199-A	Unnamed Run nr. Smith Crossroads	.39	14	.005	.008	.1	39.3	119	320	7.0	14.5	Dmt
216	Unnamed Run nr. Cherry Run	.90	14	.020	.014	.1	9.0	68	262	6.5	15.0	Dmt
26-6-9	Puffenburger Spring nr. Sugar Grove	—	15	.250	---	.1	4.5	153	325	7.2	13.0	Dmn
26-2-16	Spring on Deer Rn. nr. Upper Tract	—	16	.960	---	.1	6.4	136	290	8.0	12.5	Dmn
16	Rocky Run nr. Short Gap	.08	14	0	0	—	---	---	---	---	---	Dmn
17	Rocky Run Trib. nr. Short Gap	.21	14	0	0	—	---	---	---	---	---	Dmn
60	S. Br. Potomac R. Trib. nr. Kessel	2.14	17	.210	.064	.1	3.9	230	440	8.0	11.0	Dmn
26-A	Mill Creek Trib. nr. Rada	.75	14	0	0	—	---	---	---	---	---	Dmn
31	S. Br. Potomac R. Trib. nr. Grace	.46	14	0	0	—	---	---	---	---	---	Dmn
32	S. Br. Potomac R. Trib. nr. Millestones Mill	.41	14	0	0	—	---	---	---	---	—	Dmn
101	Johnson Run Trib. nr. Petersburg	.50	15	.008	.010	.1	7.7	85	190	6.8	18.3	Dmn
20-4-79	Sulfur Spring at Shenghai	—	15	.006	—	.1	15.5	171	390	8.0	13.0	Dmn
20-4-5	Jones Spring at Jones Spring	—	15	.022	---	.1	6.4	222	420	7.0	12.0	Dmn
25-2-4	Spring on State Farm nr. Wardensville	—	21	.347	---	.1	2.6	136	260	7.0	12.4	Do
24-3-2	Hatchery Spring at Petersburg	—	15	.904	—	.0	4.5	374	610	7.0	12.8	Do
30	Core Run nr. Romney	1.37	16	.002	.001	.0	6.4	171	330	7.3	10.0	Do
23-7-5	Bubbling Spring at Bubbling Spring	—	17	.161	---	.1	2.6	119	230	7.0	13.0	Do
50	Castle Run nr. Forks of Cacepon	1.21	17	.009	.005	.5	6.4	188	350	6.9	11.5	Do
48	Kale Hollow at Bubbling Spring	3.75	17	.006	.001	.1	10.9	154	280	7.1	11.5	Do
52	Yellow Spring Creek at Yellow Spring	.92	16	.262	.182	.3	2.6	51	85	7.0	12.5	Do
55	Dillons Run nr. Millbrook	2.05	16	.515	.162	---	3.9	154	275	8.0	14.0	Do
63	S. Br. Potomac River at McNeill	1294.00	22	149.0	.075	.1	7.1	119	255	8.0	12.2	---
64	S. Br. Potomac River at Glebe	1300.00	16	194.0	.096	.3	8.4	119	235	7.9	13.8	---
			22	158.0	.079	.1	11.6	119	255	8.0	12.6	---
23-7-4	Capon Springs at Capon Springs	—	16	.737	---	—	.1	171	280	7.2	15.6	Do
23-7-17	Yellow Spring at Yellow Spring	—	17	.189	---	.1	2.6	17	<50	6.4	12.0	Do
61	Mudlick Run nr. Old Fields	19.68	21	.831	.027	.1	---	221	422	8.0	18.8	Do
25-1-27	Spring on Mudlick Run nr. Old Fields	—	21	.003	—	—	24.0	290	580	7.5	13.7	Do
62	Mudlick Run nr. Old Fields	19.81	21	.714	.023	.1	9.7	238	468	8.0	14.0	Do
65	Unnamed Run nr. Bess	—	17	.020	—	.1	1.3	162	310	7.6	11.5	Do
78	Brushy Hollow nr. Lost River	1.55	21	.007	.003	.5	2.6	17	<50	5.0	10.8	Do
19-1-1	Warm Springs at Berkeley Springs	—	13	2.56	---	.1	1.9	153	291	7.0	22.8	Do
125	Straight Creek nr. Kline	.44	16	0	0	—	—	—	—	---	---	Do
126	Shaver Run nr. Kline	5.14	16	Trace	—	.1	12.9	26	75	5.9	13.0	Do
26-6-10	Hiner Springs nr. Moyers	—	15	1.00	—	.1	2.6	76	155	7.8	12.0	Do
24-3-7	Big Spring at Masonville	—	15	—	—	0	6.4	204	360	8.0	11.1	Do
22-6-28	Elliber Spring nr. Russeldale	—	16	.003	—	.1	1.9	34	90	6.8	12.8	Dhl
54	Dillons Run nr. Millbrook	2.02	16	.668	.215	0	6.4	171	280	6.4	13.5	Dhl
23-2-4	Creig Spring nr. North River Mills	—	17	---	---	.1	2.6	188	335	7.2	10.5	Dhl
22-6-6	Spring nr. Antioch	—	13	—	—	.1	5.2	290	500	7.4	11.5	Dhl
79	Thorny Bottom nr. Wardensville	15.60	21	0	0	—	—	---	---	---	---	Dhl
25-3-5	Spring on Dumpling Run at Brake	---	17	2.08	—	.1	.1	136	275	7.0	12.0	Dhl
10	Waxter Hollow nr. Keysar	1.20	14	0	0	—	—	---	---	---	---	Dhl
26-5-7	Pitzenberger Spring nr. Franklin	—	15	.170	—	.1	2.6	110	220	7.5	11.0	Dhl
26-5-8	Cress Spring nr. Franklin	—	15	1.81	---	.1	—	102	210	7.5	11.5	Dhl
26-2-17	Big Spring at Eagle Rock nr. Upper Tract	—	16	2.31	—	.1	6.4	136	315	7.2	11.5	Dhl
23-7-1	Beall Spring nr. Millbrook	---	16	.515	---	0	3.9	85	180	6.8	11.5	Stw
171	Beck Creek Trib. at Tomahawk	1.60	15	.210	.840	.1	8.4	273	470	8.0	11.0	Stw
172	Back Creek Trib. nr. Jones Spring	.47	15	Trace	—	.1	9.3	222	375	8.0	12.0	Stw
174	Tilhance Creek Trib. nr. Tomahawk	.45	15	0	0	—	---	—	---	—	—	Stw
89	Lunice Creek Trib. nr. Maysville	1.06	15	0	0	—	---	---	---	---	—	Stw
99	Patterson Creek Trib. nr. Williamsport	.85	15	1.06	.810	0	5.8	290	560	8.0	11.1	Stw
100	Brushy Run Trib. nr. Old Arthur	.31	15	0	0	—	---	---	---	---	---	Stw
24-3-3	Poor Farm Spring at Cabins	—	15	2.50	—	0	6.4	171	335	7.0	12.8	Stw
53	Dillons Run nr. Millbrook	2.01	16	.641	.207	0	6.4	171	275	7.5	13.0	Stw
56	North River Trib. nr. Hanging Rock	1.10	16	.009	.005	.3	7.1	171	280	8.0	11.8	Stw
57	Hiett Run at North River Mills	4.06	17	.107	.017	---	---	---	335	---	9.5	Stw
25-3-51	Spring on Warner Farm nr. Kessel	---	17	.140	—	.1	5.2	357	660	7.0	12.0	Stw
13	Turners Run nr. Short Gap	.65	14	0	0	---	---	---	---	---	---	Stw
14	Cabin Run Trib. nr. Keyser	.33	14	0	0	---	---	---	---	---	---	Stw
19-4-4	Ziler Spring nr. Largent	—	14	.535	---	.1	6.4	136	255	7.5	10.6	Stw
127	Shaver Run Trib. nr. Kline	1.46	16	0	0	—	—	---	---	---	---	Stw
26-5-9	Spring on Moyers Farm at Harper	---	15	.310	---	.1	5.1	136	290	7.2	12.0	Stw
26-6-11	Spring on Sanders Farm nr. Moyers	—	15	.628		.1	2.6	76	155	8.0	12.5	Stw
26-2-18	Reeds Creek Spring nr. Ruddle	---	16	2.56	---	.1	6.4	102	220	7.8	11.5	Stw
26-2-19	Spring on Waggy Farm nr. Ruddle	---	16	---	---	.1	12.2	110	240	7.8	11.0	Stw
90	N. Fk. Patterson Cr. Trib. at Greenland	1.36	15	.007	.003	1.0	6.4	154	360	7.2	7.8	Smc
91	New Creek nr. Mountain Valley	1.78	15	.085	.031	.5	7.7	137	230	7.5	7.8	Smc
94	Lunice Creek Trib. nr. Maysville	1.28	15	.032	.016	.2	6.4	103	225	7.2	8.0	Smc
97	N. Fk. Patterson Cr. Trib. nr. Maysville	1.79	15	0	0	---	---	---	---	---	---	Smc
98	Patterson Cr. Trib. nr. Williamsport	.35	15	.225	.415	0	18.0	290	560	7.0	11.7	Smc
6	Mill Run nr. Antioch	.63	13	---	---	0	12.9	239	420	7.5	21.5	Smc
7	New Cr. Trib. nr. New Creek	.82	13	.004	.003	.1	109.0	308	750	7.7	14.8	Smc
8	Mill Run Trib. nr. Antioch	.90	13	0	0	—	---	---	---	---	---	Smc
9	Limestone Run nr. Keyser	3.21	13	.032	.006	0	14.2	340	630	7.0	16.0	Smc
26-2-20	Spring on Waggy Farm nr. Ruddle	---	16	.073	---	.1	5.2	136	255	7.8	11.0	Smc

Table 5.--Low-flow measurements and field chemical analyses of selected streams and springs

Site or spring number	Station	Drainage area (square miles)	Date (October 1969)	Discharge (cfs)	Discharge (MGD per square mile)	Iron (mg/l)	Chloride (mg/l)1/	Total hardness (mg/l)2/	Specific conductance (micromhos at 25°C)	pH	Water temperature (°C)	Geology
128	Shaver Run Trib. nr. Kline	1.14	16	0	0	---	---	---	---	---	---	Smc
123	Unnamed Run on N. Fk. Mt. nr. Franklin	.45	14	.024	.034	.1	1.9	8.5	<50	6.2	12.0	St
26-1-15	Spring nr. Harper Gap	---	13	0	---	---	---	---	---	---	---	Ojo
74	Lower Cove Run nr. Lost City	5.60	20	.409	.047	.1	7.1	51	118	7.0	14.3	Ojo
75	Adams Run nr. Lost City	4.09	20	.481	.076	.1	2.6	119	248	8.0	16.0	Om
75-A	Lower Cove Run nr. Lost City	9.69	20	.890	.060	---	3.9	85	192	7.5	15.0	Om
76	Upper Cove Run at Basore	5.44	20	.411	.049	.1	5.8	119	255	8.0	16.8	Om
77	Trout Run nr. Wardensville	14.01	21	1.38	.064	.1	3.9	34	96	7.0	11.8	Om
25-4-1	Spring nr. Basore	---	20	.194	---	.1	4.5	153	330	8.0	10.8	Om
20-2-49	Porterfield Blue Sulfur Spring at Bedington	---	15	.002	---	.1	255.0	357	1450	7.5	13.0	Om
176	Mill Cr. Trib. at Gerrardstown	1.16	16	0	0	.1	7.7	102	235	7.5	8.5	Om
186	Three Run nr. Tarico Heights	2.07	15	0	0	---	13.5	204	422	7.0	7.3	Om
187	Goose Creek nr. Inwood	1.87	15	0	0	.1	12.2	187	367	7.0	9.0	Om
114	Dry Run Trib. nr. Cherry Grove	.88	15	.030	.022	.1	7.1	153	320	7.8	13.0	Om
115	Dry Run Trib. nr. Cherry Grove	.40	15	0	0	---	---	---	---	---	---	Om
116	Dry Run Trib. nr. Cherry Grove	.96	15	.030	.020	.1	1.9	180	395	8.0	11.0	Om
117	Pike Gap Run at Circleville	.50	14	.003	.004	.1	12.2	230	465	8.0	13.0	Om
118	Teter Run nr. Circleville	2.54	14	.137	.035	.1	4.5	212	415	8.0	13.0	Om
119	Nelson Run Trib. nr. Judy	.40	14	.001	.002	.1	6.4	238	445	7.0	14.0	Om
122	North Fork Trib. nr. Harper Gap	3.20	13	.022	.004	.1	5.8	154	410	8.0	22.0	Om
20-2-50	Porterfield Limestone Spring	---	15	.109	---	.1	20.0	323	620	8.0	14.0	Otbr
136	Opequon Cr. Trib. nr. Leetown	.51	17	0	0	---	---	---	---	---	---	Otbr
120	Mill Creek nr. Riverton	5.12	14	.210	.027	.1	10.9	135	330	7.8	14.0	Otbr
162	Opequon Cr. Trib. nr. Greensburg	1.97	15	0	0	---	---	---	---	---	---	Ob
184	Potomac R. Trib. nr. Spring Mills	.91	15	0	0	---	---	---	---	---	---	Ob
20-6-52	LeFerve Spring nr. Bunker Hill	---	15	1.50	---	.1	12.2	923	590	7.0	11.3	Ob
137	Turkey Run Trib. nr. Middleway	4.21	17	0	0	---	---	---	---	---	---	Ob
138	Bullskin Run nr. Wheatland	5.45	17	1.24	.150	.1	8.4	239	455	8.0	10.1	Ob
140	Evitts Run nr. Charles Town	3.40	17	.140	.027	.1	9.0	205	400	8.0	11.2	Ob
145	Rockymarsh Run Trib. nr. Shepardstown	3.87	16	.125	.021	.1	11.6	273	515	8.0	12.7	Ob
146	Rockymarsh Run nr. Morgan Grove	3.52	16	0	0	---	---	---	---	---	---	Ob
21-3-23	Engle Spring nr. Charles Town	---	17	1.35	---	.1	6.4	256	452	7.0	12.1	Ob
178	Mill Creek Trib. nr. Gerrardstown	1.76	16	.338	.123	.1	11.0	325	570	8.0	8.8	Ec
183	Middle Creek Trib. nr. Arden	.51	16	0	0	---	---	---	---	---	---	Ec
147	Potomac R. Trib. nr. Scrabble	.62	16	0	0	---	---	---	---	---	---	Ec
148	Rockymarsh Run Trib. nr. Scrabble	1.08	16	1.23	.740	.1	9.3	239	465	8.0	14.0	Ec
21-1-44	Spring at Shepardstown	---	16	.005	---	.1	39.9	376	775	7.0	12.0	Ec
150	Potomac R. Trib. nr. Shepardstown	.51	16	0	0	---	---	---	---	---	---	Ec
151	Rattlesnake Run nr. Shepardstown	3.17	16	.053	.011	.3	10.3	256	465	8.0	17.0	Ec
177	Mill Creek Trib. nr. Gerrardstown	1.12	16	.011	.006	.1	11.0	171	400	7.0	8.9	Ec
179	Middle Creek Trib. nr. Gerrardstown	.69	16	0	0	---	---	---	---	---	---	Ec
180	Middle Creek Trib. nr. Arden	.42	16	0	0	---	---	---	---	---	---	Ec
181	Evans Run nr. Arden	.63	16	.011	.011	.1	21.3	341	640	7.5	11.7	Ec
182	Tuscarora Creek Trib. at Nollville	1.08	16	0	0	---	---	---	---	---	---	Ec
153	Long Marsh Run Trib. nr. Franklintown	3.20	17	1.28	.260	.1	9.3	256	472	8.0	10.8	Ec
154	Elk Branch Trib. nr. Charlestown	.88	16	0	0	---	---	---	---	---	---	Ec
155	Rattlesnake Run Trib. nr. Shepardstown	1.03	16	0	0	---	---	---	---	---	---	Ec
156	Elks Run Trib. nr. Harpers Ferry	.67	16	.008	.008	1.0	12.2	359	625	8.0	14.6	Ewy
157	Rocky Branch nr. Myerstown	.69	16	Trace	---	.1	3.9	17	45	5.5	13.2	Eh
158	Hog Run nr. Myerstown	1.68	16	0	0	---	---	---	---	---	---	Eh
159	Furnace Run nr. Mountain Mission	5.62	16	.361	.042	.3	6.4	51	105	7.0	14.2	Eh
160	Forge Run nr. Mountain Mission	1.42	16	.003	.001	.2	9.0	68	160	7.5	13.5	Eh
161	Shenandoah R. Trib. nr. Silver Grove	.85	16	.018	.136	.2	13.5	102	225	8.0	14.3	Eh
94-A	Lunice Creek nr. Petersburg 3/	64.1	15	3.48	.035	.1	4.5	154	305	7.8	10.6	---
96-A	Mill Creek nr. Petersburg 3/	93.9	14	6.28	.043	0	7.1	171	300	7.0	12.8	---
95-B	Robinson Run nr. Cabins	3.43	15	.70	.130	.1	12.2	205	420	6.5	12.6	---
52-A	Cacapon R. at Yellow Spring 3/	306.0	16	36.2	.122	.2	10.9	86	275	7.8	14.5	---
45-A	North River at North River Mills 3/	183	17	3.61	.013	.3	10.3	68	160	7.0	12.0	---
46-A	Little Cacapon R. at Higginsville 3/	67.8	14	1.35	.013	.1	11.6	51	135	6.5	16.0	---
162-A	S. Fk. S. Br. Trib. nr. Sugar Grove	.92	15	.232	.162	.1	3.9	180	370	8.5	10.0	---
217-A	Sleepy Creek nr. Berkeley Springs 3/	133	14	.98	.005	.2	5.1	34	89	7.0	15.0	---

1/ Concentration of chloride is within one milligram per liter of value shown.
2/ Total hardness concentration is no greater than value shown and is within 17 milligrams per liter of value shown.
3/ Low-flow partial record station.

Pc - Conemaugh Group
Pa - Allegheny Formation
Mmc - Mauch Chunk Group
Mg - Greenbrier Group
Mp - Pocono Group
Dhs - Hampshire Formation
Dch - Chemung Group
Db - Brallier Formation
Dmt - Mahantango Formation
Dmn - Onesquethaw Group
Do - Oriskany Sandstone

Dhl - Helderberg Group
Stw - Tonoloway, Wills Creek, and Williamsport Formations
Smc - McKenzie Formation and Clinton Group
St - Tuscarora Sandstone
Ojo - Juniata and Oswego Formations
Om - Martinsburg Formation
Otbr - Trenton and Black River Groups
Ob - Beekmantown Group
Ec - Conococheague Formation
Ewy - Waynesboro Formation
Eh - Harpers Formation

Table 6 ,— Selected data from streamflow records

ion er	Stream and location of gage (downstream order)	Drainage area in square miles	Zero of gage elevation in ft above msl	~~U.S.G.S.~~ period of record (water years)	Flood data			Minimum flow		Average discharge (cfs)
					Maximum discharge (cfs)	Gage height in ft above zero of gage	Calendar year of occurrence	Minimum daily discharge (cfs)	Calendar year of occurrence	
58	No. Br. Potomac R. at Steyer, Md.	73.0	2,276.01	1956-69	6,240 (b	9.13 13.0	1963 1954)c	3.1	1965	159
52	Stony R. nr. Mount Storm *	48.8	2,554.54	1961-69	3,120	8.41	1963	1.9	1968	83.1
53	Abram Cr. at Oakmont	47.3	1,840a	1956-69	2,120 (3,830	7.78 9.82	1963 1955)c	0.2	1959,64	59.6
55	No. Br. Potomac R. at Kitzmiller, Md. *	225	1,572.26	1949-69	33,400	13.73	1954	4.6	1953	418
358	No. Br. Potomac R. at Barnum *	266	1,151.93	1966-69	12,200	9.70	1967	10	1968	—
360	No. Br. Potomac R. at Bloomington, Md. *	287	951.98	1924-27 1927-50	22,500 (29,000	14.85 17.0	1936,37 1924)c	5.4	1932	492
985	No. Br. Potomac R. at Luka, Md. *	404	946.25	1899-1905 1949-69	39,400	17.15	1954	6	1904	670
995	New Creek nr. Keyser	45.7	870a	1930-31 1947-63e	3,110	7.40	1955	0.4	1959	44.1
000	No. Br. Potomac R. at Pinto, Md. *	596	648.23	1938-69	37,000 (55,000	23.23 24	1954 1924)c	35	1943	845
030	No. Br. Potomac R. nr Cumberland, Md. *	875	585.22	1929-69	88,200	29.1	1936	38	1932	1,188
045	Patterson Cr. nr. Headsville	219	624.90	1938-69	16,000	12.20	1955	1.5	1965	156
050	Patterson Cr. at Alaska	249	580a	1930-31	3,850	8.20	1931	0.4	1930	—
055	So. Br. Potomac R. at Franklin	182	1,692.5	1940-69	15,000	11.40	1949	14	1966	160
060	No. Fk. So. Br. Potomac R. at Cabins	314	1,050.13	1940-61e	50,000	18.0	1949	5.0	1953	384
065	So. Br. Potomac R. at Petersburg	642	962.00	1928-69	62,000	22.83	1949	43	1959,66	672
070	Big Spring at Masonville	—	1,180a	1945-58 1968-69	600	2.68	1949	4.9	1948	13.0
075	So.Fk.So.Br. Potomac R. at Brandywine	102	1,556.35	1943-69	41,200	14.6	1949	1.3	1965	92.0
080	So.Fk.So.Br. Potomac R. nr. Moorefield	283	861.51	1928-35 1938-69	39,000	16.1	1949	4.4	1966	204
085	So. Br. Potomac R. nr. Springfield	1,471	562.02	(1894-96) (1899-02) (1903-06) 1928-69	143,000	34.2	1936	52	1966	1,226
98	Little Cacapon R. nr. Levels	108	540a	1966-69	5,510	10.24	1967	0.01	1968	—
100	Potomac R. at Paw Paw *	3,109	487.88	1938-66	111,000 (240,000	38.36 54.0	1942 1936)c	172	1966	3,057
105	Cacapon R. at Yellow Spring	306	858.51	1939-51	36,700	22.22	1942	19	1944	256
110	Cacapon R. at Capon Bridge	367	800a	1930-32	46,000	b	1936d	17	1932	—
115	Cacapon R. nr. Great Cacapon	677	456.78	1922-69	87,600	30.1	1936	26	1966	549
30	Potomac R. at Hancock, Md. *	4,073	383.46	1932-69	340,000	47.6	1936	205	1966	3,871
40	Back Cr. nr. Jones Spring	243	416.42	1928-31 1938-69	22,400	25.17	1942	1.1	1930	183

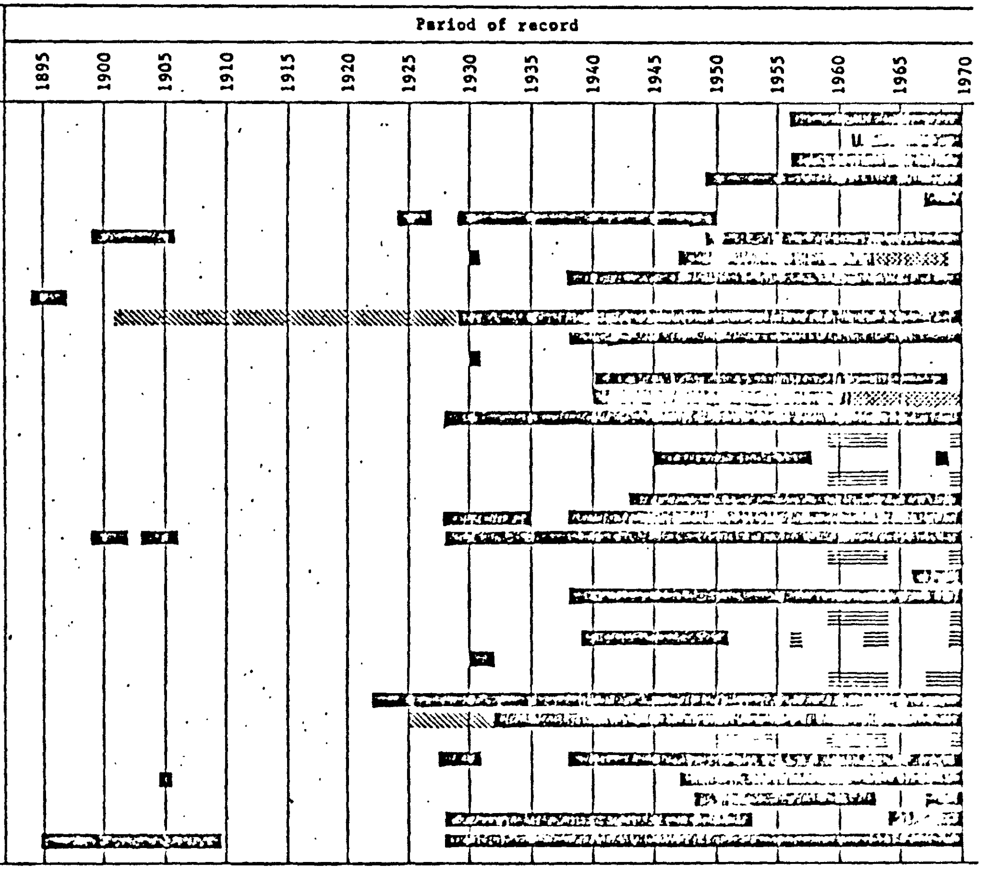
Table 6.--Selected data from streamflow records--Continued

Stream and location of gage (downstream order)	Drainage area in square miles	Zero of gage elevation in ft above msl	~~U.S.G.S.~~ period of record (water years)	Flood data			Minimum flow		Average discharge (cfs)
				Maximum discharge (cfs)	Gage height in ft above zero of gage	Calendar year of occurrence	Minimum daily discharge (cfs)	Calendar year of occurrence	
Opequon Cr. nr. Martinsburg	272	354.89	1905-06 1947-69	9,100	14.12	1950	26	1947,66	193
Tuscarora Cr. above Martinsburg	11.3	450a	1949-63 1968-69	234	5.01	1960	0.3	1954	9.35
Potomac R. at Shepherdstown *	5,936	281	1928-53 1964-69	335,000	42.1	1936	185	1966	5,575
Shenandoah R. at Millville *	3,040	293	1895-1909 1928-69	230,000	32.4	1942	194	1930	2,588

* Flow affected by regulation.
a. Altitude determined by topographic maps.
b. Not determined.
c. Occurred prior to period of record.
d. Occurred after period of record.
e. Maintained as partial record station through 1969.
f. Instantaneous discharge.

Table 7.—Availability of streamflow records.

	Station	
0	No. Br. Potomac R. at Steyer, Md.	★
2	Stony River near Mount Storm	
3	Abram Creek at Oakmont	
5	No. Br. Potomac R. at Kitzmiller, Md.	★
8	No. Br. Potomac R. at Barnum, Md.	★
0	No. Br. Potomac R. at Bloomington, Md.	★
5	No. Br. Potomac R. at Luke, Md.	★
5	New Creek near Keyser	
0	No. Br. Potomac R. at Pinto, Md.	★
5	No. Br. Potomac R. at Cumberland, Md.	★
0	No. Br. Potomac R. near Cumberland, Md.	★
5	Patterson Creek near Headsville	
0	Patterson Creek at Alaska	
55	So. Br. Potomac R. at Franklin	
50	No. Fk. So. Br. Potomac R. at Cabins	
65	So. Br. Potomac R. near Petersburg	
67	Lunice Creek near Petersburg	
70	Big Spring at Masonville	
72	Mill Creek near Petersburg	
75	So. Fk. So. Br. Potomac R. at Brandywine	
80	So. Fk. So. Br. Potomac R. near Moorefield	
85	So. Br. Potomac R. near Springfield	
98	Little Cacapon River at Higginsville	
98	Little Cacapon River near Levels	
00	Potomac River at Paw Paw	★
02	Lost River at McCauley near Baker	
05	Cacapon River at Yellow Spring	
10	Cacapon River at Capon Bridge	
12	North River at North River Mills	
15	Cacapon River near Great Cacapon	
30	Potomac River at Hancock, Md.	★
34	Sleepy Creek near Berkeley Springs	
40	Back Creek near Jones Spring	
65	Opequon Creek near Martinsburg	
70	Tuscarora Creek above Martinsburg	
80	Potomac River at Sheperdstown	★
65	Shenandoah River at Millville	



▬ Discharge records.
▩ Stage and annual maximum discharge.
▧ Records at stage in reports of U. S. Weather Bureau.
☰ One or more low-flow measurements made during year.

★ Stream-gaging station operated by U. S. Geological Survey - Maryland District.

Table 8 .—Mean monthly discharge at stream-gaging stations

Station Number	Station	Mean monthly discharge, in cubic feet per second											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
015953	Abram Creek at Oakmont	79.0	101	191	144	84.2	35.2	13.3	9.51	6.67	15.8	21.4	48.2
015995	New Creek at Keyser	52.4	81.6	126	92.5	57.8	36.8	12.2	14.4	5.65	10.4	12.4	35.8
016045	Patterson Creek near Headsville	187	304	444	299	197	107	45.2	51.8	40.6	70.6	48.6	130
016055	So. Br. Potomac R. at Franklin	189	252	396	280	219	126	72.9	67.2	64.7	66.6	81.9	148
016060	No Fk So Br Potomac R at Cabins	487	705	839	733	531	281	129	156	99.2	120	169	382
016065	So Br Potomac R near Petersburg	848	1,100	1,590	1,270	936	513	284.	269.	217	273	333	572
016075	SoFkSoBr Potomac R at Brandywine	110	147	237	156	121	69.0	28.8	26.8	38.1	46.4	54.3	88.3
016080	SoFkSoBr Potomac R nr Moorefield	216	312	474	398	307	157	79.8	98.4	71.6	109	110	166
016085	So Br Potomac R nr Springfield	1,450	1,920	2,970	2,300	1,710	1,010	520	518	374	534	584	991
016105	Cacapon River at Yellow Spring	268	381	439	426	369	229	105	123	111	198	138	300
016115	Cacapon River nr Great Cacapon	570	847	1,300	1,130	860	393	172	256	170	301	286	410
016140	Back Creek nr Jones Springs	208	328	461	338	221	121	51.4	67.4	53.9	100	110	166
016165	Opequon Creek nr Martinsburg	226	307	406	327	234	158	108	118	93.7	88.7	116	177
016170	Tuscarora Cr above Martinsburg	9.95	13.8	19.3	17.9	13.0	9.16	6.68	5.55	4.75	3.96	5.29	7.98
016365	Shenandoah River at Millville	2,910	3,700	4,940	4,260	3,240	2,280	1,440	1,750	1,280	1,880	1,510	2,260

Table 9.--Magnitude and frequency of annual low flow at stream gaging stations.

(Annual minimum flow for indicated recurrence interval and indicated period of consecutive days are adjusted to period 1930 to 1967 on basis of long-term streamflow records).

Station Number	Stream-gaging station	Period (Consecutive days)	Lowest average flow, in cubic feet per second, for indicated recurrence interval, in years.						
			1.04	1.25	2	5	10	20	50
015953	Abram Creek at Oakmont	7	8.2	4.8	2.4	0.84	0.35	0.20	0.15
		30	12	6.7	3.4	1.4	.82	.50	.32
		60	22	10	4.9	2.2	1.4	.86	.50
		120	37	19	9.6	4.9	3.0	1.7	.70
		183	50	31	18	8.8	5.1	2.8	1.1
015995	New Creek near Keyser	7	4.9	3.1	2.0	1.2	.90	.70	.50
		30	6.4	4.0	2.5	1.6	1.3	1.0	.77
		60	11	5.7	3.3	2.0	1.6	1.3	1.0
		120	18	10	5.8	3.3	2.3	1.8	1.2
		183	27	16	10	5.2	3.5	2.4	1.5
016045	Patterson Creek near Headsville	7	16	9.7	6.0	3.4	2.4	1.8	1.3
		30	23	14	8.3	5.3	4.0	2.8	1.7
		60	35	19	11	7.0	5.2	3.8	2.4
		120	82	38	19	12	9.1	6.0	3.0
		183	130	68	35	18	13	8.8	4.5
016055	South Branch Potomac River at Franklin	7	44	34	27	21	18	16	13
		30	51	39	30	24	21	18	15
		60	83	48	34	28	24	20	16
		120	120	69	46	33	28	24	18
		183	150	96	64	42	34	28	21
016060	North Fork South Branch Potomac River at Cabins	7	47	27	15	7.2	5.0	4.0	3.5
		30	73	38	19	10	8.2	6.4	4.5
		60	120	56	27	15	11	8.4	5.5
		120	230	120	62	31	20	13	7.0
		183	320	200	110	57	36	22	10
016065	South Branch Potomac River near Petersburg	7	140	100	75	57	50	45	40
		30	180	120	86	64	60	54	44
		60	250	160	100	71	66	60	47
		120	430	250	150	100	90	73	50
		183	580	360	230	150	120	89	58
016075	South Fork South Branch Potomac River at Brandywine	7	14	8.0	4.8	2.9	2.3	1.8	1.5
		30	21	11	6.4	4.1	3.3	2.8	2.4
		60	34	15	7.9	5.1	4.2	3.6	3.1
		120	65	31	15	8.6	6.5	5.1	3.8
		183	90	51	27	14	10	7.5	5.4
016080	South Fork South Branch Potomac River near Moorefield	7	37	23	15	10	7.8	6.3	5.0
		30	52	30	19	13	11	9.3	8.0
		60	77	39	23	15	13	11	10
		120	130	66	37	22	18	15	12
		183	210	120	61	33	25	20	15
016085	South Branch Potomac River near Springfield	7	230	160	110	75	62	56	52
		30	300	200	130	90	82	76	63
		60	440	260	150	110	100	88	70
		120	770	430	250	160	130	110	77
		183	1,100	650	390	240	180	130	90
016105	Cacapon River near Yellow Spring	7	40	32	25	20	17	15	14
		30	52	38	29	23	20	18	17
		60	88	52	34	25	22	21	19
		120	150	80	45	35	31	26	23
		183	250	130	72	49	44	36	26
016115	Cacapon River near Great Cacapon	7	82	65	51	40	36	32	27
		30	100	77	59	46	40	36	34
		60	170	100	70	52	46	43	38
		120	270	150	92	71	64	54	44
		183	460	250	140	98	86	71	52
016140	Back Creek near Jones Spring	7	21	13	7.4	4.7	3.8	2.7	1.4
		30	34	19	10	6.3	4.9	3.8	2.8
		60	65	29	13	8.1	6.5	5.0	3.4
		120	110	56	21	14	11	7.7	4.1
		183	170	84	42	25	19	12	6.0
016165	Opequon Creek near Martinsburg	7	72	58	45	39	34	30	26
		30	84	67	52	42	37	33	29
		60	110	82	58	46	41	37	32
		120	150	110	68	58	53	46	36
		183	220	150	87	72	65	56	43
016170	Tuscarora Creek above Martinsburg	7	3.9	2.1	1.2	.64	.46	.31	.18
		30	4.7	2.7	1.5	.80	.56	.42	.30
		60	7.0	3.9	2.0	.95	.68	.52	.39
		120	9.6	5.3	2.8	1.7	1.3	.91	.53
		183	17	8.2	4.1	2.5	1.8	1.2	.84
016365	Shenandoah River at Millville	7	970	680	510	390	340	290	240
		30	1,200	780	570	430	380	340	310
		60	1,500	940	640	470	410	370	350
		120	2,100	1,300	790	580	500	430	380
		183	2,000	[illegible]	1,000	730	600	500	410

Table 10 -- Station flood - frequency relation

Station Number	Station	Flood discharge, in cubic feet per second for indicated recurrence interval in years									
		1.01	1.05	1.11	1.25	2.00	5	10	25	50	100
015950	No. Br. Potomac R. at Steyer, Md.	---	---	---	---	3,590	4,820	5,650	6,700	---	---
015953	Abram Creek at Oakmont	530	714	838	1,020	1,490	2,200	2,700	3,360	---	---
015955	No. Br. Potomac R. at Kitzmiller, Md. *	---	---	---	---	6,380	9,920	13,800	21,100	---	---
015995	New Creek near Keyser	208	370	492	681	1,200	1,960	2,470	3,080	---	---
016045	Patterson Creek near Headsville	737	1,420	1,950	2,800	5,190	8,760	11,100	14,000	16,000	---
016055	So. Br. Potomac R. at Franklin	1,030	1,570	1,960	2,550	4,200	6,850	8,810	11,500	13,600	---
016060	No. Fk. So. Br. Potomac R. at Cabins	2,990	3,660	4,170	5,010	7,700	13,300	18,500	27,400	36,000	---
016065	So. Br. Potomac R. near Petersburg	4,180	5,380	6,270	7,690	12,100	20,800	28,600	41,400	53,400	---
016075	So. Fk. So. Br. Potomac R. at Brandywine	1,210	1,500	1,750	2,180	3,730	7,640	12,000	20,600	30,200	---
016080	So. Fk. So. Br. Potomac R. near Moorefield	1,840	2,460	2,940	3,720	6,250	11,500	16,500	25,000	33,200	---
016085	So. Br. Potomac R. near Springfield	6,060	8,330	10,100	12,900	22,100	41,100	59,000	89,000	118,000	---
016105	Cacapon River at Yellow Spring	1,010	1,840	2,550	3,790	8,160	17,700	26,700	41,600	---	---
016115	Cacapon River near Great Cacapon	2,440	3,830	4,930	6,770	12,800	25,300	36,800	55,700	73,300	---
016140	Back Creek near Jones Springs	2,050	2,520	2,870	3,440	5,210	8,710	11,900	17,100	22,000	---
016165	Opeqon Creek near Martinsburg	1,630	1,840	1,990	2,250	3,050	4,600	5,960	8,140	---	---
016170	Tuscarora Creek above Martinsburg	42	65	81	102	151	205	233	262	---	---
016365	Shenandoah River at Millville *	7,630	11,000	13,600	17,800	31,400	59,400	85,200	128,000	168,000	217,000

* Affected by regulation

Table 11 .--Magnitude and frequency of annual high flow at stream-gaging stations

Station Number	Stream-gaging station	Period (Consecutive days)	Highest average flow, in cubic feet per second, for indicated recurrence interval, in years.						
			1.05	1.25	2	5	10	25	50
015950	North Branch Potomac River at Steyer, Md.	1	---	---	2,320	3,210	3,810	---	---
		3	---	---	1,570	2,090	2,440	---	---
		7	---	---	1,130	1,410	1,560	---	---
015953	Abram Creek at Oakmont	1	353	637	985	1,300	1,420	1,520	---
		3	286	485	716	912	988	1,050	---
		7	209	349	515	664	724	774	---
		15	164	258	371	481	530	575	---
		30	125	192	266	329	353	373	---
		60	106	148	194	237	257	275	---
015955	North Branch Potomac River at Kitzmiller, Md. *	1	---	---	4,530	6,380	7,970	10,500	---
		3	---	---	3,390	4,410	5,070	5,870	---
		7	---	---	2,530	3,140	3,470	3,820	---
015995	New Creek near Keyser	1	250	433	710	1,080	1,300	1,560	---
		3	183	315	499	710	822	937	---
		7	120	205	319	443	504	563	---
		15	87	145	222	307	351	395	---
		30	71	110	161	216	245	275	---
		60	57	93	135	171	185	196	---
016045	Patterson Creek near Headsville	1	1,010	1,870	3,260	5,240	6,510	8,030	9,100
		3	716	1,300	2,150	3,160	3,700	4,260	4,610
		7	461	826	1,310	1,830	2,070	2,300	2,420
		15	315	551	873	1,230	1,420	1,600	1,710
		30	244	405	618	849	966	1,080	1,150
		60	182	314	475	626	690	743	769
016055	South Branch Potomac River at Franklin	1	941	1,500	2,370	3,640	4,500	5,610	6,430
		3	800	1,120	1,590	2,250	2,690	3,260	3,680
		7	547	730	1,010	1,440	1,740	2,160	2,490
		15	395	516	703	991	1,200	1,490	1,720
		30	297	390	518	687	797	933	1,030
		60	231	311	404	502	553	605	638
016060	North Fork South Branch Potomac River at Cabins	1	2,740	3,720	5,160	7,240	8,670	10,500	---
		3	1,940	2,560	3,440	4,660	5,470	6,510	---
		7	1,270	1,710	2,320	3,150	3,690	4,370	---
		15	993	1,220	1,570	2,090	2,450	2,940	---
		30	791	955	1,190	1,500	1,710	1,970	---
		60	612	773	969	1,190	1,320	1,460	---
016065	South Branch Potomac River near Petersburg	1	4,000	5,660	8,440	13,100	16,700	22,000	26,400
		3	3,110	4,190	5,920	8,640	10,700	13,500	15,800
		7	2,150	2,900	4,040	5,730	6,930	8,530	9,780
		15	1,550	2,070	2,860	4,010	4,830	5,910	6,760
		30	1,290	1,650	2,160	2,850	3,300	3,870	4,300
		60	999	1,300	1,690	2,160	2,450	2,780	3,010
016075	South Fork South Branch Potomac River at Brandywine	1	833	1,270	2,010	3,270	4,260	5,700	6,900
		3	658	850	1,190	1,800	2,310	3,100	3,790
		7	439	534	698	981	1,210	1,550	1,840
		15	279	351	464	640	771	954	1,100
		30	194	244	315	415	483	572	639
		60	146	186	239	304	343	389	422
016080	South Fork South Branch Potomac River near Moorefield	1	1,720	2,450	3,770	6,190	8,250	11,400	14,300
		3	1,290	1,820	2,630	3,810	4,630	5,710	6,540
		7	847	1,160	1,620	2,260	2,690	3,240	3,660
		15	533	746	1,050	1,470	1,740	2,080	2,330
		30	415	554	731	940	1,060	1,200	1,290
		60	308	414	544	690	769	856	912
016085	South Branch Potomac River near Springfield	1	7,450	10,100	15,500	26,700	37,500	56,000	74,300
		3	5,740	7,680	11,300	18,100	24,000	33,500	42,200
		7	3,960	5,360	7,670	11,400	14,300	18,500	22,000
		15	2,700	3,790	5,440	7,890	9,610	11,900	13,700
		30	2,360	2,980	3,920	5,340	6,360	7,740	8,850
		60	1,810	2,330	3,060	4,050	4,710	5,550	6,180
016105	Cacapon River at Yellow Spring	1	1,350	2,340	4,290	8,130	11,500	16,800	---
		3	1,090	1,610	2,600	4,550	6,300	9,130	---
		7	659	1,010	1,630	2,750	3,670	5,040	---
		15	442	686	1,070	1,660	2,080	2,630	---
		30	326	517	777	1,080	1,250	1,440	---
		60	263	405	574	737	812	881	---

Table 11 ,--Magnitude and frequency of annual high flow at stream-gaging stations--Continued

Station Number	Stream-gaging station	Period (Consecutive days)	Highest average flow, in cubic feet per second, for indicated recurrence interval, in years.						
			1.05	1.25	2	5	10	25	50
016115	Cacapon River near Great Cacapon	1	3,220	5,300	9,520	18,300	26,500	40,200	53,300
		3	2,450	3,820	6,350	11,000	15,000	21,200	26,600
		7	1,660	2,560	4,120	6,740	8,800	11,700	14,200
		15	1,210	1,810	2,760	4,240	5,320	6,770	7,930
		30	950	1,360	1,950	2,780	3,330	4,030	4,550
		60	726	1,020	1,440	2,010	2,380	2,860	3,210
016140	Back Creek near Jones Springs	1	1,870	2,440	3,450	5,270	6,790	9,120	11,200
		3	1,280	1,630	2,260	3,380	4,310	5,720	6,960
		7	770	1,010	1,390	2,010	2,470	3,130	3,670
		15	499	674	930	1,300	1,550	1,870	2,120
		30	348	487	669	884	1,010	1,150	1,240
		60	258	366	501	655	740	832	891
016165	Opequon Creek near Martinsburg	1	1,350	1,630	2,180	3,250	4,190	5,710	---
		3	917	1,130	1,510	2,190	2,750	3,610	---
		7	562	723	985	1,410	1,740	2,200	---
		15	350	502	719	1,010	1,200	1,440	---
		30	281	401	556	739	844	960	---
		60	200	303	437	590	674	762	---
016170	Tuscarora Creek above Martinsburg	1	29	45	68	99	118	142	---
		3	21	34	53	74	86	99	---
		7	15	25	40	55	63	70	---
		15	11	20	32	44	49	54	---
		30	10	18	27	35	39	42	---
		60	8	14	22	30	33	36	---
016365	Shenandoah River at Millville *	1	9,900	15,900	27,400	49,800	69,400	101,000	129,000
		3	7,540	12,100	20,500	36,200	49,500	70,000	88,100
		7	5,730	8,670	13,800	22,700	29,800	40,400	49,300
		15	4,260	6,310	9,700	15,200	19,400	25,400	30,200
		30	3,390	4,780	6,990	10,400	12,900	16,300	19,100
		60	2,770	3,820	5,390	7,660	9,250	11,300	12,900

* Flow influenced by regulation

Table 12.--Draft-storage-frequency relations at stream-gaging stations

Station Number	Stream-gaging station	Percent Probability of Failure	Allowable draft, in cubic feet per second, for indicated storage, in cfs-days per square mile.									
			5	10	15	20	25	30	35	40	50	60
015950	North Branch Potomac River at Steyer, Md.	20	14	19	24	27	30	33	35	38	42	47
		10	13	17	20	23	25	28	30	32	36	40
		5	11	14	17	19	21	24	26	28	32	36
015953	Abram Creek at Oakmont	20	4.9	7.2	9.3	11	13	15	16	18	21	23
		10	3.8	5.5	7.3	8.8	10	12	13	14	17	19
		5	3.4	4.4	5.5	6.5	7.6	8.6	9.6	10	12	14
015995	New Creek near Keyser	20	5.1	6.9	8.5	9.9	11	13	14	15	17	19
		10	4.1	5.7	7.4	8.7	9.9	11	12	13	---	---
		5	3.5	5.0	6.2	7.1	8.2	9.0	9.7	---	---	---
016045	Patterson Creek near Headsville	20	19	26	35	41	47	53	58	63	---	---
		10	17	24	31	36	42	---	---	---	---	---
		5	15	22	27	32	37	---	---	---	---	---
		2	14	19	23	27	32	---	---	---	---	---
016055	South Branch Potomac River at Franklin	20	38	46	53	59	64	68	73	77	84	---
		10	34	40	45	50	56	60	65	70	78	---
		5	32	39	44	48	52	55	---	---	---	---
		2	30	36	41	46	50	53	---	---	---	---
016060	North Fork South Branch Potomac River at Cabins	20	42	55	67	78	88	99	109	118	137	155
		10	35	48	60	71	81	91	101	109	127	144
		5	30	40	50	59	68	77	85	93	109	124
016065	South Branch Potomac River near Petersburg	20	120	154	180	203	224	245	264	282	313	---
		10	109	133	154	175	197	218	237	256	294	---
		5	101	124	141	155	170	184	197	211	238	---
		2	69	88	105	122	139	155	170	184	213	---
016075	South Fork South Branch Potomac River at Brandywine	20	12	15	19	23	27	29	31	34	38	42
		10	11	14	18	21	24	27	29	31	35	---
		5	10	13	17	20	22	24	26	28	---	---
		2	9.5	12	16	18	20	22	24	26	---	---
016080	South Fork South Branch Potomac River near Moorefield	20	35	47	56	64	72	79	85	---	---	---
		10	30	40	49	57	65	72	---	---	---	---
		5	26	35	42	49	56	---	---	---	---	---
		2	22	30	37	43	---	---	---	---	---	---
016085	South Branch Potomac River near Springfield	20	211	273	325	372	416	459	498	536	614	686
		10	180	242	292	341	387	428	467	---	---	---
		5	156	206	252	292	331	367	403	---	---	---
		2	125	170	211	248	287	321	---	---	---	---
016105	Cacapon River at Yellow Spring	20	49	61	72	80	88	96	104	111	124	---
		10	45	57	67	76	84	91	---	---	---	---
016115	Cacapon River near Great Cacapon	20	97	125	149	170	192	209	228	---	---	---
		10	90	115	136	154	173	190	---	---	---	---
		5	78	100	119	136	153	---	---	---	---	---
		2	70	88	103	116	---	---	---	---	---	---
016140	Back Creek near Jones Springs	20	24	33	42	50	57	63	70	76	86	---
		10	21	30	38	46	53	59	65	---	---	---
		5	17	26	33	40	47	52	57	---	---	---
		2	11	18	24	28	32	36	---	---	---	---
016165	Opequon Creek near Martinsburg	20	65	78	88	98	106	---	---	---	---	---
		10	56	69	80	88	96	---	---	---	---	---
		5	49	58	67	74	81	---	---	---	---	---
016170	Tuscarora Creek above Martinsburg	20	2.5	3.0	3.3	3.6	3.9	---	---	---	---	---
		10	2.0	2.4	2.8	3.1	3.4	---	---	---	---	---
		5	1.3	1.7	2.0	2.3	2.5	---	---	---	---	---

Note: One cfs-day equals 86,400 cubic feet or 1.98 acre-feet.

Table 13 .—Flow duration at stream - gaging stations

Station Number	Station	Variability index	Discharge, in cubic feet per second per square mile, that was equaled or exceeded for indicated per cent of time												
			1	2	5	10	20	30	50	70	80	90	95	98	99
15950	No. Br. Potomac R. at Steyer, Md.	0.58	17.8	13.0	8.22	5.34	3.01	2.19	1.07	0.479	0.301	0.164	0.107	0.070	0.059
15953	Abram Creek at Oakmont	.59	10.7	7.88	4.98	3.26	1.93	1.26	.588	.185	.096	.046	.026	.015	.010
15955	No. Br. Potomac R. at Kitzmiller, Md. *	.55	13.3	10.2	6.67	4.44	2.80	1.91	1.02	.409	.267	.164	.124	.089	.071
15995	New Creek near Keyser	.61	8.36	6.16	3.74	2.42	1.41	.902	.374	.147	.098	.064	.047	.035	.028
16045	Patterson Cr. nr. Headsville	.64	7.82	5.64	3.13	1.72	.874	.543	.239	.097	.064	.040	.028	.021	.018
16055	So. Br. Potomac R. at Franklin	.42	7.15	4.90	2.89	1.95	1.16	.814	.451	.256	.202	.164	.144	.125	.115
16060	No. Fk. So. Br. Potomac R. at Cabins	.59	9.60	7.04	4.48	2.98	1.73	1.15	.560	.256	.155	.085	.054	.035	.026
16065	So. Br. Potomac R. at Petersburg	.47	7.80	5.77	3.62	2.40	1.47	1.01	.530	.273	.197	.140	.115	.096	.087
16075	So. Fk. So. Br. Potomac R. at Brandywine	.59	8.82	6.08	3.41	2.01	1.14	.745	.343	.147	.096	.063	.046	.031	.025
16080	So. Fk. So. Br. Potomac R. nr. Moorefield	.53	7.08	4.85	2.64	1.59	.910	.620	.301	.142	.101	.071	.056	.042	.031
16085	So. Br. Potomac R. nr. Springfield	.50	6.53	4.76	2.92	1.90	1.13	.762	.401	.204	.143	.095	.073	.057	.050
16105	Cacapon R. at Yellow Spring	.48	6.53	4.69	2.90	1.88	1.12	.782	.406	.198	.153	.112	.093	.082	.077
16115	Cacapon R. nr. Great Cacapon	.51	7.06	5.00	2.97	1.85	1.04	.676	.323	.162	.125	.094	.078	.065	.059
16140	Back Cr. nr. Jones Springs	.62	7.63	5.33	3.03	1.80	.943	.594	.258	.108	.072	.044	.031	.022	.017
16165	Opequon Cr. nr. Martinsburg	.36	5.00	3.46	2.13	1.49	.975	.699	.423	.280	.227	.184	.156	.130	.118
16170	Tuscarora Cr. nr. Martinsburg	.42	4.60	3.54	2.57	2.04	1.46	1.04	.513	.305	.239	.177	.133	.110	.087
16365	Shenandoah R. at Millville *	.37	5.81	4.19	2.61	1.78	1.12	.785	.502	.327	.257	.196	.160	.134	.120

* Affected by regulation

Table 14.—Selected data on U. S. Soil Conservation Service floodwater retarding structures - Cont.

SCS Site Number (see p1,2)	Stream	Latitude	Longitude	Drainage area (square miles)	Surface area(a) (acres)	Temporary floodwater storage capacity (acre feet)
	South Fork Watershed					
1	Shooks Run	38° 56' 20"	78° 59' 54"	6.42	56	1,780
2	Stump Run	38° 59' 33"	79° 00' 35"	4.16	31	1,110
4	Rohrbaugh Run	38° 50' 04"	79° 03' 59"	9.05	47	2,385
5	Rodabaugh Run	38° 48' 33"	79° 05' 33"	2.34	17	498
6	Wilson Run	38° 47' 07"	79° 16' 10"	4.73	29	1,009
9	Dice Run	38° 40' 37"	79° 10' 03"	2.68	23	571
10	Stony Run	38° 39' 30"	79° 11' 21"	2.68	23	571
11	Road Run	38° 38' 56"	79° 12' 00"	2.92	26	627
12	Detimer Run	38° 38' 25"	79° 13' 14"	2.34	27	503
13	Hawes Run	38° 36' 06"	79° 12' 24"	3.69	32	803
14	Broad Run	38° 36' 56"	79° 14' 39"	5.55	56	1,168
15	Miller Run	38° 35' 30"	79° 14' 52"	5.58	39	1,189
16	George Run	38° 35' 08"	79° 15' 13"	3.78	49	805
17 *	Lick Run	38° 33' 32"	79° 16' 40"	17.27	138	4,605
18	Stony Run	38° 29' 44"	79° 15' 05"	4.39	25	936
19 *	Brushy Run FK	38° 28' 18"	79° 19' 35"	15.15	128	4,041
20 *	So. Fk. So. Branch Potomac R.	38° 26' 25"	79° 21' 43"	10.81	104	2,306
21	Little Rough Run	38° 42' 20"	79° 09' 06"	2.58	18	550
27	Dry River Hollow	38° 36' 23"	79° 12' 10"	2.20	22	481
32	Tributary to South Fork	38° 28' 55"	79° 19' 02"	0.38	8	82
33 *	Tributary to South Fork	38° 28' 27"	79° 19' 06"	0.85	19	182
35	Tributary to South Fork	38° 27' 24"	79° 20' 44"	0.54	11	115
36	Little Stony Run	38° 29' 57"	79° 18' 57"	2.93	34	651
37	Camp Run	38° 45' 20"	79° 07' 31"	5.63	39	1,200
	Lost River Watershed					
4 *	Kimsey Run	38° 57' 26"	78° 48' 43"	32.61	d	d
10 *	Camp Branch	38° 02' 48"	78° 47' 53"	6.70	d	d
16 *	Lower Cove Run	38° 55' 29"	78° 49' 52"	27.42	d	d
23 *	Culler Run	38° 51' 08"	78° 55' 09"	9.95	d	d
27 *	Upper Cove Run	38° 50' 39"	78° 49' 46"	3.32	d	d
	Warm Spring Run Watershed					
1	Unnamed Run	39° 37' 15"	78° 13' 13"	0.14	1.9	17
2	Unnamed Run	39° 37' 02"	78° 13' 19"	0.13	2.1	16
3	Tributary to Warm Spring Run	39° 36' 22"	78° 13' 46"	0.45	6.1	71
4	Tributary to Warm Spring Run	39° 36' 35"	78° 14' 08"	0.25	4.2	46
5	Unnamed Run	39° 35' 23"	78° 14' 16"	0.31	4.8	48
6	Tributary to Warm Springs Run	39° 35' 21"	78° 13' 52"	0.16	2.9	20
7	Unnamed Run	39° 35' 36"	78° 14' 13"	0.13	1.7	14
8	Warm Spring Run	39° 34' 37"	78° 15' 23"	0.24	8.2	38
9	Tributary to Warm Spring Run	39° 36' 41"	78° 13' 01"	0.18	3.3	26

Note - Data for this table was obtained from published U. S. Soil Conservation Service watershed work plans.
* - Planned structure
a - Surface area at emergency spilling crest
b - In series with site No. 41
c - Located in Virginia
d - Data not available

Table 14.—Selected data on U. S. Soil Conservation Service floodwater retarding structures.

SCS Site Number (sec 21,2)	Stream	Latitude	Longitude	Drainage area (square miles)	Surface area(s) (acres)	Temporary floodwater storage capacity (acre feet)
	New Creek - White's Run Watershed					
1	Tributary to New Creek	39° 26' 00"	78° 59' 50"	0.35	6.4	90
4 *	Parr Spring Run	39° 24' 45"	79° 00' 25"	1.27	18.8	244
5	Tributary to New Creek	39° 23' 40"	79° 01' 05"	1.05	34.9	205
6 *	Tributary to New Creek	39° 22' 35"	79° 02' 35"	0.63	12.4	113
7	Tributary to New Creek	39° 22' 15"	79° 02' 20"	0.54	9.3	86
9	Tributary to New Creek	39° 22' 55"	79° 00' 30"	1.16	22.7	232
10	Tributary to Ash Spring Run	39° 21' 10"	79° 03' 25"	0.70	9.4	125
11 *	Tributary to New Creek	39° 20' 30"	79° 04' 40"	0.46	5.0	75
12	Tributary to New Creek	39° 17' 35"	79° 06' 50"	0.48	7.8	80
14	Linton Creek	39° 16' 20"	79° 07' 50"	5.07	67.2	844
16	Thunderhill Run	39° 26' 25"	79° 00' 25"	1.30	12.4	244
17	Ash Spring Run	39° 21' 25"	79° 03' 25"	1.70	14.3	358
	Patterson Creek Watershed					
1	Patterson Creek	39° 07' 19"	79° 05' 36"	3.06	48.5	513
2	Tributary to Patterson Creek	39° 07' 18"	79° 04' 54"	2.67	35.0	450
3	Thorn Run	39° 08' 35"	79° 04' 58"	2.69	35.1	469
4	Middle Fork	39° 10' 41"	79° 04' 37"	7.73	70.0	1,298
6	Tributary to Elklick Run	39° 12' 30"	79° 10' 00"	2.10b	16.8	309
12	Thorn Run	39° 12' 30"	79° 12' 41"	8.74	74.0	1,781
13	Rosser Run	39° 13' 02"	79° 02' 29"	6.88	23.0	1,174
14	Harness Run	39° 15' 23"	79° 00' 24"	1.55	14.9	243
15	Mikes Run	39° 17' 12"	78° 58' 21"	17.81	176.8	3,590
20	Liller Run	39° 21' 00"	78° 58' 40"	1.56	15.4	251
21 *	Mill Run	39° 20' 03"	78° 59' 38"	5.25	55.2	1,017
22	Wild Meadow Run	39° 18' 43"	78° 56' 57"	2.92	29.8	550
23 *	Elliber Run	39° 16' 43"	78° 55' 58"	2.56	25.5	467
24	Tributary to Patterson Creek	39° 19' 26"	78° 54' 51"	1.11	15.5	163
25 *	Johnson Run	39° 21' 35"	78° 54' 16"	1.12	13.9	166
26	Tributary to Patterson Creek	39° 22' 03"	78° 53' 27"	1.66	19.6	269
27 *	Tributary to Patterson Creek	39° 22' 17"	78° 52' 59"	1.14	15.7	170
28 *	Cabin Run	39° 24' 48"	78° 56' 00"	6.56	78.5	1,182
30	Tributary to Cabin Run	39° 25' 50"	78° 54' 15"	1.53	14.7	222
31 *	Tributary to Cabin Run	39° 27' 09"	78° 52' 33"	2.34	29.0	416
32 *	Pargut Run	39° 27' 22"	78° 52' 17"	3.44	35.0	606
36 *	Tributary to Patterson Creek	39° 25' 16"	78° 52' 00"	0.97	12.5	136
37 *	Tributary to Patterson Creek	39° 25' 39"	78° 52' 11"	2.96	40.3	576
38	Hollenbeck Run	39° 24' 58"	78° 50' 40"	3.40	34.7	554
41	North Fork	39° 11' 36"	79° 03' 29"	29.53	186.8	5,203
43 *	Staggs Run	39° 23' 34"	78° 54' 27"	1.93	20.1	320
44	Long Pasture Run	39° 28' 42"	78° 46' 48"	1.21	19.8	221
45	Graveyard Run	39° 29' 23"	78° 46' 24"	0.56	8.9	93
46	Painter Run	39° 28' 58"	78° 45' 34"	1.76	25.5	204
47	Tributary to Patterson Creek	39° 17' 54"	78° 56' 09"	0.69	10.2	96
48 *	Pursley Run	39° 16' 21"	78° 59' 20"	1.67	20.7	312
49	Tributary to Patterson Creek	39° 07' 49"	79° 04' 28"	2.27	34.7	310
50 *	Horseshoe Creek	39° 28' 30"	78° 49' 08"	11.03	106.2	2,024
52	Mud Run	39° 21' 04"	78° 53' 22"	0.98	16.2	162
	South Branch Potomac Sub-watershed					
6 *	Reeds Creek	38° 45' 48"	79° 19' 38"	14.55	113.0	2,577
7 *	Mill Run	38° 47' 20"	79° 15' 30"	16.14	102.4	2,536
10 *	Blackthorn Creek	38° 37' 20"	79° 20' 00"	16.67	123.0	2,786
11 *	Smith Creek	38° 37' 40"	79° 20' 05"	20.47	112.8	3,508
17 *	Whitethorn Creek	38° 30' 12"	79° 22' 17"	10.95	110.2	2,220
19 *	Strait Creek (c)	38° 26' 35"	79° 31' 50"	4.51	29.8	773
20 *	S. Branch Potomac River (c)	38° 29' 12"	79° 34' 58"	13.64	191.0	2,803
23 *	S. Branch Potomac River (c)	38° 29' 00"	79° 31' 42"	29.47	82.8	2,595
	Lunice Creek Watershed					
5 *	S. Fk. Lunice Creek	39° 04' 40"	79° 08' 30"	21.70	148.0	3,270
9	Lunice Creek	39° 06' 30"	79° 14' 15"	3.96	18.8	525
10	Saltblock Run	39° 07' 40"	79° 12' 45"	2.01	18.7	256
11	Unnamed Run	39° 08' 25"	79° 12' 20"	3.46	25.8	416
17 *	Lunice Creek	39° 06' 00"	79° 08' 35"	16.28	132.2	2,923
	North and South Mill Creek Watershed					
2 *	Long Run	39° 55' 43"	79° 06' 32"	d	d	d
3 *	Rough Run	38° 54' 05"	79° 06' 54"	d	d	d
4 *	Tributary to South Mill Creek	38° 53' 15"	79° 07' 38"	d	d	d
6 *	Wolfpen Hollow	38° 52' 23"	79° 08' 18"	d	d	d
7 *	South Mill Creek	38° 51' 26"	79° 09' 36"	d	d	d
16 *	Tributary to Johnson Run	38° 57' 58"	79° 09' 13"	d	d	d
18 *	North Mill Creek	38° 52' 45"	79° 12' 42"	d	d	d

Table 15.—Summary of time-of-travel computations

					Time-of-travel				Peak concentration			
Sample site	Distance from mouth	Discharge	Area T-C curve	Percent recovery	Leading edge	Peak	Trailing edge	Velocity of peak	Observed C_{obs}	Adjusted C_c	Relative C_r	Unit C_u
	(miles)	cfs	µg/1-hrs		hours	hours	hours	MPH	µg/1	µg/1	$\frac{\mu g/1}{lbs}$	$\frac{\mu g/1 \text{ x } cfs}{lbs}$
1*	69.0	600	---	---	0	0	0	---	---	---	---	---
2	66.2	700	63.2	84	1.6	1.8	3.3	1.56	86	102	8.61	6030
3	58.6	800	54.7	83	7.6	9.1	12.8	1.04	25	30	2.53	2020
4	54.0	850	42.6	69	10.8	13.4	18.1	1.07	14.9	22	1.86	1580
5	42.2	880	35.7	60	21.1	24.4	30.2	1.07	6.7	11	0.93	820
6	31.8	900	37.0	63	32.4	36.6	47.8	0.85	5.2	8.3	0.70	630
7	30.7	900	---	---	(33.6)	(37.8)	(49.0)	0.92	---	---	---	---
7*	30.7	900	---	---	0	0	0	---	---	---	---	---
8	27.1	1180	51.8	69	2.2	3.0	4.4	1.20	53	77	3.85	4540
9	23.4	1150	52.3	68	6.0	7.0	10.0	0.92	33	49	2.45	2820
10	13.4	1000	50.8	57	14.0	16.0	22.0	1.11	14.5	25	1.25	1250
11	0.6	985	52.5	58	25.2	30.0	40.0	0.91	8.4	14	0.70	690

* Dye injection site.

µg/1 = Micrograms per liter (or parts per billion)

Table 16.--Ranges of transmissivity and storage coefficients for Allegany and Washington Counties, Md. (Slaughter and Darling, 1962).

Hydrologic Unit	Geologic Formation	Range of Storage Coefficient	Range of Transmissivity Coefficient (ft^2/day)
10	Conemaugh	—	818-1,380
	Pottsville	—	63.0
	Allegheny		
	Mauch Chunk		
8	Pocono	.0042-.0006	129-210
	Hampshire	—	28.2-71.0
	Chemung	—	20.1-174
7	—	—	3.4-322
6,7	—	—	1,880-5,360
5	Helderberg	.002-.004	1,610-6,030
	Tonoloway		
	Tonoloway	.001-.008	1,340-1,740
	Wills Creek		
	Wills Creek		4.0-2,010
4	Clinton	—	16.8-161
	Juniata		
3	Martinsburg	—	10.1-29.5
2	Beekmantown	.0014-.145	16,100-36,200
	Conococheague		295-2,540
	Tomstown		6.0-576
1	Harpers		67
	Catoctin	.002-.004	242-590

Note-Transmissivity and storage coefficients are probably similar for the Potomac River basin in West Virginia.

(MISSING TABLE 17)

Table 18.--Ranges of field hydraulic conductivity (K) of about the top 50 feet of bedrock as determined by the U. S. Soil Conservation Service.

Hydrologic Unit	Geologic Unit	Dam Site No.	K(ft/day)	Remarks
7	Brallier Shale	Patterson # 1 Creek	0.0-0.0	
		4	0.0-3.5	
		6	0.1-6.7	
		12	0.0-2.0	
		14	0.0-6.0	
		15	0.0-5.4	
		20	0.3-2.1	
		22	0.0-1.9	
		32	0.0-17.4	In one well for interval between 0 and 10 feet permeability is 4,420 gpd/ft^2.
		38	0.0-9.9	
		41	0.0-7.2	
		46	0.1-4.3	
		S. Fk. S. Br. Potomac R.# 4	0.0-48	
		14	0.0-10.3+	
		15	0.0-19.7	
		18	---	
		21	0.0-110	
		35	0.0-16.0	
		36	---	
		Lunice #11 Creek	0.0-31.5	
	Hamilton Formation	Patterson # 2 Creek	0.0-2.39	
		26	0.0-10.3	
		52	0.0-10	Concretionary zones have slightly higher permeabilities.
		Lunice # 9 Creek	0.1-2.9	
	Marcellus Shale	Patterson #27 Creek	0.0-10.2	
		49	0.0-0.4	
		New Creek #10	0.0-1.4	
		12	0.0-1.0	
		14	0.0-13.1	
		Lunice #10 Creek	0.0-4.9	
5	Wills Creek Shale	New Creek # 9	0.0-4.9	

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Change ppm to mg/l

Table 4

Source or cause and significance of dissolved mineral constituents and properties of water

Constituent or property	Source or cause	Significance
Silica (SiO_2)	Dissolved from practically all rocks and soils.	Together with calcium and magnesium, silica forms a low-heat conducting hard glassy scale in boilers and turbines. Silica inhibits deterioration of zeolite-type water softeners and corrosion of iron pipes by soft water.
Iron (Fe)	Dissolved from practically all rocks and soils. Found in some industrial wastes. Can be corroded from iron pipes, pumps and other equipment.	More than 0.1 ppm often precipitates on exposure to air, causing turbidity, staining and tastes and colors which are objectionable in food, beverage, textile processes and ice manufacture as well as causing problems in domestic use such as staining plumbing fixtures and laundry. Federal drinking-water standards recommend a maximum of 0.3 ppm in finished supply. 1/
Manganese (Mn)	Dissolved from some rocks, soils, and lake bottom sediments. Sources associated with those of iron.	Some objectionable features as iron. Causes dark brown or black stains. Federal drinking-water standards recommend a maximum concentration of 0.05 ppm. 1/ Manganese removal associated with those of iron but more difficult and generally less complete.
Calcium (Ca), Magnesium (Mg)	Dissolved from practically all soils and rocks, but especially from limestone, dolomite, and gypsum.	Causes most of the hardness and scale-forming properties of water; detergent consuming (see hardness). Water low in calcium and magnesium desired in electroplating, tanning, dyeing, and in textile manufacturing. Small amounts desirable to prevent corrosion.
Sodium (Na)	Dissolved from practically all rocks and soils. Found in industrial wastes and sewage.	More than 50 ppm sodium and potassium in the presence of suspended matter causes foam in boilers which accelerates scale formation and corrosion. More than 65 ppm of sodium car cause problems in ice manufacture. (Durfor and Becker, 1964a, p. 17)
Bicarbonate (HCO_3) Carbonate (CO_3)	Action of carbon dioxide in water on carbonate cementing material and rocks, such as limestone and dolomite.	Produces alkalinity. On heating in the presence of calcium and magnesium can form scales in pipes and release corrosive carbon-dioxide gas. Aid in coagulation for the removal of suspended matter from water.
Sulfate (SO_4)	Dissolved from rocks and soils containing gypsum, sulfides, and other sulfur compounds. May be derived from industrial wastes, both liquid and atmospheric.	Sulfate in water containing calcium forms hard scale in steam boilers. In large amounts, sulfate in combination with other ions gives bitter taste to water. Some calcium sulfate is considered beneficial in brewing processes. Federal drinking-water standards recommend that the sulfate content should not exceed 250 ppm. 1/
Chloride (Cl)	Dissolved from rocks and soils. Present in sewage and industrial wastes.	Some people can detect salty taste in concentrations exceeding 100 ppm. In large quantities increases the corrosiveness of water. Federal drinking-water standards recommend a maximum concentration of 250 ppm. 1/ Present available treatment methods not generally economical for most uses.
Fluoride (F)	Dissolved in small to minute quantities from most rocks and soils. Added to many waters by fluoridation of public supplies.	Fluoride concentrations of small magnitude have beneficial effect on the structure and resistance to decay of children's teeth. Fluoride in excess of 8.0 pp causes pronounced mottling and disfiguration of teeth. 1/
Nitrate (NO_3)	Decaying organic matter, sewage, fertilizers and nitrates in soils.	Small amounts of nitrate help reduce cracking of high-pressure boiler steel. It encourages growth of algae and other organisms which produce undesirable taste and odors. Federal drinking-water standards recommend a maximum concentration of ~~46 ppm 1/~~; concentrations in excess of this limit are suspected as cause of methemoglobinemia in infants. 10 mg/l 2/
Dissolved solids (residue on evaporation)	Chiefly mineral constituents dissolved from rocks and soils. Includes some water of crystallization.	Federal drinking-water standards recommend maximum of 500 ppm. 1/ Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes.
Hardness as $CaCO_3$	In most waters nearly all hardness due to calcium and magnesium.	Consumes soap and synthetic detergents. Although less of a factor with synthetic detergents than with soap, it is still economical to soften hard waters ~~(Hultman, 1958)~~.
Specific conductance	Mineral content of the water.	Guide to mineral content. It is a measure of the capacity of the water to conduct a current of electricity, and varies with the concentration and degree of ionization of the different minerals in solution.
pH	Hydrogen ion concentration.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote increased alkalinity; values lower than 7.0 indicate increased acidity. Corrosiveness of water generally increased with decreasing pH, but excessively alkaline waters may also attack metals.
Color	Decaying vegetation; peat, leaves, roots and other organic substances, industrial wastes and sewage and certain minerals.	Water for domestic and some industrial uses should be free from perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes.
Turbidity	Suspended and colloidal matter. Sources can be soil erosion, industrial wastes, micro-organisms.	Turbid water aesthetically objectionable. Also, objectionable in many industrial processes, generally removed by sedimentation, clarification or filtration.
Alkyl benzene sulfonate (ABS)	Synthetic detergents in domestic and industrial wastes.	Causestastes and odors and causes foam on streams and in treatment plants. Federal drinking-water standards recommend a limit of 0.5 ppm. 1/ Treatment somewhat difficult and generally incomplete.

1/ U.S. Public Health Service (1962).
2/ U.S. Dept of Interior (1968)

Table ~~5~~ 20

Recommended maximum concentrations, ~~in parts per million,~~ in milligrams per liter of major chemical constituents of water for industrial, domestic, and agricultural uses.[1]

Use	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Nitrate (NO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids (residue at 180°C)	Hardness (as $CaCO_3$)
Domestic	--	0.30	0.05	30-50	125-500	10	1,000-2,000	--	~~45~~ 10	250	250	0.8-1.7	500	500
Industrial														
Air conditioning	--	--	.50	--	--	--	--	--	--	--	--	--	--	50
Boiler feed water														
0-150 (psi)	40	--	--	--	--	50		--	--	--	--	--	500-3,000 a/	80
150-250 (psi)	20	--	--	--	--	50		--	--	--	--	--	500-2,500 a/	40
250-400 (psi)	5	--	--	--	--	50		--	--	--	--	--	100-1,500 a/	10
over 400 (psi)	1	--	--	--	--	50		--	--	--	--	--	50 a/	2
Brewing and distilling	50	.10-1.0	.10	100-500	30	--	--	75-150	30	100-500 b/	60-100	1.0	500-1,000	200-300
Canning and freezing	--	.20	.20	--	--	--	--	--	--	--	1,000-1,500 c/	1.0	850	50-85
Carbonate beverages	--	.10-2.0	.20 .20	--	--	--	--	30-170	--	250	250	.2-1.0	850	200-250
Photographic processing	--	.10	--	d/	--	--	--	--	--	100 b/	25	10	--	200
Food equipment, washing	--	.20	--	--	--	--	--	--	--	--	250	1.0	850	10
Food processing, general	--	.20	.20	--	--	--	--	30-250	--	--	--	1.0	850	10-250
Ice manufacturing	--	--	.20	--	--	65	--	--	--	--	300 b/	1.0	170-1,300	--
Clear plastic manufacturing	--	--	.02	--	--	--	--	--	--	--	--	--	200	--
Paper manufacturing														
Fine paper	20	.10	.05	--	--	--	--	45-75	--	--	--	--	200	100
Kraft paper bleached	50	.20	.10	--	--	--	--	75	--	--	--	--	300	100
Kraft paper unbleached	100	1.0	.50	--	--	--	--	150	--	--	200	--	500	200
Soda and sulfate paper	20	.10	.05	20	12	--	--	75	--	--	75	--	250	100
Ground wood pulp	50	.30	.50	--	--	--	--	150	--	--	75	--	500	200
Rayon manufacturing	--	0-.05	.03	--	--	--	--	75	--	--	--	--	100-200	8-55
Textile manufacturing	--	.10-1.0	.25	10	5	--	--	--	--	100	100	--	--	0-50
Laundering	--	.20 1.0	--	0	--	--	--	60	--	--	--	--	--	0-50
Tanning processes	--	.10 2.0	.20	--	--	--	--	135	--	--	--	--	--	50-135
Dairy wash waters	--	--	--	--	--	--	--	--	--	60	30	--	850	--
Steel manufacturing	--	--	--	--	--	--	--	--	--	--	175	--	--	50
Agricultural Irrigation	10-50	--	.50 g/	--	24	100-200	--	---	--	200-500	100	10	700	--
Livestock	--	--	10 f/	1,000	500	2,000	--	170	2,700	500	1,500	1.0	2,500	--
Fish and other aquatic life	--	1-2 g/	1.0	300-1,000	--	--	--	--	--	--	400-2,000	1.5	2,500	--

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1/ Various chemicals themselves may not have harmful effects at certain concentrations; however, when placed in combination with other minerals they may produce detrimental effects. Hence, many limiting concentrations are given as ranges rather than as simple values. U.S. Public Health Service (1962), McKee and Wolf (1963) ~~or~~ Durfor and Becker (1964), should be consulted if there is any question as to the suitability of a given water for a given purpose. Table ~~X~~ 19 of this report gives supplementary information about sources or causes and significance of chemical constituents.

a U.S. Dept. of Interior (1968)

a/ Depends upon design of boiler.
b/ As $CaSO_4$
c/ As NaCl.
d/ See hardness.
e/ Varies with plant species.
f/ Varies with type of livestock.
g/ Depends upon pH of water.

MISSING TABLE 21

Table ~~21~~ 22.--Chemical analyses of ground water in the Potomac River basin in West Virginia.

Analytical results are in milligrams per liter except specific conductance, pH, and color.

Well Number	Date of Collection	Specific Conductance (micro-mhos at 25°C)	pH	Temperature (C°)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Iron (Fe)	Manganese (Mn)	Dissolved Solids (calculated)	Hardness		Color	Field Specific Conductance (micromohs)	Geology	Remarks
																		Calcium, Magnesium	Non-carbonate				
19-1-1	5-16-68	285	7.6	19	5.7	29	5.9	19	2.8	82	22	32	0.2	3.8	—		160	97	30	10		Do	
do	9-17-68	360	7.6	21	7.7	36	7.2	25	3.5	90	39	42	0.1	1.0	—		206	120	46	5	380		
do	4-23-69	307	7.7	22	8.7	50	5.2	4.3	0.9	168	15	2.0	0.1	0.4	—		170	147	9	0	290		
do	5-21-35			22	12.0	49	4.9	5.4	1.5	175	15.0	0.6		0.3	4.0		235						1/
do	12-30-16			23	2.1	55	9.7	1.7			13.4	2.6			8.7								1/CO_3-140 mg/l.
do	1899				5.71	46	1.2	6.0			5.0	11.6			0.23		188						1/CO_3-52 mg/l.
19-1-7	1-18-71	91	6.5		11	5.1	1.8	4.5	0.9	22	11	11	0.1	2.6	0.18	0.02	59	20	2	5		St	Sr-0.100mg/l, Li-0.140mg/l.
19-1-11	4-69		6.0			53.7	8.4				98.4	1.5			0.4	0.01		169	0.4			Do & Dmn	2/sampled after pumping at 50gpm for about 24 hrs.
do	do		6.65			120.9	16.4				214	2.5			1.2	0.33		37	2.1			Do & Dmn	2/pumped at 18gpm for about 24 hrs; sampled 48 hrs after shutdown.
do	do		6.2			49.2	6.6				77.8	1.5			0.4	0.22		151	0.2			Do & Dmn	2/sampled after pumping at 18gpm for about 24 hrs.
do	do		6.7			149.1	20.3				256.8	3.5			5.6	0.67		467	0.2			Do & Dmn	2/pumped at 18gpm for about 24 hrs; sampled 62 hrs after shutdown.
19-1-12	6-5-69		5.6			24.5	16.9				49.8	2.5			0.08	0.05		78	0.3			Do & Dmn	2/sampled as well was being pumped for normal plant use.
do	6-24-69		6.2			36.7	5.0				60.4	2.5			0.05	0.05		112	0.4			Do & Dmn	2/sampled after a period of shutdown. 3/
19-4-4	11-14-69	169	8.4	10	6.5	26	4.2	0.9	1.2	87	11	1.4	0.0	0.3	0.04	0.0	95	83	11	4	172	Stw	1/
do	5-23-35				6.7	50	8.6	3.5		144	8.9	1.3		0.5	0.12		146						1/
19-6-7	2-14-61	280	7.3		6.6	41	9.0	1.1	0.5	154	17	2.5	0.1	0.5	0.06	0.01	154	139	13	0		Stw	PO_4-0.02, Al-0.1.
20-1-5	5-21-31			12	12	78	5.0	4.3	2.0	243	6.9	7.4		13.0	0.06		344					Ob	1/H_2S-2.6 mg/l.
20-1-16	9-12-57		6.6	56	51					118	51	4.0	0.2	0.3	5.8			126	30		266		
20-1-18	do		5.8	59						36	20	34	0.1	28	0.39			66	36		212		
20-1-31	do		6.9	60						109	23	3.0	0.1	1.1	0.18			96	6		209		
20-1-84	9-12-57		7.4	62						345	30	4.0	0.4	12	0.16			323	40		592		
20-1-85	11-22-30				7.8	76	16	2.0	2.5	283	13	4.0		22	0.08		272	232	24			Ob	
20-1-85							1.60	3.1			1.2	11.0	1.4	4.4	0.14	0.01	522	278					4/Cr-0.0, Pb-0.0,chlorinated and fluoridated.
do	3-14-51		7.8	58	11	79	17	2.7		298	18	6	1.8		0		a282	230					
do	2-27-52		7.5		11	80	16	1.6	1.8	286	18	3.5	-.1	14	0.19		279	264			468		
20-2-8	9-12-57		7.6							90	249	18	0.2	0.1	6.9			264	190		565		
20-2-30	9-12-57		7.2							296	17	5.0	0.2	23	0.41			269	26		516		

TABLE 22 CON'T

20-2-42	5-14-70	719	7.6		4.7	82	35	12	14	346	51	12	0.4	48	0.14	0.02	429	349	65	0	690		
20-2-49	5-21-35			13	14	100	32	26	5	291	237	349		0.0	0.12		1175					Ob	1/H_2S=13.2 mg/l.
20-2-50	5-21-35			13	11	92	11	9.9		266	35	9.5		9.0	0.24		331					Ob	1/
20-3-17	5-14-70	557	7.8		11	110	6.0	3.3	2.1	302	23	7.2	0.2	19	0.02	0.01	331	229	52	1	540		
20-3-26	9-12-57		7.9	62						360	15	19	0.4	12	0.17			329	34		623		
20-3-30	9-13-57		7.1	62						375	167	5.0	0.3	0.4	2.8			428	121		789		
20-3-36	do		7.3	75						292	34	7.5	0.5	7.1	0.26			282	43		523		
20-3-48	do		7.2	62						280	13	5.6	0.1	16	0.15			257	28		475		
20-4-2	9-12-57		6.4	60						90	6.8	6.0	0.1	0.3	5.0			60	0		146		
20-4-15	do		8.0	56						128	8.8	5.0	0.2	0.1	0.32			84	0		217		
20-4-35	do		7.1	55						138	8.6	1.0	0.2	2.9	3.3			111	0		234		
20-4-37	do		7.3	60						344	32	16	0.4	44	0.22			334	52		675		
20-4-59	do		6.7	56						60	15	4.0	0.2	0.2	3.0			43	0		126		
20-4-65	do		7.2	58						385	103	121	0.1	3.1	0.30			498	183		1020		
20-4-72	5-8-70	649	7.5		13	83	34	3.4	1.6	370	27	4.6	0.3	29			375	347	44	0	640		
20-4-79	5-21-35		14	27.0	46	11		18	148	60	11	0.2					306						1/H_2S=3.2.
20-4-79	10-15-69	410	8.4	13.0	10	46	13	15	1.2	148	64	15	0.1	0.2			240	169	47	4	390	Dmt	Al=0.0.
20-5-6	9-26-45		7.4		9	102	16	24		342	42	18	0.2	29	0.46		417	320					
20-5-16	1943		8.0			79	9	3.6		275	11	3		1.4	0.15		297	234	9				
20-5-17	do		7.7		16	110	4			293	20	5.5			0.3		612	291	51				
20-5-23	1-25-45		6.9	50						162	145	78		46	10			375					
20-5-26	do		7.3	65						242	381	15		0.0	1.7			540					
20-5-43	6-25-56		7.4		39	186	35	6	3	281	359	14	0.5	0.2	5.0		a786	607					
20-5-43	3-30-56		7.3		25	192	38	31	3.6	290	436	11	0.5	0.1	3.1		a883	636					
20-5-52	9-13-57		6.8	60						162	57	16	0.2	0.2	1.7			168	35		352		
20-5-56	5-21-35			12	10	91	9.6	4.5		281	11	2.0		14.0	0.12		321					Oc or Ob	
20-5-58	4-25-68	580	7.9	12	11	94	15	4.2	1.9	336	18	6.3	0.2	14			330	296	21	0		Ob	
do	5-28-68	530	8.0	16	11	98	14	3.5	1.8	335	17	6.5	0.2	11			328	302	28	0			
20-6-33	9-13-57		7.3	57						456	67	24	0.5	2.4	0.70			417	44		840		
20-6-44	do		6.8	57						112	47	16	0.2	3.0	0.82			146	54		318		
20-6-52	4-11-68	515	7.8	12	7.9	91	17	2.2	2.3	320	22	5.9	0.3	12			318	297	35	0		Ob	
do	5-28-68	498	8.2	14	9.5	88	16	2.4	2.3	314	22	5.6	0.2	11			311	286	28	0			
do	9-24-68	558	7.8	16	10	98	17	2.8	1.8	342	22	6.3	0.2	7.5			334	315	34	0	625		

Table ~~21.~~ 22.—Chemical analyses of ground water in the Potomac River basin in West Virginia - Cont.

Well Number	Date of Collection	Specific Conductance (micro-mhos at 25°C)	pH	Temperature (C°)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Iron (Fe)	Manganese (Mn)	Dissolved Solids (calculated)	Hardness		Color	Field Specific Conductance (micromohs)	Geology	Remarks
																		Calcium, Magnesium	Non-carbonate				
21-1-1	9-13-57		7.3	63						385	47	4.5	0.7	7.8	0.09			364	52		653		
21-1-17	5-14-70	508	7.6		12	79	15	3.2	1.8	244	17	7.6	0.3	44	0.07	0.00	300	259	59	0	500		
21-1-19	do	884	7.6		12	105	38	9.1	17	348	48	31	0.4	108	0.24	0.01	540	417	134	0	890		
21-1-25	9-13-57		7.5	61						385	21	7.9	0.6	40	0.15			370	54		663		
21-1-39	10-15-70		7.1	—		130	13	3.1	2.5			9.0	0.2		0.01	0.01	478	286				Ec	4/
21-1-45	10-66	—	7.5					2.4	1.0		11.1	4.5		12			318	257	12				3/
21-2-15	9-13-57		7.1	59						330	15	4.0	0.1	15	0.18			300	30		545		
21-2-27	5-14-70	776	7.2	13	9.5	124	7.2	31	6.5	408	37	35	0.3	0.1	0.36	2.2	452	339	5	3	750		
21-2-28	9-13-57		7.2	64						318	11	4.5	0.2	14	0.13			280	20		511		
21-2-43	6-18-68	480	7.7	12	9.8	96	8.1	1.8	1.3	304	20	3.0	0.2	12			301	273	24	0	550	Ob	
21-3-1	9-13-57		7.3	67						276	27	13	0.2	29	0.17			277	51		544		
21-3-9	5-8-70	711	7.7	11	12	94	34	4.6	9.8	360	43	16	0.3	38	0.00	0.00	429	375	80	1	740		
21-3-20	9-13-57		7.4	63						264	13	4.7	0.2	19	0.09			249	32		454		
21-3-23	5-16-33			11	21	48	10	5.3		138	13	2.8		20			260					Ob	1/
21-3-28	1-26-45		7.6	41						252	13	4		23	0.07			222					
21-3-28	5-3-57		7.7	54	11	62	15	1.9	1.9	238	5	4	0.2	15	0.16			216	21		415		
21-3-51	5-8-70	560	7.7	12	11	83	20	4.3	2.8	292	27	8.5	0.3	23	0.00	0.00	324	290	50	2	535		
21-4-7	5-8-70	679	7.9		8.5	71	30	25	9.2	306	58	25	0.6	24	0.00	0.00	401	301	50	0	680		
21-4-9	9-13-57		7.3	60						378	133	6.0	0.7	3.9	0.21			451	141		785		
21-4-15	do		7.2	65						424	14	14	0.6	5.7	0.11			395	48		738		
21-4-18	5-8-70	776	8.0	10	13	93	47	6.4	4.0	442	39	20	0.4	12	0.00	0.00	452	426	64	2	745		
21-4-26	5-14-70	730	8.0		15	74	35	23	4.8	308	56	23	0.4	60	0.90	0.02	442	329	76	0	700		
21-4-29	9-13-57		6.8	55						104	20	3.0	0.1	0	0.30			93	8		212		
21-5-8	do		7.2	62						312	9.6	6.0	0.4	30	0.12			290	34		533		
21-5-21	do		7.4	59						446	34	3.0	0.6	2.0	0.51			410	44		687		
21-5-28	12-56		7.4		11	8.5	4.5			649	4.5	4.5		1.1	0.21			640					

22-1-4												8300						2300					well 640 ft deep when sampled.
22-1-6	2-15-61	337	6.3		16	29	8.7	22	1.0	48	48	23	0.1	36	0.06	0.02	208	109	69	1		Dmm	PO_4=0.02, Al=0.1.
22-3-7	1946											141											6/well 290 ft deep when sampled; total solids - 672 mg/l.
22-3-8	11-29-46										1483	576											6/sampled between depths of 1682 and 1689 ft.
22-3-9	4-9-68	485	8.2	11	6.2	83	13	3.3	2.4	248	39	9.0	0.3	4.1			282	261	58	2		Dhl	
do	5-25-35			12	12.0	76	12	2.1	1.6	247	31	1.5		4.0	0.3		277					Dhl	
22-3-10	4-9-68	220	8.2	9	5.0	31	6.3	1.0	2.3	89	28	3.4	0.2	1.3			122	104	31	2		Stw	
do	5-16-68	250	7.8	—	6.1	37	7.9	1.9	1.1	105	40	3.0	0.2	1.0			150	125	39	0			
do	9-18-68	380	8.1	11	7.1	56	12	1.6	1.0	140	74	2.0	0.2	1.4			224	189	75	1	385		
22-3-17	11-13-69	188	8.2	9.3	7.1	8.2	15	2.5	1.5	102	4.1	4.8	0.1	1.4	6.5	0.52	95	82	0	4	190	Smc	
22-4-3	12-20-69	157	7.0	10.9	7.6	26	2.4	1.0	1.3	80	10	1.0	0.4	1.3	0.08	0.02	90	75	10	0	170	Do	
22-5-17	4-16-69	381	7.2	—	7.0	32	12	16	2.1	88	25	56	0.3	0.5			201	130	58	1	395	Pc	Zn=7.3 mg/l.
22-5-22	12-20-69	56	6.6	7.5	6.3	2.3	3.1	0.4	1.2	21	8.7	0.3	0.1	0.1	12	0.50	35	19	2	0	108	Ppv	Zn=2.51 mg/l.
22-5-23	4-16-69	279	7.3	—	6.7	28	4.8	17	2.3	55	34	36	0.2	2.6			159	90	45	3	250	Pc	
22-5-26	1-19-71	727	4.9	—	5.6	16	12	96	2.9	2	12	210	0.1	5.1	0.20	0.31	363	98	96	5		Ppv	high chloride possibly derived from salt used on highway.
22-6-5	12-15-42					49		b2410		403		3720											6/total solids=6258 mg/l.
do	6-5-43					65		b2280		392		3515											6/total solids=6277 mg/l.
23-1-16	5-7-69	200	7.9	13.3	9.6	35	2.7	1.8	0.5	112	11	0.8	0.1	0.3			117	99	7	0	202	Do	
23-1-16	12-69	—	7.3				0.01					5	0.1		0.03		209	104				Do	7/
23-1-17	11-14-69	275	8.5	15	20	32	10	11	1.0	158	7.1	4.0	0.2	0.0	0.06	0.15	167	121	0	2	273	Dch	
23-1-19	12-22-69	321	7.0	11.3	10	46	7.8	10	4.0	177	32	3.6	0.2	0.3	—	—	201	147	2	7	310	Qal	
23-1-20	10-6-69	958	7.1	—	15	182	26	12	1.2	449	185	11	0.2	0.0	0.62	0.06	653	561	193	0	870	Dmt	
23-1-22	2-64		8.6	76.5		448	332	7600	540	32	2280							2840					8/CO_3=44. Specific conductance=44,500. Cl=13,400. Dissolved solids=25,240.
23-2-17	5-16-69	326	8.0	—	20	30	18	13	1.3	206	3.5	1.0	0.2	0.1			188	149	0	0	315	Dhs	
23-2-18	5-7-69	304	7.7	—	20	29	15	13	0.8	178	8.9	2.6	0.2	0.8			178	134	0	0	295	Dhs	
23-2-20	12-22-69	128	6.2	10.4	19	3.9	11	6.0	1.2	78	0.4	1.2	0.1	0.1	—	—	81	55	0	0	241	Dch	
23-3-10	5-6-69	575	7.9	—	18	98	16	7.1	0.7	285	80	1.9	0.2	0.3			362	311	.77	0	600	Dmn	
23-3-11	11-14-69	301	8.1	11.5	10	38	13	2.5	1.1	194	1.8	1.0	0.1	0.2	2.5	0.20	163	149	0	3	300	Smc	
23-4-9	3-29-68	450	8.0	—	7.4	84	9.6	1.0	1.3	164	27	1.5	0.1	5.2			167	249	33	0		Dhl	
do	5-12-69	492	7.8	13.0	18	79	18	1.5	1.0	264	44	1.5	0.2	4.0			297	271	55		470		
23-5-13	11-13-69	5110	8.5	—	8.3	18	4.4	990	1.8	375	75	1270	1.8	0.0	0.11	0.00	2570	63	0	2	4500	Dbh	
23-6-3	2-14-61	278	6.8	53	22	19	17	13	0.4	165	5.6	4.5	0.2	0.4	0.11	0.06	165	120	0	1		Dch	slightly milky. PO_4=0.07, Al=0.1.
23-6-22	5-6-69	296	7.7		16	35	12	9.9	0.3	167	6.2	8.8	0.2	0.1			170	137	0	0	310	Dch	

Well Number	Date of Collection	Specific Conductance (micro-mhos at 25°C)	pH	Temperature (C°)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Iron (Fe)	Manganese (Mn)	Dissolved Solids (calculated)	Hardness		Color	Field Specific Conductance (micromohs)	Geology	Remarks
																		Calcium, Magnesium	Non-carbonate				
23-6-24	12-21-69	121	6.9		4.1	12	2.9	3.6	4.0	31	20	5.0	0.1	3.3	0.55	0.04	70	42	17	1	135	Qal	
23-7-4	5-23-35			17	8.6	50	7.6	5.9		166	12.0	1.0		0.4			204					Stw	
do				19	10.1	50	6.0	6.8	1.1		7.3	0.5			0.28								1/CO_3=111, Li=4.7.
23-7-17	10-17-69	44	7.6	12	7.3	5.6	0.9	0.5	1.0	24	2.7	1.0	0.1	0.1	0.1		31	18	0	1	50	Do	field pH=6.4.
23-7-17	5-23-35			12	8.0	4.0	1.1	0.9	1.2	19	2.7	1.7					36					Do	1/
23-7-18	1-18-71	2880	7.2	1.0	6.1	160	9.7	410	3.6	185	40	8.2	0.2	0.1			1540	440	290	10	2700	Do	high chloride possible derived from salt used on highway.
23-7-30	11-30-69	138	6.2	11	5.7					84	3.8	1.0		0.1				64					
24-1-23	4-16-69	373	8.2	—	6.2	58	9.5	0.9	1.6	152	9.5	34	0.1	0.9			196	184	59	0	380	Pc	
24-1-26	12-20-69	466	8.4	--	8.4	1.8	0.4	112	0.7	266	22	1.1	0.3	0.3	0.04	0.04	284	6	0	0	455	Smc	
24-1-27	12-20-69	440	7.5	11.0	6.3	60	20	3.9	1.1	266	26	7.8	0.2	16	0.01	0.02	252	232	47	2	421	Dhl	
24-1-38	12-16-70	3700	2.6	10.0	39	310	100	12	1.8	0	2090	2.4	1.2	0.1	320	4.8	3330	1190	3170				small part of this water derived from mine workings in Maryland.
24-3-1	2-15-61	192	6.9	44	3.6	32	2.9	1.8	0.2	84	20	2.0	0.1	3.1	0.06	0.01	108	92	24	1		Qal & Dmn	PO_4=0.02, Al=0.1.
24-3-2	5-30-35			13	13	104	15.0	8.0		205	140	1.7		1.5			462					Do	1/
24-3-6	2-15-61	192	6.9		3.6	32	2.9	1.8	0.2	84	20	2.0	0.1	3.1	0.06	0.01	108	92	24	1			
24-3-7	4-4-68	258	7.8	12	6.2	46	5.0	0.6	1.0	146	12	1.0	0.1	2.8			147	136	16	2		Stw & Dhl	
do	9-16-68	295	8.3	13	8.0	48	7.3	1.0	0.7	154	20	0.9	0.1	1.3			167	150	18	1	310		
do	3-20-70		7.6				5.7	0.9				5.0	0.2	8.0			218	150					4/
do	5.31-35			12	6.0	47	6.4	2.9		143	10	1.0		1.3			168						1/
25-1-1	3-27-70	282	7.7	6.8	5.6	39	5.4	7.9	2.3	72	50	11	0.1	10	0.00	0.00	166	120	61	0	242	Qal	well unused since 1949.
25-2-10	1-4-61	432	6.8	50	12	72	9.8	3.8	1.3	215	47	3.0	0.1	0.9	0.84	9.8	258	221	44	2		Dmn	PO_4=0.20, Al=0.1.
25-2-26	5-8-69	60	7.1	11.5	6.2	8.8	1.8	1.0	0.5	33	4.3	0.6	0.1	0.3			40	30	3	0	70	Do	
25-2-27	5-8-69	18	4.7	9	6.3	0.4	0.4	0.7	0.3	0	4.7	1.1	0.1	0.1		0.01	14	3	3	0	50	Do	
25-2-28	11-13-69	129	8.1	12.2	6.8	22	1.9	1.0	0.7	76	1.8	0.6	0.0	0.1	0.02	0.00	72	63	1	2	135	Do	
25-2-37	1-18-71	144	7.2		8.1	19	4.9	0.6	0.7	68	15	1.0	0.1	0.1	0.05	0.00	82	68	12	5		Do	
25-3-25	5-26-69	7570	7.8		10	360	1330	99	2.1	170	5980	12	0.2	19			7900	6370	6240	7	7000	Dmn & Dmt	sample stored at room temperature for 7 months before analysis.
25-3-26	4-17-69	3580	7.5		13	403	382	56	1.3	365	2150	76	1.2	0.0	18	8.7	3260	2580	2280	0	4000	Dmt	
25-3-27	4-17-69	1150	4.9	12	11	105	78	34	12	2	632	22	1.1	16			917	583	582	0		Dmt	

5-3-45	4-17-69	1950	8.5		9.6	9.6	2.1	470	0.9	876	0.0	200	3.9	0.0	0.09	0.00	1150	33	0	—	2200	Dmt & Dmn	
5-3-52	4-17-69	460	8.4		13	81	7.0	5.6	1.1	211	56	5.1	0.2	3.3			282	231	48	1	500	Dmt & Dmn	
5-4-15	5-21-35			13	36	8.4	4.8	66	2.9	209	26	1.9										Dhs	1/H_2S=4.0 mg/l.
6-1-6	2-20-70	521	8.0		8.2	52	8.5	45	2.5	196	48	39	0.3	0.1	0.52	0.05	300	165	4	0	675	Smc	
6-1-14	4-1-68	83	7.3	7	3.4	13	1.4	1.0	0.5	34	9.2	0.7	0.0	1.6			48	39	11	3		Mp	
6-4-11	5-9-68	92	7.3	11	3.4	14	1.5	1.3	1.0	45	5.6	1.0	0.1	1.0			51	41	4	2		Stw	
do	6-5-68	100	7.3	12	4.4	16	1.7	1.1	0.7	53	6.4	0.8	0.1	0.7			58	47	4	0			
6-5-1	4-17-69	164	7.7	11	3.9	30	2.6	0.5	0.9	91	7.2	0.9	0.1	0.8			92	86	11	2	175	Stw	
-5-7	5-18-35			9	8.8	28	1.7	1.9	1.0	85	6.5	0.8		0.8	0.4		93					Stw	1/
-5-10	5-18-35			12	7.2	38	3.6	1.0	0.9	124	5.8	0.6		1.0	0.4		119					Dhl	1/
-5-26	1-21-71	217	7.5	—	6.6	35	2.9	2.5	1.1	54	11	7.0	0.2	46	0.09	0.00	138	100	56	5	205	Do	
-6-1	3-18-60		8.1	22	6.0	21.9	10.8	7.8		80	32.0	2.0	0.0	—	—	—	c198	80	19.2	25		Db	
do	2-21-61	233	7.1	55	12	17	8.8	18	0.3	101	32	1.5	0.2	0.5	0.14	0.18	141	78	0	2		Db	PO_4=0.04, Al=0.1.
-6-12	6-1-35			12	5.5	39	4.4	6.6		129	7.4	1.1		0.8			188					Do & Dmn	1/spring reportedly flows 2 hrs then is dry 2 hrs.

1/ Analysis taken from Price and others, 1936.
2/ Analyzed by Wayne Laboratories, Waynesboro, Pa.
3/ All determinations but pH were made on filtered samples.
4/ Analyzed by West Virginia Department of Health.
5/ Analyzed by Penniman and Browne, Inc., Baltimore, Md.
6/ Analyzed by West Virginia Pulp and Paper Co., Luke, Md.
7/ Analysis reported by Buchart & Horn.
8/ Analyzed by Hall Laboratories for Shell Oil Company, Midland, Texas; gas well.
a. Sum of determined constituents.
b. Calculated.
c. Calculated from specific conductance.

Al - Aluminum
CO_3 - Carbonate
Cr - Chromium
H_2S - Hydrogen Sulfide
Li - Lithium
Pb - Lead
PO_4 - Phosphate
Sr - Strontium
Zn - Zinc

Db - Brallier Formation
Dbh - Brallier Formation & Harrell Shale
Dch - Chemung Group
Dhl - Helderberg Group
Dhs - Hampshire Formation
Dmn - Onesquethaw Group
Dmt - Mahantango Formation
Do - Oriskany Sandstone
Ec - Conococheague Formation
Mp - Pocono Group
Ob - Beekmantown Group
Pc - Conemaugh Group
Ppv - Pottsville Group
Qal - Quaternary Alluvium
Smc - McKenzie Formation & Clinton Group
St - Tuscarora Sandstone
Stw - Tonoloway, Wills Creek, & Williamsport Formations.

Table 23.—"Typical" analyses reconstructed from median values obtained from 1960 to 1970.

Parameters (mg/l)	Cacapon River and major tribs.	S. Br. Potomac and major tribs.	Abram Ck. and Stony River	Small Streams, Jefferson and Berkeley Counties
Calcium(Ca)	19	30	12	82
Magnesium(Mg)	3.5	4.4	3.0	13
Sodium(Na)	2.0	2.0	3.0	3.4
Potassium(K)	1.4	1.1	0.8	3.1
Bicarbonate(HCO_3)	62	94	2.0	264
Sulfate(SO_4)	11	17	66	24
Chloride(Cl)	2.6	2.0	8.0	6.0
Nitrate(NO_3)	0.4	0.2	1.2	12
Dissolved solids	68	111	195	294
Hardness as $CaCO_3$	57	89	100	253
Hardness noncarbonate	11	14	76	33
pH*	7.5	7.5	5.6	7.9
Conductance**	110	182	350	462

* units
** micromhos at 25°C

1c [illegible]

Table 24.— CHEMICAL ANALYSES OF SELECTED STREAMS— MEDIAN, MAXIMUM, and MINIMUM VALUES

er : yses -71)	Med. Max. Min.	Specific Conductance (Micromhos at 25.0°C)	pH	Chloride (Cl) mg/l	Hardness as $CaCO_3$ ~~(Ca-Mg)~~ mg/l	Iron (Fe) mg/l
		01595200 Stony River near Mt. Storm				
	Med.	155	5.0	8-16	34-42	.1
)	Max.	275	7.8	30	68-77	.6
	Min.	50	4.0	8.0	17-34	.0
		01595300 Abrams Creek at Oakmont				
	Med.	360	4.5	8.6	94-102	.6
8	Max.	1,000	5.5	2.24	308-325	1.3
	Min.	195	4.0	6.43	51-60	.0
		01599500 New Creek near Keyser				
	Med.	260	7.2	15-22	103-120	.3
5	Max.	280	8.0	30-37	120-137	.1
	Min.	235	7.2	7-15	86-102	.1
		01604500 Patterson Creek near Headsville				
	Med.	265	7.2	8-16	93-102	.1
18	Max.	335	8.0	16-24	144-153	.6
	Min.	80	7.0	5.10	17-26	.1
		01605500 So. Branch Potomac River at Franklin				
	Med.	200	8.0	7-15	86-103	.1
4	Max.	200	8.0	7-15	103-120	.5
	Min.	165	7.2	2	68-86	.1
		01605600 Friends Run near Franklin				
	Med.	130	7.8	8-16	42-51	.1
15	Max.	220	8.0	22-30	85-94	.3
	Min.	55	6.8	5.14	8.6-17	.0
		01606000 No. Fork of So. Branch Potomac River at Cabins				
	Med.	150	7.4	11.6	51-68	.1
16	Max.	255	8.0	15-22	94-102	.6
	Min.	120	6.8	8	43-51	.0
		01606500 So. Branch Potomac River near Petersburg				
	Med.	185	7.5	8	60-68	.1
18	Max.	255	8.0	15-22	85-94	.3
	Min.	100	6.0	6-22	26-34	0

Table 24.- CHEMICAL ANALYSES OF SELECTED STREAMS. MEDIAN, MAXIMUM, MINIMUM VALUES (continued).

umber of alyses 69-71)	Med. Max. Min.	Specific Conductance (Micromhos at 25.0°C)	pH	Chloride (Cl) mg/l	Hardness as CaCO3 (~~Ca-Mg~~) mg/l	Iron (Fe) mg/l
01607500 So. Fork of So. Branch Potomac River at Brandywine						
17	Med.	155	7.5	8	60-68	.1
	Max.	215	8.0	15-22	85-94	.6
	Min.	90.0	6.0	6-22	26-34	.0
01608000 S. Fork of So. Branch Potomac River near Moorefield						
18	Med.	160	7.0	8	68-106	.3
	Max.	225	8.0	15-22	94-102	.6
	Min.	115	6.6	6.4	34-43	.0
016080500 Fort Run near Moorefield						
17	Med.	80	6.8	8	17-34	.1
	Max.	155	7.0	8-16	43-51	.3
	Min.	65	6.0	6.43	17-26	.0
01608400 Buffalo Creek near Romney						
16	Med.	105	6.4	8-16	34-43	.0
	Max.	280	7.0	15-22	42-51	.6
	Min.	60	6.0	4.5	17-26	.0
01608500 So. Branch Potomac River near Springfield						
18	Med.	220	7.5	8-16	86-103	.1
	Max.	317	9.0	34-51	128-137	.6
	Min.	155	6.0	7-15	60-68	.0
01609800 Little Cacapon River near Levels						
18	Med.	120	7.0	8-16	34-42	.1
	Max.	130	7.2	15-22	51-60	.2
	Min.	80	6.0	6-43	17-26	.0
01611500 Cacapon River near Great Cacapon						
18	Med.	135	7.2	10.7	51-68	.1
	Max.	250	8.0	15-22	92-111	.6
	Min.	100	5.5	6.43	26-34	.0
01614000 Back Creek near Jones Springs						
18	Med.	180	7.0	8-16	86-102	.1
	Max.	325	8.0	15-22	106-111	.6
	Min.	110	6.4	6.4	26-34	.0

Table 24. - CHEMICAL ANALYSES OF SELECTED STREAMS
MEDIAN, MAXIMUM, MINIMUM VALUES (continued)

es)	Med. Max. Min.	Specific Conductance Micromhos at 25.0°C	pH	Chloride (Cl) mg/l	Hardness as $CaCO_3$ ~~(Ca+Mg)~~ mg/l	Iron (Fe) mg/l
01616500 Opequon Creek near Martinsburg						
	Med.	575	8.0	16-24	256-273	.1
	Max.	670	9.0	32-40	462-481	1.0
	Min.	360	7.0	9.6	137-145	.0
0161700 Tuscarora Creek above Martinsburg						
	Med.	520	7.9	8-16	256-265	.1
	Max.	570	9.0	15-22	481-500	.6
	Min.	360	6.6	6.4	145-154	.0
01636500 Shenandoah River at Millville						
	Med.	350	7.9	8-16	154-162	.1
	Max.	610	9.0	22-30	180-188	2.0
	Min.	220	7.0	7-15	86-103	.0

lc heading

Table 25.— CHEMICAL ANALYSES OF SELECTED STREAMS (DATA FURNISHED BY W. VA. DEPARTMENT OF NATURAL RESOURCES) MEDIAN, MAXIMUM, and MINIMUM VALUES

ar yses)	Med. Max. Min.	Specific Conductance (Micromhos at 25.0°C)	pH	Chloride (Cl) mg/l	Hardness As $CaCO_3$ ~~(Ca-Mg)~~ mg/l	Iron (Fe) mg/l	Dissolved Oxygen (DO) mg/l
		Opequon Creek, Rt. 51 Bridge, near Terico Heights					
	Med.	540	8.2	19	270	.06	10.5
	Max.	700	8.5	38	205	5.5	15.4
	Min.	303	7.6	7	116	.01	5.6
		Back Creek, Rt. 9 Bridge, west of Hedgesville					
	Med.	205	7.9	5	94	.14	9.7
	Max.	250	8.3	13	126	.41	13.8
	Min.	73	7.1	2	34	.01	6.9
		Back Creek, Rt. 45 Bridge, west of Mill Gap					
	Med.	119	8.0	5	92	.15	10.0
	Max.	275	8.3	14	134	1.9	13.7
	Min.	72	7.1	2	34	.01	5.7
		Sleepy Creek, Rt. 9 Bridge, 5 mi. east of Berkeley Springs					
	Med.	94	7.3	4	38	.25	9.2
	Max.	139	7.9	27	60	3.1	13.7
	Min.	52	6.3	1	8	.02	5.8
		North Branch Potomac at Pinto, Rt. 9 Bridge					
	Med.	680	7.0	83	214	.9	7.6
	Max.	1400	7.6	212	370	3.9	11.8
	Min.	179	5.1	9	76	.2	4.3
		South Branch Potomac, Rt. 33 Bridge, at Franklin					
	Med.	194	8.3	2	102	.6	11.4
	Max.	220	8.9	9	120	.3	15.7
	Min.	139	7.4	0	74	.0	7.5
		North Fork South Branch Potomac, at Rt. 33 Bridge					
	Med.	140	7.8	3	64	.04	10.0
	Max.	191	8.4	22	92	.22	12.9
	Min.	70	6.9	0	36	.01	7.8
		Opequon Creek, at Rt. 12 Bridge, near Bedington					
	Med.	539	8.1	19	276	.1	11.0
	Max.	685	8.3	35	308	5.1	5.3
	Min.	212	7.6	7	116	.01	15.1
		Potomac River at Paw Paw, Rt. 9 Bridge					
	Med.	420	7.5	28	144	.2	9.8
	Max.	950	8.3	89	246	9.7	14.0
	Min.	128	6.6	3	54	.01	5.9
		South Branch Potomac, Rt. 33 Bridge, near Springfield					
	Med.	219	8.0	5	98	.08	9.0
	Max.	300	8.2	11	140	.42	13.7
	Min.	114	7.2	2	50	.01	5.7

Table 26.—Effect of temperature on properties of water.

Temperature (°C)	(°F)	Density (gm/cm^3)	Abs. Viscosity (centipoises)	Pressure (mm Hg)	Dissolved Oxygen Saturation (mg/l)
0	32	0.99987	1.7921	4.58	14.6
4	39.2	1.00000			
5	41	0.99999	1.5188	6.54	12.8
10	50	0.99973	1.3077	9.21	11.3
15	59	0.99913	1.1404	12.8	10.2
20	68	0.99823	1.0050	17.5	9.2
25	77	0.99707	0.8937	23.8	8.4
30	86	0.99567	0.8007	31.8	7.6
35	95	0.99406	0.7225	42.2	7.1
40	104	0.99224	0.6560	55.3	6.6

From Federal Water Quality Administration, Industrial Waste Guide on Thermal Pollution, 1968.

Delete

Table 27.—Frequency of specific conductance of selected streams in the Potomac River Basin during the study period

STREAM AND LOCATION	Specific conductance, in micromhos at 25° celsius that ~~which~~ was equaled or exceeded for indicated percent of time.				
	5%	25%	50%	75%	95%
Abram Creek at Oakmont	-	865	286	215	165
South Branch of the Potomac at Franklin	200	198	183	172	169
South Branch of the Potomac Near Springfield	324	241	194	171	145
Patterson Creek near Headsville	290	274	247	165	100
Cacapon River near Great Capon	172	165	121	109	104
Opequon Creek near Martinsburg	627	620	595	535	305
Shenandoah River at Millville	525	485	390	305	250

see revised table on
P. 212

Ranges of water hardness of streams and springs sampled during period of [illegible]

Table 28.--~~Number of streams~~ and springs in the Potomac River basin having water hardness values as shown.

	Soft	Moderately Hard	Hard	Very Hard
Stream~~s~~ samples	49	30	24	33
Spring~~s~~ samples	7	6	15	9

at various flows

Table 29.—Hardness of surface water, July 1967 to December 1969.
(Data from West Virginia Department of Natural Resources)

TREAM AND LOCATION	Number of Analyses	Hardness, as $CaCO_3$ in mg/l, that was equaled or exceeded for indicated percent of time. 1%	10%	50%	90%	99%
orth Fork South Branch Potomac River at Judy Gap	24	92	90	64	38	36
outh Branch Potomac River near Franklin	24	120	110	102	84	74
outh Branch Potomac River near Springfield	24	140	122	98	70	50
orth Branch Potomac River at Pinto	24	370	348	214	98	70
orth Branch Potomac River at Paw Paw	31	246	212	142	72	54
leepy Creek near Berkeley Springs	25	60	58	38	20	8
ack Creek near Hedgesville	24	126	124	94	42	34
ack Creek near Mill Gap	24	134	132	96	46	34
pequon Creek at Route 12 Bridge	24	308	300	276	142	116
pequon Creek near Terico Heights	24	306	296	270	148	116

Table 30.—Chemical analyses for the North Branch the Potomac River from mile 338.2 to mile 277. (Values for June, July, August 1969)

Number of Analyses	Med. Max. Min.	pH	Biochemical Oxygen Demand (BOD) mg/l	Dissolved Oxygen (DO) mg/l	Dissolved Oxygen (Percent Saturation)
			AT MILE 338.2		
	Med.	3.9	2.0	9.0	---
6	Max.	4.0	2.0	9.0	113
	Min.	3.5	1.0	8.0	86
			AT MILE 337.5		
	Med.	5.2	22	5.0	---
6	Max.	7.5	28	5.0	62
	Min.	4.8	18	4.0	44
			AT MILE 331		
	Med.	7.0	20	5.0	---
6	Max.	7.4	12	6.0	70
	Min.	4.8	28	4.0	43
			AT MILE 326		
	Med.	7.2	24	4.0	---
6	Max.	7.6	26	7.0	80
	Min.	5.1	9	3.0	36
			AT MILE 314		
	Med.	7.0	8.0	5.0	---
3	Max.	7.0	9.0	6.0	69
	Min.	6.5	6.0	4.2	51
			AT MILE 313.5		
	Med.	6.8	42	2.5	---
3	Max.	7.0	43	3.0	36
	Min.	6.7	26	2.0	29
			AT MILE 308.5		
	Med.	7.2	---	---	---
6	Max.	7.5	---	---	---
	Min.	4.2	---	---	---
			AT MILE 277		
	Med.	---	1.7*	7.9*	---
2	Max.	8.1	2.7	10.0	121
	Min.	7.6	0.6	5.9	74

* Mean

Table 31.--Selected ways of removing or reducing chemical constituents that exceed recommended concentrations.

Problem Chemical Constituent	Symptoms	Treatment
Hardness Calcium (Ca) and Magnesium (Mg)	Forms white scale in tea kettles, plumbing, and as rings in bath tubs. Also consumes soap.	1. Lime-soda treatment - chemical reactions convert most of Ca and Mg in solution to insoluble calcium carbonate and magnesium hydroxide. The resulting sludge can then be removed by sedimentation and filtration. 2. Ion exchange - zeolite minerals or synthetic resin beads exchange sodium (Na) ions in their structure for Ca and Mg in the water. When the exchange capacity is exhausted, regeneration is accomplished by back flushing with a strong salt (sodium chloride) solution. The resin beads have a greater exchange capacity than the zeolite minerals.
Iron (Fe)	Forms hard reddish brown stains on sinks, commodes, and tubs. May stain laundry brown and impart objectionable taste to food and beverages such as coffee and tea. A slimy deposit indicates the presence of iron bacteria.	1. Oxidation and filtration - aeration followed by sedimentation will usually remove Fe and Mn when organic matter is not present. Chloride or potassium permanganate is also used to oxidize Fe and Mn which is then filtered from the water. These agents are commonly used when the water is high in organic matter as it may be in surface water or ground water containing iron bacteria. The water should be made alkaline before any Fe or Mn removal is attempted. 2. Oxidation and filtration through manganese green sand - the green sand gives up oxygen to produce insoluble iron hydroxide and manganese oxide. When the available oxygen is exhausted, regeneration is accomplished by back flushing the green sand with potassium permanganate. 3. Chemical stabilizer - sodium hexametaphosphate (polyphosphate) stabilizes Fe and Mn and delays precipitation. Delay time varies with the amount of polyphosphate added. The polyphosphate must be added before the water is exposed to air.
Manganese (Mn)	Same objectionable features as iron, but forms brown or black stains.	
Hydrogen Sulfide (H_2S)	Has foul rotten egg smell and is usually corrosive to plumbing.	Aeration - permits H_2S to escape to atmosphere. Aeration can be accomplished by spraying water into the air, trickling it through beds of coarse coke or stone, permitting it to cascade over steps, or by bubbling air into it (either in an open tank or in a closed system). After aeration, water may still be corrosive because of dissolved oxygen.
Chloride (Cl)	Has salty taste and is usually corrosive.	Demineralization by ion exchange - two types of resin beads remove nearly all dissolved mineral matter by cation and anion exchange. When the exchange capacity is exhausted, regeneration is accomplished by back flushing one type resin with acid (usually sulfuric acid) and the other type with alkali (usually sodium hydroxide). Cost is quite high for water containing more than 2500 mg/l dissolved solids. Cost can be reduced if mixing demineralized water with raw water will produce an acceptable water.
Sulfate (SO_4)	Has bitter taste and may have laxative effect and is usually corrosive.	
Nitrate (NO_3)	May or may not have unusual odors associated with it. More than 45 mg/l may cause methemoglobinemia in infants but not adults.	
Others		

Table 32.—Public and some industrial water-supply systems in the Potomac River basin in West Virginia.

lower by one line

arles Town

Name	Approximate population served	Approx. amount of water used (mgd)		Source of water
		Ground water	Surface water	
		Berkeley Co.		
Blair Limestone Co., Blairton	300	0.15		Well
Berkeley Co. Public Service District, Bunker Hill	4,000	0.660		Spring and limestone quarry
Martinsburg Municipal Water Works	18,000	2.0		Spring and limestone quarry, well
Opequon Public Service District, Martinsburg	2,000	0.216		Limestone quarry
Veterans Administration Center, Martinsburg		0.27		Wells
Capital Cement Co., Martinsburg		1.5		Wells
C. H. Musselman Co., Inwood		0.5		Berkeley Co. Pub. Ser. Dist., wells
		Grant Co.		
Bayard Water Co.	450	0.050		Spring and wells
Petersburg Municipal Water Works	2,000		0.275	South Branch Potomac R., auxiliary well used when river is muddy
Petersburg Trout Hatchery		0.58		Spring
Spring Run Trout Hatchery				Spring
		Hampshire Co.		
Romney Municipal Water Works	2,200		0.30	South Branch Potomac River
Springfield Water Works		0.006		Spring
		Hardy Co.		
Moorefield Water Works	2,000		0.35	South Fork South Branch Potomac River
Wardensville Water Works	250	0.02		Spring
		Jefferson Co.		
Charleston Water Department	7,200	0.65		Evitts Run well, springs
Harpers Ferry Municipal Water Works	2,700	0.17		Spring
Shepherdstown Water Works				Potomac River
Charleston Race Track		0.025		Well
Shenandoah Downs Race Track		0.060		Spring
Leetown Fish Hatchery		1.2		Spring and wells
		Mineral Co.		
Elk Garden Water Works	475	0.021		Well and spring
Fort Ashby Water Works	1,000		0.037	Painter Run
Keyser Water Works	7,100	0.410	0.410 1/	Spring, New Creek
Piedmont Water Works	1,730		0.250 1/	Savage River in Maryland
Short Gap Water Works				Spring
		Morgan Co.		
Berkeley Springs Water Works	1,300	0.185		Spring
Paw Paw Public Service District	800	0.040		Wells
		Pendleton Co.		
Circleville Water Department	75		0.020	Bouses Run
Franklin Municipal Water Works	700	0.30		Spring
Navy base near Sugar Grove		0.001	0.025	Well and South Fork South Branch Potomac River

1/ Water obtained outside of the Potomac River basin of West Virginia.

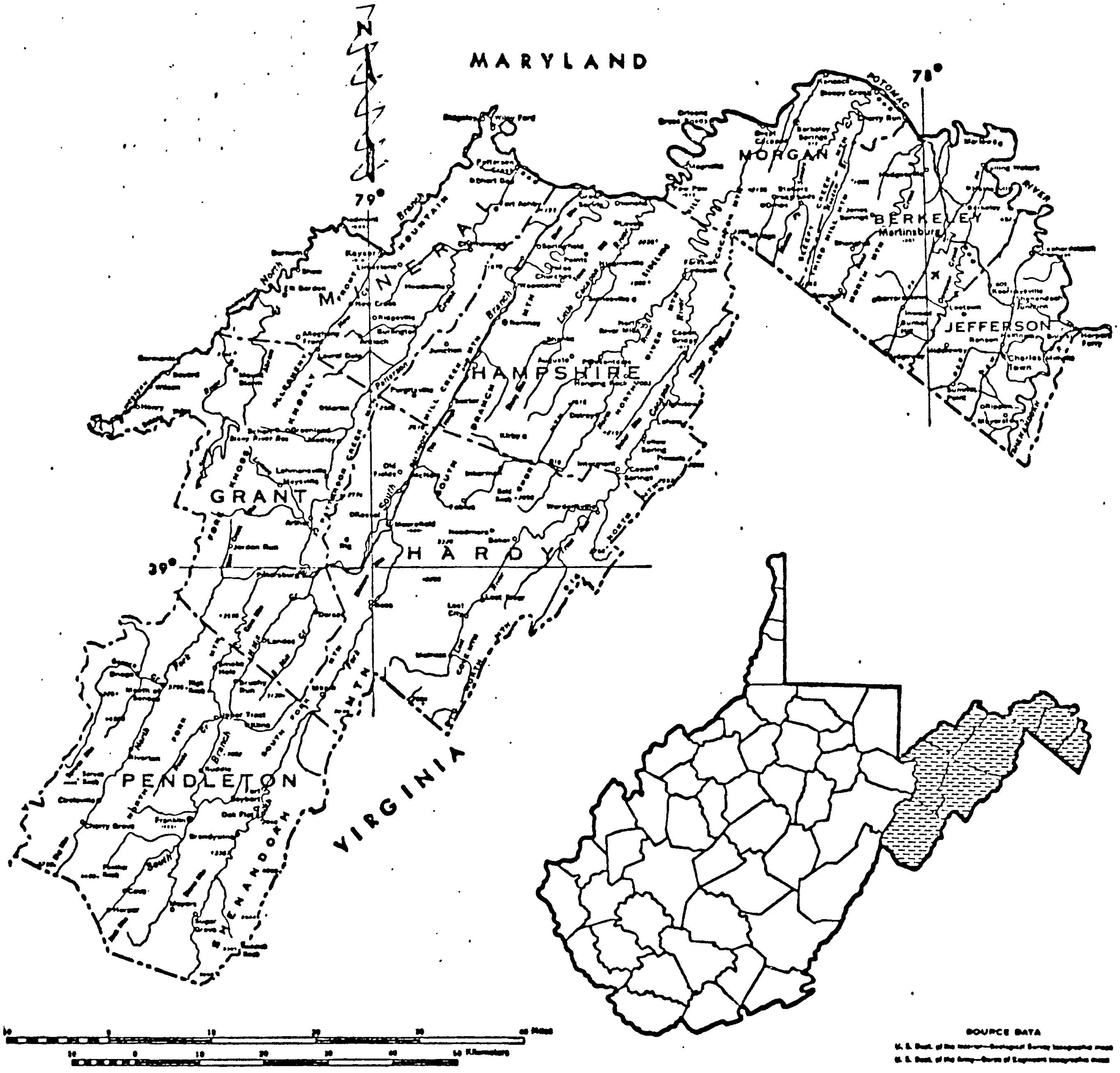


Figure 1.--Index map of the Potomac River basin in West Virginia.

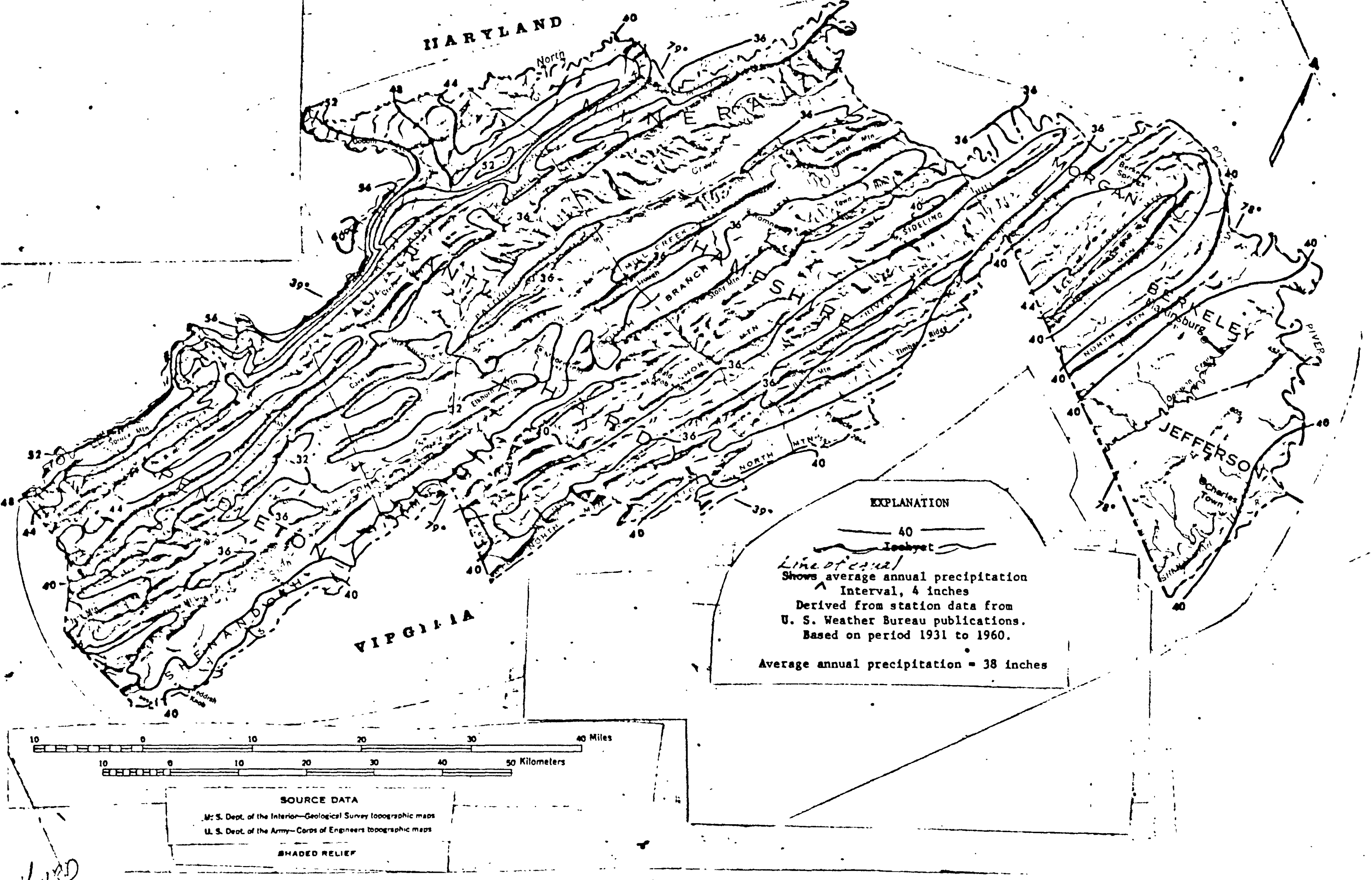
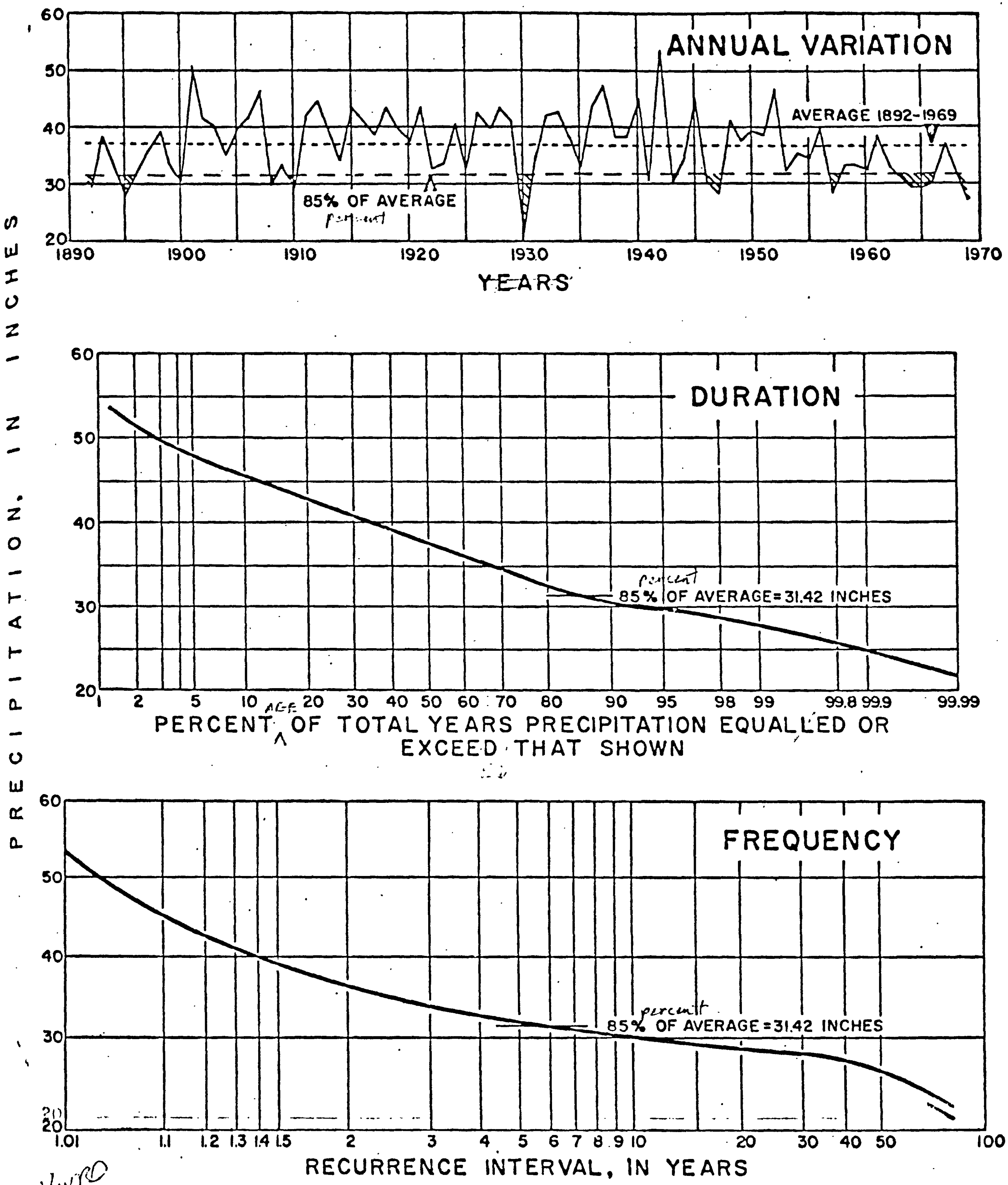


Figure 3.--Map showing average annual precipitation.



reh/wro

Figure 4.-Variation, duration, and frequency of annual precipitation at Martinsburg.

Figure 5.--The hydrologic cycle in the Potomac River basin in West Virginia.

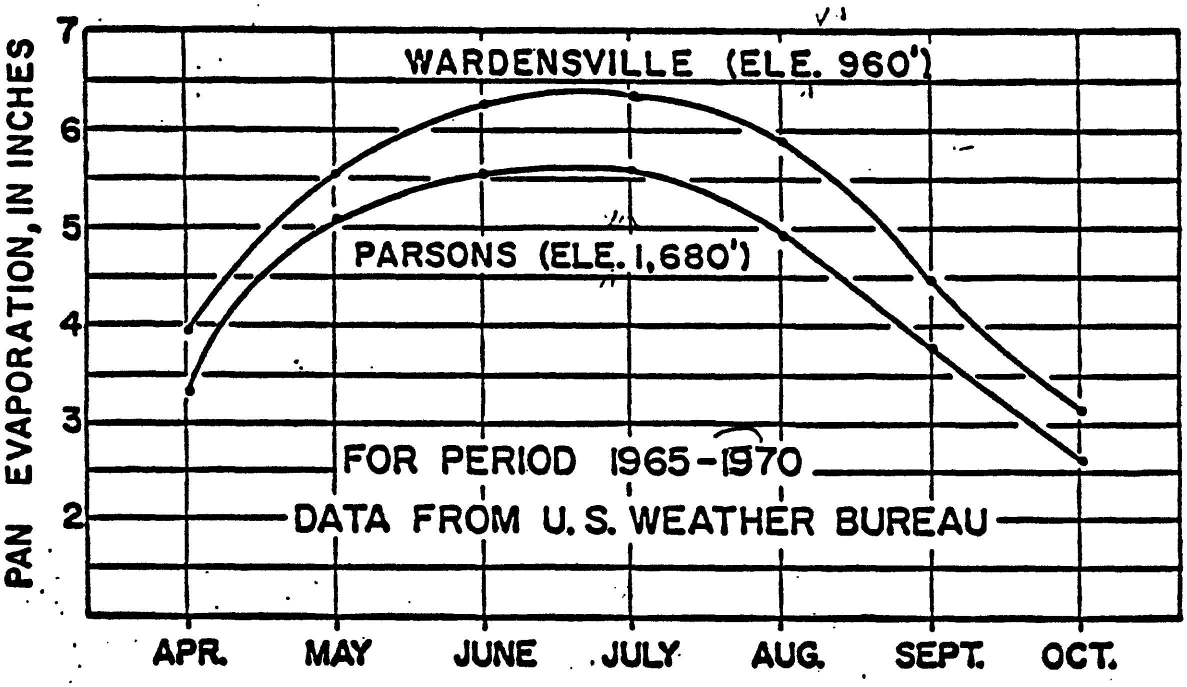


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Figure 6.—Average class A pan evaporation at Wardensville and Parsons

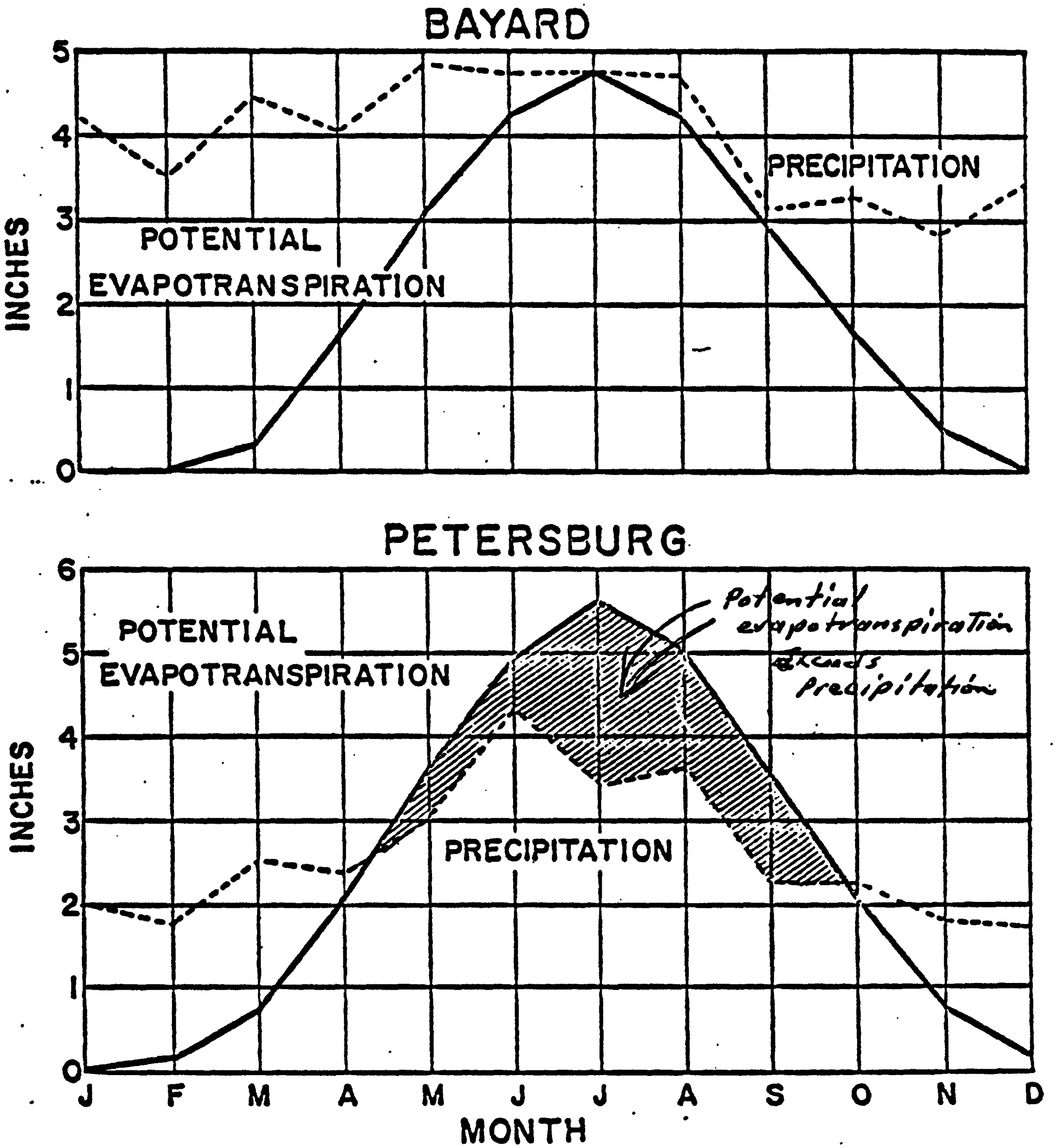
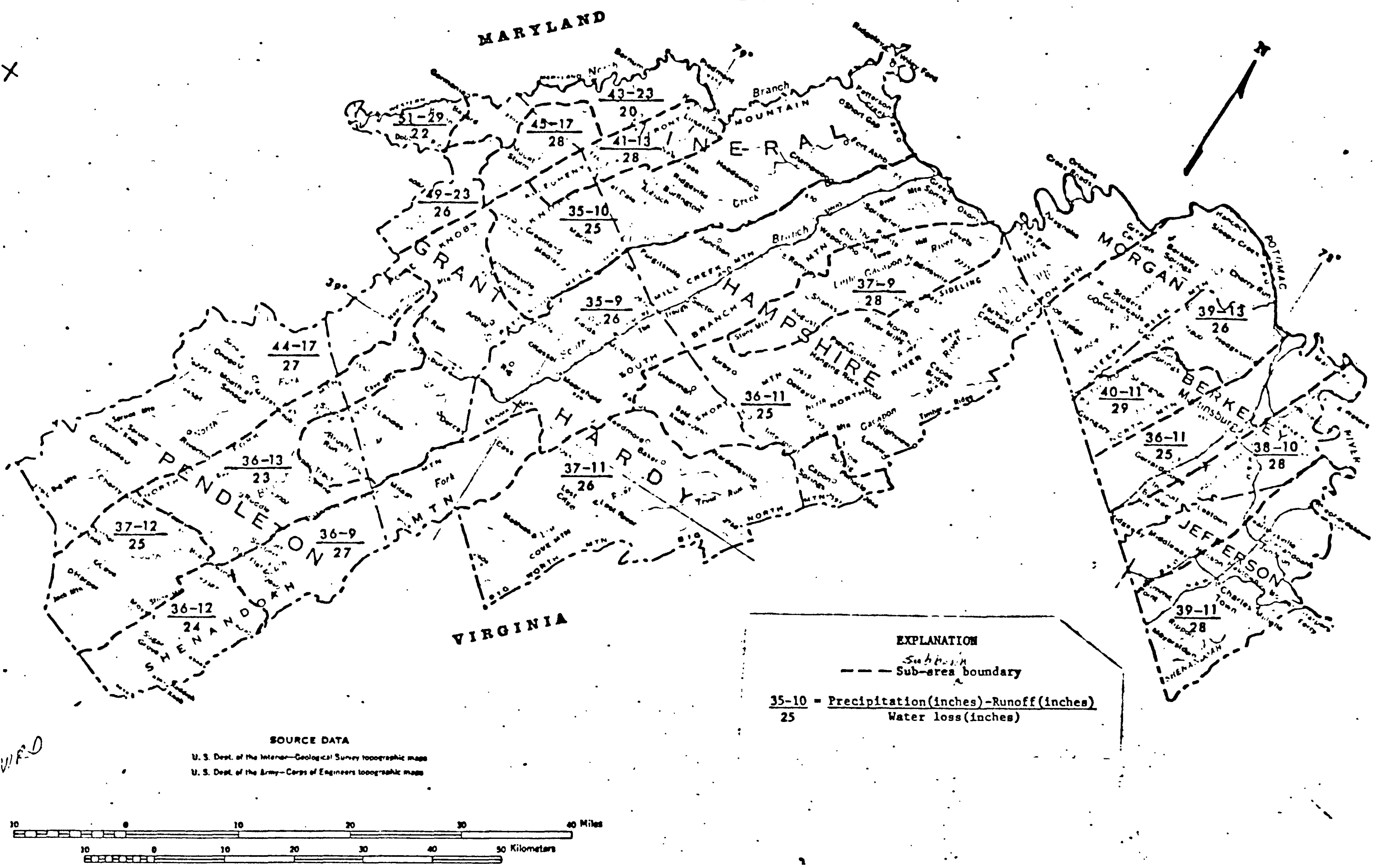


FIGURE 7- MONTHLY POTENTIAL EVAPOTRANSPIRATION AND PRECIPITATION AT ~~FOR~~ PETERSBURG AND BAYARD.

Refined



N/ WRD

Figure 8.--Average annual precipitation, runoff, and water loss.

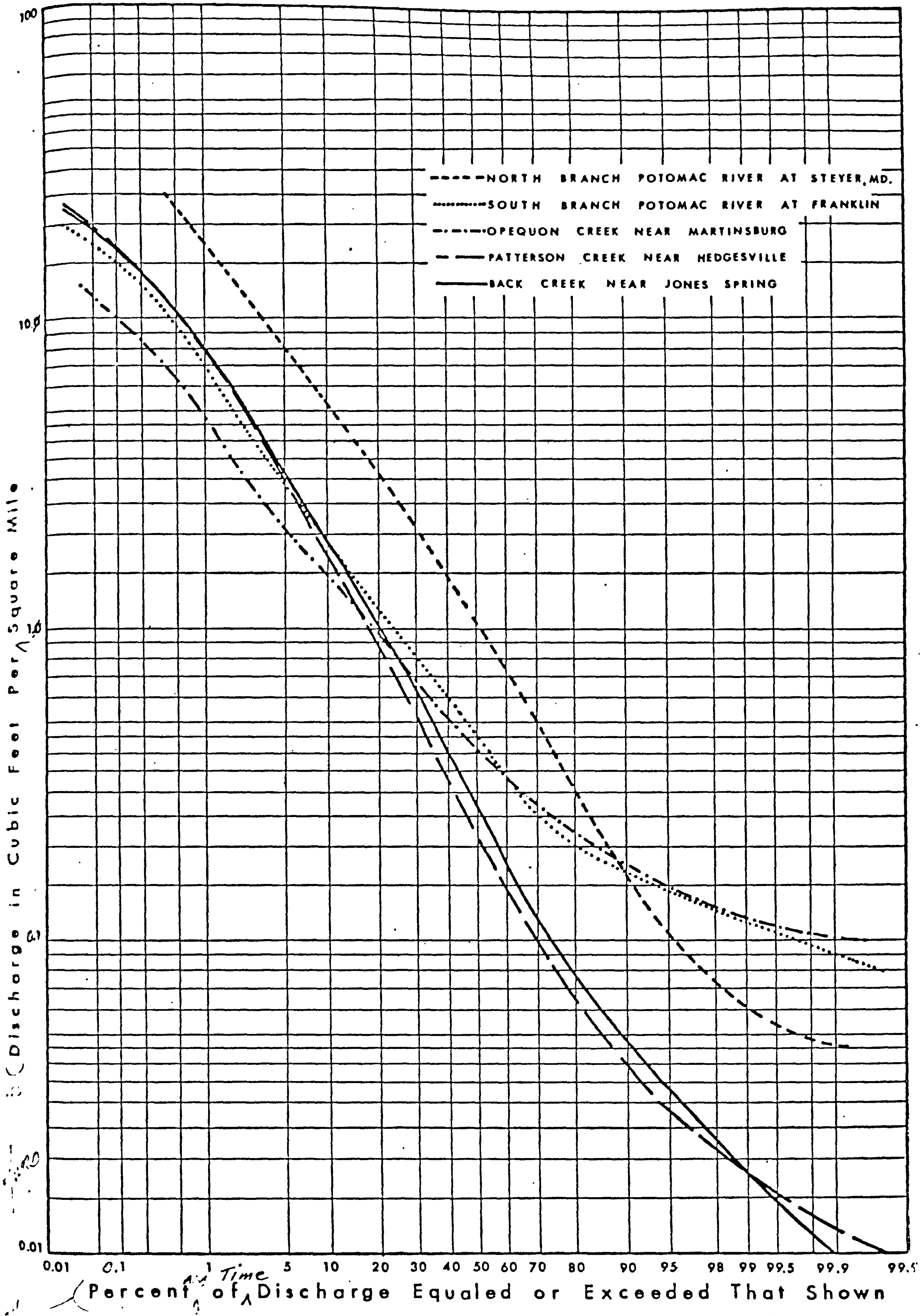


Figure 9.--Flow-duration curves of selected streams in the Potomac River basin.

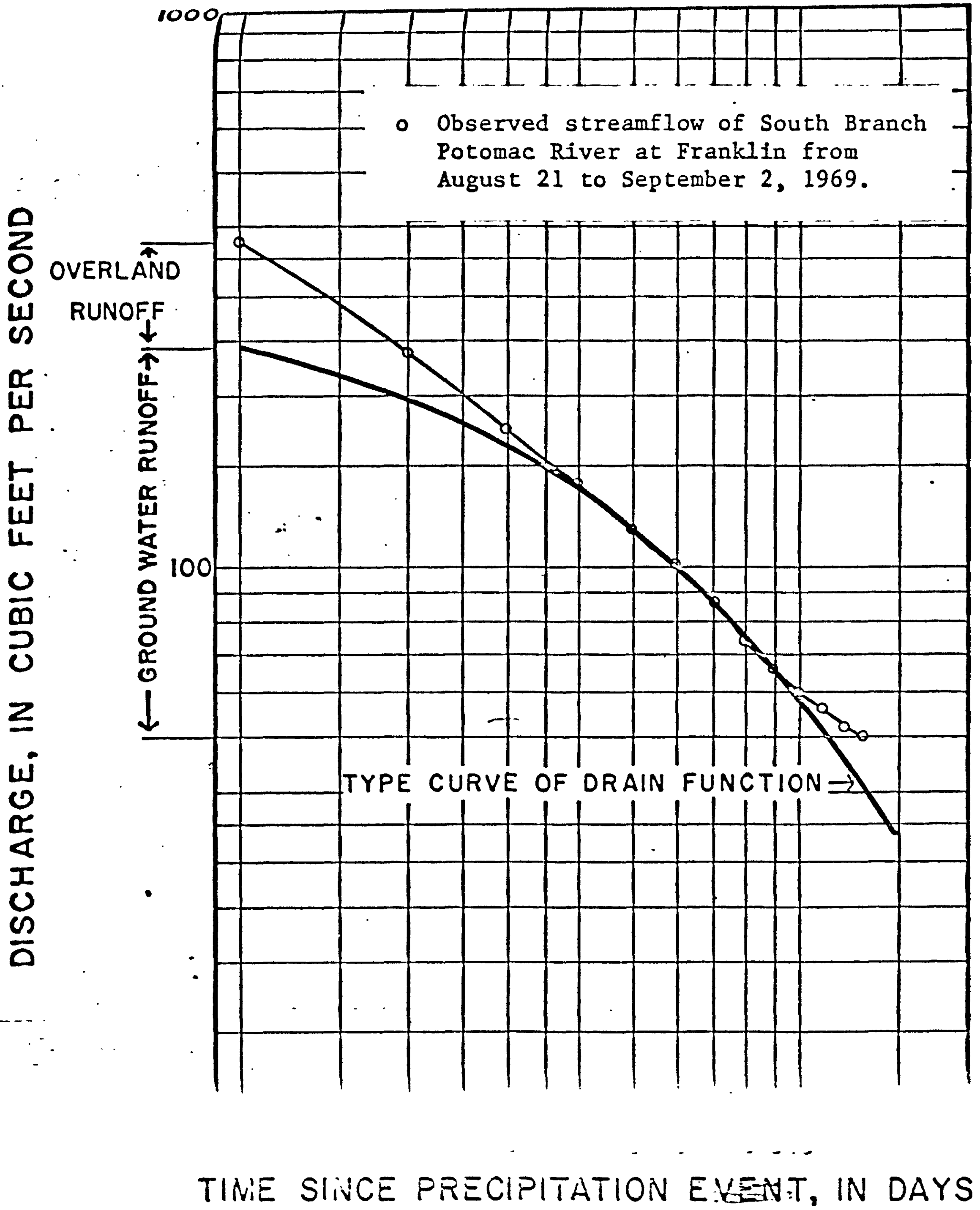
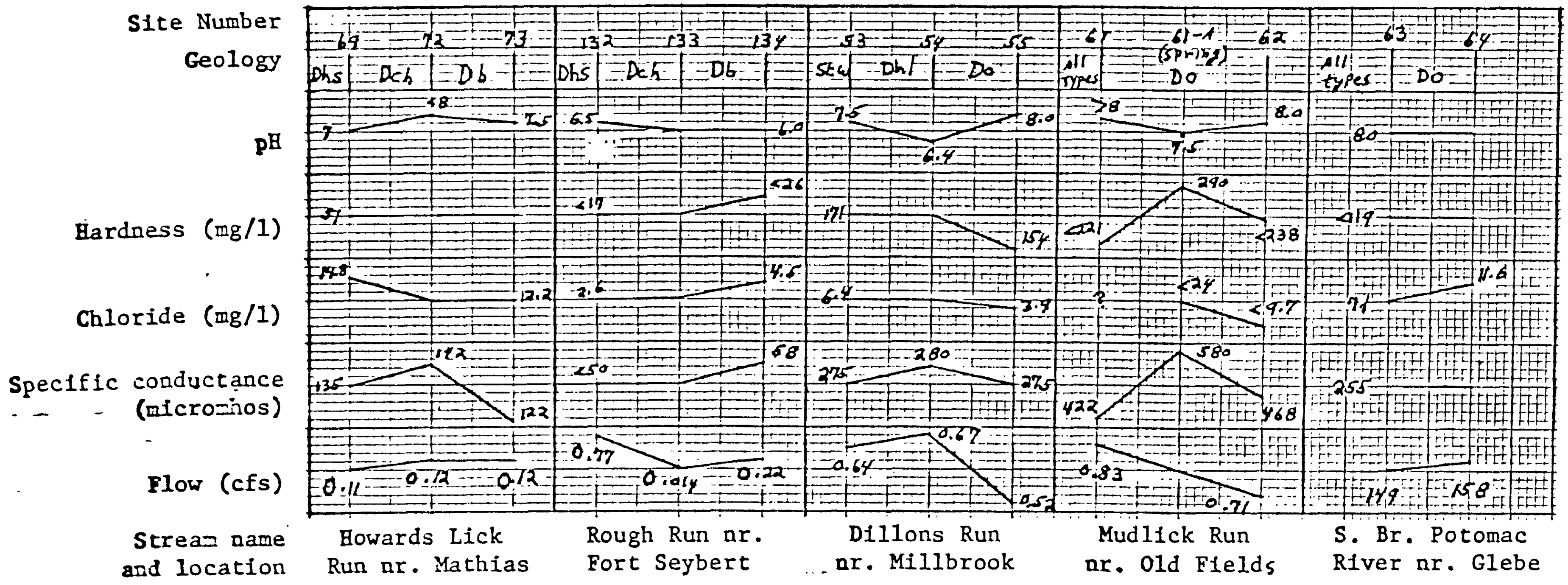


Figure 10.--Analysis of streamflow of South Branch Potomac River at Franklin



EXPLANATION

All types/various combinations of geologic formations.

Dhs	Hampshire Formation	Stw	Tonoloway and Wills Creek Formations
Dch	Chemung Group	Dhl	Helderberg Group
Db	Brallier Formation	Do	Oriskany Sandstone

Note: Streamflow is from low site numbers to high site numbers. Sites are located at or near geologic contacts. Site locations are shown on Plate 2.

Figure 11.—Changes in quality and quantity of surface water at baseflow as related to changes in the geology ~~beneath~~ of the stream, beds.

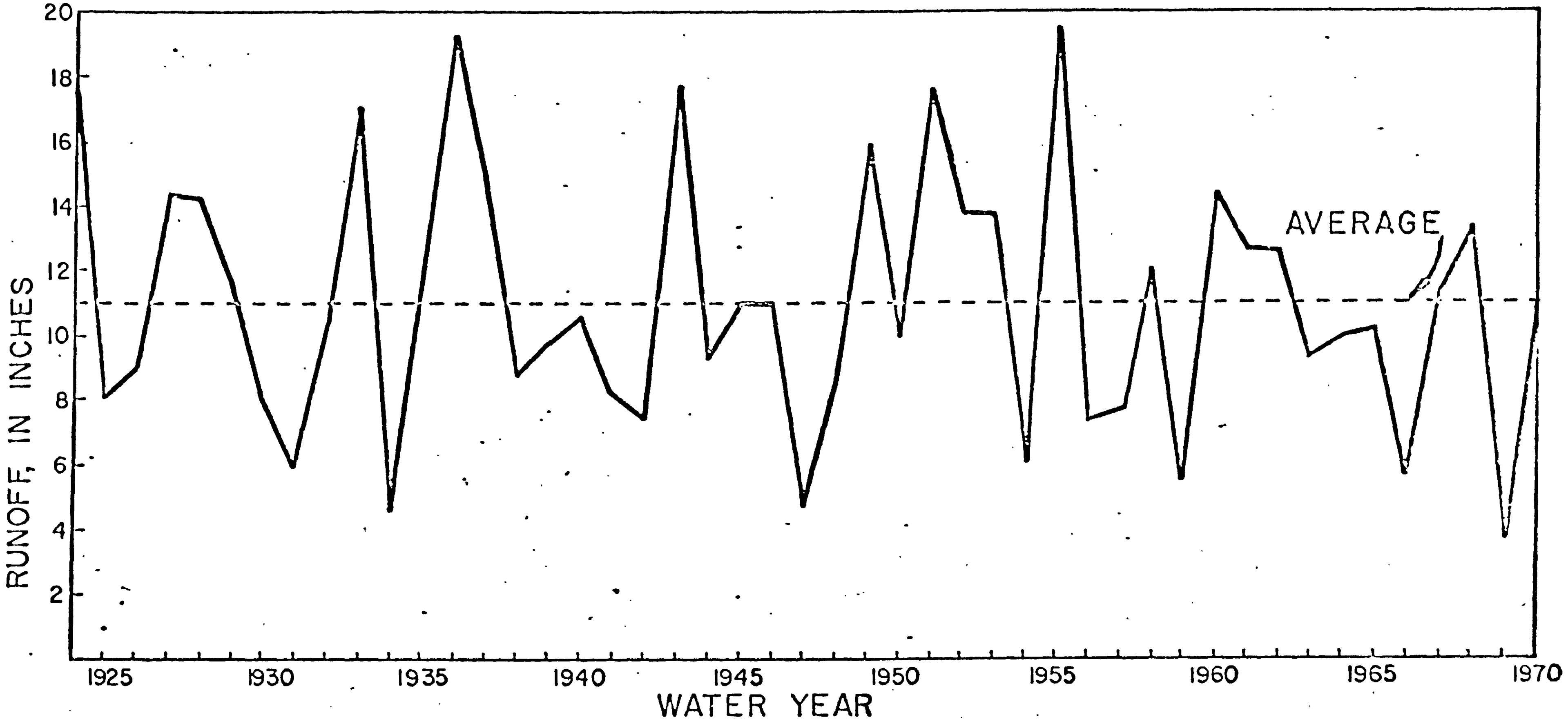


Figure 12.--Chronological variation of annual runoff of Cacapon River near Great Cacapon.

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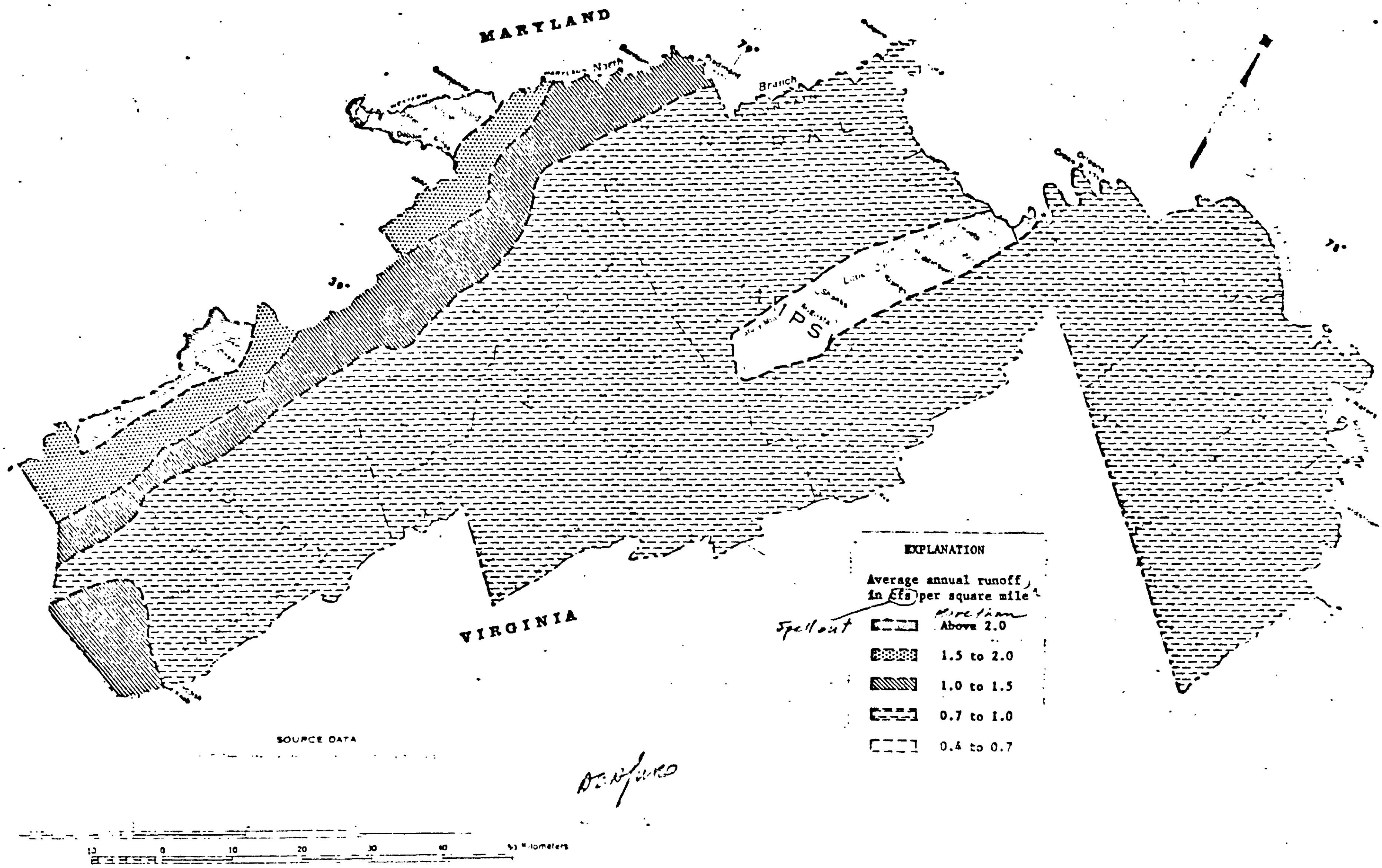

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Figure ~~14~~.—Map showing average annual runoff.

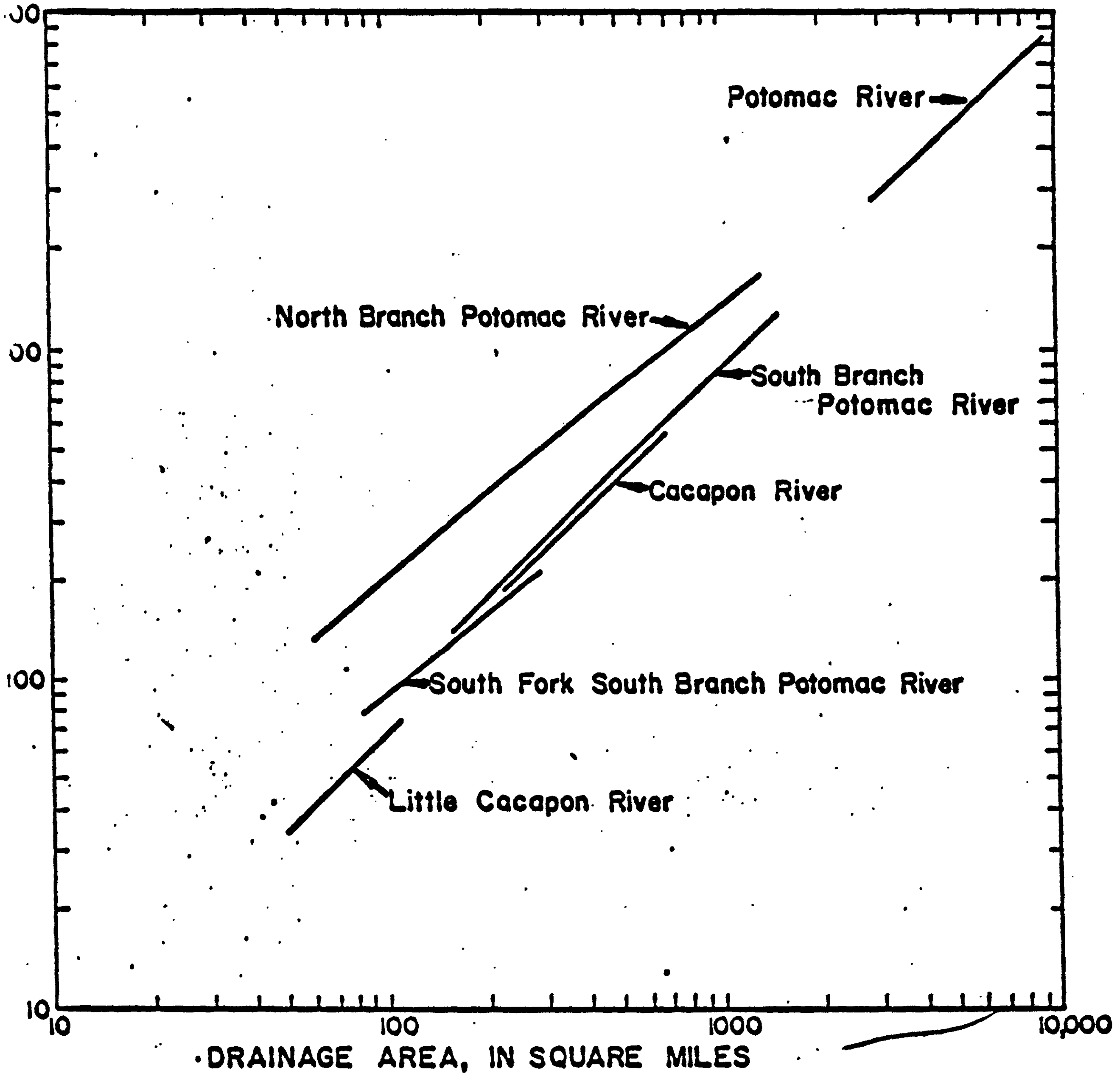

Figure 14.—Relation of average annual discharge to drainage area.

BZ/WRD

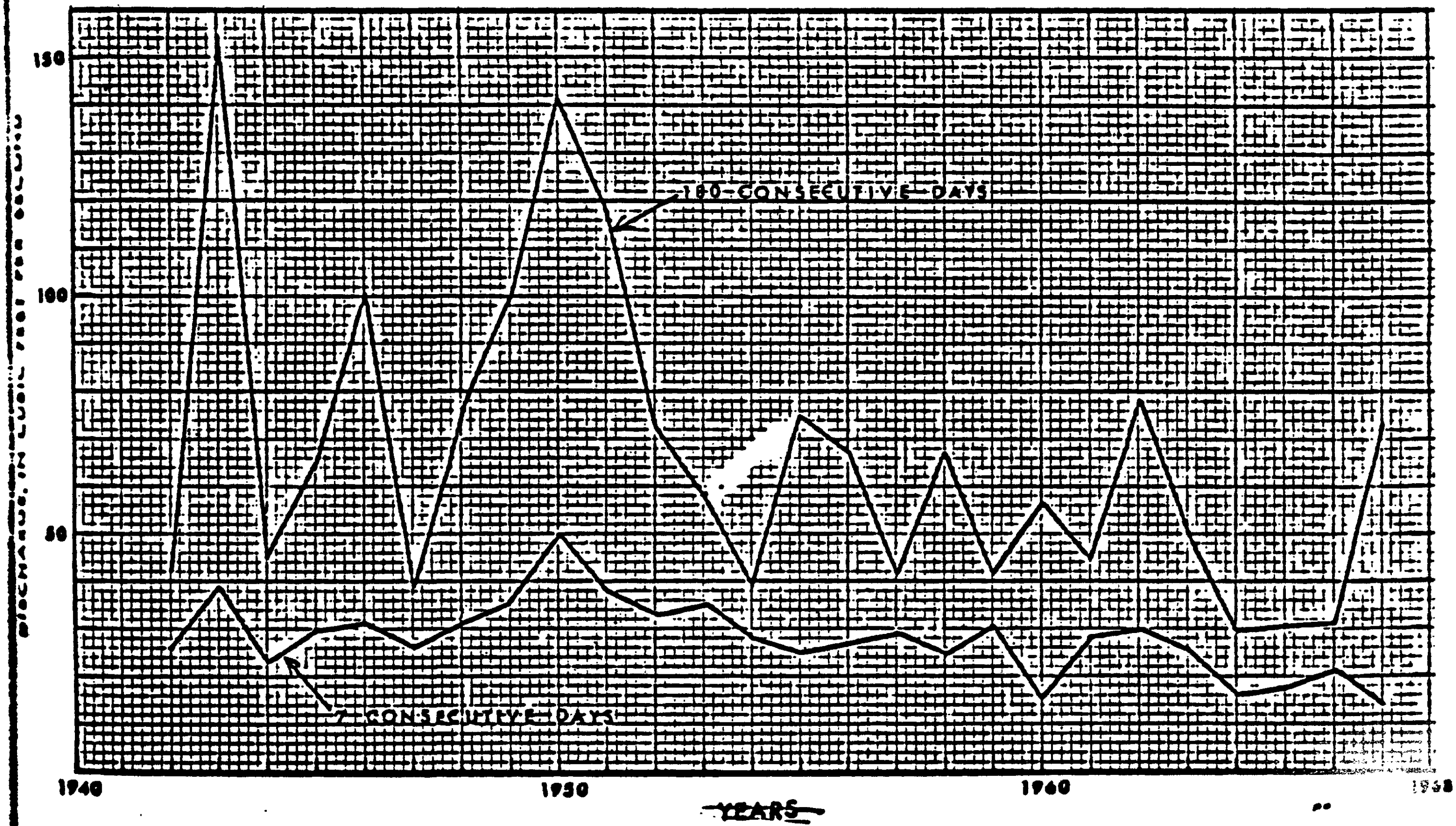

Figure 15.-Annual variation of lowest mean flow for South Branch Potomac River at Franklin.

BEH/WRO

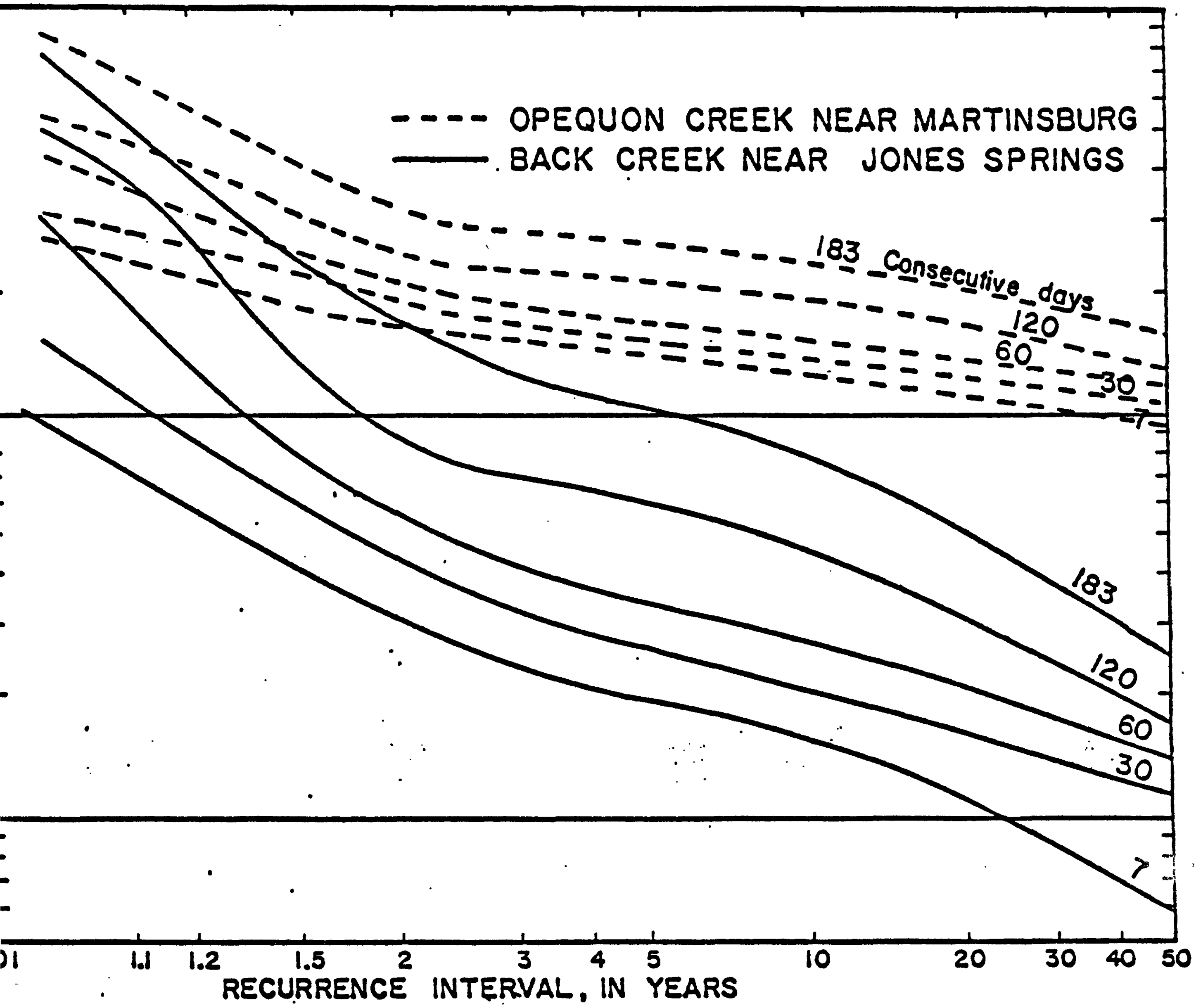

Figure 16.—Low - flow frequency curves for Back Creek and Opequon Creek.

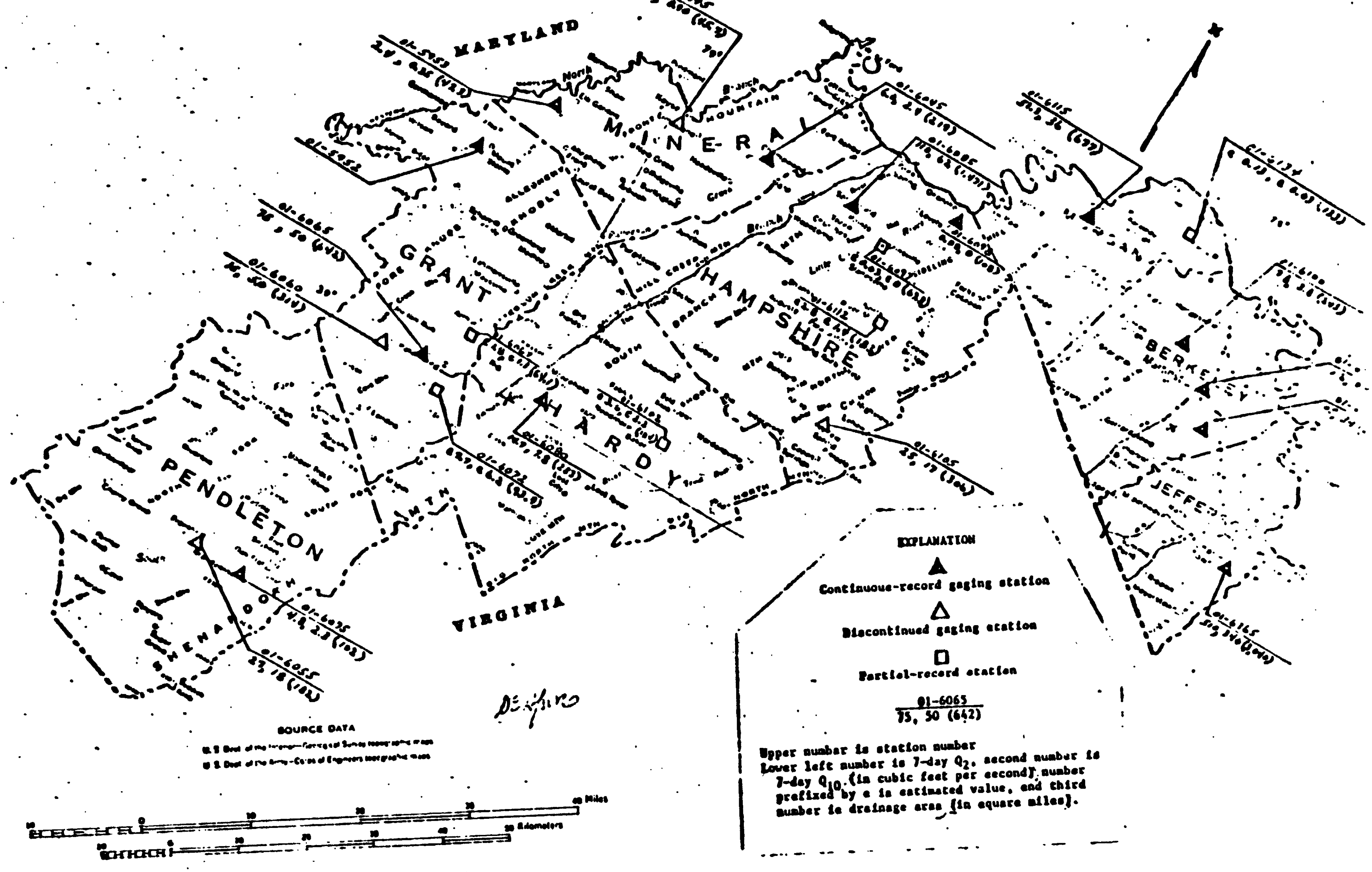

Figure ~~16~~ 17.--Map showing lowest mean flow for 7-consecutive days having recurrence intervals of 2 years and 10 years.

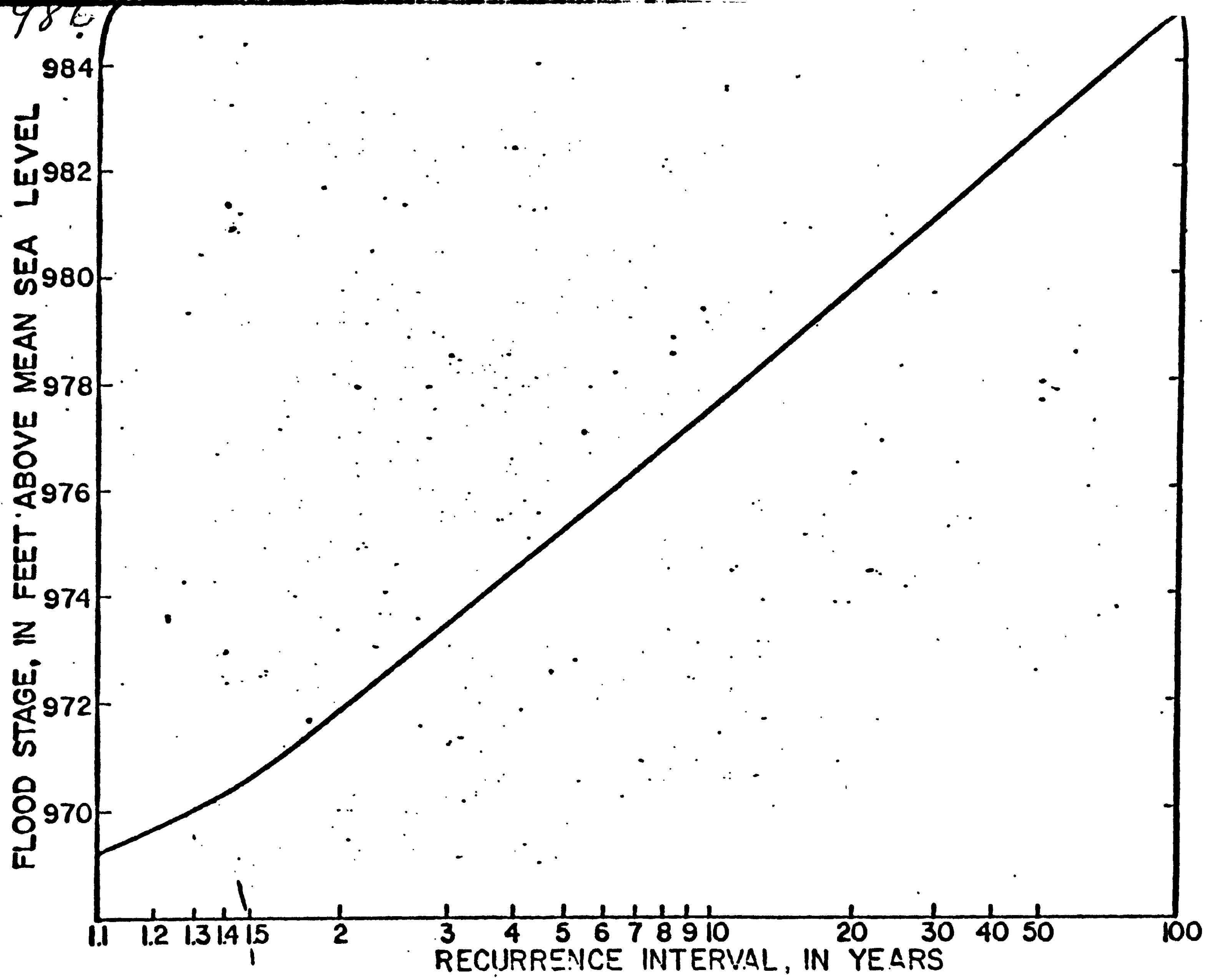

Figure 15.--Frequency of annual flood stages on South Branch Potomac River near Petersburg.

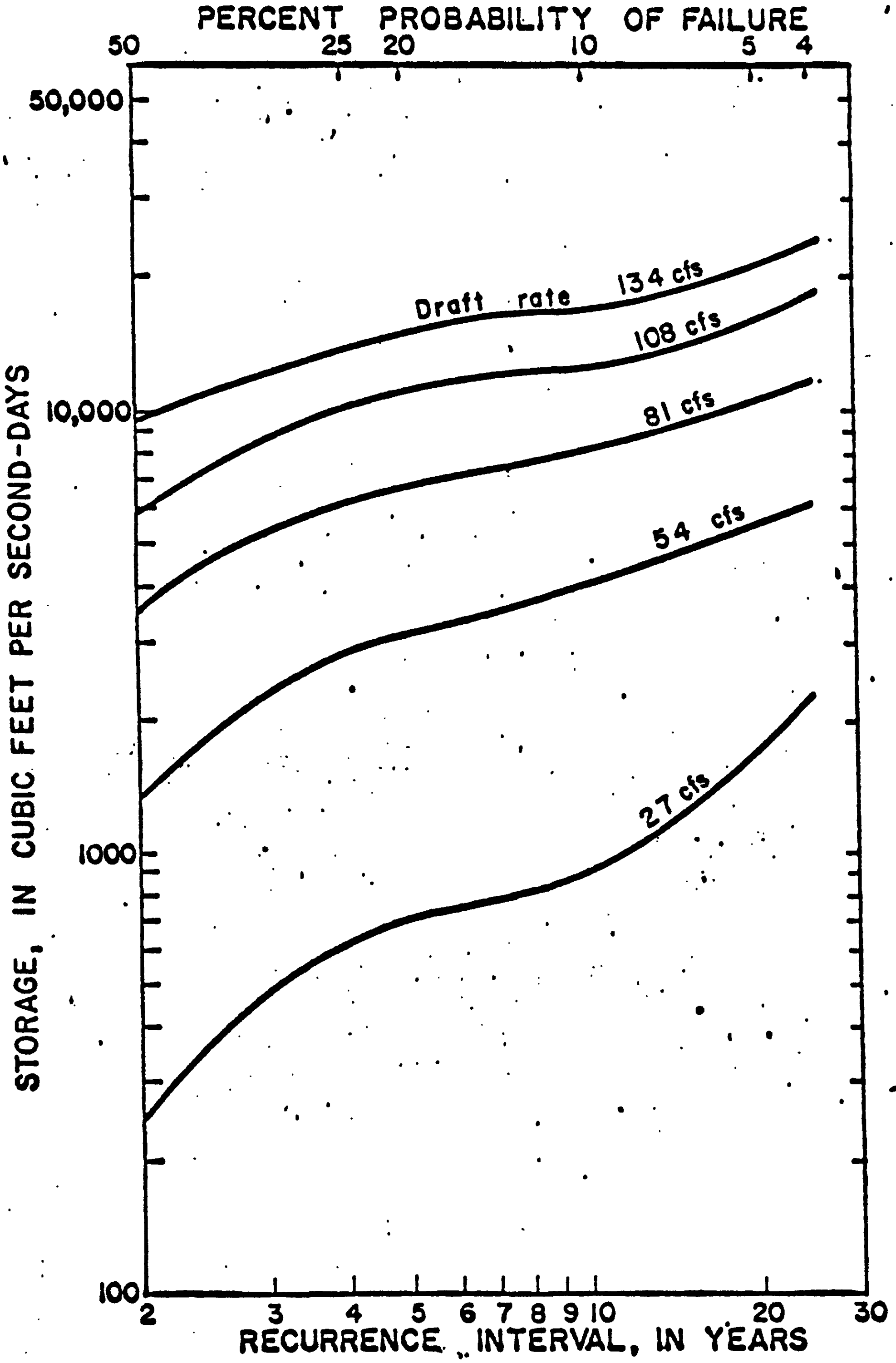

Figure 19.--Draft-storage-frequency curves for North Fork South Branch Potomac River at Cabins.

OEH/WRO

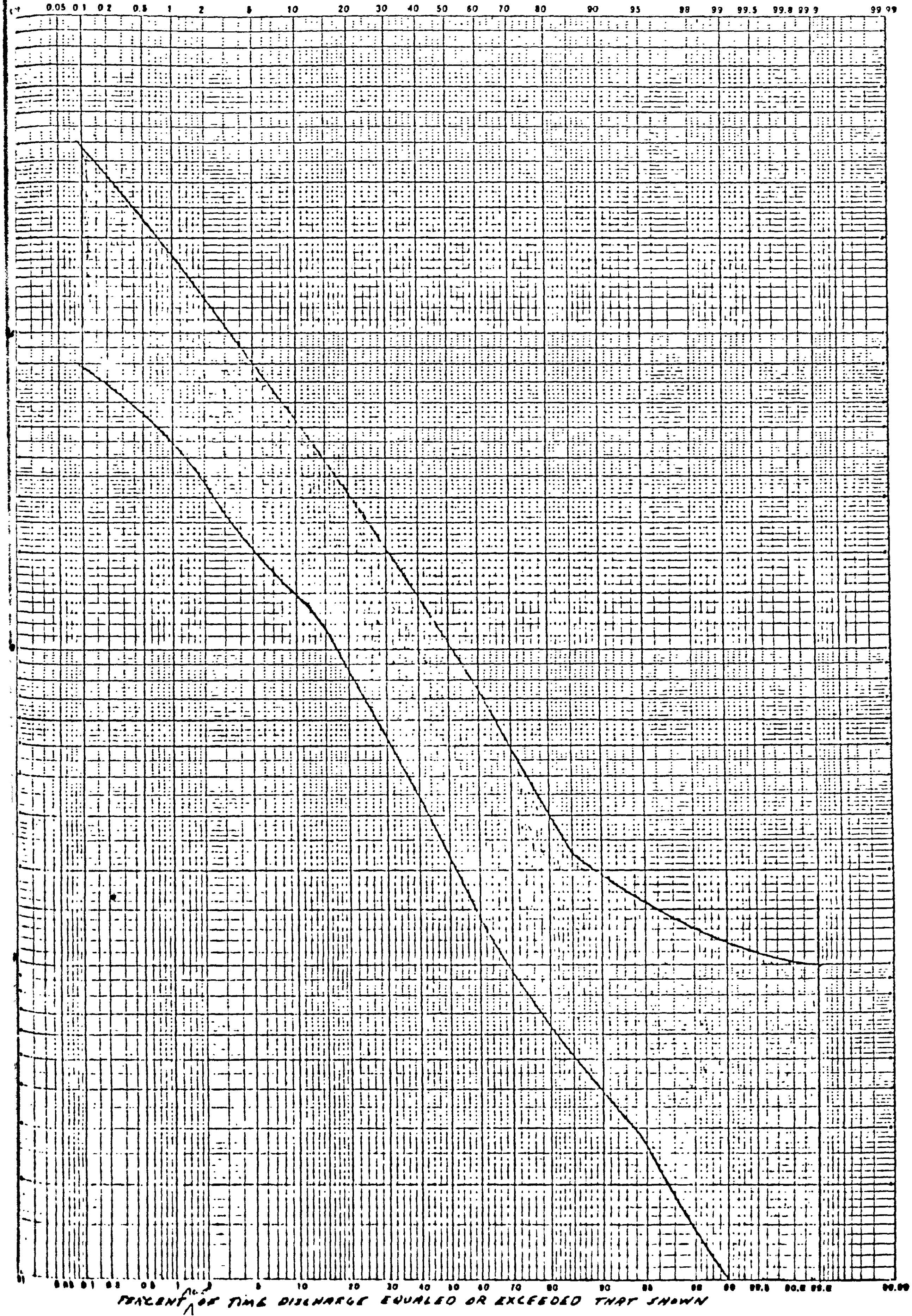

Figure ~~22.~~ 20--Range of flow duration. for 117 gaging stati

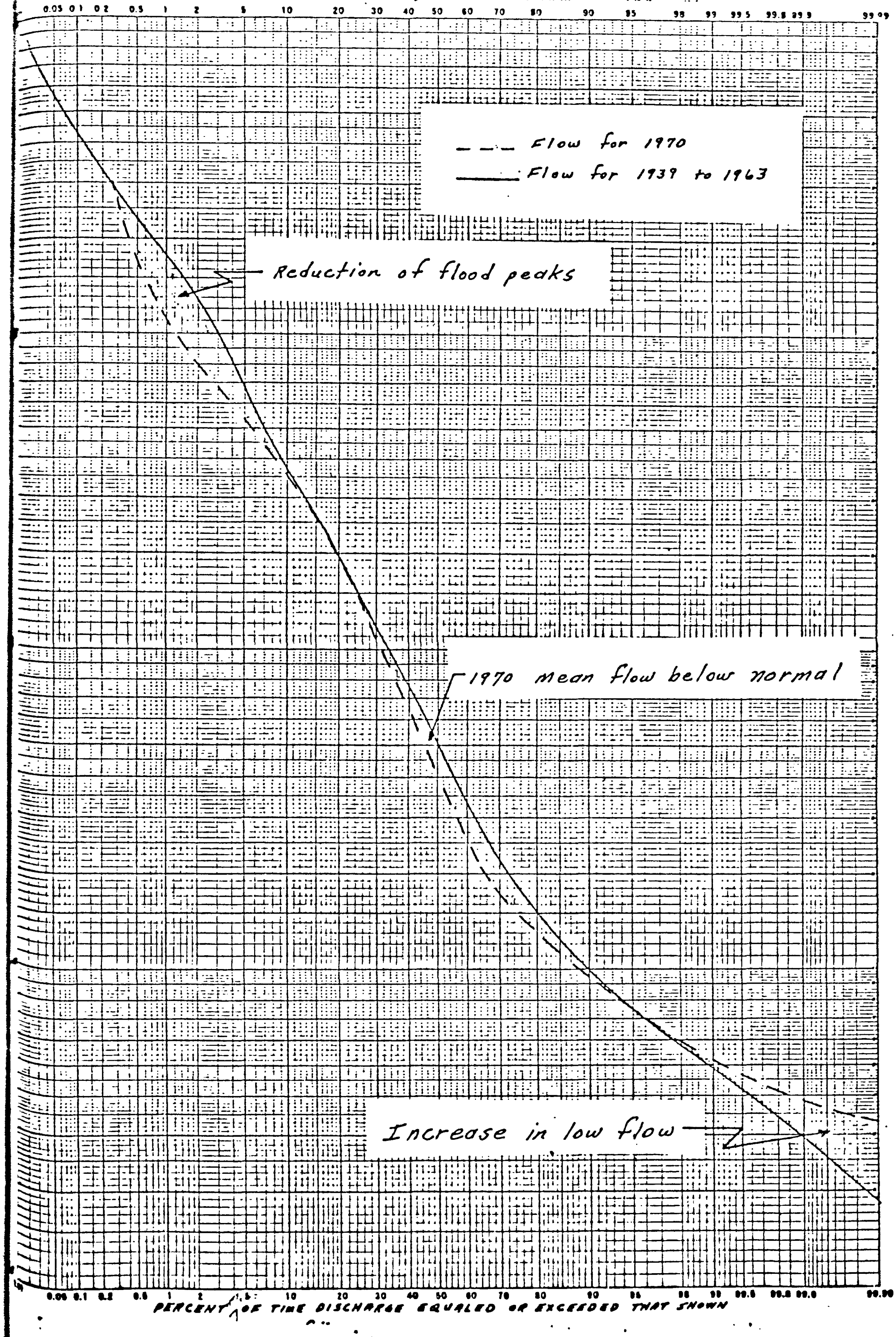

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Figure ~~27~~.--Flow duration differences of Patterson Creek near Headsville

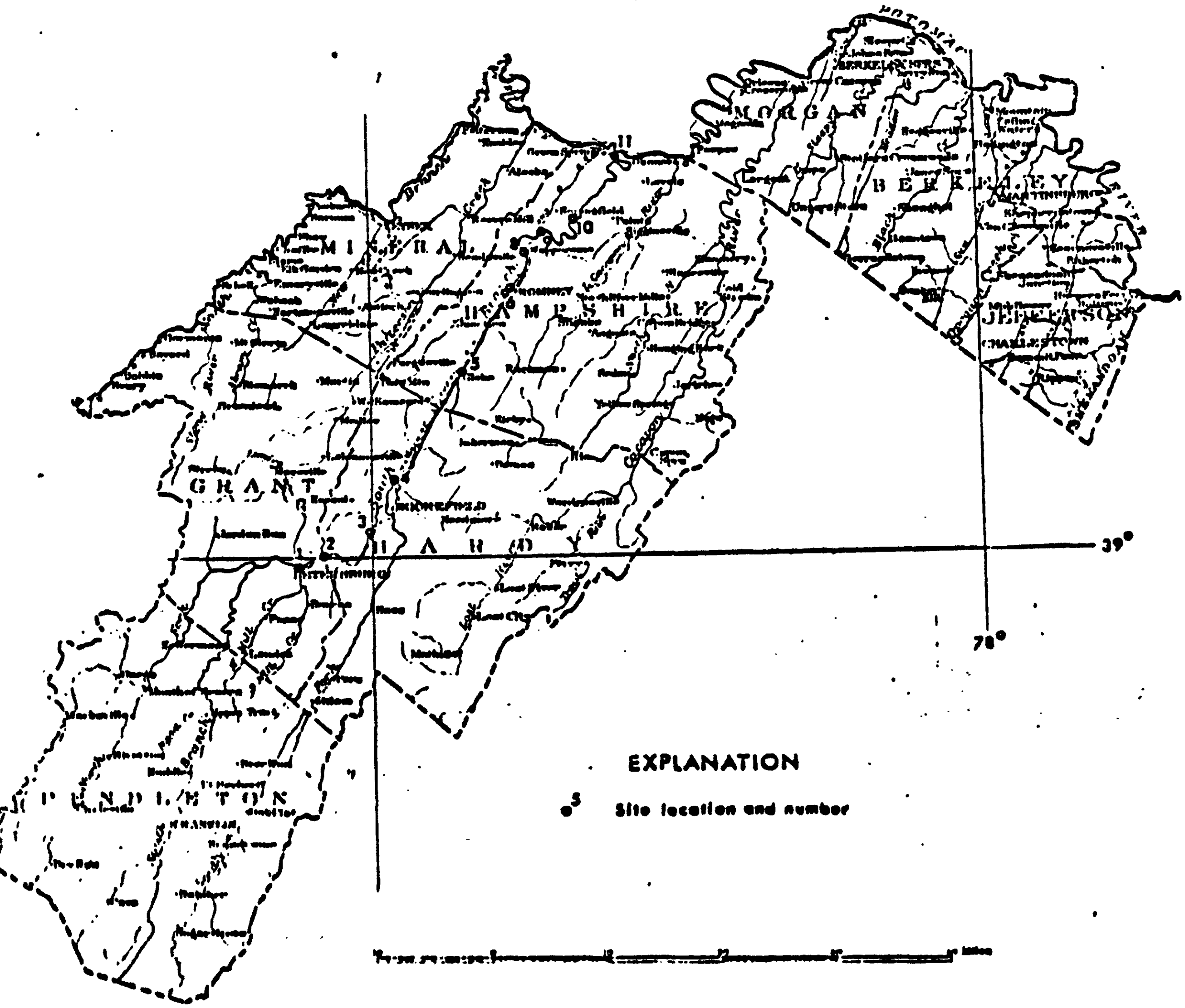


Figure ~~21~~ 22. -- Map showing location of time-of-travel sampling sites.

RE P/WRD

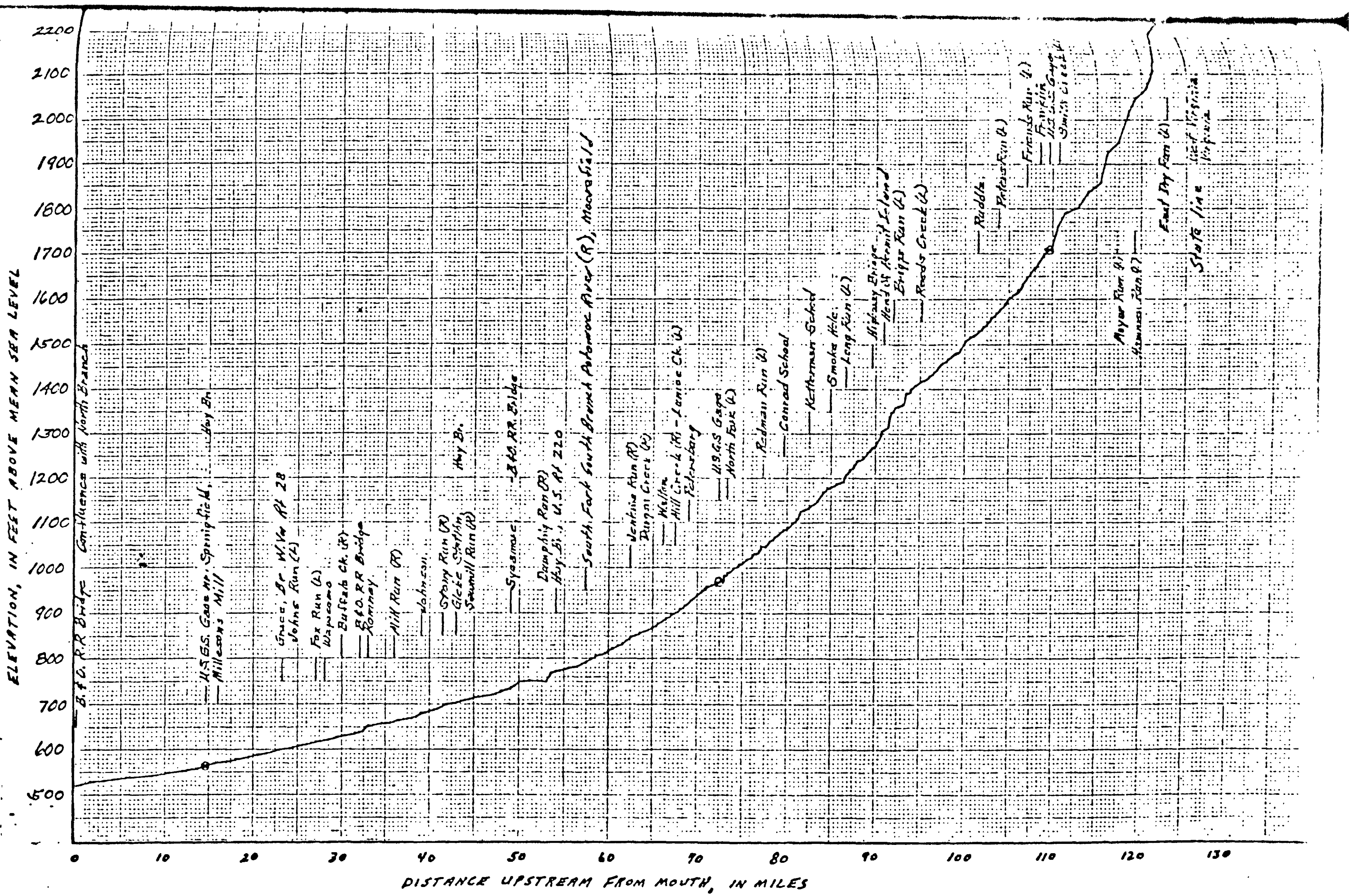


Figure ~~25.~~ 23--Profile of South Branch Potomac River.

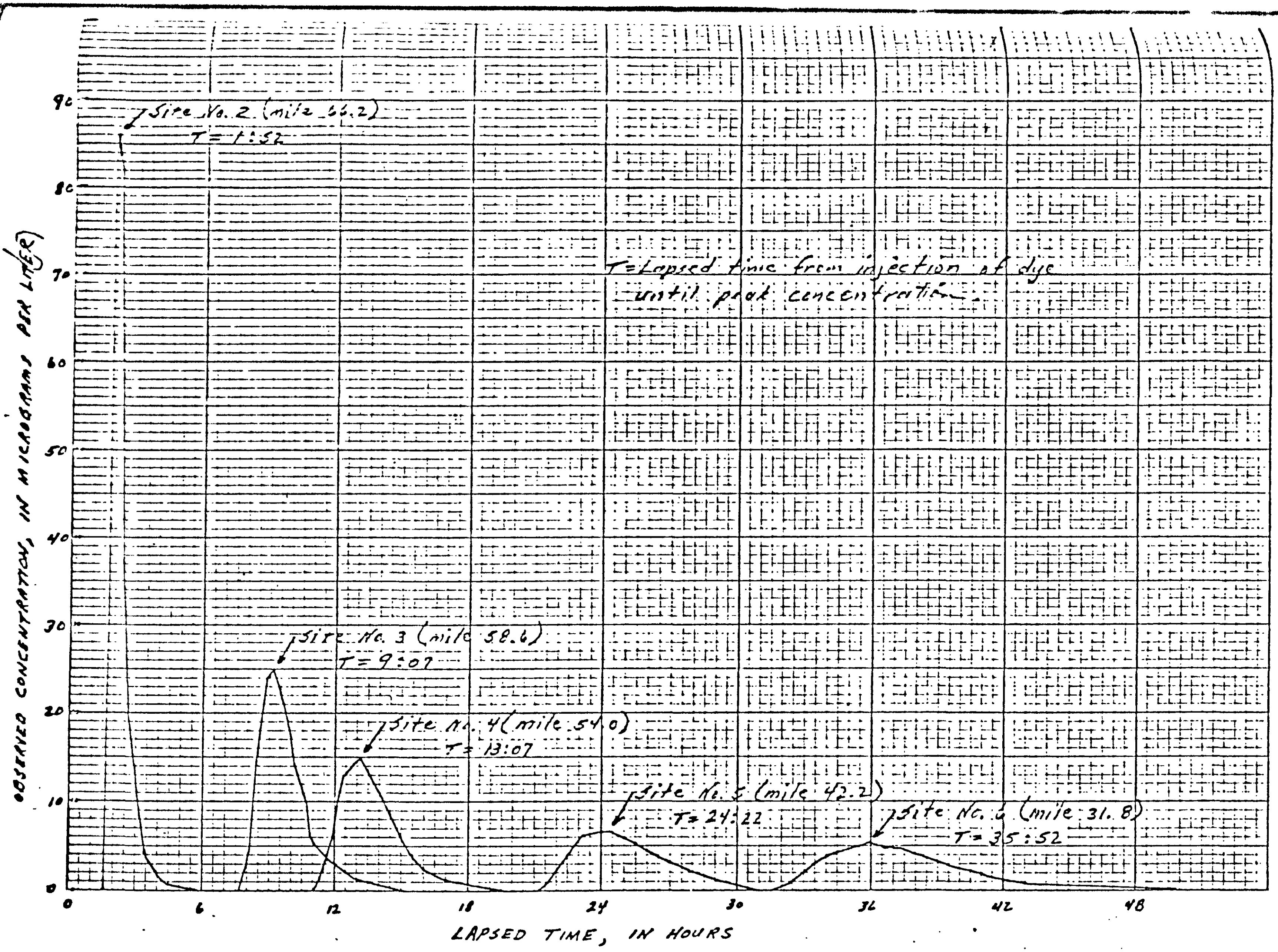


Figure ~~26.~~ 24--Observed time-concentration curves for South Branch Potomac River between Petersburg and Romney.

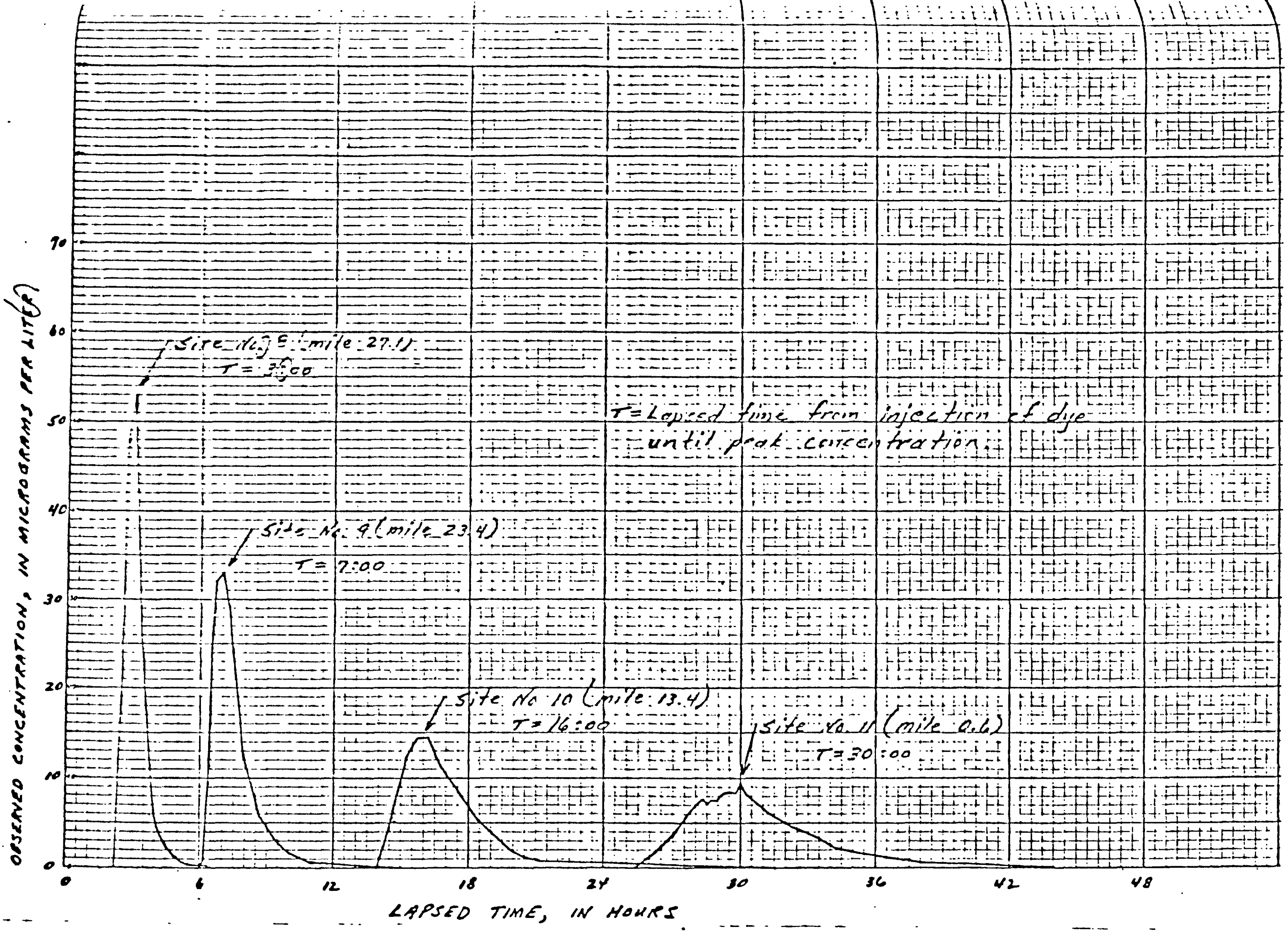


Figure ~~27~~ 25.—Observed time-concentration curves for South Branch Potomac River between Romney and the mouth.

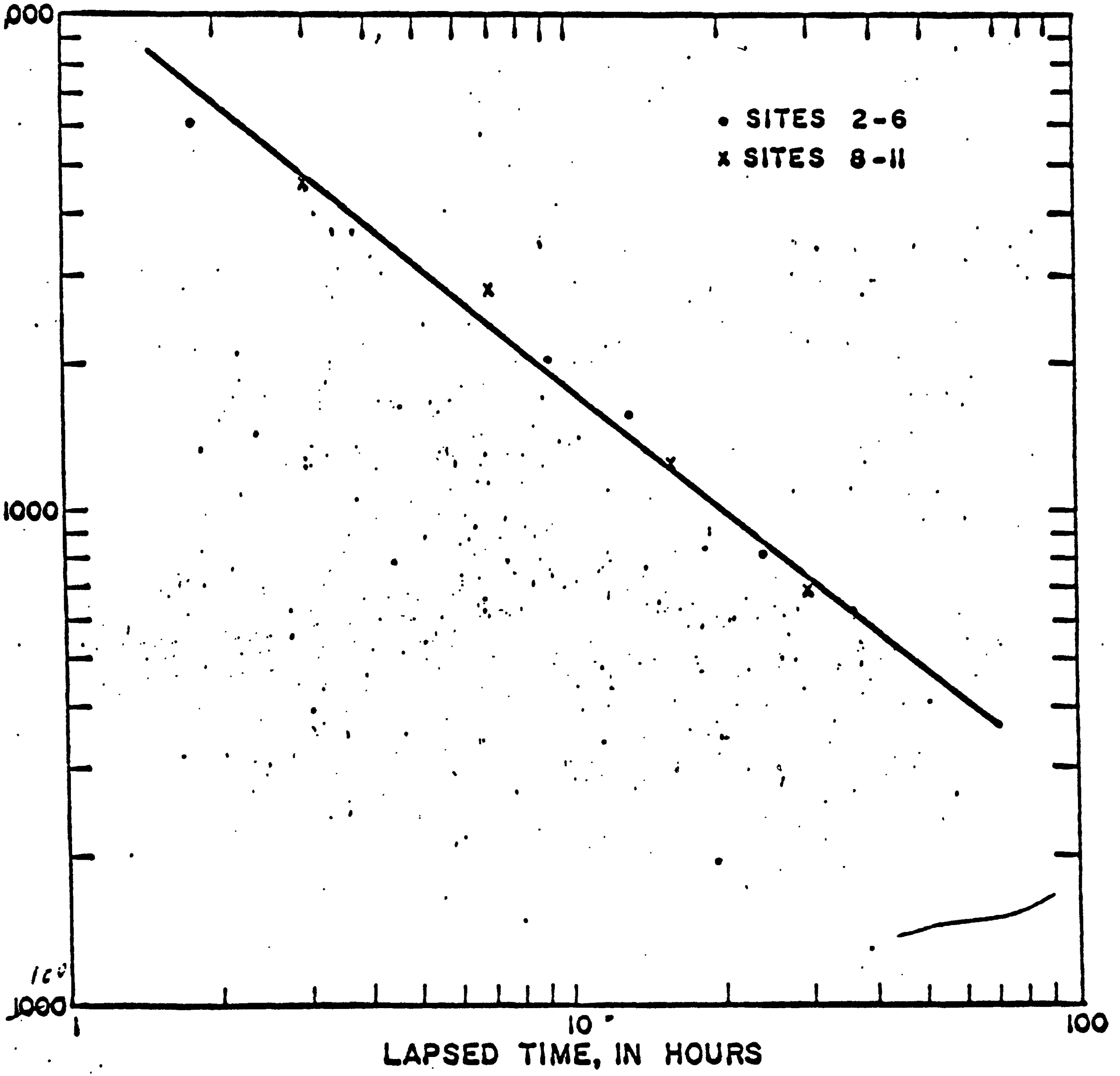
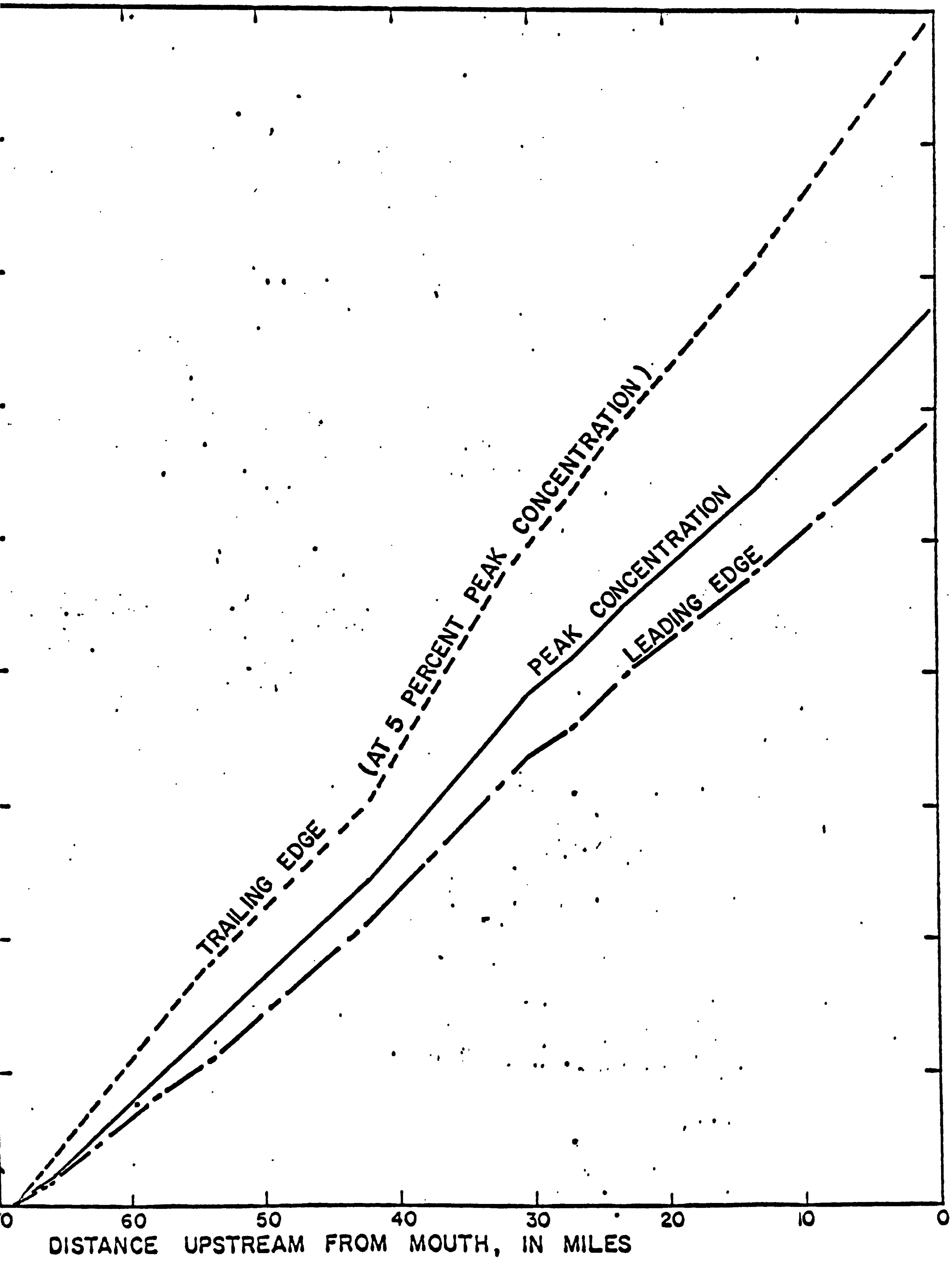


Figure 26.--Peak-concentration attenuation curve.



igure 27.--Traveltime - distance relation on South Branch Potomac River.

A

B

C

Figure 28.--Photographs of limestone quarrys at (A) Mechanicsburg Gap near Romney, (B) a gap near New Creek, and (C) a gap near Baker.

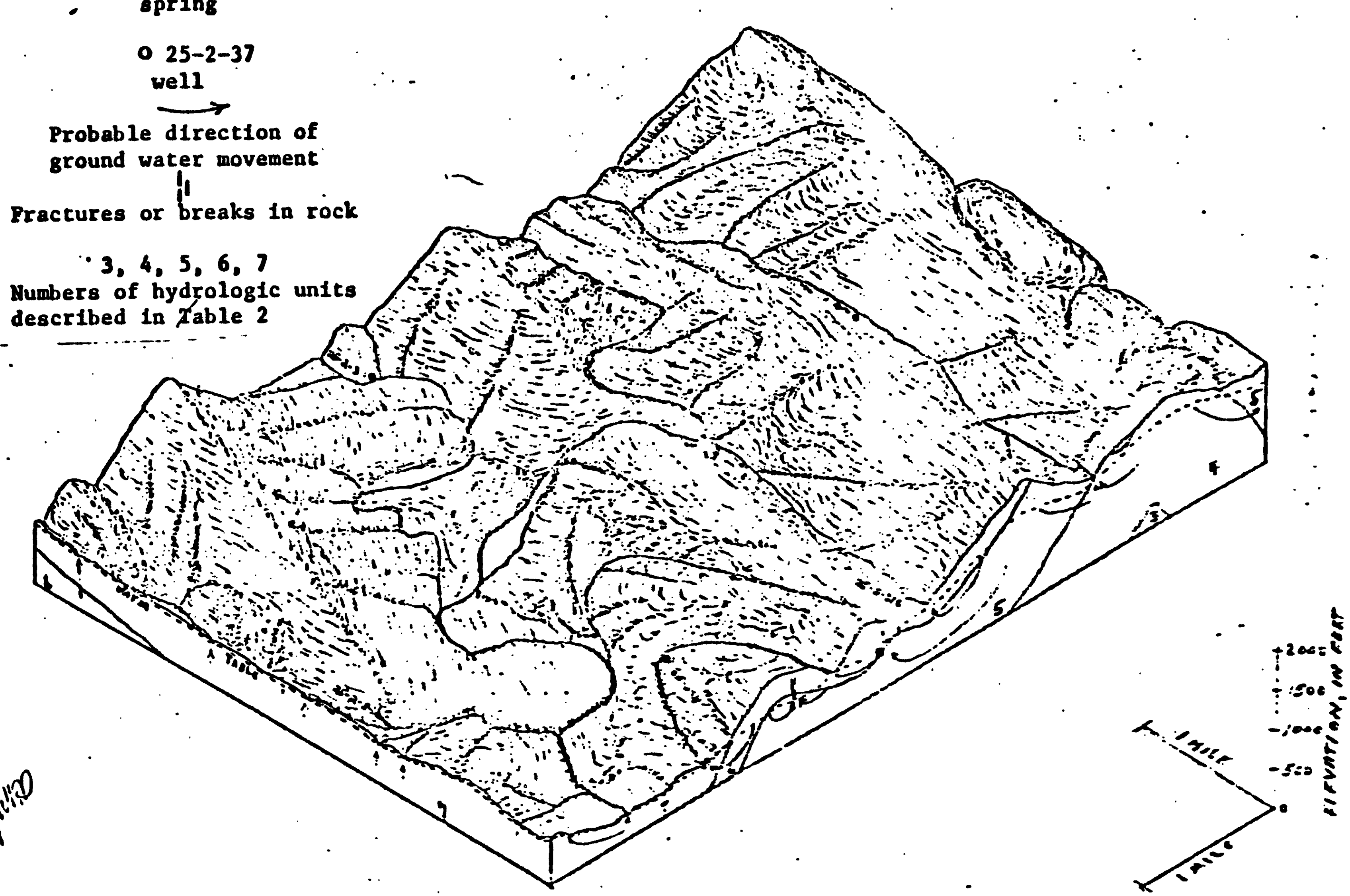
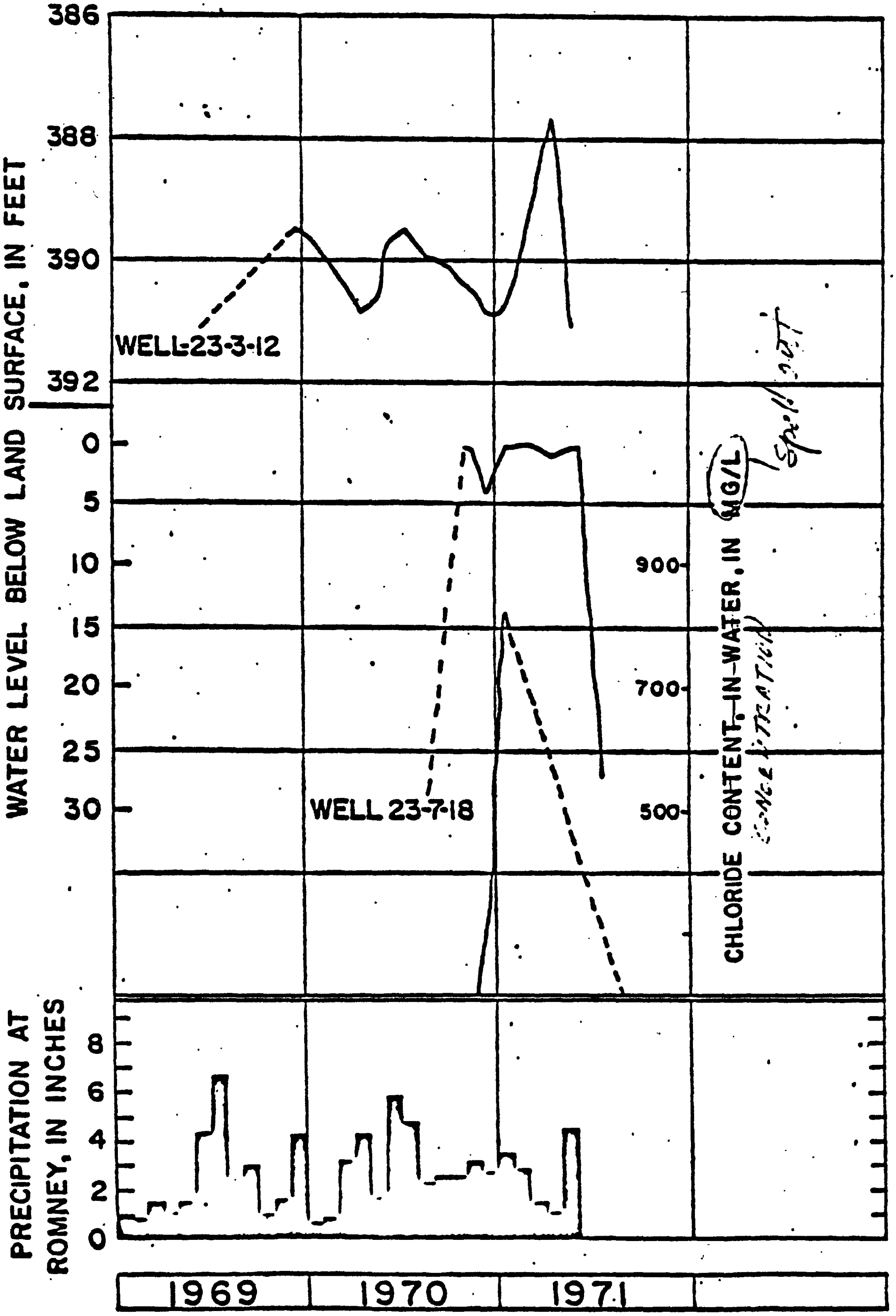


Figure ~~31~~ 29.--Diagram showing the general hydrology of a high-relief area near [illegible]



ure 32.--Water levels in wells 23-7-18 and 23-~~2~~3-12, precipitation at Romney, and chloride content in water from well 23-7-18.

Sample site	Fe	Cl	Hardness	pH	Sp. cond.	Remarks
S_1	<0.1	<8	479	8	745	Iron deposited on wall
S2	3.0	<8	< 357	7.0	600	Do.
S3	<0.1	<8	< 204	8	340	Calcite deposited on wall
S4	<0.1	<8	>221	<8	382	Yellow deposit on wall
S5	<0.1	<8	< 340	8	555	H_2S odor, very wet walls
S6	<0.1	<8	>255	>8	410	very wet walls
S7	0.1	<8	<323	8	490	sample from drainage ditch

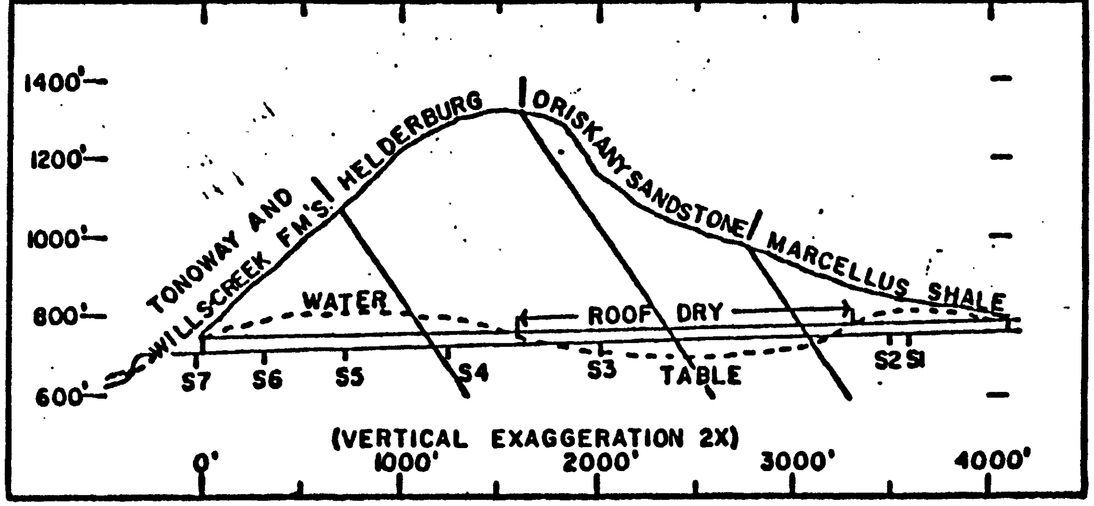
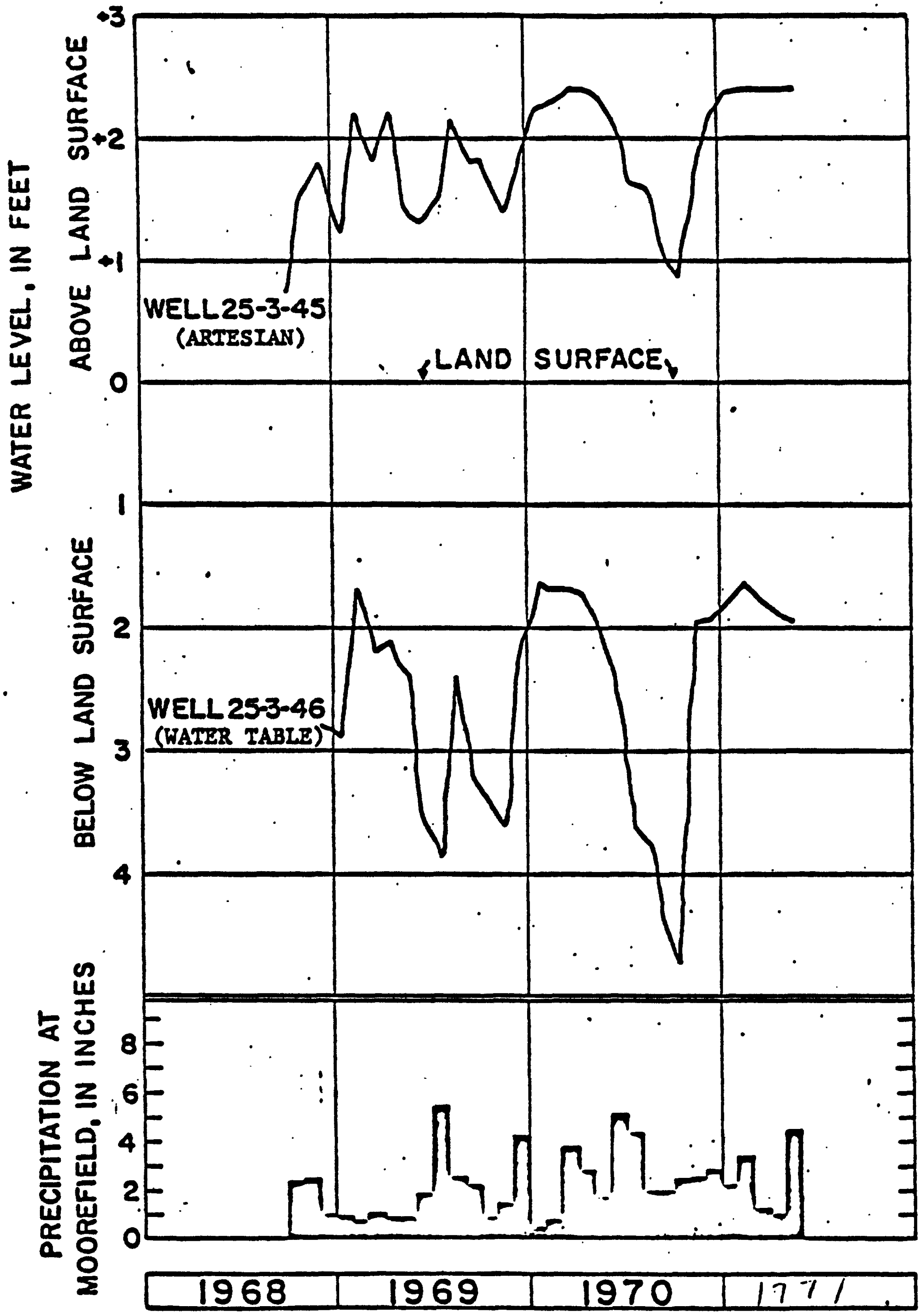


Figure ~~35~~ 33.—Cross section of Knobley Mountain near Short Gap showing railroad tunnel, sampling sites, and probable water table.



gure 36.--Water-level fluctuations in a deep artesian well compared to water-level fluctuations in an adjacent shallow water-table well and

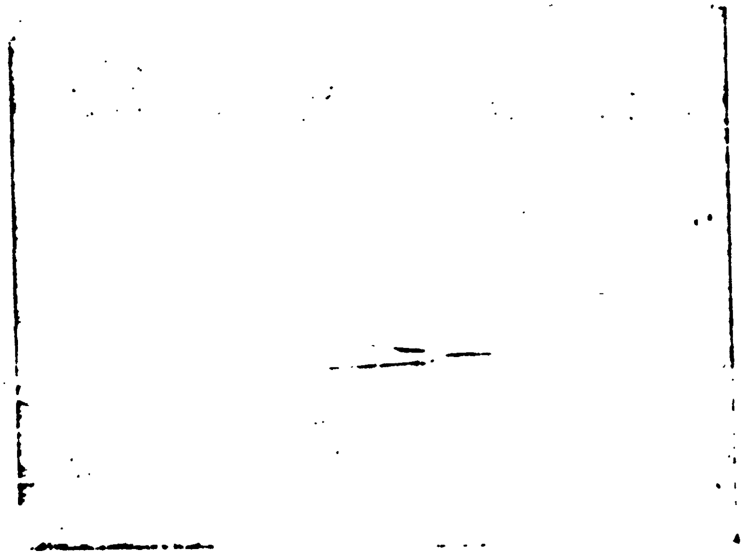


Figure 34.--Photograph of jointing in Oriskany Sandstone.

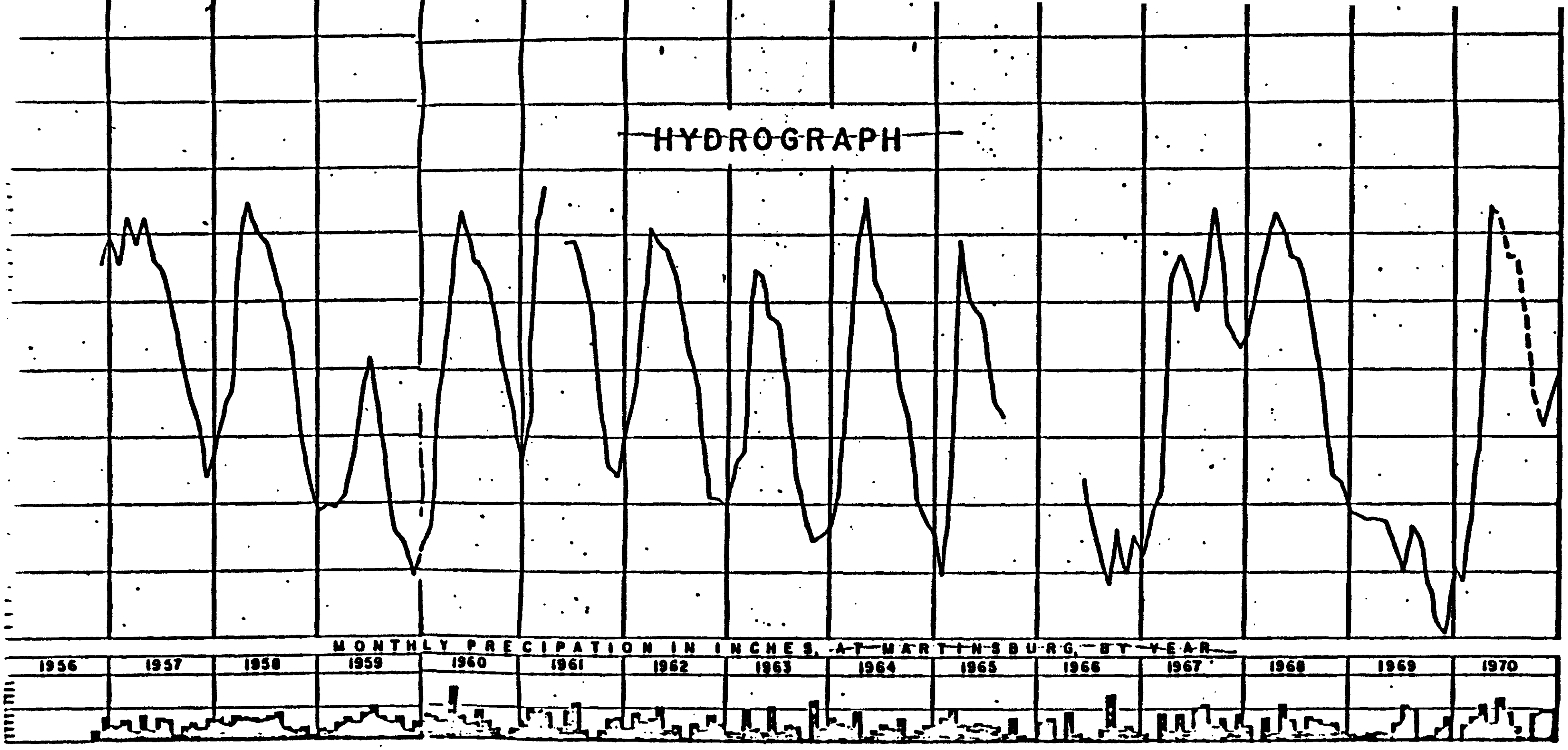


Figure ~~38~~ 35.--Hydrograph of water-level fluctuations in well 20-5-7 and precipitation at Martinsburg.

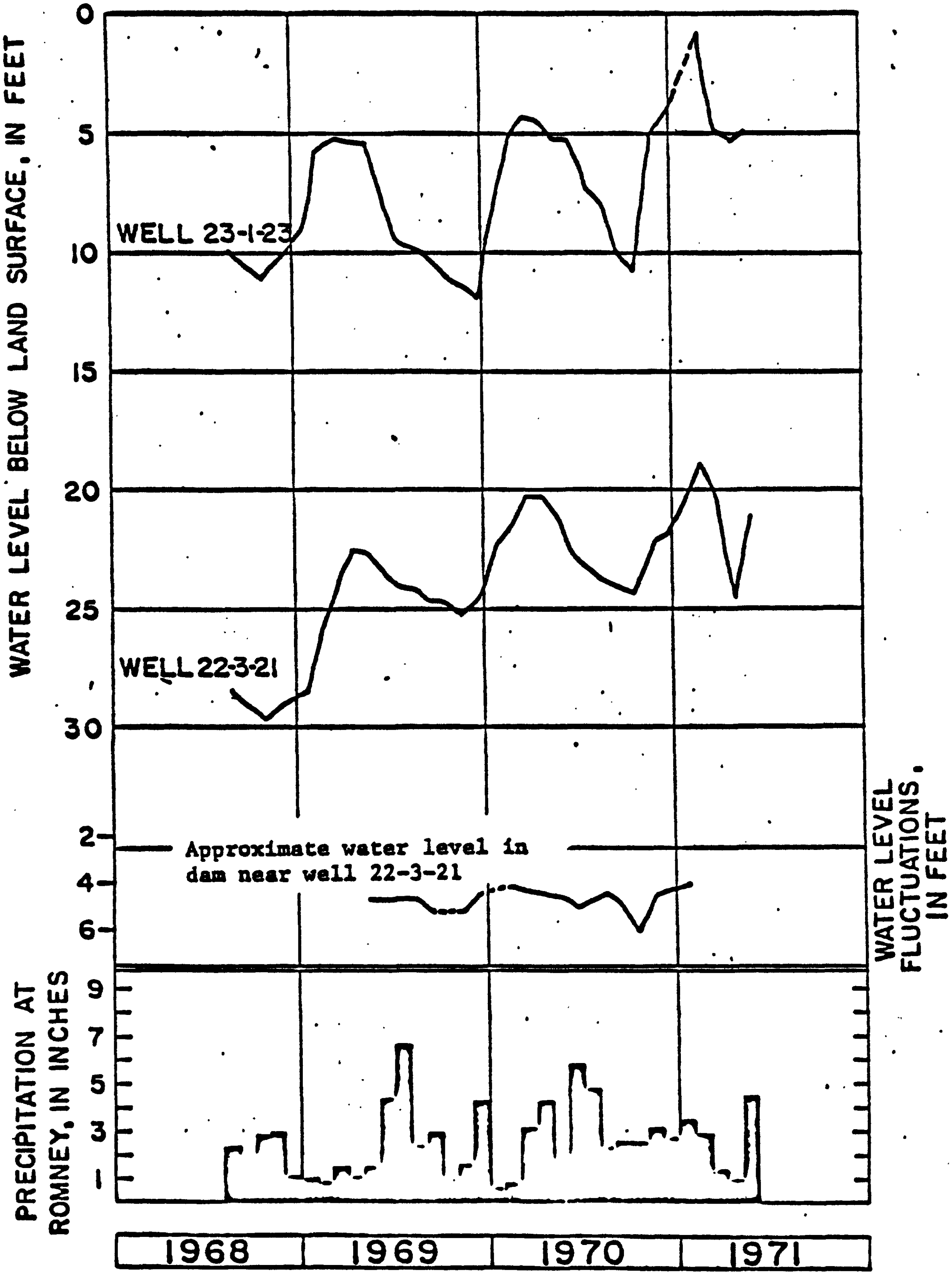


Figure 37.--Water levels of wells 22-3-21 and 23-1-23, precipitation at Romney, and approximate water-level fluctuations in dam near well 22-3-21.

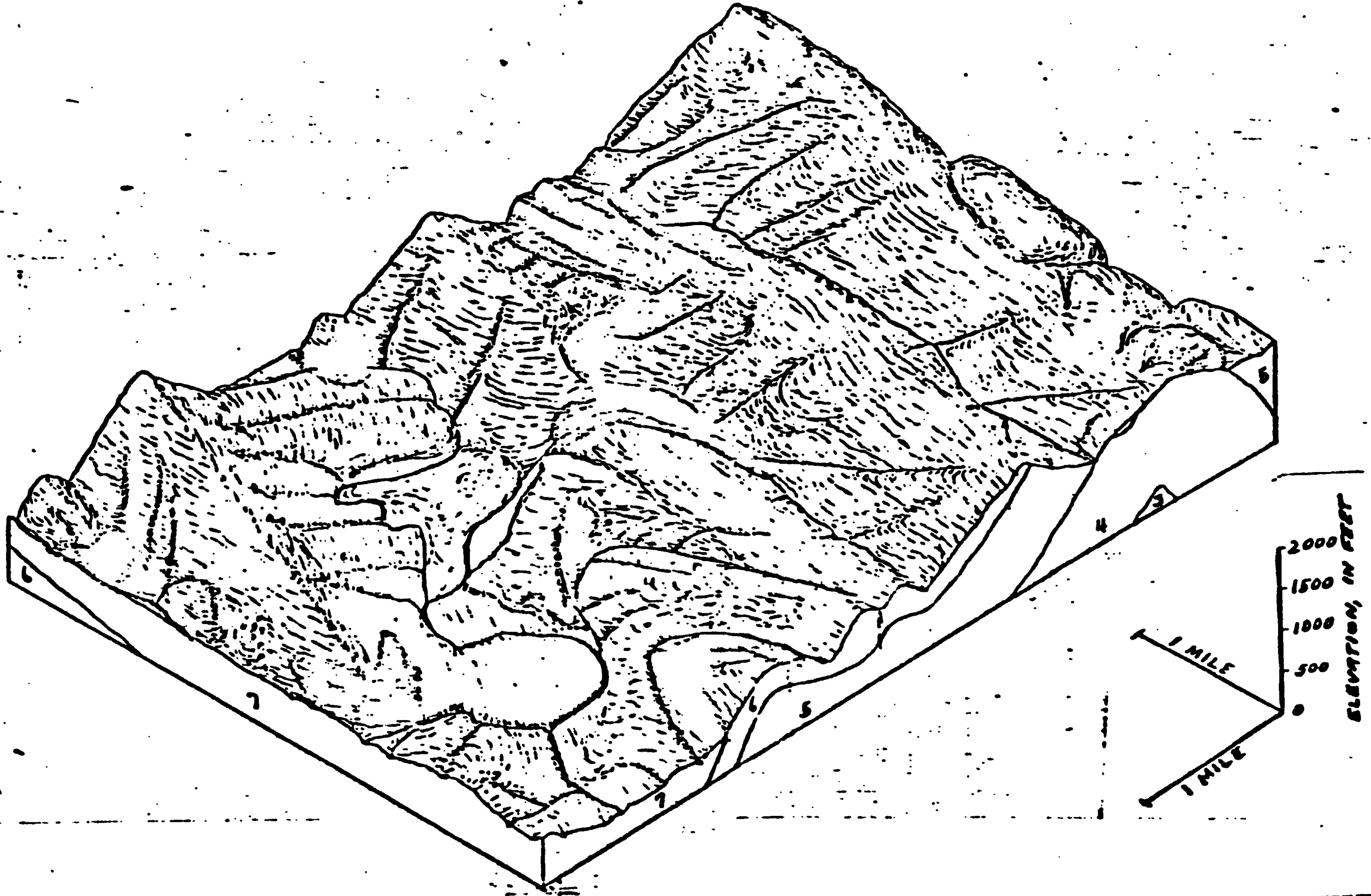


Figure ~~41~~ 38.--~~Best~~ places where to obtain relatively large quantities of good quality ground water from wells or springs.

may be obtained

To be deleted

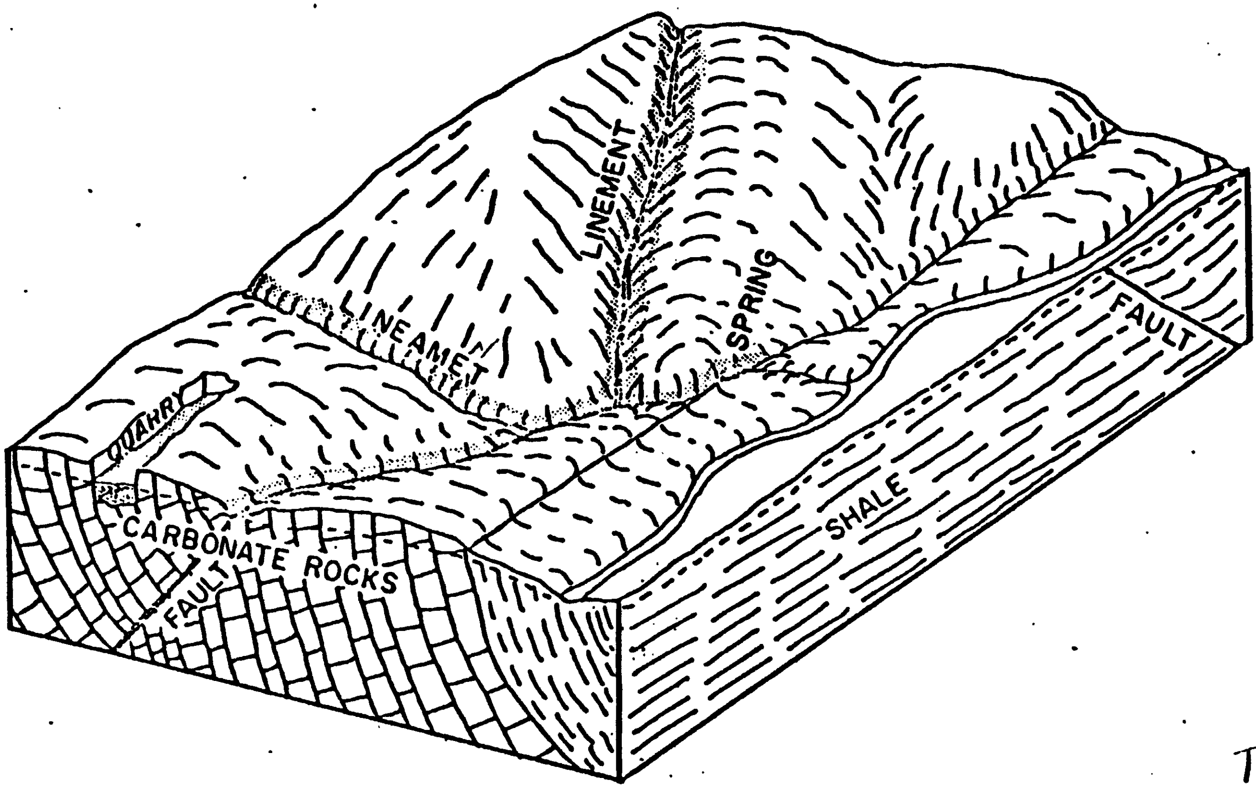


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Figure ~~42~~39.--Places to develop moderate to large ground-water supplies in areas underlain by carbonate rocks.

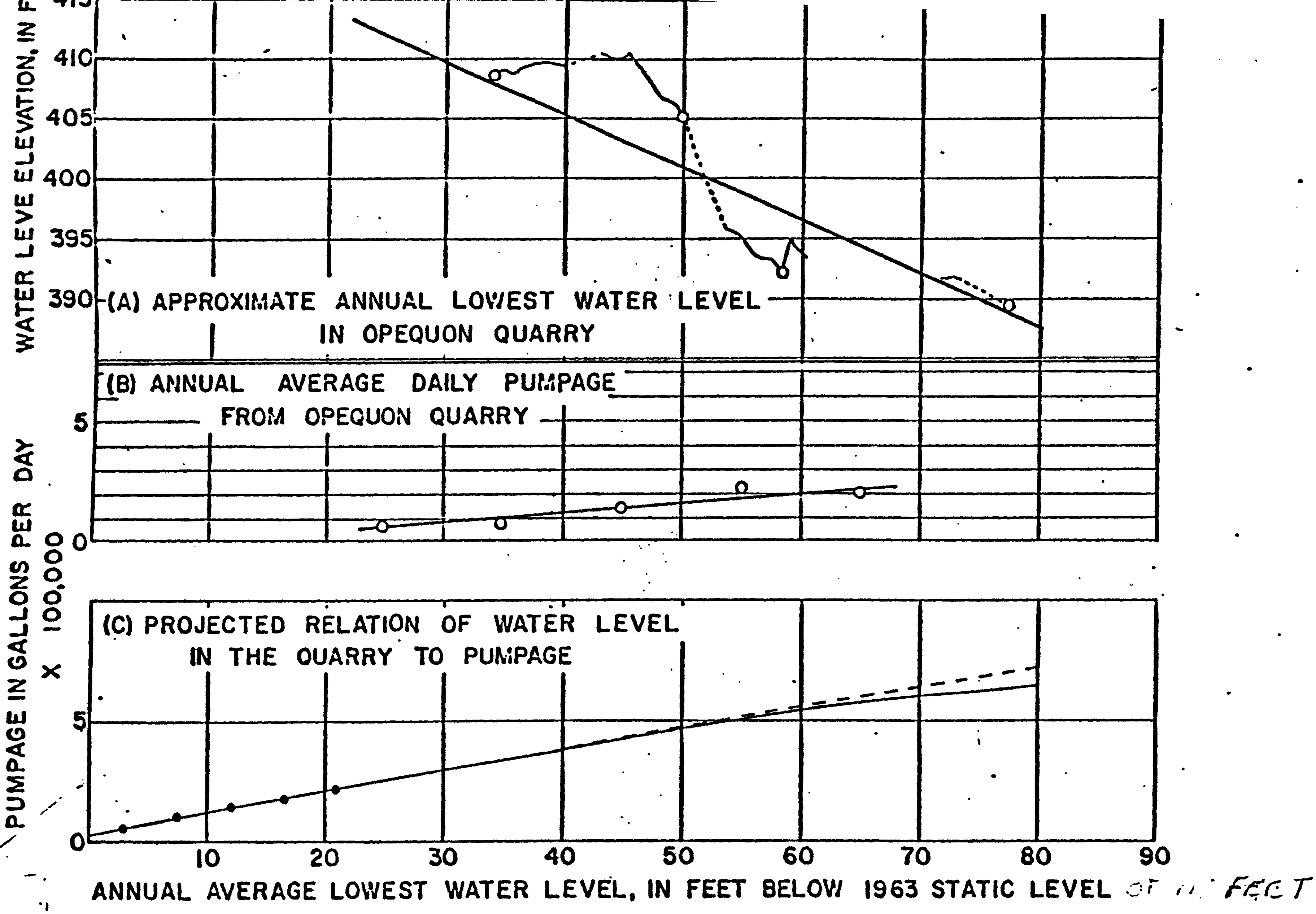
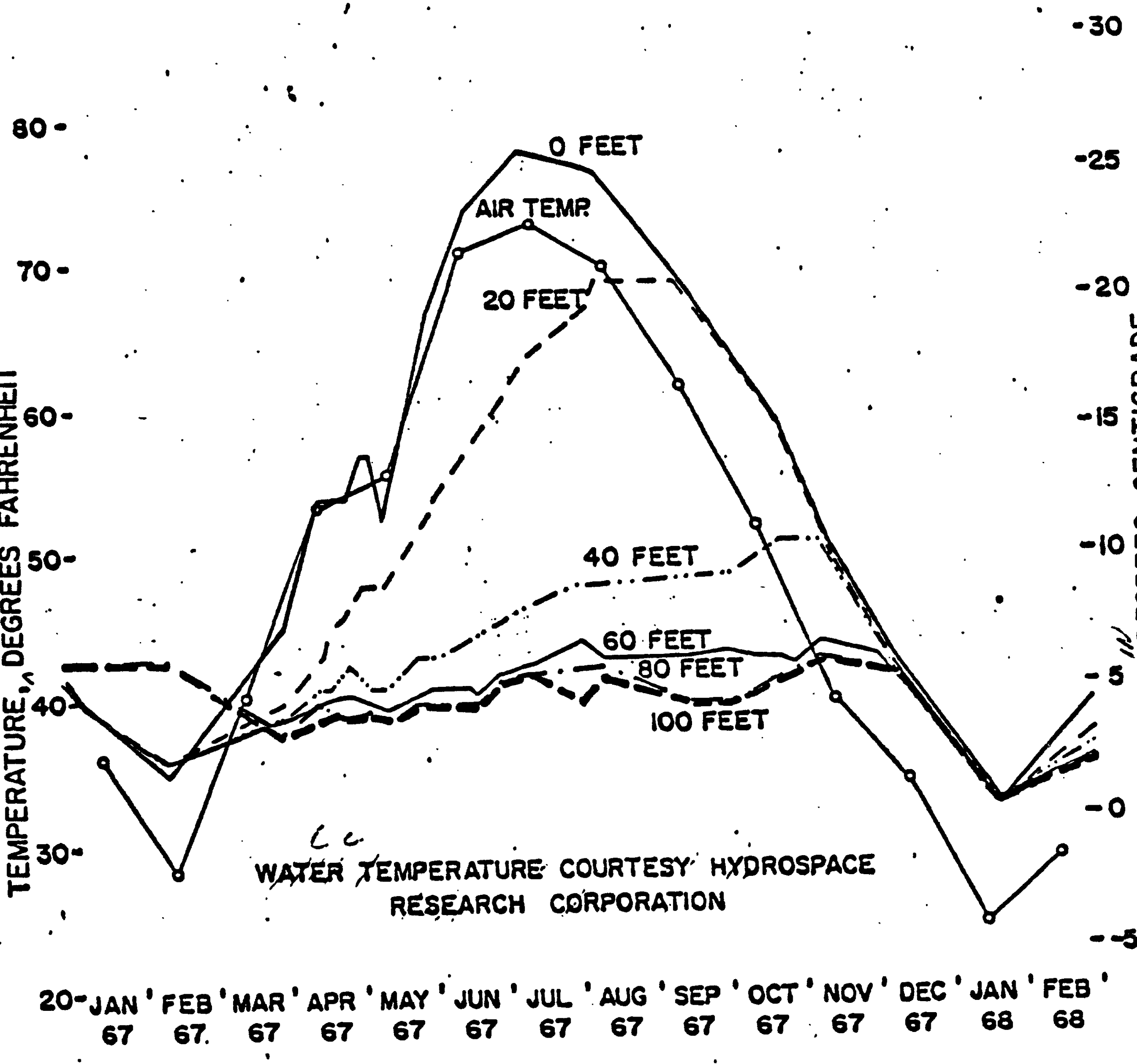


Figure ~~43~~ 40.--Approximate lowest water level in Opequon Quarry, average daily pumpage from the quarry, and relation of water level in the quarry to pumpage.



igure 41.— Water temperature at various depths in the Martinsburg Quarry near Martinsburg and average monthly air temperature at Martinsburg Airport.

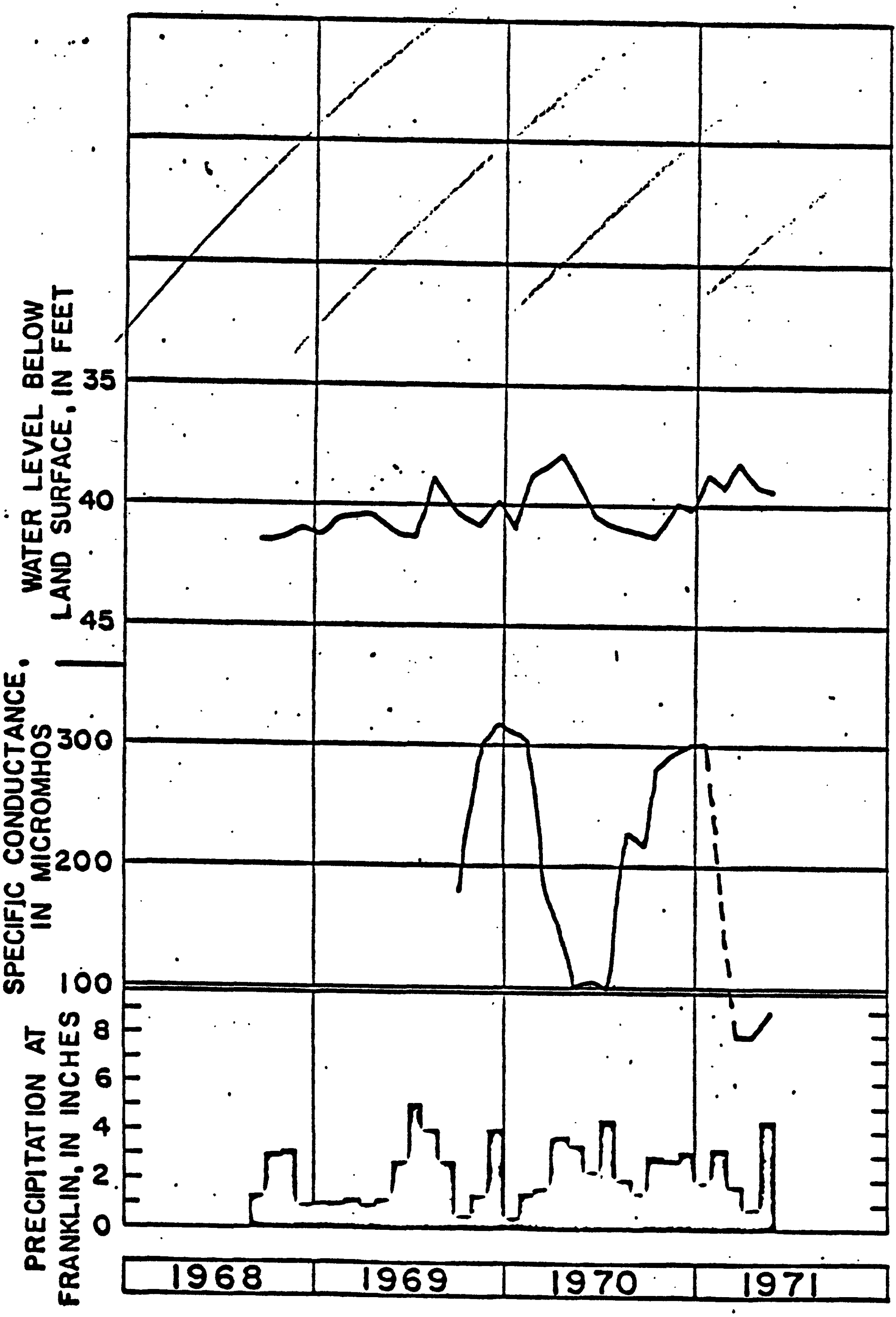
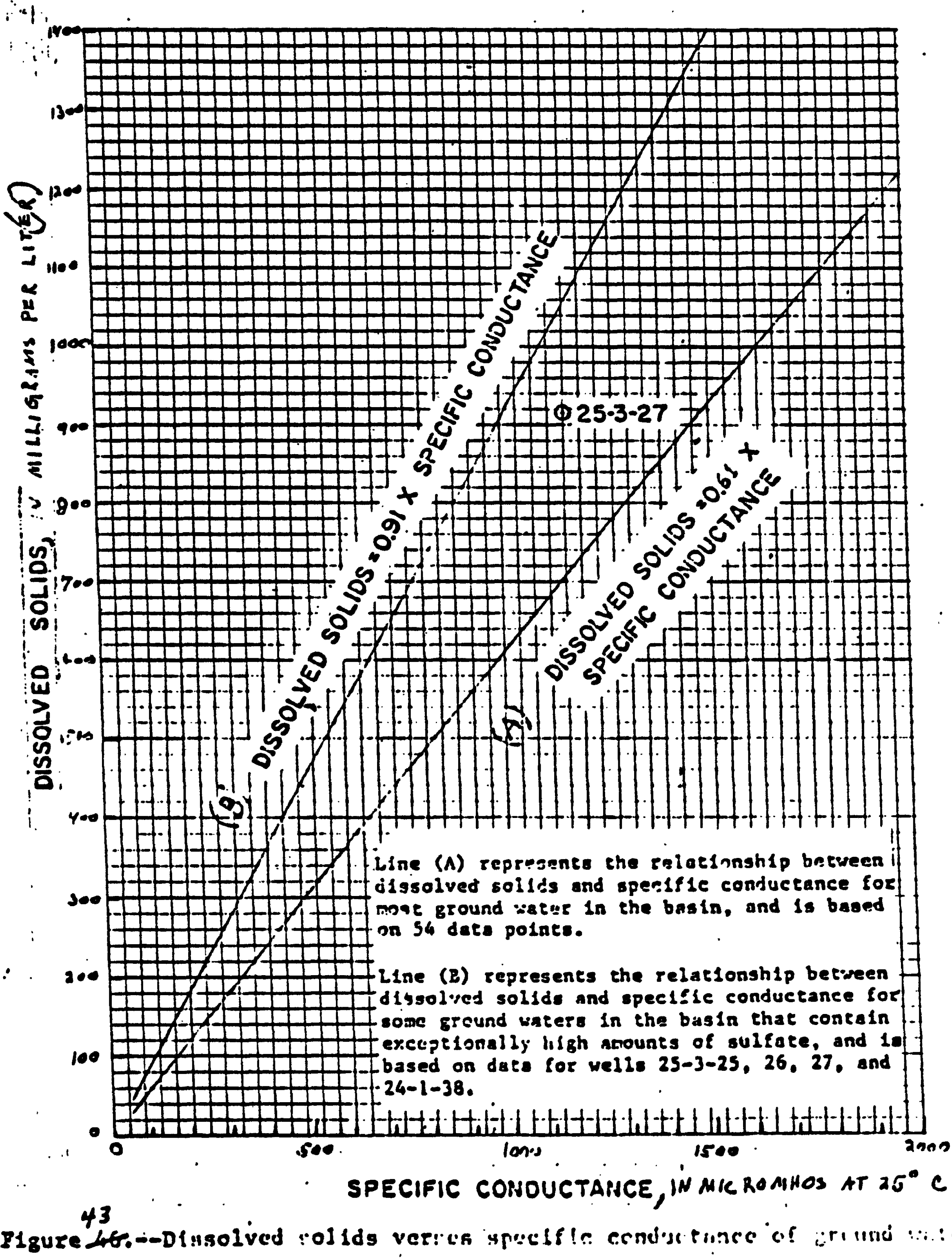


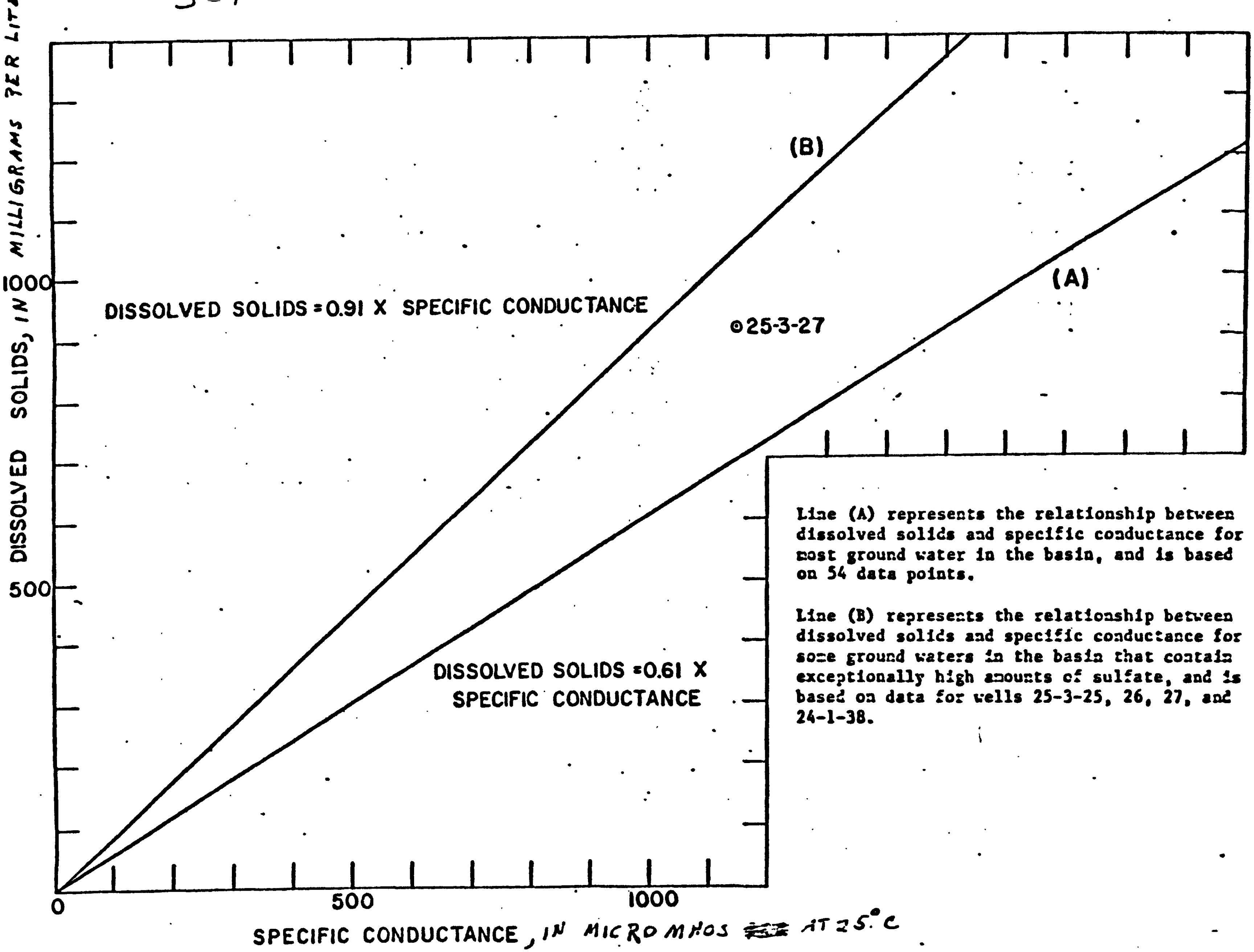
Figure 42.--Water level and specific conductance of water from well 26-2-14 and precipitation at Franklin.



Line (A) represents the relationship between dissolved solids and specific conductance for most ground water in the basin, and is based on 54 data points.

Line (B) represents the relationship between dissolved solids and specific conductance for some ground waters in the basin that contain exceptionally high amounts of sulfate, and is based on data for wells 25-3-25, 26, 27, and 24-1-38.

Figure ~~46~~ 43.--Dissolved solids versus specific conductance of ground water.



Line (A) represents the relationship between dissolved solids and specific conductance for most ground water in the basin, and is based on 54 data points.

Line (B) represents the relationship between dissolved solids and specific conductance for some ground waters in the basin that contain exceptionally high amounts of sulfate, and is based on data for wells 25-3-25, 26, 27, and 24-1-38.

Figure ~~46~~ 43.--Dissolved solids verses specific conductance of ground water.

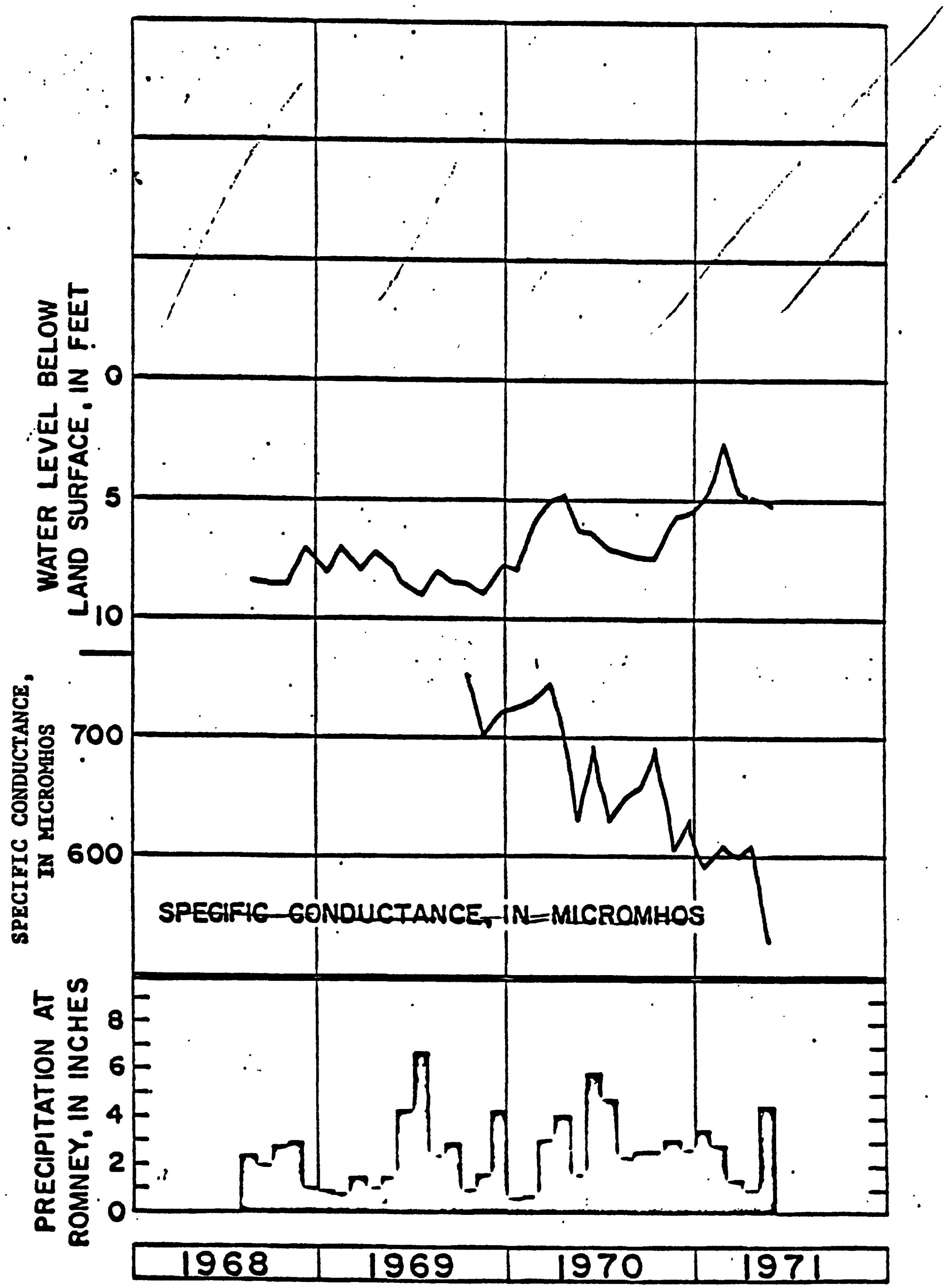


Figure 44.--Water level and specific conductance of water from well 23-5-17 and precipitation at Romney.

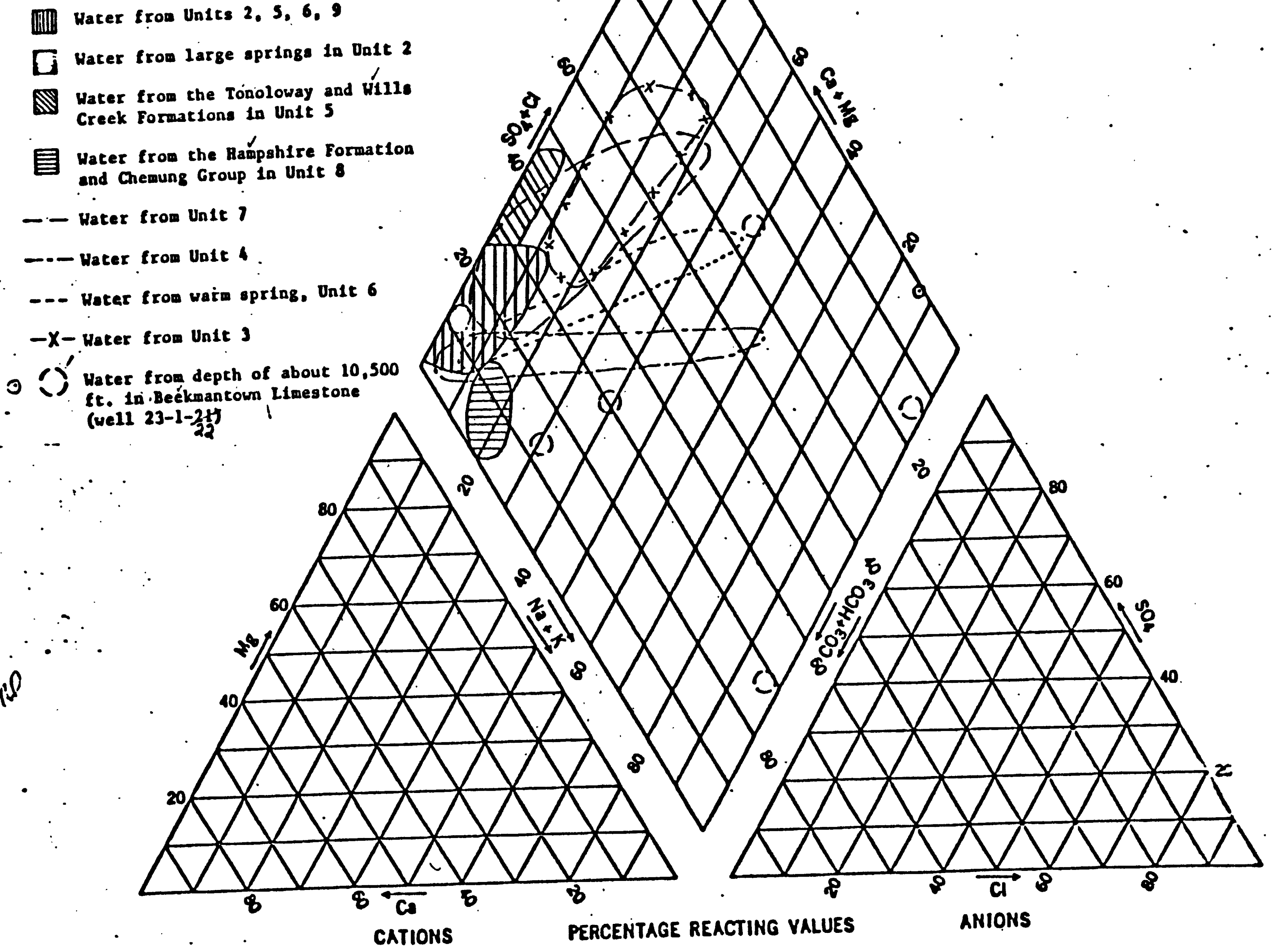
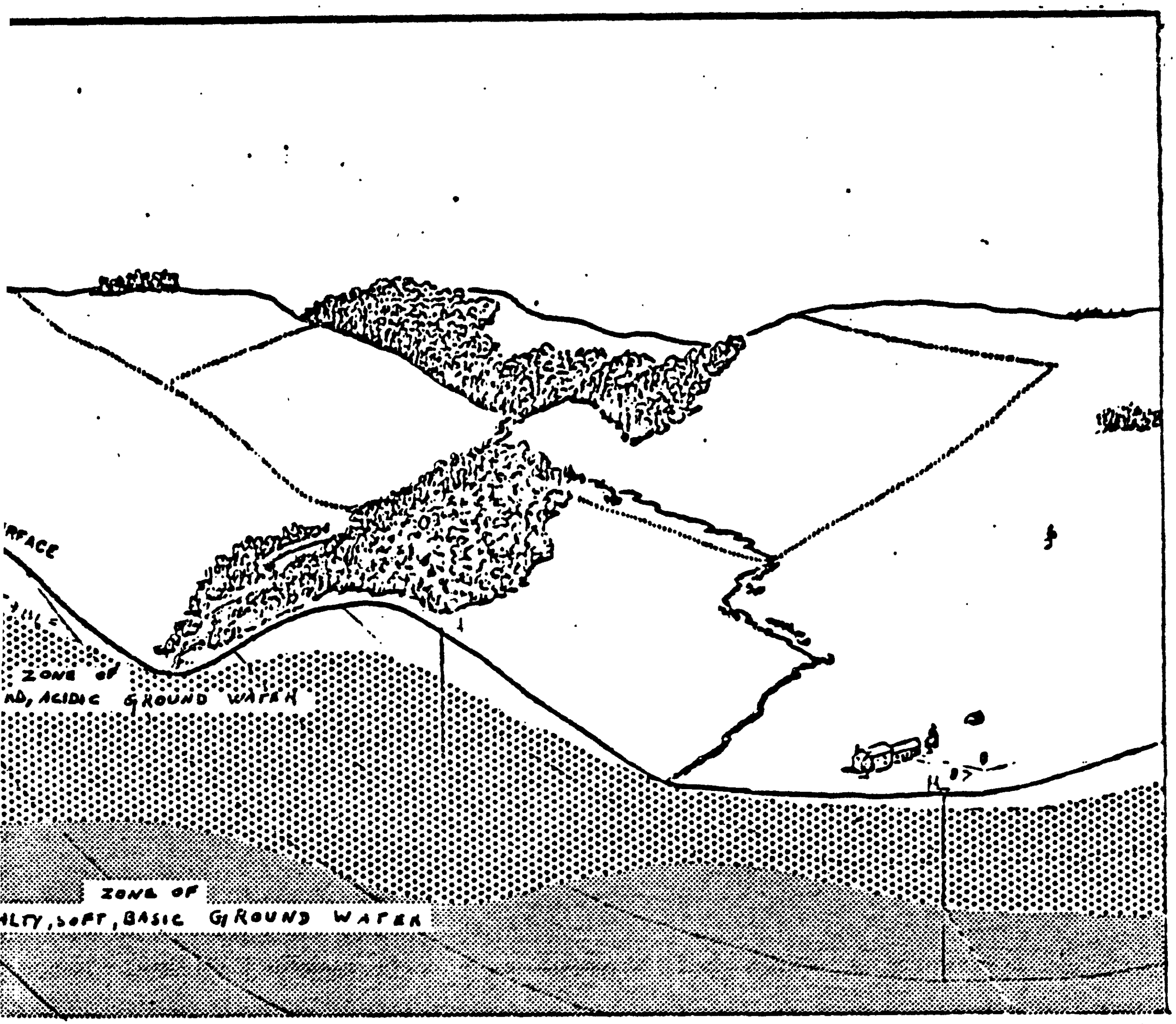


Figure ~~44~~ 45.--Trilinear diagram showing relative chemical content of ground water from various sources.



re 45A.—Diagram showing the zones of fresh and salty ground water in the synclinal beds of shale and siltstone beneath Patterson Creek and Mill Creek valleys. Well A ~~produces~~ yields fresh water and well B ~~produces~~ yields salty water.

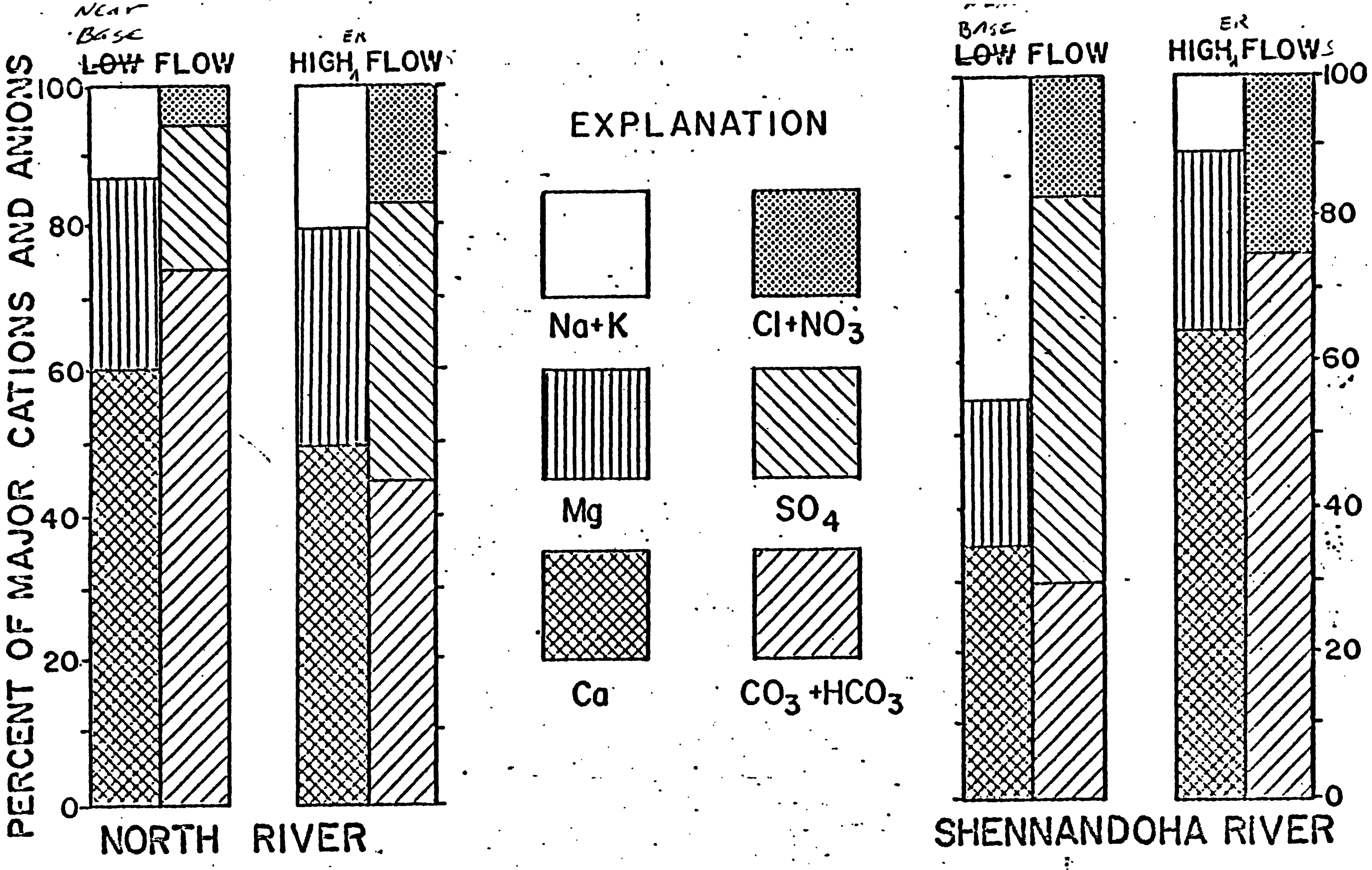


Figure ~~46.~~ 46--Changes in proportion of major ions with changes in flow.

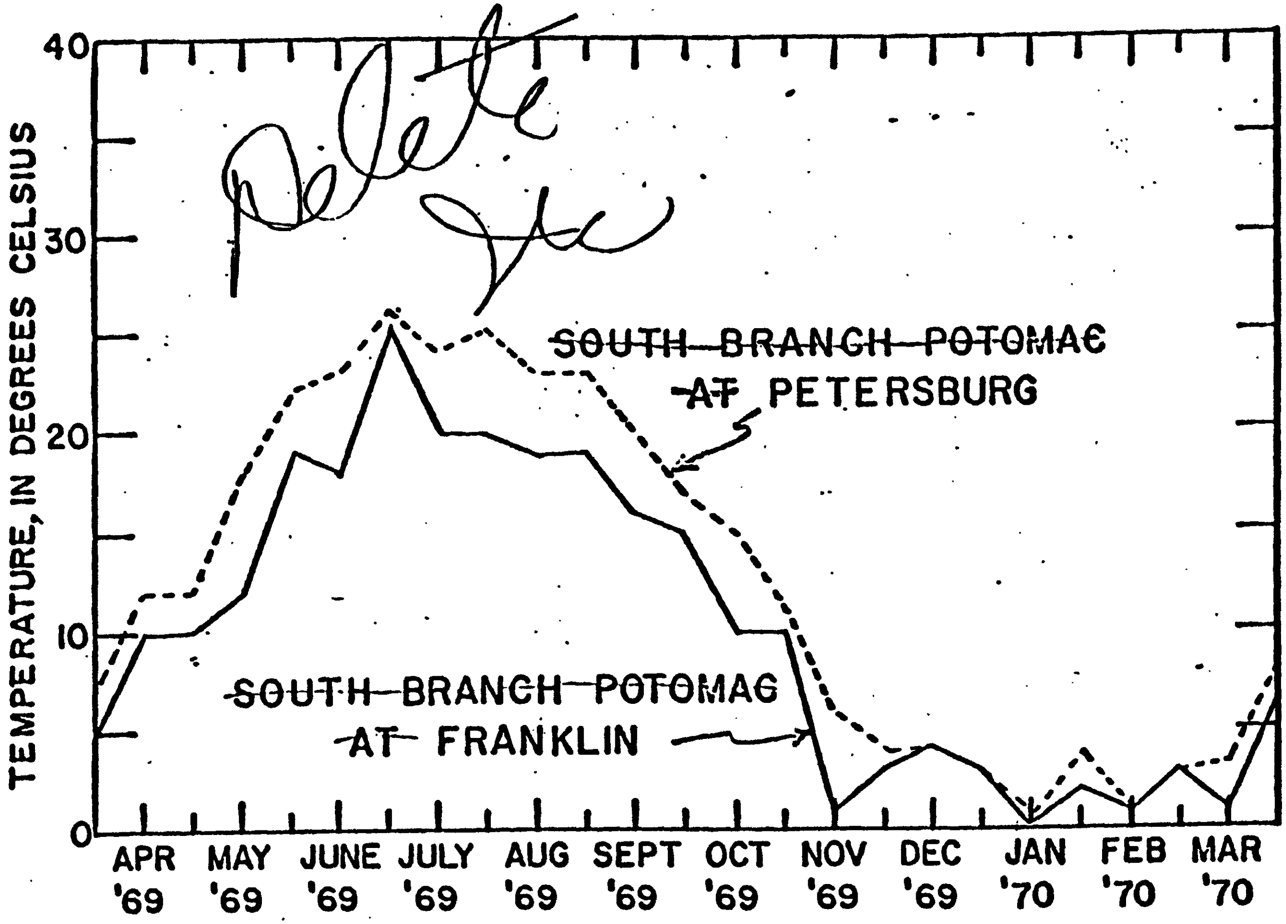


Figure ~~49~~ 47.--Once daily water temperatures for the first and fifteenth day of each month for South Branch Potomac River at Franklin and Petersburg.

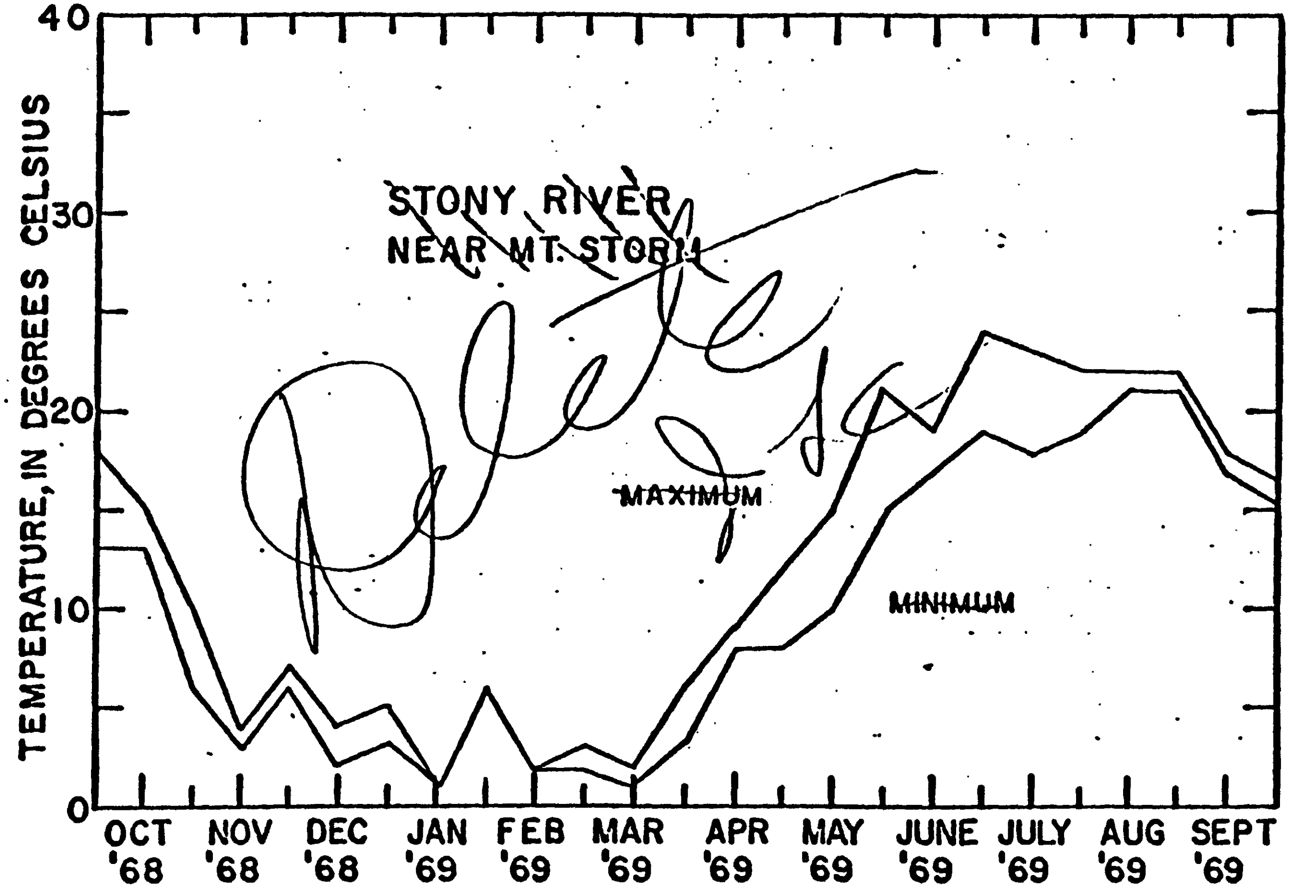


Figure ~~50~~ 48.—Maximum and minimum daily water temperature for the first and fifteenth day of each month for Stony River near Mount Storm.

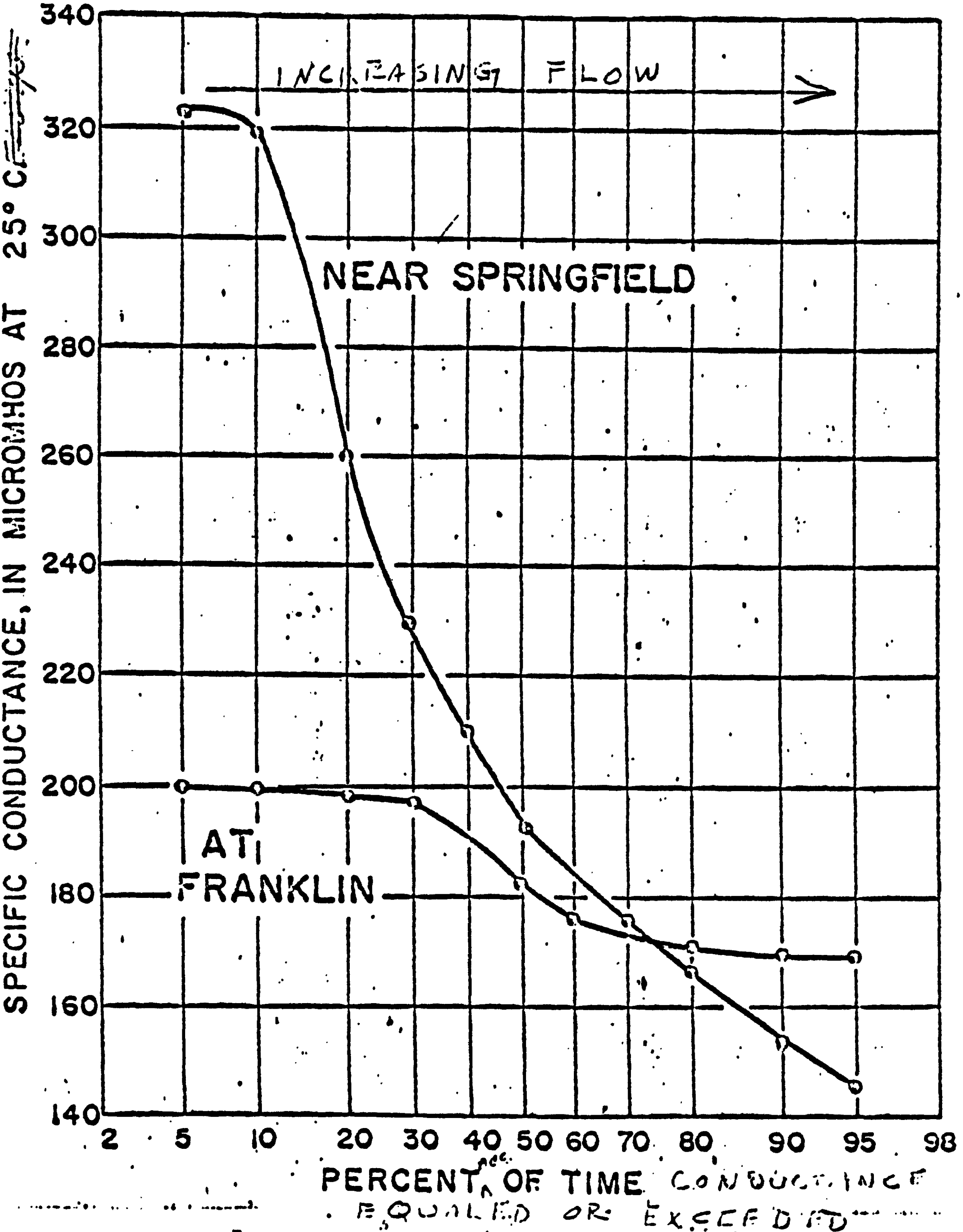
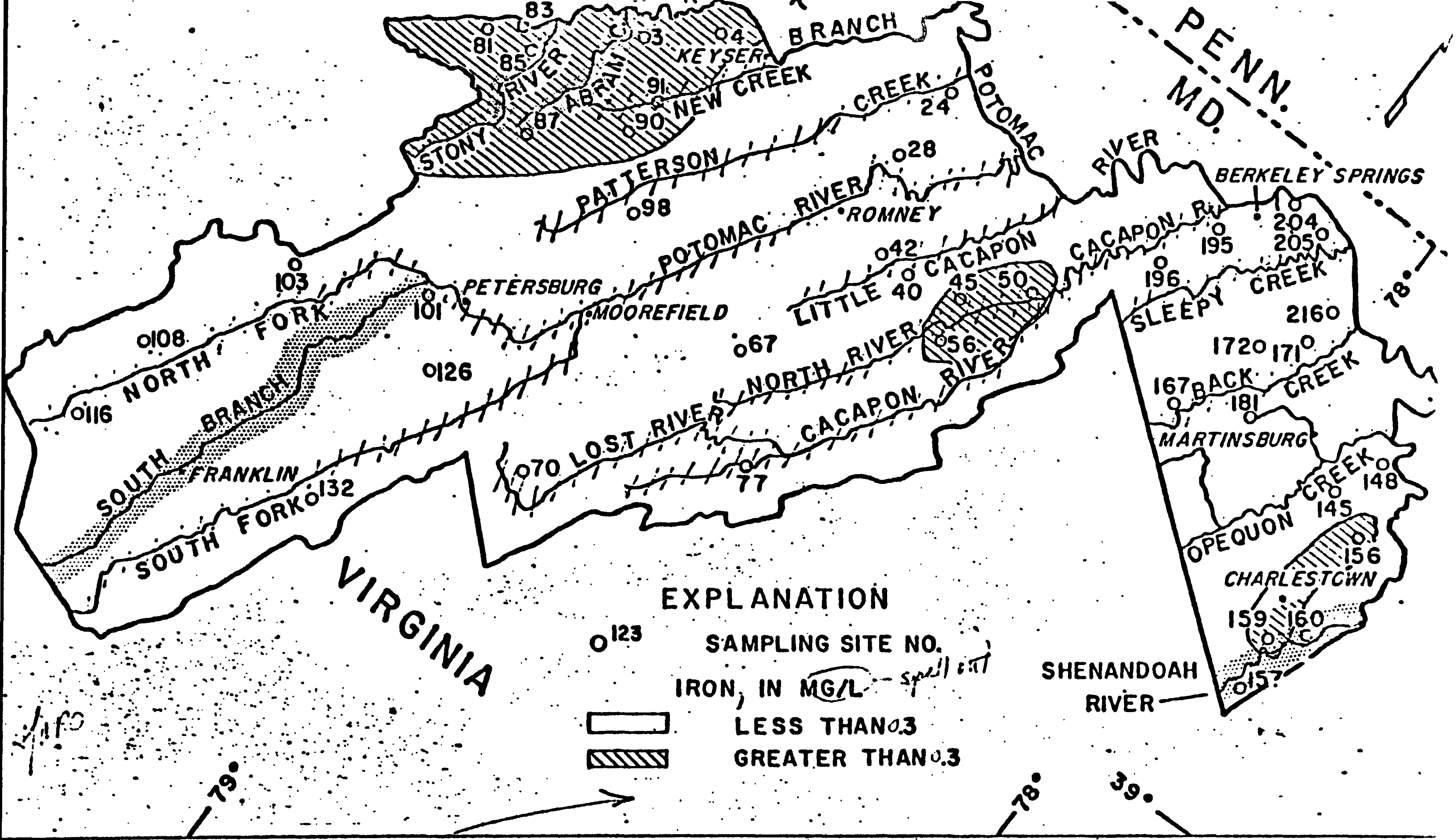


Figure ~~52.~~ 50 -- Duration curves of specific conductance of South Branch Potomac River at Franklin and near Springfield.



RANGES

Less than 5.0

6.2 - 7.8

More than 7.8

Figure ~~54~~ ~~52~~ 51.- Iron concentration and pH of surface water at low flow.

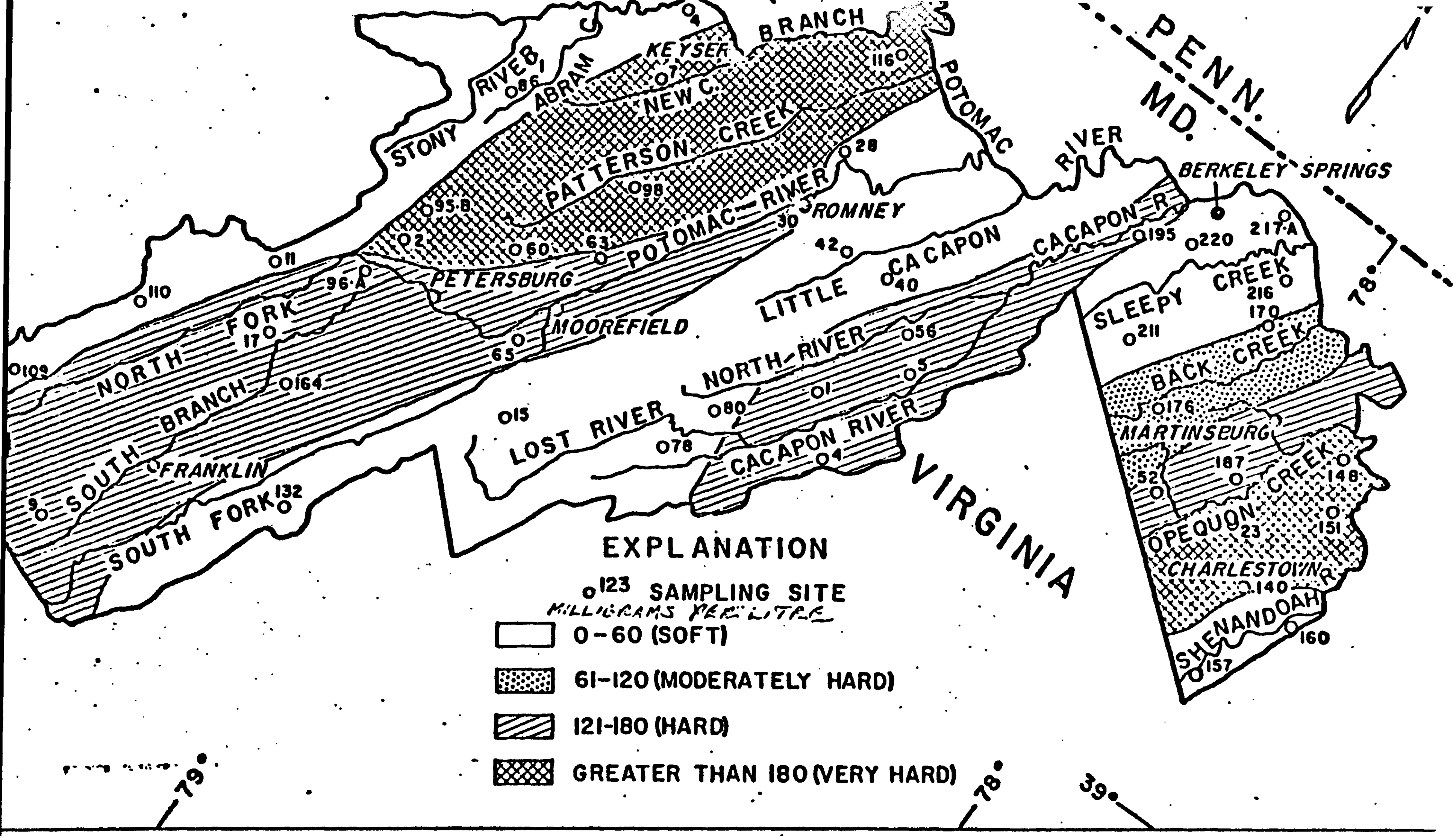


Figure ~~53~~ ~~51~~ 52.- Hardness concentration of surface water at low flow.

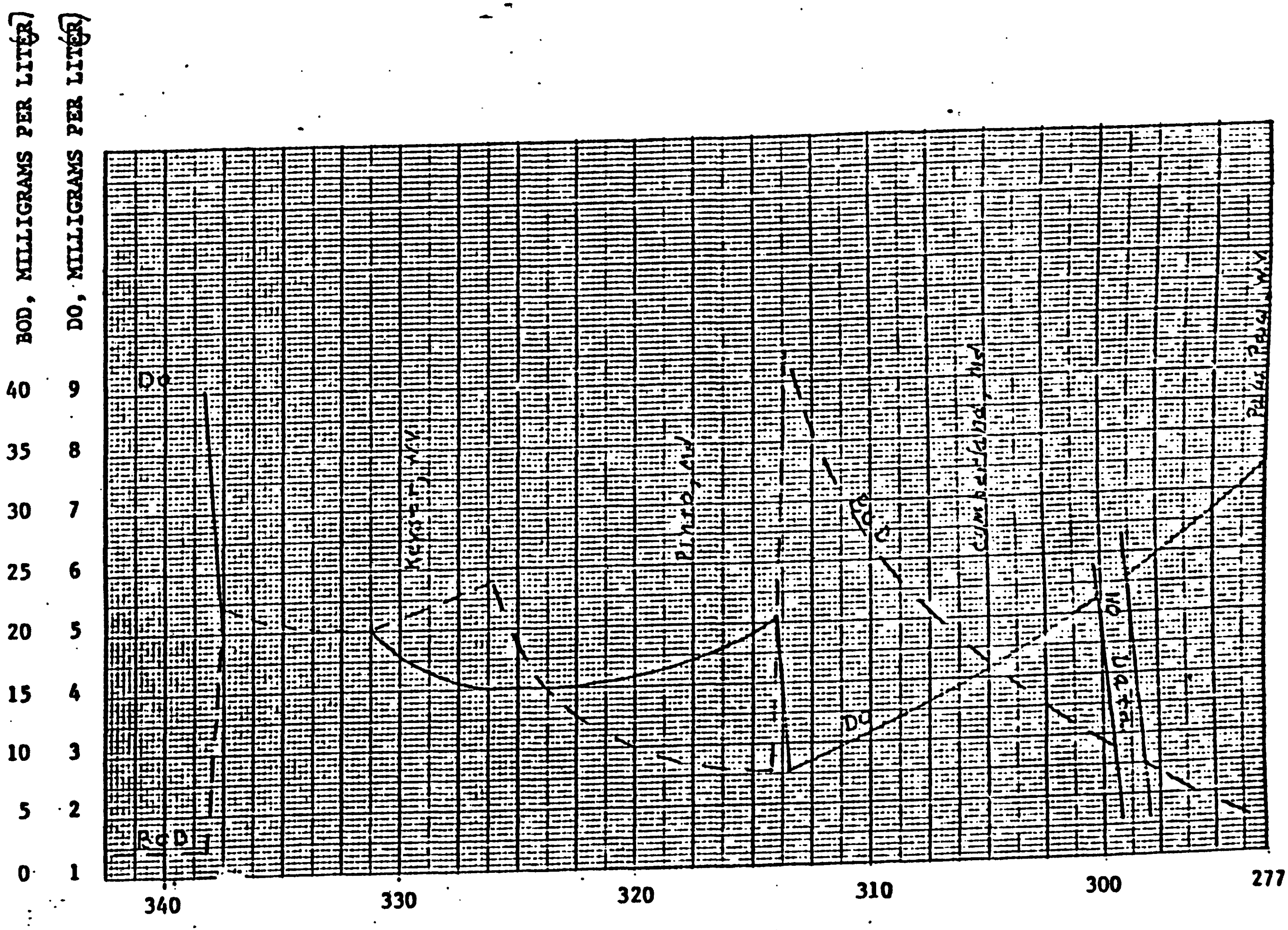


Figure 53.--Dissolved oxygen-biochemical oxygen demand relationships on North Branch Potomac River. (Based on median values from June-August 1969.)

Superseded

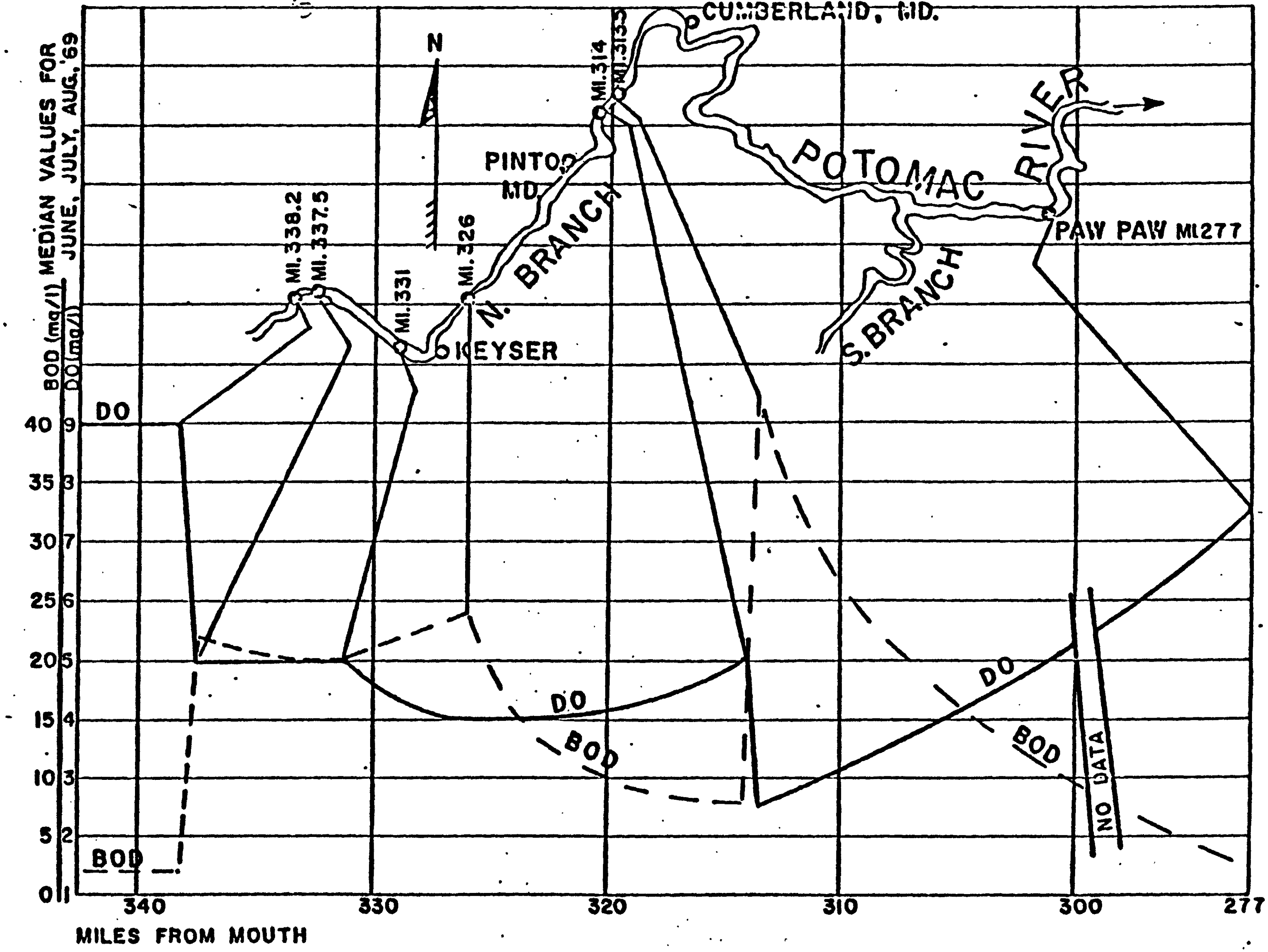


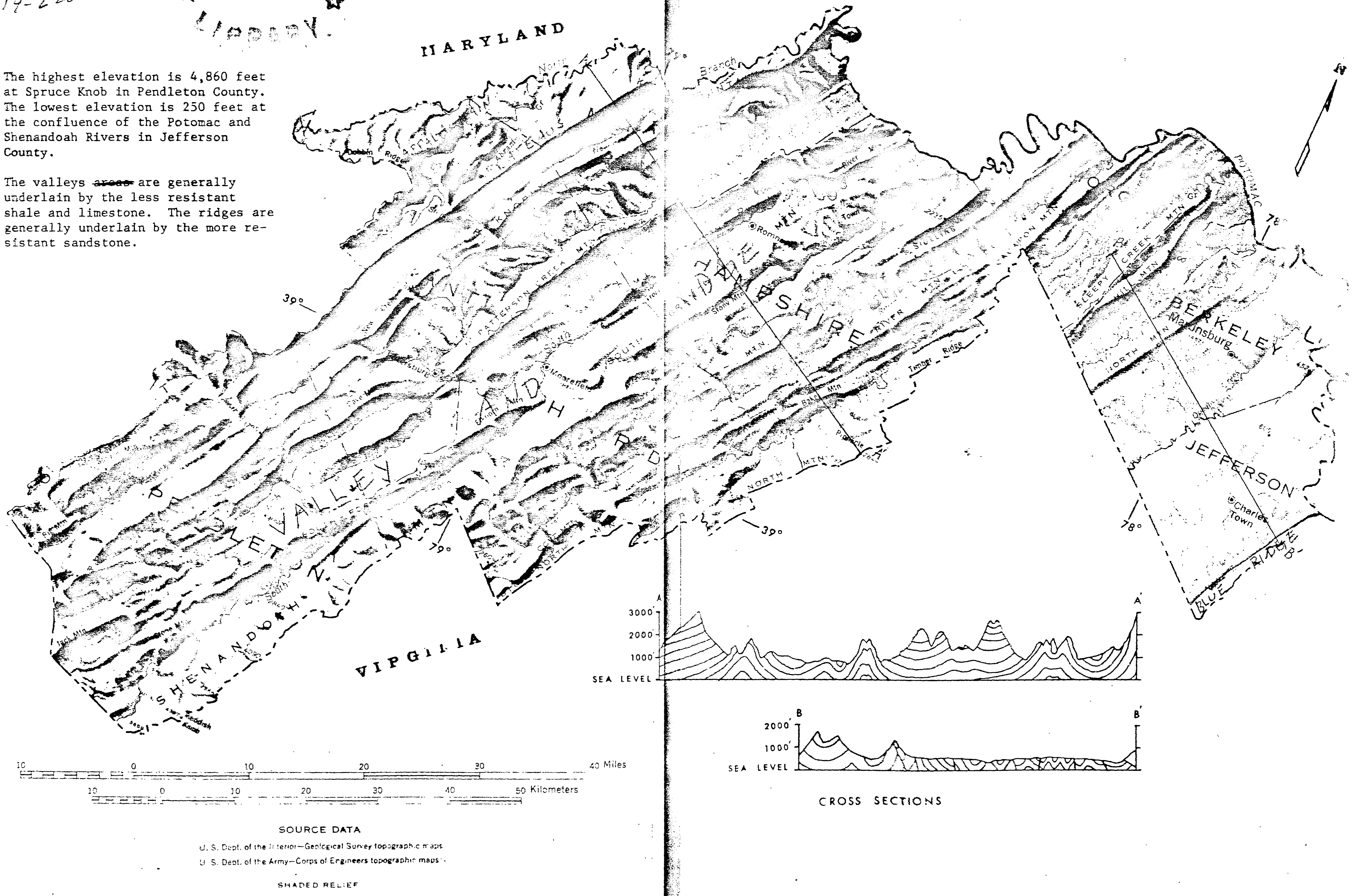
Figure ~~55~~ 53.--Dissolved oxygen-biochemical oxygen demand relationships on North Branch Potomac River.

74-220

74-220

The highest elevation is 4,860 feet at Spruce Knob in Pendleton County. The lowest elevation is 250 feet at the confluence of the Potomac and Shenandoah Rivers in Jefferson County.

The valleys ~~areas~~ are generally underlain by the less resistant shale and limestone. The ridges are generally underlain by the more resistant sandstone.



SOURCE DATA

U. S. Dept. of the Interior—Geological Survey topographic maps

U. S. Dept. of the Army—Corps of Engineers topographic maps

SHADED RELIEF

Figure 2.--Relief map and cross sections showing physiographic provinces ~~and~~ general rock structure