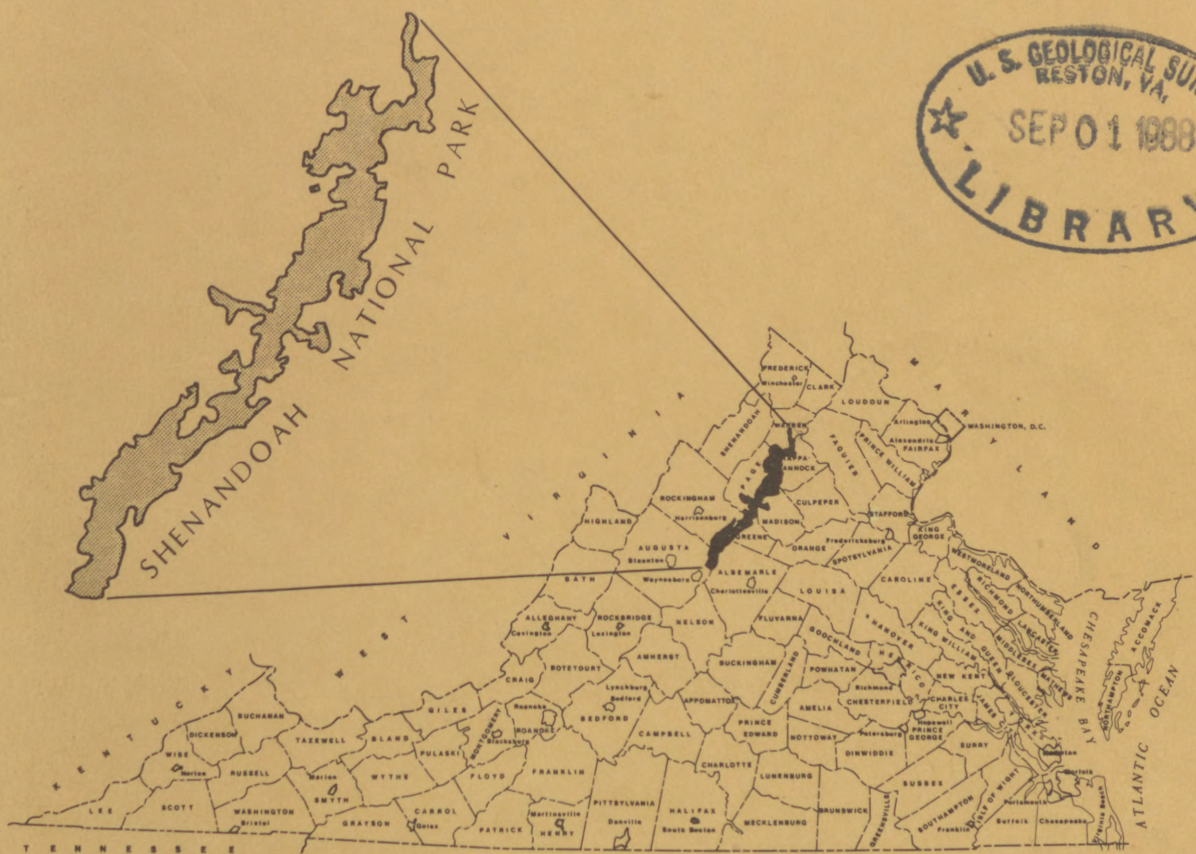
HYDROLOGIC CONDITIONS AND TRENDS IN SHENANDOAH NATIONAL PARK, VIRGINIA, 1983-84

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 87-4131



Prepared in cooperation with
NATIONAL PARK SERVICE

HYDROLOGIC CONDITIONS AND TRENDS

IN SHENANDOAH NATIONAL PARK, VIRGINIA, 1983-84

By Dennis D. Lynch

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4131

Prepared in cooperation with

NATIONAL PARK SERVICE

Richmond, Virginia

1987

DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:
Chief, Virginia Office
U.S. Geological Survey
3600 West Broad Street, Room 606
Richmond, Virginia 23230

Copies of this report can be
purchased from:
Books and Open-File Reports Section
U.S. Geological Survey
Federal Building, Box 25425
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

[Plate is in pocket]

TABLES

CONVERSION TABLE

The following factors may be used to convert the inch-pound units in this report to metric (International System) units:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Rate	
cubic foot per second (ft^3)	0.02832	cubic meter per second (m^3)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
dubic feet per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer ($m^2/s/km^2$)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

HYDROLOGIC CONDITIONS AND TRENDS IN SHENANDOAH NATIONAL PARK, VIRGINIA, 1983-84

By Dennis D. Lynch

ABSTRACT

Hydrologic conditions from 1983 through 1984 and trends were studied in Shenandoah National Park to provide basic data for current and future research and to assist the National Park Service in addressing specific water-management questions. The study primarily focuses on (1) the amount and variability of precipitation, surface water, and ground water in the Park, and (2) long-term trends in ground-water levels in relation to climate and ground-water withdrawals.

Maps showing precipitation amounts during a normal year and during a dry year with a 10-year recurrence interval are provided. Normal annual precipitation ranges from 52 inches on the higher peaks to 38 inches in the northern foothills, and averages 45 inches. Precipitation for a dry year with a 10-year recurrence interval averages 80 percent of normal. In the mid 1960's and early 1980's, the Park received below-normal precipitation. The 3-year totals from 1963 through 1965 at seven stations in or near the Park were the lowest on record and had recurrence intervals that ranged from 40 to 100 years. The dry years of 1980 and 1981 were much less severe at these seven stations. Precipitation totals at the seven stations for the 2-year period had recurrence intervals of 3 to 40 years.

In this report, surface water is primarily assessed in terms of low-flow statistics. Seven-day, 2-year, and 7-day, 10-year low-flow values are estimated for 29 streams in the Park. Low-flow values for basins underlain by sedimentary rocks are four times lower than elsewhere in the Park because these basins generally have steep slopes, poorly fractured bedrock, and a thin regolith. Seven-day, 2-year low-flow values average 0.13 and 0.032 cubic feet per second per square mile for streams that drain crystalline and sedimentary rocks, respectively.

Ground-water levels at 23 wells and discharges from 8 springs were measured in 1983 and 1984 and are compared to measurements made during the 1960's. Generally, ground-water levels have remained stable or have increased slightly in the last 20 years. Long-term changes appear to be related to climate and unrelated to long-term ground-water withdrawals. However, short-term effects of withdrawals may be important in some areas, especially during dry periods. If the ground-water system is not adequately recharged between pumping seasons, supplies may be insufficient to meet demands in the following year. Generally, such shortages are only temporary, because normal precipitation in the fall and winter after a dry period fully recharges the ground-water system by the spring.

Ground-water resources at Skyland, a major lodging area in the Park, have been insufficient to meet water-supply demands in 4 (1980, 1981, 1983, and 1985) of the last 6 years (1980-85). Large losses in the water distribution system appear to explain the shortages. Withdrawals from a water-supply well at Big Meadows--another major lodging area in the Park--may be linked to the steady disappearance of a rare wetland floral community. Because of these withdrawals, water levels in this wetland during years with normal precipita-

tion amounts may be a few feet lower than would occur naturally; this may adversely affect the survival of shallow rooting plants.

INTRODUCTION

Background

Shenandoah National Park was established in 1936; it traverses a 70-mile segment of the Blue Ridge mountains in northern Virginia (fig. 1). Ranging in width from 2 to 10 miles, this Park occupies more than 300 square miles in parts of eight counties. U.S. Highway 211, which passes through Thornton Gap to the north, and U.S. Highway 33, which passes through Swift Run Gap to the south, divide the Park into the northern, central, and southern sections. Skyline Drive, which extends the entire length of the Park and generally follows the topographic divide, provides the primary route of travel in the Park. Skyline Drive ends at the southernmost boundary of the Park where the Blue Ridge Parkway begins. The Blue Ridge Parkway follows the mountain crests of the Blue Ridge through central and southern Virginia and into North Carolina.

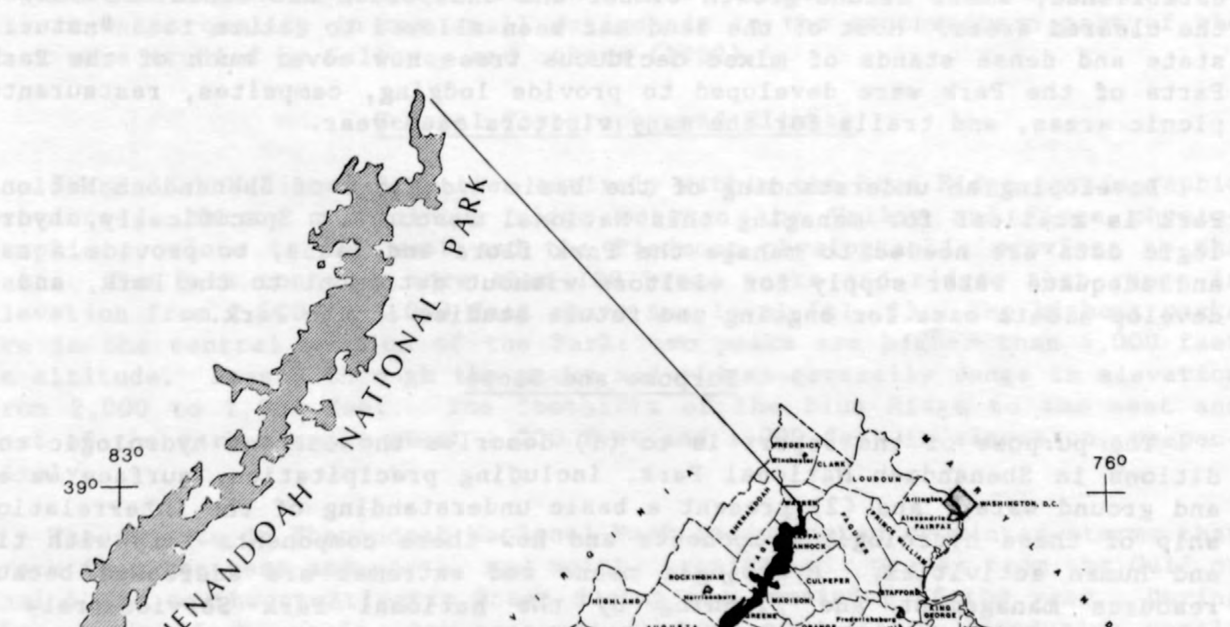


Figure 1.--Location of Shenandoah National Park in Virginia.

Indians were the first to inhabit the lands that currently comprise Shenandoah National Park. Small areas of forest were cleared for agriculture and hunting. Early colonial settlers cleared additional land for homesites and farmland. Most homesites were located in the northern half and the southeastern quarter of the Park. Only in these areas were conditions suitable for small farms (Gathright, 1976). Homesites were scarce in the southwestern quarter of the Park because of thin and rocky soils, steep slopes, and unreliable water supplies.

Overall, the effect of Indians and early settlers on this land was slight. It was not until the late nineteenth century that large-scale logging began as a result of growing demands for lumber in the northeastern United States and railroad accessibility at the foot of the Blue Ridge. Logging, together with the chestnut blight, left this area nearly devoid of virgin timber stands by the early twentieth century. At the time the Shenandoah National Park was established, small second-growth timber and underbrush had reclaimed many of the cleared areas. Most of the land has been allowed to return to a "natural" state and dense stands of mixed deciduous trees now cover much of the Park. Parts of the Park were developed to provide lodging, campsites, restaurants, picnic areas, and trails for the many visitors each year.

Developing an understanding of the basic hydrology of Shenandoah National Park is critical for managing this National resource. Specifically, hydrologic data are needed to manage the Park flora and fauna, to provide a safe and adequate water supply for visitors without detriment to the Park, and to develop a data base for ongoing and future studies in the Park.

Purpose and Scope

The purpose of the report is to (1) describe the current hydrologic conditions in Shenandoah National Park, including precipitation, surface water, and ground water; and (2) present a basic understanding of the interrelationship of these hydrologic components and how these components vary with time and human activities. Hydrologic means and extremes are addressed because resource management and planning by the National Park Service rely on knowledge of a wide variety of conditions.

Hydrologic information for this report was collected by the U.S. Geological Survey from July 1982 to December 1984. Data were collected from 9 precipitation stations, 32 surface-water sites, 8 springs, and 28 wells in and around Shenandoah National Park. These data are combined in this report with concurrent and historical data collected by the National Park Service; the Virginia Department of Mines, Minerals and Energy; the National Oceanic and Atmospheric Administration; the University of Virginia; the Virginia Water Control Board; and the U.S. Geological Survey.

Previous Studies

The geology of the Blue Ridge physiographic province and, more specifically, Shenandoah National Park, has been extensively studied for the last 100 years by Rogers (1884), Furcron (1934), King (1950), Bloomer and Werner (1955), Reed (1955, 1969), Brent (1960), Nelson (1962), Allen (1963, 1967), and Schwab (1970, 1971). More recently, Gathright (1976) published a series of three geologic maps in an extensive report of the geology of Shenandoah National Park. Gathright's discussions of stratigraphy, structure, and mineralogy in this report and in a subsequent report (Gathright and others, 1977) were used extensively in preparing several sections of this report.

Ground-water conditions in Shenandoah National Park were studied extensively in the 1960's by DeKay (1972), which focused on the development of water supplies for Park facilities. Monthly flows were measured at 30 springs for a period of 11 years. In addition, initial water levels were measured in 38 test holes drilled for the study and "safe yields" were determined. Two studies (Haelen, 1985; Vreeland, 1983) addressed flow routing of ground water and surface water in a small watershed in the Park.

The chemical quality of 56 streams was studied extensively in the early 1980's to determine the sensitivity of Shenandoah National Park to acid deposition (Lynch and Dise, 1985). The effects of acid deposition on stream-water quality in two small watersheds in the southwestern part of the Park were studied by Galloway and others (1982).

General Topography and Climate

Shenandoah National Park lies entirely within the Blue Ridge physiographic province--a narrow mountainous ridge between the Valley and Ridge physiographic province to the west and the Piedmont physiographic province to the east. The Park contains more than 100 broad peaks and ridges that range in elevation from 2,500 to 4,050 feet above sea level (pl. 1). The highest peaks are in the central section of the Park; two peaks are higher than 4,000 feet in altitude. Passes through the peaks and ridges generally range in elevation from 2,000 to 2,500 feet. The foothills of the Blue Ridge to the west and east of the Park average about 1,200 feet and 1,000 feet in elevation, respectively.

The climate in Shenandoah National Park is dominated by winter storms that track from the west and north, and moist, tropical air masses from the Gulf of Mexico and southwest Atlantic Ocean during the remainder of the year. During the winter, large-scale, low-pressure systems predominate, producing gentle and evenly distributed precipitation that lasts for many hours. In contrast, summer precipitation often occurs as local showers and thunderstorms with limited areal distribution, high intensity, and short duration.

Precipitation amounts are fairly evenly distributed throughout the year. Normal monthly precipitation (1951-80 mean) at Big Meadows (elevation 3,535 feet) ranges from a minimum of 3.06 inches in February to a maximum of 5.27 inches in August. Precipitation at Park Headquarters (elevation 1,200 feet) follows a similar trend: amounts are lowest in February, averaging 2.39 inches, and highest in August, averaging 4.12 inches.

Topography affects the distribution of precipitation in the Park. Cooling of an air mass as it is mechanically lifted over a mountain barrier may result in orographic precipitation. During the passage of frontal systems, the orographic effect often produces intensified precipitation at higher elevations. Occasionally, precipitation will be limited to higher elevations, leaving the foothills and upslope areas dry. Nonfrontal storms, such as thundershowers, also may be triggered or intensified as they are lifted over the Blue Ridge. The net effect of mountains in the Park is to increase precipitation by 4 to 5 inches per year for every 1,000-foot increase in elevation.

Mean annual air temperatures increase with decreasing elevations in the Park. From 1962-71 the annual temperature at Park Headquarters (elevation 1,200 feet) averaged 11.2°C (degrees Celsius) compared with 7.8°C at Big Meadows (elevation 3,535 feet) (Dekay, 1972). During the winter months, storms frequently drop rain in the foothills and snow at higher elevations in the Park because of this temperature gradient.

Acknowledgments

The staff of Shenandoah National Park are gratefully acknowledged for their assistance in the collection of rainfall data during the study and for their help in providing original records of well construction and water use in the Park. James Galloway and George Hornberger, University of Virginia, are also acknowledged for providing valuable precipitation records for the White Oak Run drainage basin. Larry Huffman, currently a graduate student at University of Virginia, deserves special recognition for his valuable comments and help during the early stages of the report.

GEOLOGIC AND HYDROGEOLOGIC SETTING

Stratigraphy

The geology of Shenandoah National Park is the result of several erosional, depositional, tectonic, and volcanic events that began in the Precambrian and continued through the Ordovician Period. Granite, basalt, and clastic sedimentary rocks are the dominant rock types of the seven formations in the Park. Chronologically, these formations in ascending order are the Old Rag Granite (Furcron, 1934) (8 percent of the Park's area), Pedlar Formation (Allen, 1963) (25 percent), Swift Run Formation (1 percent), Catoctin Formation (38 percent), Weverton Formation (3 percent), Harpers (Hampton) Formation (17 percent), and Antietam (Erwin) Formation (8 percent). Carbonate rocks of Cambrian and Ordovician age are found along the western boundary but are not exposed in the Park. A map of the surficial geology of the Park, based on the work of Gathright (1976), is provided in figure 2. Because of their limited distribution in the Park, the Weverton Formation is combined with the Harpers (Hampton) Formation, and the Swift Run Formation is combined with the Catoctin Formation in figure 2. The following description of each formation and the geologic history of the area is primarily based on the report by Gathright (1976).

The oldest rocks in the Park are those of the Old Rag Granite and the Pedlar Formation, which crystallized 1.1 billion years ago during the Precambrian and comprise the core of the Blue Ridge anticlinorium. These plutonic rocks formed at great depths and were subsequently uplifted over the next 300 million years. Today, these rocks form many prominent peaks in the eastern half of the Park.

The Old Rag Granite (Furcron, 1934) is a light-gray, coarse, resistant granite intruded locally by metabasaltic dikes. It is well exposed on the summit of Old Rag Mountain, where wind and water have eroded jointed blocks into rounded boulders. This formation is unconformably overlain by the Swift Run and Catoctin Formations to the west and south, and grades into the Pedlar Formation to the north and northwest.

The Pedlar Formation (Allen, 1963) is a medium-grained, feldspathic granodiorite. Intense metamorphism has given the rock an equigranular fabric, but local shearing and faulting have produced a gneissic foliation, especially in the northern half of the Park. The Pedlar Formation is unconformably overlain by the Swift Run, Catoctin, and Weverton Formations to the north and south. It grades laterally into the Old Rag Granite to the east.

During the late Precambrian, volcanic ash, pumice, and breccia from early volcanism and granitic debris from the eroded plutonic rocks were cemented by hot mineralizing liquids to form the Swift Run Formation. This formation consists of interbedded metaconglomerate, metasandstone, phyllite, and volcano-clastic rocks. The Swift Run Formation grades upward into or is interbedded with the Catoctin Formation. On figure 2 and in subsequent discussions, the Swift Run Formation is included with the overlying Catoctin Formation.

The Catoctin Formation is a resistant sequence of thick, epidote-rich metabasalt beds interlayered with thin beds of phyllite, slate, metasandstone, metaconglomerate, and volcano-clastics. Alternating episodes of lava flow, volcanic explosions, and erosion of plutonic rocks produced this thick (2000 feet) sequence. These once-mobile lavas are preserved as greenstone--a metabasalt that forms most of the high ridges and peaks in the Park. The Catoctin Formation overlies or is interbedded with the Swift Run Formation and lies unconformably below the Weverton Formation.

Cambrian rocks within the Park are represented by the metamorphosed clastic sedimentary rocks of the Chilhowee Group, which has three intertonguing units: the Weverton Formation, Harpers Formation in the northern part of the area or equivalent Hampton Formation in the southern part, and Antietam Formation in the northern part of the area or equivalent Erwin Formation in the southern part. These units commonly form steep ridges, v-shaped valleys, and talus slopes on the western side of the Blue Ridge. The Weverton Formation is a 100- to 500-foot-thick sequence of light-gray, feldspathic quartzite beds interlayered with phyllite and metasandstone, and is characterized by randomly spaced layers of quartz pebbles. These deposits are the result of fluvial erosion of the older Catoctin, Swift Run, and Pedlar Formations. The Weverton Formation unconformably overlies the Catoctin Formation and is distinguished by an absence of epidote in its sediments (Gathright, 1976). The Weverton Formation grades upward into the Harpers (Hampton) Formation where the contact is marked by quartz pebbles. On figure 2 and in subsequent discussions, the Weverton Formation is included with the Harpers (Hampton) Formation.

The lower third of the Harpers (Hampton) Formation is a sequence of grayish-green laminated phyllite interlayered with thin beds of metasandstone and metasiltstone. Its upper two-thirds consists of an alternating sequence of phyllite and metasandstone beds and 25- to 100-foot-thick quartzite beds that are locally ferruginous. The average total formation thickness is 2,000 feet. These beds were deposited as lagoonal sands and muds by transgressing Cambrian seas and were later metamorphosed upon burial. The Harpers (Hampton)

Formation conformably overlies the Weverton Formation and underlies the Antietam (Erwin) Formation.

The Antietam (Erwin) Formation is a 750- to 1,000-foot-thick sequence of very resistant, light-gray quartzite interlayered with friable metasandstone and phyllite in the lower half of the formation. These rocks were formed through burial and metamorphosis of white beach and bar sands deposited by the sea as it transgressed westward during basin subsidence. This unit forms many prominent peaks and ledges in the southwestern corner of the Park. Iron and manganese have been mined in the upper half of the formation along the Park's western boundary. The Antietam (Erwin) Formation conformably overlies the Harpers (Hampton) Formation and has an upper contact with Cambrian carbonate rocks west of the Park.

Structure

Structural features in the geology of the Park were created by tectonic events that occurred throughout the Paleozoic Era. These features include cleavage, jointing, folding, and faulting. Cleavage, a parallel, planar, or sheer fabric on rock surfaces, is a common structural feature in the Park. It is most prevalent among micaceous metasedimentary rocks and metatuffs of the Swift Run Formation. Folding of these rocks through tectonic uplift during the Paleozoic caused differential slip on shear planes where cleavage subsequently developed. Cleavage is also found in heavily faulted quartzites of the Harpers (Hampton) and Antietam (Erwin) Formations.

Jointing is as common as cleavage in the Park. It appears as near vertical to horizontal fractures in rock exposures such as Antietam (Erwin) quartzite ledges and the granite blocks on the summit of Old Rag Mountain. Most jointing in the Park is thought to be the result of folding or vertical movements in the crust following folding.

The results of the compressional forces of folding are preserved as large asymmetrical folds in the Antietam (Erwin), Harpers (Hampton), and Weverton quartzites in the southwestern part of the Park. In cross section, structural folds resemble waves, each consisting of a crest and two adjacent troughs connected by limbs. The amplitude--one-half the vertical distance between a crest and its adjoining trough--is a good indication of the size of a fold. Gathright (1976) reports folds with amplitudes of several hundred to about 1,000 feet in the Antietam (Erwin) and Weverton Formations. Folds with amplitudes less than 100 feet also are common in these formations.

The geologic development of the Blue Ridge was heavily influenced by faulting. Typically, faults are marked either by shallow depressions containing rock fragments or by an escarpment where resistant and nonresistant rocks meet at the base. Mylonites (slaty rocks crushed and milled during faulting) and cataclastic gneisses commonly indicate faults in plutonic rocks. Faults usually are obscured by alluvial gravel, regolith, or talus. Faulting of the Antietam (Erwin) quartzites has produced a tectonic breccia consisting of cemented, angular quartzite fragments.

There are two major types of faults within the Park. The first type includes high-angle reverse and thrust faults, which generally have a northeast-southwest trend and dip to the southeast. Displacement of thousands

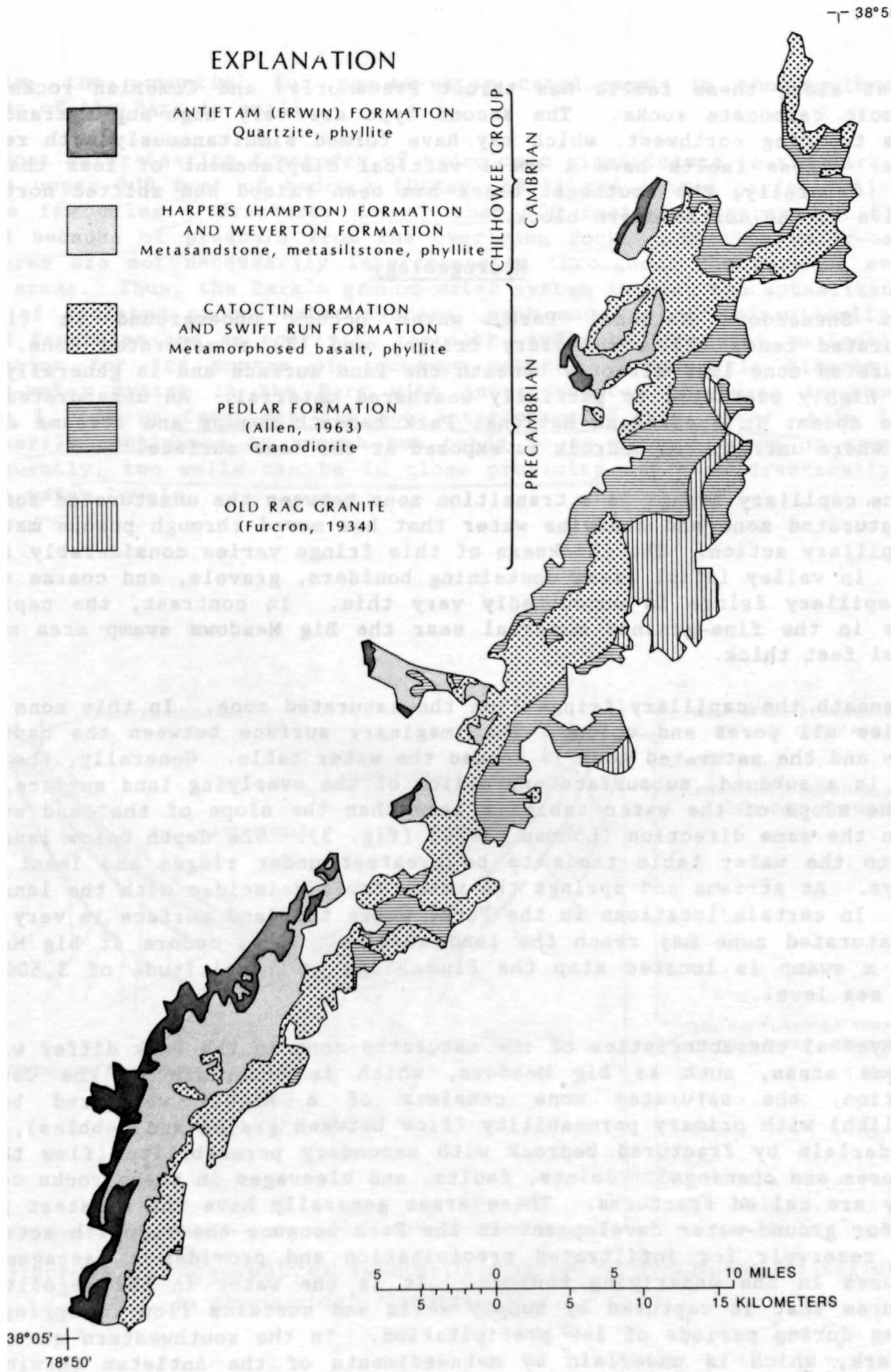


Figure 2.--Geology of Shenandoah National Park.

of feet along these faults has thrust Precambrian and Cambrian rocks over Paleozoic carbonate rocks. The second type are very high-angle transverse faults trending northwest, which may have formed simultaneously with reverse faults. These faults have a small vertical displacement of less than 500 feet. Generally, the southwest block has been raised and shifted northwest relative to the northeastern block.

Hydrogeology

In Shenandoah National Park, water occurs underground in (1) an unsaturated zone, (2) a capillary fringe, and (3) a saturated zone. The unsaturated zone lies directly beneath the land surface and is generally made up of highly weathered to partially weathered material. An unsaturated zone may be absent in Shenandoah National Park beneath swamps and streams and in areas where unfractured bedrock is exposed at the land surface.

The capillary fringe is a transition zone between the unsaturated zone and the saturated zone and contains water that has moved through porous material by capillary action. The thickness of this fringe varies considerably in the Park. In valley infill areas containing boulders, gravels, and coarse sands, the capillary fringe is undoubtedly very thin. In contrast, the capillary fringe in the fine-grained material near the Big Meadows swamp area may be several feet thick.

Beneath the capillary fringe lies the saturated zone. In this zone water occupies all pores and voids. The imaginary surface between the capillary fringe and the saturated zone is termed the water table. Generally, the water table is a subdued, subsurface expression of the overlying land surface, that is, the slope of the water table is less than the slope of the land surface but in the same direction (Lohman, 1979) (fig. 3). The depth below land surface to the water table tends to be greatest under ridges and least under valleys. At streams and springs the water table coincides with the land surface. In certain locations in the Park, where the land surface is very flat, the saturated zone may reach the land surface. This occurs at Big Meadows where a swamp is located atop the Blue Ridge at an altitude of 3,500 feet above sea level.

Physical characteristics of the saturated zone in the Park differ widely. In some areas, such as Big Meadows, which is underlain by the Catoctin Formation, the saturated zone consists of a highly weathered bedrock (regolith) with primary permeability (flow between grains and pebbles), which is underlain by fractured bedrock with secondary permeability (flow through fractures and openings). Joints, faults, and cleavages in these rocks collectively are called fractures. These areas generally have the greatest potential for ground-water development in the Park because the regolith acts as a large reservoir for infiltrated precipitation and provides a passageway to fractures in the underlying bedrock. It is the water in the regolith and fractures that is captured by supply wells and sustains flow in springs and streams during periods of low precipitation. In the southwestern quarter of the Park, which is underlain by metasediments of the Antietam (Erwin) and Harpers (Hampton) Formations, the saturated zone generally consists of poorly fractured bedrock with little or no saturated regolith. Only a small quantity of ground water is stored in the regolith and underlying rocks, thus springs and streams commonly go dry during periods of low precipitation. Consequently, the potential for ground-water development in the southwestern quarter of the Park is small.

Most water-bearing fractures of hydrologic significance in the Park exist in the upper 300 feet of bedrock (DeKay, 1972) and extend horizontally less than a few miles. Fractures deeper than 300 feet are sparse and tightly closed because of pressure from the overlying rocks. Shallow water-bearing fractures are not necessarily interconnected throughout the Park or even in local areas. Thus, the Park's ground-water system is best conceptualized as a group of isolated ground-water systems, each made up of hydraulically connected fractures and an overlying regolith--and each dependent on local precipitation for its source of recharge water. A schematic diagram of a ground-water system in the Park with interconnected fractures is shown in figure 3. Where fractures are not interconnected, the water table is not necessarily continuous or smooth but tends to be discontinuous or steplike. Consequently, two wells can be in close proximity but have drastically different water levels.

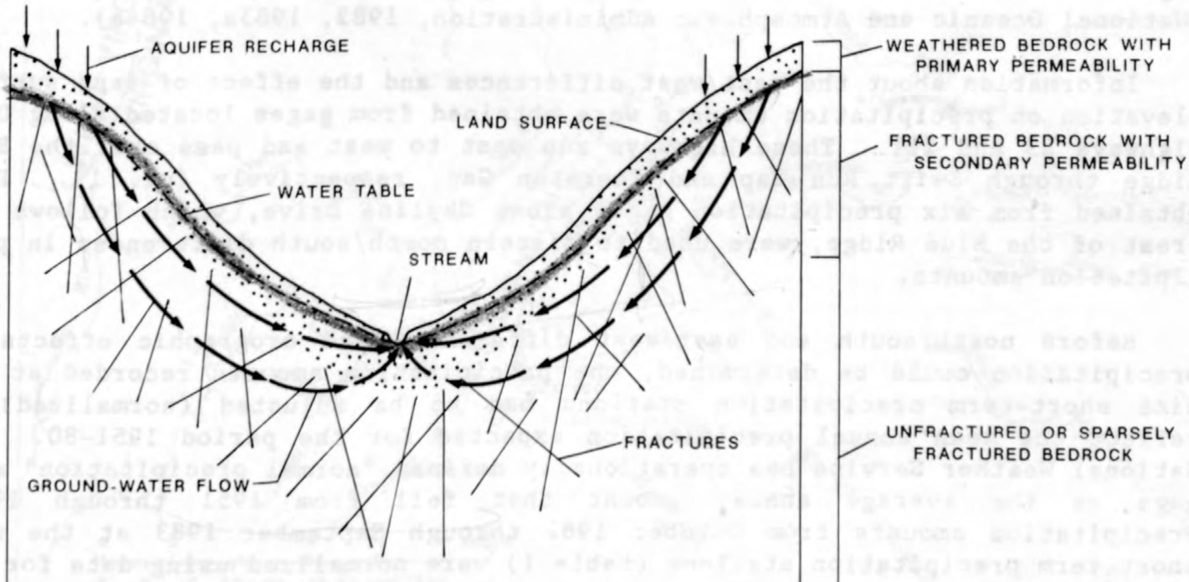


Figure 3.--Conceptualized schematic diagram of ground-water system in Shenandoah National Park.

HYDROLOGIC CONDITIONS AND TRENDS

In this section, current hydrologic conditions in Shenandoah National Park are discussed, and hydrologic trends are evaluated from long-term data. This section is divided into five subsections: (1) precipitation, (2) surface water, (3) ground water, (4) water budget, and (5) site-specific investigations. The various components of the hydrologic cycle are quantified and discussed in the first three subsections. The water-budget subsection explores the relationship among these components of the hydrologic cycle in the Park. The site-specific investigations subsection explores the conditions of water resources at two major developed areas in the Park.

Precipitation

Normal

Nine continuous-recording precipitation gages were installed in Shenandoah National Park in the summer of 1982 to improve the definition of precipitation patterns in the Park (pl. 1). Five gages were operational by the beginning of July and the other four by the beginning of September. All gages were maintained through September of 1983, and data from several gages are available through January 1984. Appendix 1 provides daily precipitation at these nine gages and at the National Park Service gages at Luray and Big Meadows (National Oceanic and Atmospheric Administration, 1982, 1983a, 1984a).

Information about the east/west differences and the effect of land surface elevation on precipitation amounts were obtained from gages located along U.S. Highways 33 and 211. These highways run east to west and pass over the Blue Ridge through Swift Run Gap and Thornton Gap, respectively (pl. 1). Data obtained from six precipitation gages along Skyline Drive, which follows the crest of the Blue Ridge, were used to discern north/south differences in precipitation amounts.

Before north/south and east/west differences and orographic effects in precipitation could be determined, the precipitation amounts recorded at the nine short-term precipitation stations had to be adjusted (normalized) to reflect the mean annual precipitation expected for the period 1951-80. The National Weather Service has operationally defined "normal precipitation" at a gage as the average annual amount that fell from 1951 through 1980. Precipitation amounts from October 1982 through September 1983 at the nine short-term precipitation stations (table 1) were normalized using data for the same period from seven long-term stations (National Oceanic and Atmospheric Administration, 1984b) in and around the Park (table 2). The long-term stations (fig. 4) were used to identify areas of the Park that deviated from normal during this period. Precipitation amounts at the short-term stations were adjusted accordingly. Precipitation amounts at the seven long-term stations ranged from 95 percent of normal to 13 percent greater-than-normal during this period, with the largest deviations in and around the northern half of the Park.

A map showing normal annual precipitation in the Park was developed using normal annual precipitation amounts at the seven long-term stations (table 2) and the normalized precipitation amounts at the nine short-term stations (table 1). The effect of land surface elevation on precipitation amounts was determined at four Park locations. For every 1,000 foot gain in elevation,

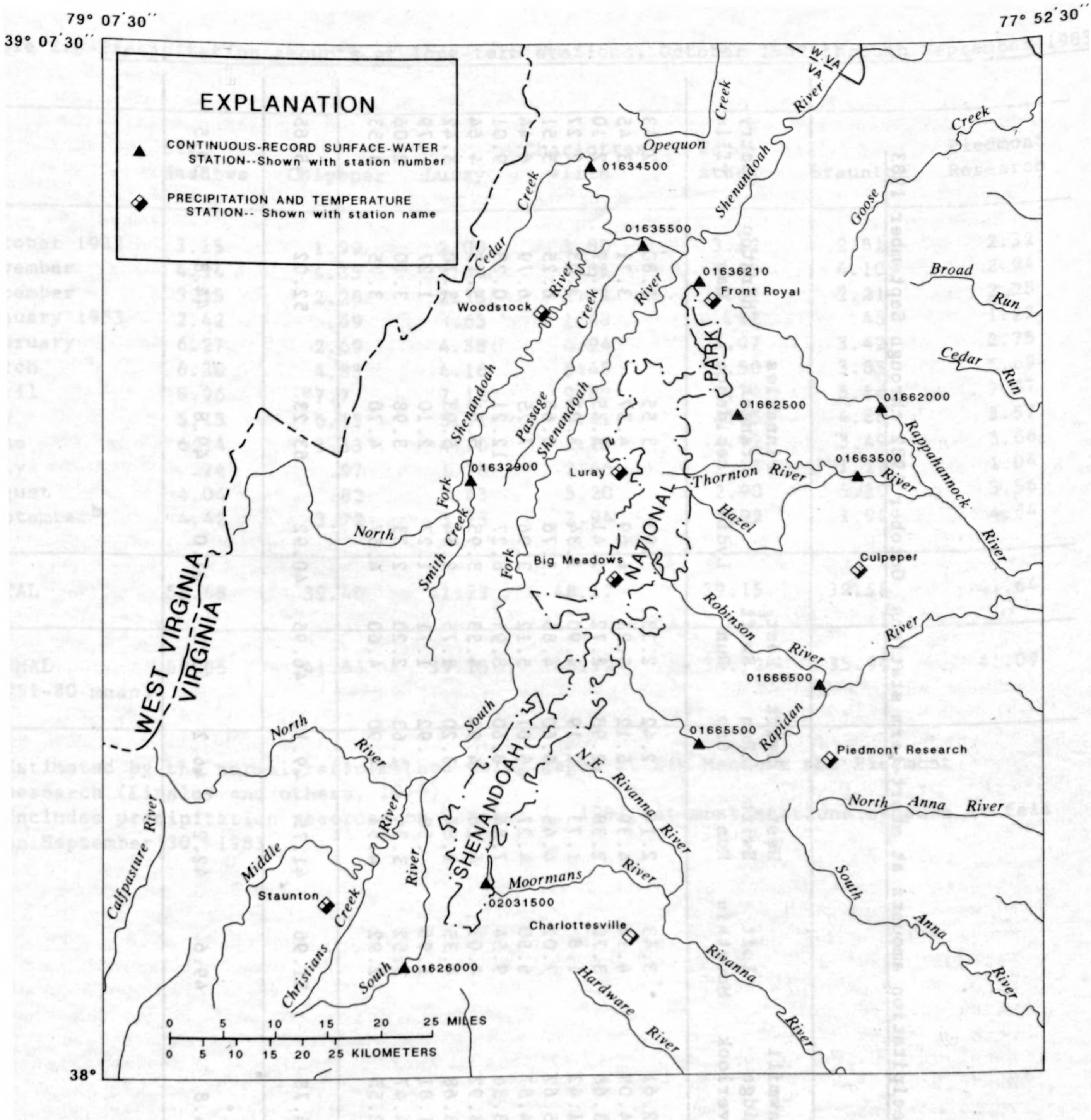


Figure 4.--Location of long-term surface-water and weather stations used in the study.

Table 1.--Precipitation amounts at short-term stations, October 1982 through September 1983

	Sawmill Ridge Overlook	Loft Mountain	West Swift Run	Swift Run Gap	East Swift Run	Lydia	Pinnacles ranger residence	Thorntop Gap	Sperry-ville
October 1982	2.61	3.43	2.14	2.42	2.33	1.93	3.55	2.80	2.43
November	4.09	4.14	4.39	5.12	5.25	4.69	4.37	3.71	3.45
December	3.68	3.70	2.38	2.98	2.72	2.41	3.35	2.19	2.10
January 1983	1.42	1.8	1.73	2.19	1.90	1.34	3.03	3.03	2.27
February	5.62	7.01	4.45	5.60	4.85	3.76	6.65	6.25	5.51
March	4.57	5.50	4.27	5.61	5.12	3.96	7.75	6.79	6.44
April	8.36	9.54	7.84	8.60	8.94	8.27	12.21	10.28	9.01
May	3.92	4.01	4.26	4.94	4.58	3.95	5.61	5.15	4.64
June	3.68	4.35	1.84	3.20	2.75	2.54	5.93	3.70	3.42
July	1.81	1.96	.58	.92	1.71	1.27	2.10	1.27	.79
August	4.47	3.52	3.34	2.63	2.20	2.23	3.98	3.10	2.06
September	2.55	2.92	4.53	4.90	4.60	4.57	4.70	3.75	3.53
TOTAL	46.78	51.96	41.75	49.11	46.95	40.92	63.23	52.02	45.65
ESTIMATED NORMAL	44.8	49.6	42.2	46.2	43.0	41.0	49.8	44.8	39.5

Table 2.--Precipitation amounts at long-term stations, October 1982 through September 1983

	Big Meadows	Culpeper	Luray	Charlottes-ville	Wood-stock	Staunton	Piedmont Research
October 1982	3.15	1.99	2.00	3.80	3.12	2.81	2.32
November	4.94	4.33	3.06	2.01	3.45	4.10	2.94
December	3.15	2.26	2.13	2.71	1.91	2.21	2.28
January 1983	2.42	.69	.63	1.48	.92	.45	1.22
February	6.27	2.69	4.38	4.94	3.97	3.42	2.75
March	6.30	4.83	4.16	5.45	3.50	3.83	5.69
April	8.96	[a]7.7	7.12	9.82	5.74	5.86	7.97
May	5.15	6.13	5.11	4.41	4.65	4.88	3.57
June	6.14	3.33	4.10	2.75	4.92	3.49	3.66
July	.74	.97	1.78	2.66	1.15	1.27	1.04
August	4.04	.82	3.63	5.20	2.90	5.30	3.56
September[b]	4.42	3.72	3.13	2.94	2.92	1.94	4.64
TOTAL	55.68	39.46	41.23	48.17	39.15	39.56	41.64
NORMAL (1951-80 mean)	50.65	41.64	39.25	45.72	34.72	35.96	41.09

[a] Estimated by the normal-ratio-method using gages at Big Meadows and Piedmont Research (Linsley and others, 1975).

[b] Includes precipitation recorded on October 1, 1983, at most stations because it fell on September 30, 1983.

annual precipitation amounts increase by 4.2 and 4.7 inches to the west and east of Swift Run Gap, respectively, and 4.9 and 5.2 inches to the west and east of Thornton Gap, respectively. This orographic effect was extrapolated throughout the Park and tied into the points of known precipitation amounts to produce a generalized map of normal annual precipitation (pl. 1).

Normal annual precipitation ranges from less than 38 inches in some of the lower foothills in the northern half of the Park (elevation 900 feet) to over 52 inches at the highest peaks in the central part of the Park (elevation 4,000 feet). Parkwide precipitation averages 45 inches per year. In general, the Park's western foothills receive about 1 inch more precipitation per year than the eastern foothills at the same elevation and latitude. Apparently, because the majority of storms that drop precipitation in Shenandoah National Park track from the west or southwest, the western slopes of the Park receive slightly more precipitation because of the orographic effect where air masses rising over hills tend to yield greater amounts of precipitation on windward slopes than on leeward slopes. (Linsley and others, 1975). Because peaks in the Park only reach 4,000 feet, east/west differences in precipitation are small.

Small north/south differences in normal annual precipitation may also be evident in Shenandoah National Park (pl. 1). At the same elevation, areas in the northern part of the Park receive about 1.5 inches less precipitation per year than areas in the southern part. A slight orographic rain shadow produced by a series of mountains 10 miles west of the Park may be responsible for this difference. These mountains parallel the northern two-thirds of Shenandoah National Park, and reach an elevation of more than 3,000 feet. The early loss of cloud moisture from eastward moving air masses as they are uplifted by these mountains, and the diversion of storms around these mountains, may reduce the amount of precipitation in the northern part of the Park.

During Dry Periods

Seven long-term precipitation stations (table 3) were used to determine the spatial distribution of annual precipitation amounts in the Park for a 1-year dry period with a 10-year recurrence interval (10-percent chance of occurrence in any given year). To accomplish this, a frequency distribution of annual precipitation amounts (National Oceanic and Atmospheric Administration, 1984b) was defined for each station. Plotting positions were assigned using Weibull's (1939) formula and curves were fitted graphically on normal-probability paper. Estimates of precipitation amounts for a 1-year dry period with a 10-year recurrence interval were obtained from these plots and are given in table 3.

Precipitation amounts during a 1-year dry period with a 10-year recurrence interval range from 78 to 81 percent of the normal annual precipitation at the seven long-term stations, and average 80 percent of normal (table 3). Consequently, it is assumed that the annual precipitation amount during a similar dry period at the nine short-term stations in the Park also is 80 percent of normal. The map on plate 1 showing the distribution of precipitation during a 1-year dry period with a 10-year recurrence interval was developed using these data from the long- and short-term stations. The method used to define lines of equal precipitation amounts is identical to the method described above for the map of normal annual precipitation.

Precipitation during a dry period lasting 1 year, with a 10-year recurrence interval, ranges from less than 30 inches in the lowest foothills of the northern section of the Park to 42 inches at the highest peaks in the central section. As expected, the orographic effect and the north/south and east/west distribution of precipitation during dry periods are similar to that described for a period of normal precipitation. The western side of the Park receives slightly more precipitation than the eastern side, and the southern section receives more precipitation than the northern section. Overall, precipitation in the Park averages about 36 inches during a 1-year dry period with a 10-year recurrence interval (pl. 1).

The recurrence interval of precipitation amounts reported in calendar years 1963 through 1965, and 1980 and 1981, are provided in table 4 for the seven long-term stations to place these two recent dry periods in perspective. Recurrence intervals for precipitation amounts during the following 2- and 3-year dry periods also are provided in table 4: 1963 through 1964, 1964 through 1965, 1963 through 1965, and 1980 through 1981. Recurrence intervals for these dry periods were obtained from graphical frequency curves of precipitation amounts during all possible 2- and 3-year periods (consecutive years only) for the period of record. Recurrence intervals calculated for precipitation amounts during consecutive years is used to quantify the severity of dry periods lasting more than 1 year. In terms of ground-water availability

Table 3.--Estimated precipitation during a 1-year dry period with a 10-year recurrence interval at long-term stations

	Big Meadows	Culpeper	Luray	Charlottes-ville	Wood-stock	Staunton	Piedmont Research
Period of record (years)	1935-41 1943-83 (48)	1931-50 1952-83 (52)	1941-83 (43)	1931-83 (53)	1931-43 1947-83 (50)	1931-83 (53)	1947-83 (37)
Precipitation during a 1-year dry period with a 10-year recurrence interval, in inches	40.5	33.8	31.9	35.5	27.8	28.0	32.3
Percent of normal	80	81	81	78	80	78	79

Table 4.--Quantity and approximate recurrence interval of precipitation during selected dry periods

[Precipitation amount, in inches, and associated recurrence interval, in years, shown in parentheses]

	Big Meadows	Culpeper	Luray	Charlottes-ville	Wood-stock	Staunton	Piedmont Research
Calendar year 1980	47.8 (3)	36.4 (5)	33.9 (6)	34.7 (12)	32.8 (3)	33.0 (4)	31.4 (15)
Calendar year 1981	47.8 (3)	38.2 (3)	32.4 (9)	36.4 (8)	31.9 (3)	27.8 (10)	34.8 (5)
Two consecutive years 1980-1981	95.6 (3)	74.6 (6)	66.3 (13)	71.1 (40)	64.7 (4)	60.8 (10)	66.2 (20)
Calendar year 1963	41.7 (8)	32.9 (15)	29.7 (19)	30.4 (33)	28.8 (7)	25.7 (17)	30.4 (25)
Calendar year 1964	43.2 (6)	35.0 (7)	35.7 (4)	42.3 (3)	26.8 (15)	25.5 (18)	34.1 (6)
Calendar year 1965	33.7 (50)	30.1 (40)	28.4 (29)	35.6 (10)	28.2 (9)	25.8 (17)	32.5 (9)
Two consecutive years 1963-1964	84.9 (10)	67.9 (20)	65.4 (17)	72.7 (30)	55.6 (25)	51.2 (50)	64.5 (28)
Two consecutive years 1964-1965	76.9 (40)	65.1 (40)	64.1 (23)	77.9 (10)	55.0 (29)	51.3 (50)	66.6 (19)
Three consecutive years 1963-1965	118.6 (50)	98.0 (60)	93.8 (70)	108.3 (60)	83.8 (40)	76.9 (100)	97.0 (70)

in the Park, dry periods of moderate severity lasting 2 or more years may have a larger impact than a more severe dry period lasting only 1 year.

The severity of precipitation shortages during the individual years of 1980 and 1981, and during the combined 2-year period, differed considerably throughout the Park. This dry period was relatively mild at Big Meadows, with recurrence intervals of 3 years for calendar years 1980 and 1981, and a recurrence interval of 3 years for the 2-year period. In contrast, precipitation shortages in Charlottesville, near the southeastern part of the Park, were quite severe. Precipitation amounts in 1980 and 1981 had 12- and 8-year recurrence intervals, respectively. The recurrence interval for total precipitation during this 2-year period was about 40 years. Overall, 2-year (1980-81) precipitation totals at the seven long-term stations averaged 86 percent of normal and had a recurrence interval of 10 to 15 years (table 4).

Precipitation shortages at the seven long-term precipitation stations generally were more extreme during the year 1963-65 than during the early 1980's. For example, the recurrence intervals for drought years 1963, 1964, and 1965 at Big Meadows were 8, 6, and 50 years, respectively (table 4); for the combined 2-year periods, the recurrence intervals were 10 years (1963-64) and 40 years (1964-65). Only at the Charlottesville and Piedmont Research stations were drought conditions of 1980 and 1981 near the severity of the 1963 through 1965 dry period.

Perhaps the most notable feature of the dry period in the 1960's was its long duration. Extreme conditions persisted for 3 to 4 years; 1963 through 1965 was the driest period. At all seven long-term precipitation stations in and around the Park, this 3-year period is the driest on record, averaging 78 percent of normal. The median recurrence interval for this dry period is estimated at 60 years. In short, the dry period in Shenandoah National Park during the mid-1960's was considerably more severe, and of longer duration, than the dry period of the early 1980's, and undoubtedly had a greater impact on the surface-water and ground-water resources.

Seasonal Patterns

Areal coverage

The areal coverage of precipitation from a storm event depends on the weather system producing the precipitation. Summer showers and thunderstorms generally produce localized precipitation in the Park, as illustrated by three typical storms in 1983 (fig. 5). Hourly precipitation data for Front Royal (station A in figures 5 and 6) are obtained from NOAA (1983b). Thundershowers on June 18, 1983, dropped more than 1 inch of rain on most Park areas south of Big Meadows but left the northern third of the Park virtually dry. A reversal of this pattern occurred 3 days later. Thundershowers dropped 1 to 3 inches of rain on the northern half of the Park and only about 0.1 inches on the southern half. Big Meadows received 3.22 inches of rain during this storm. A storm on September 12, 1983, provides an example of very localized rainfall in the Park (fig. 5). Rain gages along U.S. Highway 33 passing through Swift Run Gap recorded nearly 2 inches of rain in 3 hours, while Pinnacles ranger residence to the north and Loft Mountain to the south recorded only 0.25 and 0.13 inches, respectively.

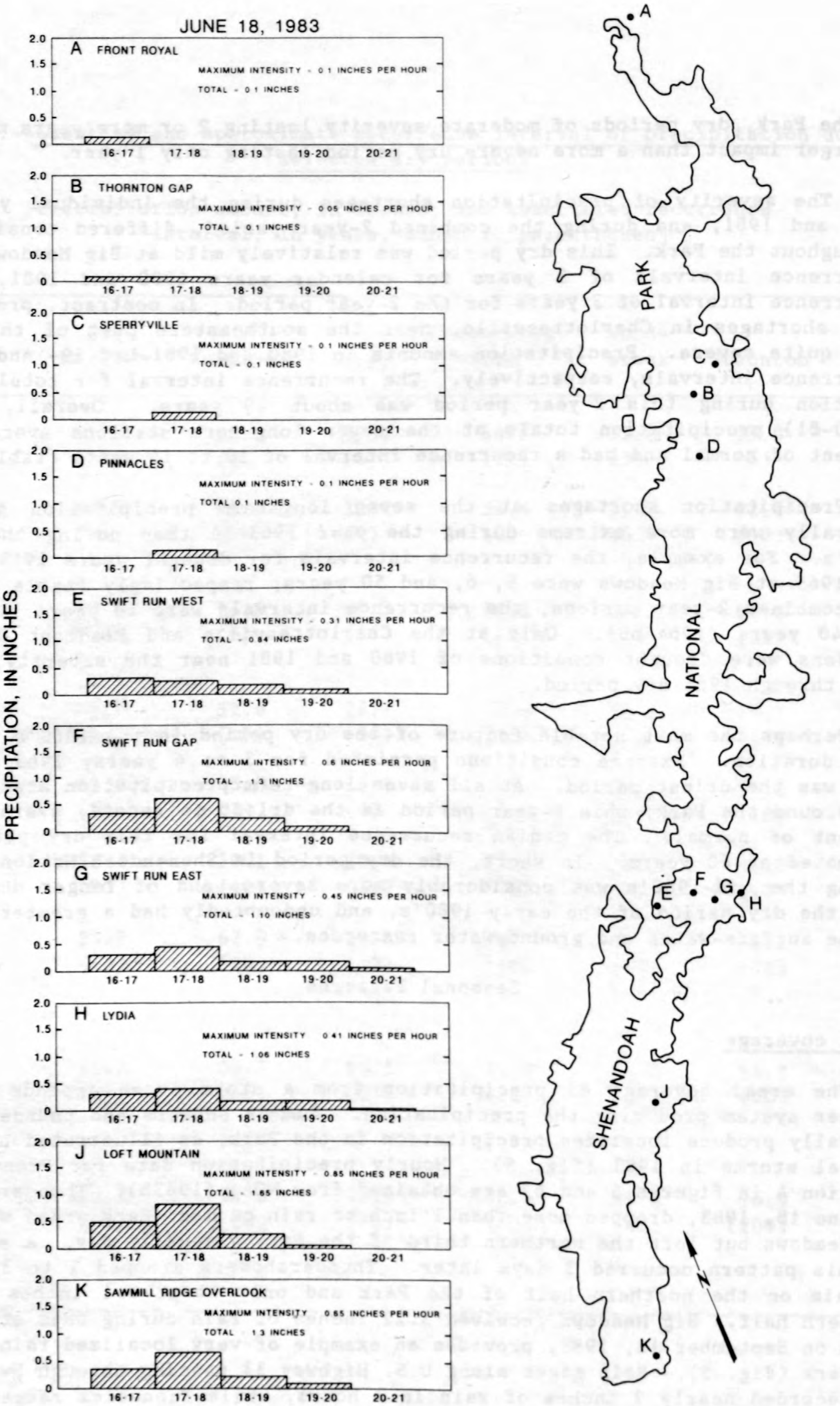
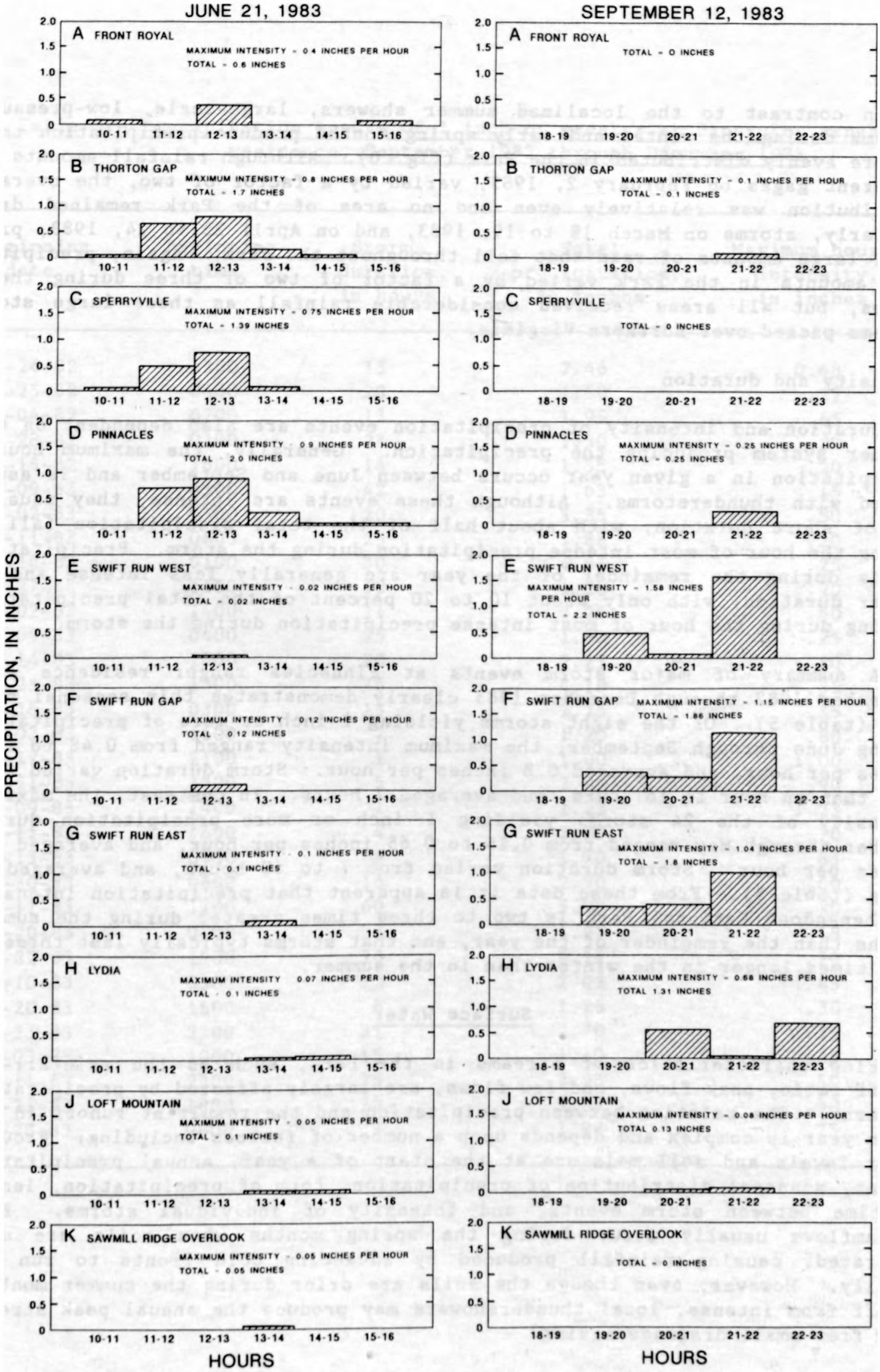


Figure 5.--Areal and temporal distribution of precipitation amounts for three typical summer storms.


JUNE 21, 1983
SEPTEMBER 12, 1983
PRECIPITATION, IN INCHES
A FRONT ROYAL
MAXIMUM INTENSITY - 0.4 INCHES PER HOUR
TOTAL - 0.6 INCHES
A FRONT ROYAL
TOTAL - 0 INCHES
B THORTON GAP
MAXIMUM INTENSITY - 0.8 INCHES PER HOUR
TOTAL - 1.7 INCHES
B THORTON GAP
MAXIMUM INTENSITY - 0.1 INCHES PER HOUR
TOTAL - 0.1 INCHES
C SPERRYVILLE
MAXIMUM INTENSITY - 0.75 INCHES PER HOUR
TOTAL - 1.39 INCHES
C SPERRYVILLE
TOTAL - 0 INCHES
D PINNACLES
MAXIMUM INTENSITY - 0.9 INCHES PER HOUR
TOTAL - 2.0 INCHES
D PINNACLES
MAXIMUM INTENSITY - 0.25 INCHES PER HOUR
TOTAL - 0.25 INCHES
E SWIFT RUN WEST
MAXIMUM INTENSITY - 0.02 INCHES PER HOUR
TOTAL - 0.02 INCHES
E SWIFT RUN WEST
MAXIMUM INTENSITY - 1.58 INCHES PER HOUR
TOTAL - 2.2 INCHES
F SWIFT RUN GAP
MAXIMUM INTENSITY - 0.12 INCHES PER HOUR
TOTAL - 0.12 INCHES
F SWIFT RUN GAP
MAXIMUM INTENSITY - 1.15 INCHES PER HOUR
TOTAL - 1.86 INCHES
G SWIFT RUN EAST
MAXIMUM INTENSITY - 0.1 INCHES PER HOUR
TOTAL - 0.1 INCHES
G SWIFT RUN EAST
MAXIMUM INTENSITY - 1.04 INCHES PER HOUR
TOTAL - 1.8 INCHES
H LYDIA
MAXIMUM INTENSITY - 0.07 INCHES PER HOUR
TOTAL - 0.1 INCHES
H LYDIA
MAXIMUM INTENSITY - 0.68 INCHES PER HOUR
TOTAL 1.31 INCHES
J LOFT MOUNTAIN
MAXIMUM INTENSITY - 0.05 INCHES PER HOUR
TOTAL - 0.1 INCHES
J LOFT MOUNTAIN
MAXIMUM INTENSITY - 0.08 INCHES PER HOUR
TOTAL 0.13 INCHES
K SAWMILL RIDGE OVERLOOK
MAXIMUM INTENSITY - 0.05 INCHES PER HOUR
TOTAL - 0.05 INCHES
K SAWMILL RIDGE OVERLOOK
TOTAL - 0 INCHES
10-11
11-12
12-13
13-14
14-15
15-16
18-19
19-20
20-21
21-22
22-23
HOURS
HOURS

In contrast to the localized summer showers, large-scale, low-pressure systems during the winter and early spring months produce precipitation that is more evenly distributed in the Park (fig. 6). Although rainfall amounts at different gages on February 2, 1983, varied by a factor of two, the overall distribution was relatively even and no area of the Park remained dry. Similarly, storms on March 18 to 19, 1983, and on April 23 to 24, 1983, produced large amounts of rain that fell throughout the Park. Again, precipitation amounts in the Park varied by a factor of two or three during these storms, but all areas received considerable rainfall as these large storm systems passed over northern Virginia.

Intensity and duration

Duration and intensity of precipitation events are also dependent on the weather system producing the precipitation. Generally, the maximum hourly precipitation in a given year occurs between June and September and is associated with thunderstorms. Although these events are intense, they usually are of short duration, with about half of the total precipitation falling during the hour of most intense precipitation during the storm. Precipitation events during the remainder of the year are generally less intense and of longer duration, with only about 10 to 20 percent of the total precipitation falling during the hour of most intense precipitation during the storm.

A summary of major storm events at Pinnacles ranger residence from September 1982 through December 1983 clearly demonstrates this seasonal pattern (table 5). Of the eight storms yielding 1 inch or more of precipitation during June through September, the maximum intensity ranged from 0.48 to 1.23 inches per hour, and averaged 0.8 inches per hour. Storm duration varied from less than an hour to 16 hours, and averaged 7 hours. In contrast, the maximum intensity of the 24 storms yielding 1 inch or more precipitation during October through May ranged from 0.15 to 0.65 inches per hour, and averaged 0.3 inches per hour. Storm duration varied from 7 to 60 hours, and averaged 23 hours (table 5). From these data it is apparent that precipitation intensity in Shenandoah National Park is two to three times greater during the summer months than the remainder of the year, and that storms typically last three to four times longer in the winter than in the summer.

Surface Water

Flow characteristics of streams in the Park, such as the rainfall-to-runoff ratio, peak flows, and low flows, are largely affected by precipitation patterns. The relation between precipitation and the resultant runoff in any given year is complex and depends upon a number of factors including: groundwater levels and soil moisture at the start of a year, annual precipitation amount, seasonal distribution of precipitation, form of precipitation, length of time between storm events, and intensity of individual storms. Peak streamflows usually occur during the spring months when soils are more saturated, causing rainfall produced by advancing cold fronts to run off readily. However, even though the soils are drier during the summer months, runoff from intense, local thundershowers may produce the annual peak streamflow from small drainage basins.

The lowest streamflow in a year generally occurs after a period of little or no precipitation during June through September. Evapotranspiration sharply

Table 5.--Precipitation events of 1 inch or greater at Pinnacles ranger residence, September 1982 through December 1983

Beginning date	Beginning time	Storm duration, in hours	Total precipitation, in inches	Maximum hourly intensity, in inches
09-26-82	1300	15	2.46	0.48
10-25-82	0400	20	1.60	.22
11-04-82	0200	13	1.95	.65
11-28-82	0300	23	1.30	.20
12-15-82	1800	14	1.55	.20
01-09-83	0300	42	1.63	.15
02-02-83	0300	20	3.35	.50
02-11-83	0600	25	1.85	.20
03-18-83	0100	30	4.65	.25
03-27-83	1100	10	1.20	.20
04-02-83	1400	11	3.25	.50
04-09-83	0400	25	1.80	.25
04-14-83	2000	20	2.23	.40
04-23-83	1300	36	4.18	.32
05-16-83	0300	13	2.75	.35
06-03-83	1600	7	1.20	.80
06-17-83	2100	1	1.00	1.00
06-21-83	1200	5	2.00	.90
08-09-83	1400	1	1.23	1.23
08-11-83	1600	4	1.00	.70
09-13-83	0900	9	1.70	.83
09-30-83	0600	16	2.20	.60
10-11-83	1100	60	5.90	.30
10-20-83	0700	28	1.95	.15
10-22-83	1900	26	2.15	.20
11-10-83	0300	12	2.02	.45
11-20-83	1500	8	1.25	.30
11-23-83	2300	31	2.70	.35
12-03-83	1900	15	1.10	.25
12-11-83	2300	35	2.95	.50
12-21-83	1800	20	2.03	.30
12-28-83	0600	7	1.23	.25

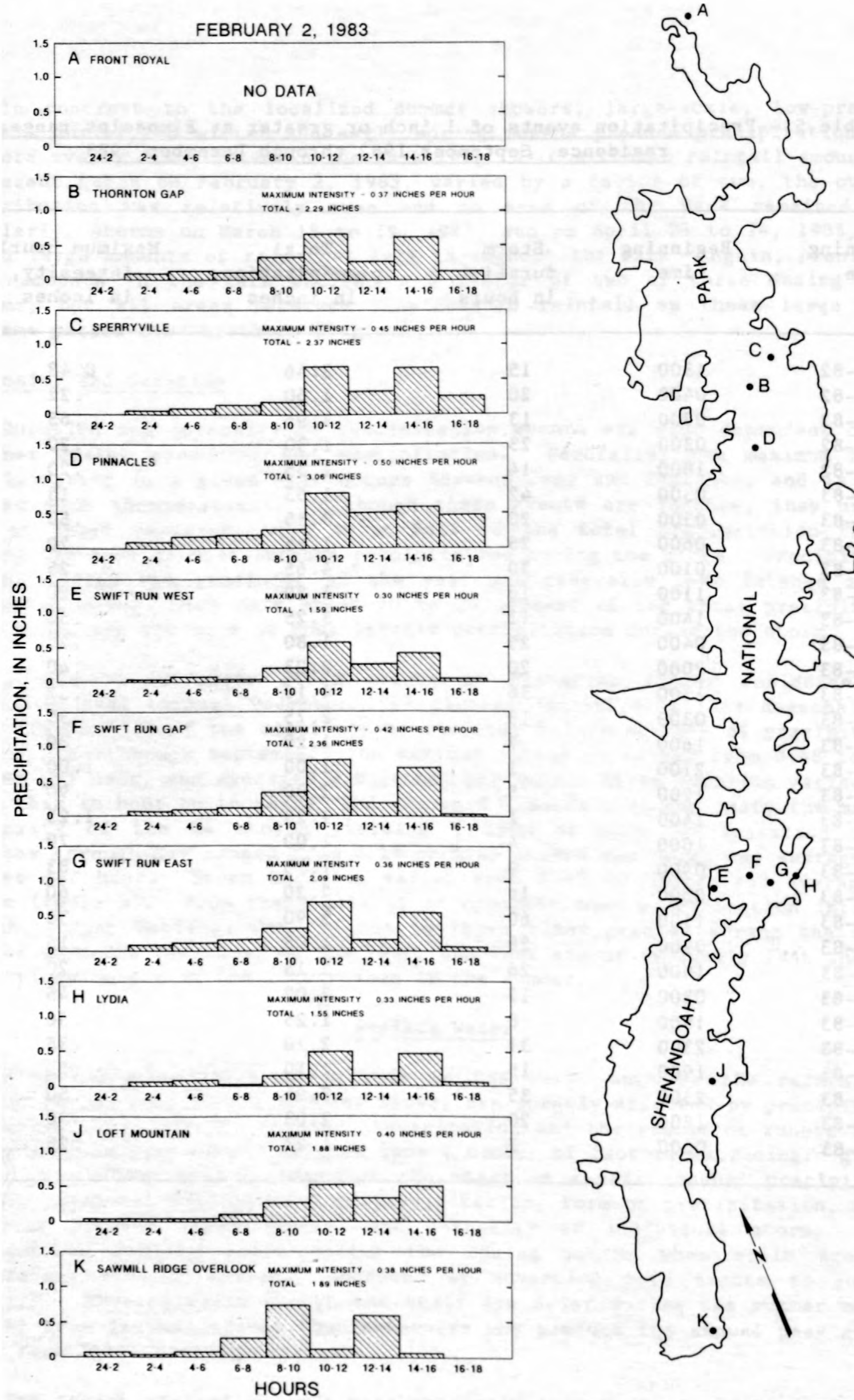
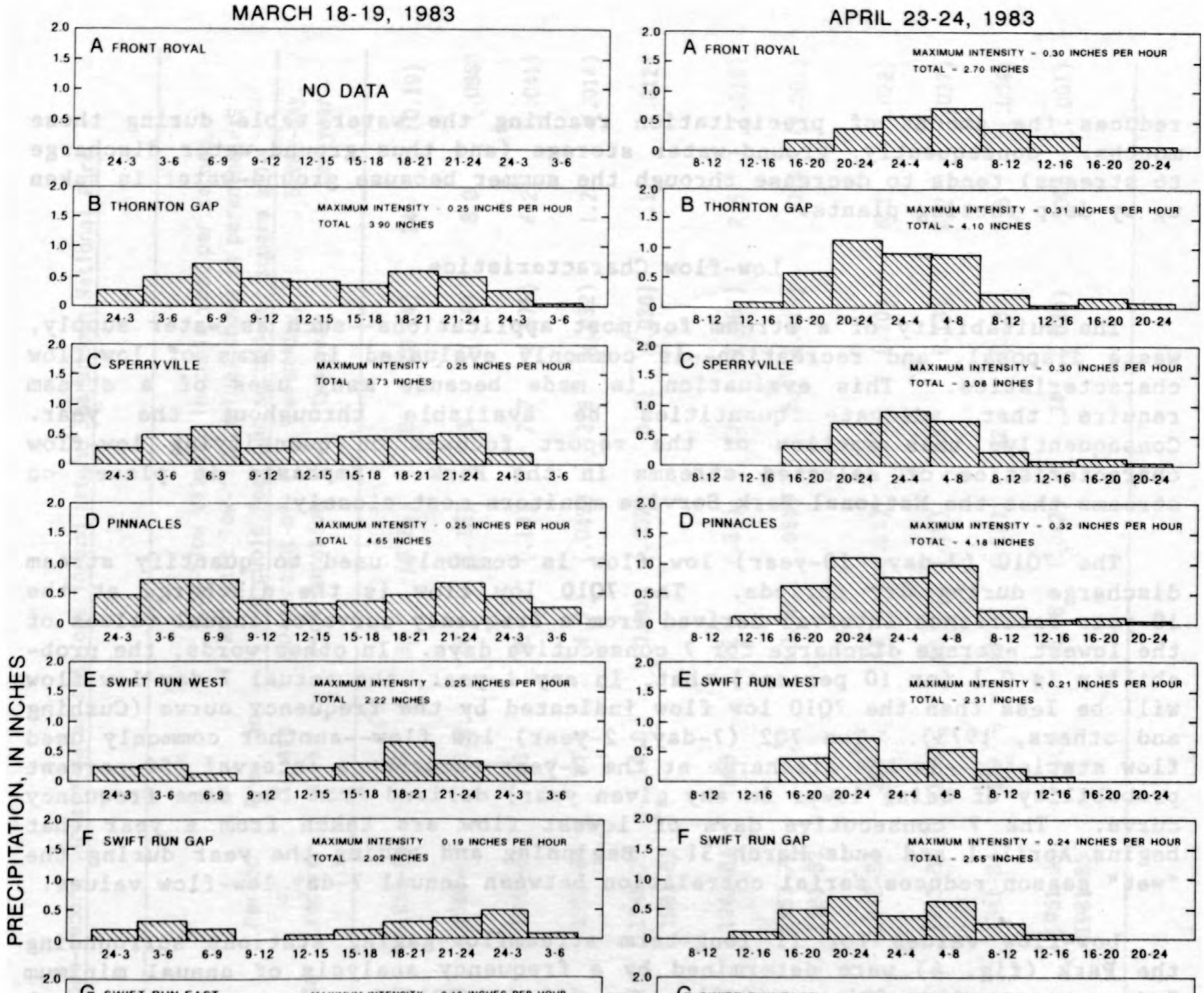


Figure 6.--Areal and temporal distribution of precipitation amounts for three typical winter storms.


MARCH 18-19, 1983
APRIL 23-24, 1983
PRECIPITATION, IN INCHES
A FRONT ROYAL
NO DATA
A FRONT ROYAL
MAXIMUM INTENSITY = 0.30 INCHES PER HOUR
TOTAL = 2.70 INCHES
B THORNTON GAP
MAXIMUM INTENSITY - 0.25 INCHES PER HOUR
TOTAL 3.90 INCHES
B THORNTON GAP
MAXIMUM INTENSITY = 0.31 INCHES PER HOUR
TOTAL = 4.10 INCHES
C SPERRYVILLE
MAXIMUM INTENSITY 0.25 INCHES PER HOUR
TOTAL 3.73 INCHES
C SPERRYVILLE
MAXIMUM INTENSITY = 0.30 INCHES PER HOUR
TOTAL - 3.08 INCHES
D PINNACLES
MAXIMUM INTENSITY - 0.25 INCHES PER HOUR
TOTAL 4.65 INCHES
D PINNACLES
MAXIMUM INTENSITY = 0.32 INCHES PER HOUR
TOTAL = 4.18 INCHES
E SWIFT RUN WEST
MAXIMUM INTENSITY 0.25 INCHES PER HOUR
TOTAL 2.22 INCHES
E SWIFT RUN WEST
MAXIMUM INTENSITY = 0.21 INCHES PER HOUR
TOTAL - 2.31 INCHES
F SWIFT RUN GAP
MAXIMUM INTENSITY 0.19 INCHES PER HOUR
TOTAL 2.02 INCHES
F SWIFT RUN GAP
MAXIMUM INTENSITY = 0.24 INCHES PER HOUR
TOTAL = 2.65 INCHES
G SWIFT RUN EAST
MAXIMUM INTENSITY 0.18 INCHES PER HOUR
TOTAL 1.89 INCHES
G SWIFT RUN EAST
MAXIMUM INTENSITY = 0.22 INCHES PER HOUR
TOTAL -2.32 INCHES
H LYDIA
MAXIMUM INTENSITY - 0.16 INCHES PER HOUR
TOTAL 1.43 INCHES
H LYDIA
MAXIMUM INTENSITY = 0.26 INCHES PER HOUR
TOTAL = 2.18 INCHES
J LOFT MOUNTAIN
MAXIMUM INTENSITY 0.55 INCHES PER HOUR
TOTAL 4.75 INCHES
J LOFT MOUNTAIN
MAXIMUM INTENSITY = 0.34 INCHES PER HOUR
TOTAL = 4.15 INCHES
K SAWMILL RIDGE OVERLOOK
MAXIMUM INTENSITY 0.55 INCHES PER HOUR
TOTAL 4.39 INCHES
K SAWMILL RIDGE OVERLOOK
MAXIMUM INTENSITY = 0.32 INCHES PER HOUR
TOTAL = 4.00 INCHES
24-3 3-6 6-9 9-12 12-15 15-18 18-21 21-24 24-3 3-6
8-12 12-16 16-20 20-24 24-4 4-8 8-12 12-16 16-20 20-24
HOURS
HOURS

reduces the amount of precipitation reaching the water table during these months. Consequently, ground-water storage (and thus ground-water discharge to streams) tends to decrease through the summer because ground-water is taken up by deep rooting plants.

Low-flow Characteristics

The suitability of a stream for most applications--such as water supply, waste disposal, and recreation--is commonly evaluated in terms of low-flow characteristics. This evaluation is made because many uses of a stream require that adequate quantities be available throughout the year. Consequently, this section of the report focuses on quantifying low-flow characteristics of selected streams in the Park. Emphasis is placed on streams that the National Park Service monitors most closely.

The 7Q10 (7-day, 10-year) low flow is commonly used to quantify stream discharge during dry periods. The 7Q10 low flow is the discharge at the 10-year recurrence interval derived from a frequency curve of annual values of the lowest average discharge for 7 consecutive days. In other words, the probability is 0.1 (or 10 percent) that, in any 1 year, the actual 7-day low flow will be less than the 7Q10 low flow indicated by the frequency curve (Cushing and others, 1973). The 7Q2 (7-day, 2-year) low flow--another commonly used flow statistic--is the discharge at the 2-year recurrence interval (50-percent probability of being lower in any given year) derived from the same frequency curve. The 7 consecutive days of lowest flow are taken from a year that begins April 1 and ends March 31. Beginning and ending the year during the "wet" season reduces serial correlation between annual 7-day low-flow values.

Low-flow values for 11 long-term streamflow-gaging stations surrounding the Park (fig. 4) were determined by a frequency analysis of annual minimum 7-day average flow (Riggs, 1968). The 7Q2 and 7Q10 low-flow values for each station are given in table 6. Flow-duration curves of mean daily discharge were used to estimate the discharge at 90-percent-of-flow duration for each station (table 6) (Searcy, 1959). The 90-percent-of-flow duration represents the discharge that is equaled or exceeded on 90 percent of the days during an average year.

Low-flow values for 29 partial-record stations on the periphery of the Park (pl. 1) were estimated by obtaining several discharge measurements at the stations during base-flow periods from August 1981 through September 1983, and graphically comparing them to concurrent daily discharge data at nearby long-term streamflow-gaging stations either on the same stream or on streams with similar drainage-basin characteristics (Riggs, 1972). For example, base-flow measurements of Hughes River near Nethers (01662150) were plotted against concurrent daily mean flows at Robinson River near Locust Dale (01666500) (fig. 7). A line fitted to these points was used to estimate 7Q2 and 7Q10 low-flow values and 90-percent-of-flow duration for Hughes River from corresponding values at the long-term gaging station given in table 6. Because of climatic conditions during the study, several measurements were made when discharges at the long-term gaging stations were lower than their estimated 7Q2 low-flow value, but no measurements were made when discharges were lower than the 7Q10 low-flow value. Consequently, the 7Q10 values for partial-record stations are obtained from extensions of the graphical lines, which reduces the confidence in these values. Table 7 provides the 7Q2 and 7Q10 low-flow estimates, and

Table 6.--Low-flow characteristics of long-term, continuous-record surface-water stations in and around Shenandoah National Park

Station number	Station name	Latitude	Longitude	Period of record	Area, in square miles	Low-flow values, in cubic feet per second, and unit low-flow values shown in parentheses, in cubic feet per second per square mile: 90-percent-of-flow duration		Seven-day, two-year		Seven-day, ten-year	
01626000	South River near Waynesboro	380327	0785430	1952-84	127	32	(0.25)	30	(0.24)	24	(0.19)
01632900	Smith Creek near New Market	384136	0783835	1960-84	93.2	14	(.15)	13	(.14)	8.0	(.086)
01634500	Cedar Creek near Winchester	390452	0781947	1937-84	103	10	(.10)	7.7	(.075)	4.2	(.041)
01635500	Passage Creek near Buckton	385729	0781601	1932-84	87.8	4.3	(.049)	2.8	(.032)	1.2	(.014)
01636210	Happy Creek at Front Royal	385420	0781110	1948-77 1981-83	14.0	0.80	(.057)	0.51	(.036)	.17	(.012)
01662000	Rappahannock River near Warrenton	384105	0775415	1942-84	195	22	(.11)	13	(.067)	2.5	(.013)
01662500	Rush River at Washington	384250	0780905	1953-77 1981-83	14.7	0.90	(.061)	.28	(.019)	.004	(<.001)
01663500	Hazel River at Rixeyville	383530	0775755	1942-84	287	45	(.16)	29	(.10)	6.2	(.022)
01665500	Rapidan River near Ruckersville	381650	0782025	1942-84	114	22	(.19)	15	(.13)	4.2	(.037)
01666500	Robinson River near Locust Dale	381930	0780545	1943-84	179	40	(.22)	32	(.18)	9.6	(.054)
02031500	N.F. Moormans River near Whitehall	380825	0784505	1951-63 1981-83	11.4	0.48	(.042)	.34	(.030)	.005	(<.001)

the estimates of discharge at 90-percent-of-flow duration, for the 29 partial-record stations.

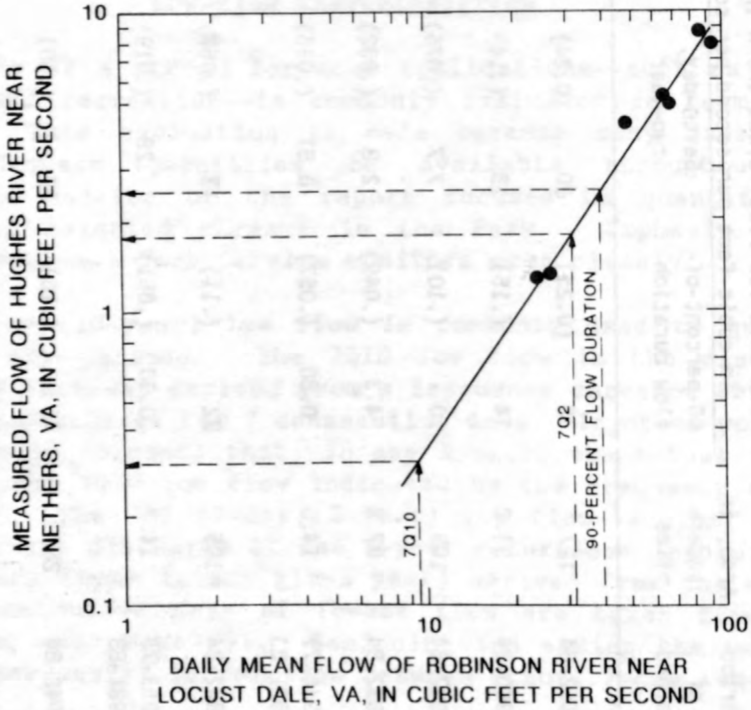


Figure 7.--Relation of base-flow measurements of Hughes River near Nethers to concurrent daily mean flows of Robinson River near Locust Dale (gaged).

Relation of low-flow values to basin characteristics

Differences in drainage-basin characteristics are largely responsible for the variations in low-flow values seen in table 7. Basin characteristics, such as drainage area, geologic and topographic setting, regolith thickness, local climate, and vegetative cover, all influence the low-flow characteristics of the receiving stream. Because vegetative cover is uniform in the Park, and the climatic conditions of individual basins do not vary greatly, these characteristics are probably of secondary importance in explaining the differences in low-flow values.

Drainage-basin size and underlying rock type, given in table 7, appear to explain much of the observed low-flow variability at the 29 partial-record stations. This is clearly seen in a plot of 7Q2 low-flow values as a function of drainage area for basins predominantly (greater than 80 percent of the area) underlain by crystalline rocks (Catoctin Formation and Pedlar Formation of Allen, 1963 and the Old Rag Granite of Furcron, 1934) and for

Table 7.--Drainage-basin characteristics and estimated low-flow values of partial-record surface-water stations in and around Shenandoah National Park

Station number	Station name	Latitude	Longitude	Area, in square miles	Drainage basin rock type, in percent		Number of low-flow measurements	Lowest measured flow, in cubic feet per second	Low-flow values, in cubic feet per second, and unit low-flow values shown in parentheses, in cubic feet per second per square mile		
					Crystalline	Sedimentary			90-percent-of-flow duration	Seven-day, two-year	Seven-day, ten-year
01626900	Sawmill Run near Dooms	380546	0784838	3.62	19	81	10	0.02	0.17 (0.047)	0.08 (0.022)	<0.01 (<0.003)
01627100	Meadow Run near Crimora	380929	0784838	3.45	0	100	14	.09	.25 (.072)	.15 (.043)	.03 (.009)
01627400	Paine Run near Harriston	381155	0784738	4.92	0	100	12	.05	.3 (.061)	.2 (.041)	.02 (.004)
01628060	White Oak Run near Grottoes	381501	0784457	1.94	0	100	[a] (--)	.0	<.1 (<.005)	<.01 (<.005)	.0 (.0)
01628700	Twomile Run near McGaheysville	382004	0784020	2.17	0	100	10	.05	.07 (.032)	.05 (.023)	.015 (.007)
01628900	Hawksbill Creek trib near Swift Run	382047	0783435	1.32	100	0	10	.10	.17 (.13)	.13 (.10)	.03 (.023)
01629120	East Branch Naked Creek near Jollett	382807	0782950	4.58	81	19	18	.21	.8 (.17)	.5 (.11)	.04 (.009)
01629920	Little Hawksbill Creek trib near Ida	383323	0782555	.78	100	0	19	.05	.11 (.14)	.07 (.09)	.02 (.026)
01630542	Pass Creek near Thornton Gap	383905	0782114	2.00	100	0	12	.15	.40 (.20)	.25 (.12)	.05 (.025)
01630585	Jeremys Run near Oak Hill	384318	0782315	9.65	61	39	19	.001	.10 (.010)	.025 (.003)	<.01 (<.001)
01630620	Overall Run near Bentonville	384818	0782034	4.40	69	31	15	.04	.13 (.030)	.06 (.014)	<.01 (<.002)
01630649	Phils Arm Run near Browntown	384734	0781429	.98	100	0	10	.016	.12 (.12)	.07 (.07)	.01 (.01)
01630680	Lands Run near Browntown	384920	0781222	1.38	100	0	10	.08	.20 (.14)	.13 (.09)	.04 (.03)
01662100	Hazel River near Nethers	383654	0781544	5.15	100	0	13	.59	1.6 (.31)	1.0 (.19)	.2 (.04)
01662150	Hughes River near Nethers	383427	0781749	9.92	100	0	7	1.24	2.5 (.25)	1.8 (.18)	.3 (.03)
01662160	Brokenback Run near Nethers	383416	0781801	4.30	100	0	13	.26	.75 (.17)	.5 (.12)	.05 (.012)
01662190	Ragged Run near Etlan	383156	0781744	1.14	100	0	12	.05	.14 (.12)	.09 (.08)	.02 (.018)
01662310	Thornton River AB Beech Spring Hollow near Sperryville	383912	0781623	6.40	100	0	10	.56	1.7 (.27)	1.0 (.16)	.3 (.05)
01662350	N.F. Thornton River near Sperryville	384136	0781633	7.21	94	6	13	.23	.8 (.11)	.5 (.07)	.09 (.012)
01662370	Piney River near Sperryville	384146	0781530	5.58	100	0	7	.24	.8 (.14)	.5 (.09)	.10 (.018)
01662480	Rush River at Rt. 622 near Washington	384429	0781308	2.34	100	0	5	.15	.35 (.15)	.21 (.09)	.05 (.021)
01662490	Rush River near Washington	384337	0781013	11.1	100	0	9	.10	.92 (.08)	.34 (.031)	<.01 (<.001)
01665260	Rapidan River near Graves Mill	382638	0782211	9.74	100	0	6	1.4	3.6 (.37)	2.4 (.25)	.5 (.05)
01665270	Staunton River at mouth nr Graves Mill	382638	0782212	4.21	100	0	10	.45	1.6 (.38)	.9 (.21)	.14 (.033)
01665340	Conway River near Kinderhook	382459	0782617	9.66	100	0	8	.81	2.1 (.22)	1.4 (.14)	.3 (.03)
01665440	South River near McMullen	382201	0782738	4.94	100	0	11	.15	.9 (.18)	.6 (.12)	.06 (.012)
01665740	Robinson River near Syria	383214	0782049	9.53	100	0	8	.41	2.3 (.24)	1.5 (.16)	.15 (.016)
01665800	Rose River near Syria	383055	0782159	9.15	100	0	8	.58	3.2 (.35)	2.1 (.22)	.3 (.03)
02032545	Ivy Creek near Boonesville	381607	0783645	6.11	83	17	13	.0	.12 (.020)	.05 (.008)	.0 (.0)

[a]Operated as a continuous-record gage for several years.

basins predominantly underlain by sedimentary rocks (Harpers and Antietam Formations). For streams draining either crystalline or sedimentary rocks, 7Q2 low-flow values increase as drainage area increases (fig. 8). Ivy Creek

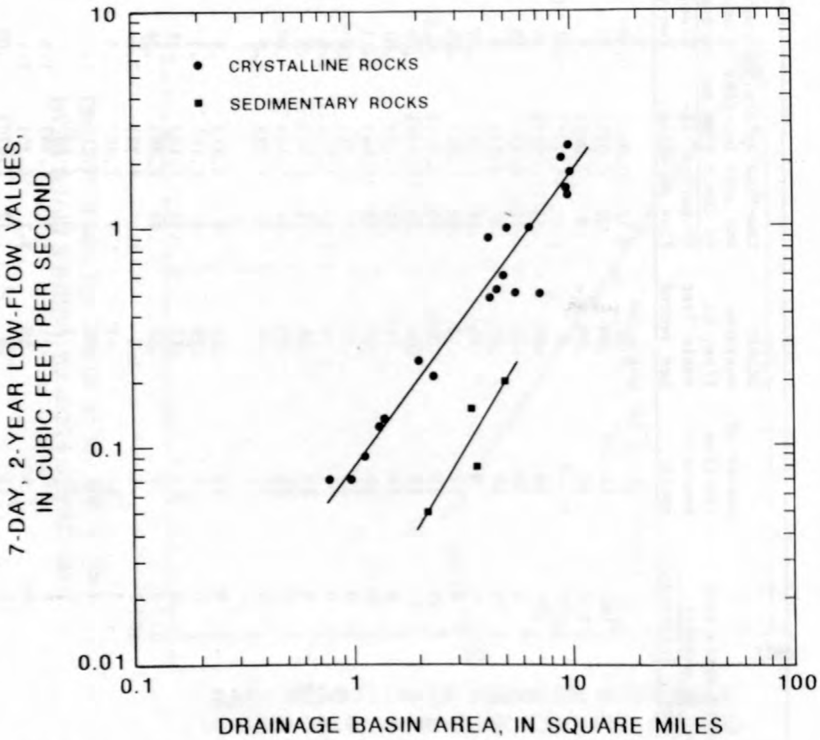


Figure 8.--Relations between 7-day, 2-year low-flow value and drainage area for basins dominated (greater than 80 percent) by crystalline or sedimentary rocks.

near Boonesville (02032545), Rush River near Washington (01662490), and White Oak Run near Grottoes (01628060) are not included in figure 8. Both the Ivy Creek and Rush River drainage basins contain large, developed, low-relief areas outside the Park that undoubtedly respond differently during periods of base flow than basins entirely within mountainous, undeveloped areas. The White Oak Run station is located on an alluvial fan that transmits a large part of the water leaving the basin during base-flow periods (Vreeland, 1983). Consequently, low-flow estimates obtained from this station probably do not reflect the actual low-flow values for other sites on this stream.

As evident in figure 8, for a given drainage area, 7Q2 low-flow values for streams draining crystalline rocks are about four times greater than low-flow values for streams draining sedimentary rocks. The average unit low-flow value for streams draining the crystalline and sedimentary rocks in the Park are 0.13 (standard deviation = 0.05, n=20) and 0.032 (standard deviation = 0.011, n=4) $(ft^3/s)/mi^2$ (cubic feet per second per square mile), respectively. This difference in unit low-flow values is statistically significant at the 99-percent confidence level. Unit low-flow values for streams draining the individual geologic formations included in the crystalline rock group are very similar, averaging 0.12, 0.14, and 0.10 $(ft^3/s)/mi^2$ for the Catoctin

Formation, Pedlar Formation, and Old Rag Granite, respectively. These slight differences in unit low-flow values are not significant at the 95-percent confidence level.

Depth and permeability of the regolith, slope of the land surface, and extent of bedrock fracturing, all affect the quantity of water a basin yields during dry periods. These features, which are strongly controlled by bedrock geology, differ considerably in the Park. Where crystalline rocks are gently inclined drainage areas have developed with a thick (10 to 60 feet) regolith. These areas store large quantities of ground water that sustain streamflow during dry periods. Although steep slopes and a thin regolith can be found in some areas of the Park underlain by crystalline rocks, and undoubtedly ground-water discharge from these areas is small during dry periods, most drainage basins in crystalline rock of 1 square mile or more contain large areas of thick (greater than 10 feet) regolith.

Drainage basins that developed in sedimentary rocks in the Park (Harpers and Antietam Formations) have relatively steep slopes and generally contain a thin (less than 10 feet) to nonexistent regolith. The poor development of regolith is a result of the steep slopes and the extreme resistance of the bedrock (quartzite and metasediments) to weathering processes. As a result of these basin characteristics, little ground water infiltrates and storage is low, which accounts for the relatively low unit 7Q2 low-flow values for streams draining sedimentary rocks.

Gain and loss surveys during base-flow periods

Gain and loss surveys were made in the Park during a period of base flow to verify that the surface-water stations established on the periphery of the Park provide a good indication of flow conditions of these same streams in the Park. These surveys entailed synoptic measurements of discharge along a stream course to determine the location of stream-water gains and losses. North Fork Moormans River, Brokenback Run, Staunton River, Paine Run, and Jeremys Run were selected for the surveys because they are underlain by different geologic formations and because they are readily accessible from roads and trails. Surveys were made during a dry period in late August and early September, 1983. Streamflows were below 90-percent-of-flow duration during the surveys, except for North Fork Moormans River, which was at 73-percent-of-flow duration. (One inch of rain on the southern part of the Park the day before the North Fork Moormans River survey accounted for the higher flows.) Flows in Staunton River and Brokenback Run were both below their estimated 7Q2 low-flow values during the surveys.

Results of the gain and loss surveys indicate that, during base-flow periods, stations on the periphery of the Park generally have unit flows comparable to upstream stations in the Park. This is particularly notable for the North Fork Moormans River where unit flows at six stations only ranged from 0.12 to 0.17 $(ft^3/s)/mi^2$ (table 8). This stream appears to gain water throughout its course and in quantities that are proportional to the drainage area.

Brokenback Run and Staunton River, which are predominantly underlain by Old Rag Granite and Pedlar Formation, respectively, also tend to gain water throughout their courses. However, a disproportionately large share of water comes from the headwater areas. On August 31, 1983, 81 percent of the discharge at the Staunton River partial-record station (01665270) came from the upper 48 percent of the drainage basin (table 9). Similarly, on August 30, 1983, 47 percent of the discharge at the Brokenback Run partial-record station (01662160) came from the upper 29 percent of the drainage basin (table 10). The upper parts of these basins have gentler slopes and perhaps a thicker regolith than areas farther downstream, and may provide more ground-water storage for sustaining flows during dry periods. This phenomenon of greater unit base flows at higher elevation may be fairly common for streams draining crystalline rocks in the Park.

In contrast to the streams draining crystalline rocks, the unit discharge of Paine Run, which is underlain by sedimentary rocks of the Harpers and Antietam Formations, was less in the upper basin than at the partial-record station (01627400) at the Park boundary during a gain and loss survey (table 11). Typical of basins underlain by sedimentary rocks in the Park, the head-water section of Paine Run is generally steeper than areas farther down slope, and the stream channel changes from a very steep, well-confined channel in the upper stream reaches (40 percent slope at an elevation of 2,400 feet) to a gently sloping channel running through valley infill in the lower reaches (2 percent slope at an elevation of 1,400 feet). Apparently, the steep-headwater areas and their associated thin regolith do not store and discharge ground water during dry periods as readily as the lower-lying areas in the basin. Once the channel slope drops below 3 percent, at an elevation of about 1,600 feet, Paine Run tends to gain water along its course in quantities propor-tional to the drainage area, as evidenced by constant unit discharges during the survey (table 11). At an elevation of 1,360 feet, however, Paine Run is

Table 8.--Gain and loss survey of North Fork Moormans River, August 29, 1983

Station altitude, in feet above mean sea level	Drainage area, in square miles	Discharge, in cubic feet per second	Unit discharge, in cubic feet per second per square mile
1970	1.62	0.27	0.17
1800	2.60	.34	.13
1750	3.65	.46	.13
1570	5.82	.69	.12
1230	9.12	1.3	.14
[a]1010	11.4	1.8	.16

[a] Gaging station 02031500

Table 9.--Gain and loss survey of Staunton River, August 31, 1983

Station altitude, in feet above mean sea level	Drainage area, in square miles	Discharge, in cubic feet per second	Unit discharge, in cubic feet per second per square mile
2940	0.50	0.14	0.28
2440	.94	.26	.28
2000	2.02	.60	.30
1680	2.55	.57	.22
1280	3.23	.54	.17
[a]1000	4.21	.74	.18

[a] Partial-record station 01665270

Table 10.--Gain and loss survey of Brokenback Run, August 30, 1983

Station altitude, in feet above mean sea level	Drainage area, in square miles	Discharge, in cubic feet per second	Unit discharge, in cubic feet per second per square mile
2490	0.57	0.17	0.30
1980	1.25	.20	.16
1710	1.64	.19	.12
1360	2.90	.19	.07
1150	3.47	.24	.07
[a]1010	4.30	.43	.10

[a] Partial-record station 01662160

outside the Park boundary and is underlain by extensive alluvial deposits over dolomite and limestone (Gathright and others, 1977). During the gain and loss survey Paine Run disappeared and resurfaced several times in this area, and finally disappeared altogether into the alluvium farther downstream. There is strong evidence that the partial-record station on Overall Run (01630620) was located too far out in the alluvial deposits west of the Park, which accounts for its abnormally low 7Q2 and 7Q10 low-flow values in table 7. Discharges measured at the Overall Run partial-record station undoubtedly do not reflect the low-flow characteristics of this stream in the Park.

Table 11.--Gain and loss survey of Paine Run, September 2, 1983

Station altitude, in feet above mean sea level	Drainage area, in square miles	Discharge, in cubic feet per second	Unit discharge, in cubic feet per second per square mile
1710	1.18	0.03	0.03
1580	1.84	.14	.08
1490	3.26	.20	.06
1440	3.74	.22	.06
[a]1390	4.92	.28	.06
1360	5.01	.0	.0
1340	5.06	.08	.02

[a] Partial-record station 01627400

Jeremys Run was selected for a gain and loss survey because it represents a special hydrologic case. Above an elevation of 1,700 feet, this stream responded similarly to Brokenback Run. Unit flows on September 1, 1983, were greatest in the upper stream reaches during the survey and dropped off downstream (table 12). As in the Brokenback Run basin, the slope of the upper Jeremys Run basin is gentler than the remainder of the basin and undoubtedly has a better developed regolith for storage of ground water. Unlike Brokenback Run, however, the unit flows in the lower reaches of Jeremys Run did not stabilize. Unit flows continued to decline downstream, reaching zero discharge at an elevation of 1,180 feet. During base-flow periods, most of the water leaving the basin moves through extensive deposits of valley infill at lower stream elevations. Although streamflow reappears below an elevation of 1,180 feet, the low unit flows suggest that the majority of water leaving the basin was not detected by a measure of surface runoff.

Table 12.--Gain and loss survey of Jeremys Run, September 1, 1983

Station altitude, in feet above mean sea level	Drainage area, in square miles	Discharge, in cubic feet per second	Unit discharge, in cubic feet per second per square mile
2540	0.52	0.09	0.173
1870	2.00	.16	.080
1730	2.48	.20	.081
1490	3.62	.12	.033
1280	4.79	.13	.027
1180	5.85	.0	0
1120	7.10	.04	.006
1020	7.91	.11	.014
920	9.63	.14	.015
[a]910	9.65	.08	.008
880	9.72	.0	.0

[a] Partial-record station 01630585

The Jeremys Run drainage basin is not typical of most basins in Shenandoah National Park. However, the gain and loss survey on this stream points out that significant quantities of water leaving basins can move through alluvial deposits and valley infill areas and never be detected by measures of surface runoff. Jermeys Run probably represents an extreme case in Shenandoah National Park, but subsurface flow through transmissive deposits may account for much of the variation in low-flow characteristics not accounted for by drainage basin size and underlying rock types.

Low-flow trends

The lack of long-term streamflow-gaging stations in the Park precludes a direct evaluation of low-flow trends of individual streams. A generalized picture of low flows in the Park is obtained by evaluating the long-term record from nearby sites. Two sites--Rappahannock River near Warrenton (01662000) and Rapidan River near Ruckersville (01665500)--were selected because (1) more than 40 years of record are available, (2) they have relatively small drainage basins (less than 200 square miles) that are underlain by crystalline rocks similar to those in the Park, and (3) these sites are on rivers with headwaters in two different sections of the Park. The headwaters of the Rappahannock and Rapidan rivers are in the northern and central sections of the Park, respectively.

The mean flow for the lowest seven consecutive days in each of the years 1943 through 1984 are plotted in figure 9 for both surface-water sites. As expected, years with below-normal precipitation, especially during spring and summer, are the years with very low mean 7-day low flows. At Rappahannock River at Warrenton, the mean 7-day low flow was less than 2.5 ft^3/s in 1944, 1954, 1957, 1963, 1964, and 1966. Each of these years was marked by precipitation amounts well below normal from May through October. The most extreme low-flow year at the Rappahannock station was 1954 (7-day mean low flow of 1.0 ft^3/s), which was characterized by a very dry summer preceded by 12 months of below-normal precipitation.

Low-flow trends are similar for the Rapidan River. The mean 7-day low flow was less than 4.5 ft^3/s in 1953, 1954, and 1963 through 1966. Again, these years were all much drier than normal. The most extreme low-flow year was 1966 (1.1 ft^3/s), which was characterized by an extremely dry period from June through August, and was preceded by 3 years of drought (1963 through 1965).

To put the recent low flows into perspective, recurrence intervals of the 7-day low-flow values were calculated for the years 1980, 1981, and 1983, as well as for the 10 years with the lowest flows from 1943 through 1979 (table 13). Recurrence intervals (in years) were estimated using a Log-Pearson type III fit of the annual low-flow data. Although 7-day low-flow values were quite low in 1980, 1981 and 1983, with recurrence intervals ranging from 3 to 6 years, this period did not approach the extreme conditions reported in the 1950's and 1960's (table 13). On six occasions from 1943 through 1979, annual 7-day low-flow values at Rappahannock River near Warrenton were less than any 7-day low-flow value recorded from 1980 through 1984; on eight occasions from 1943 through 1979, annual 7-day low-flow values at Rapidan River near Ruckersville were less than any 7-day low-flow value recorded from 1980 through 1984. Although low flows at these two stations (and probably in the Park as well) in 1980, 1981 and 1983 generally were less than the median low flow, these years cannot be considered extreme low-flow years in context of the past 42 years of record. It should be noted, however, that low flows in 1980, 1981 and 1983 do appear extreme if they are considered only in context of the past 18 years of record (1967 through 1984). This is because the period 1967 through 1979 was generally wetter-than-normal (National Oceanic and Atmospheric Administration, 1984b). Thus, even though the 7-day low flow in 1983 is the lowest or second lowest recorded at these stations in the past 18 years, the recurrence interval of the 1983 7-day low flow is only 5 to 6

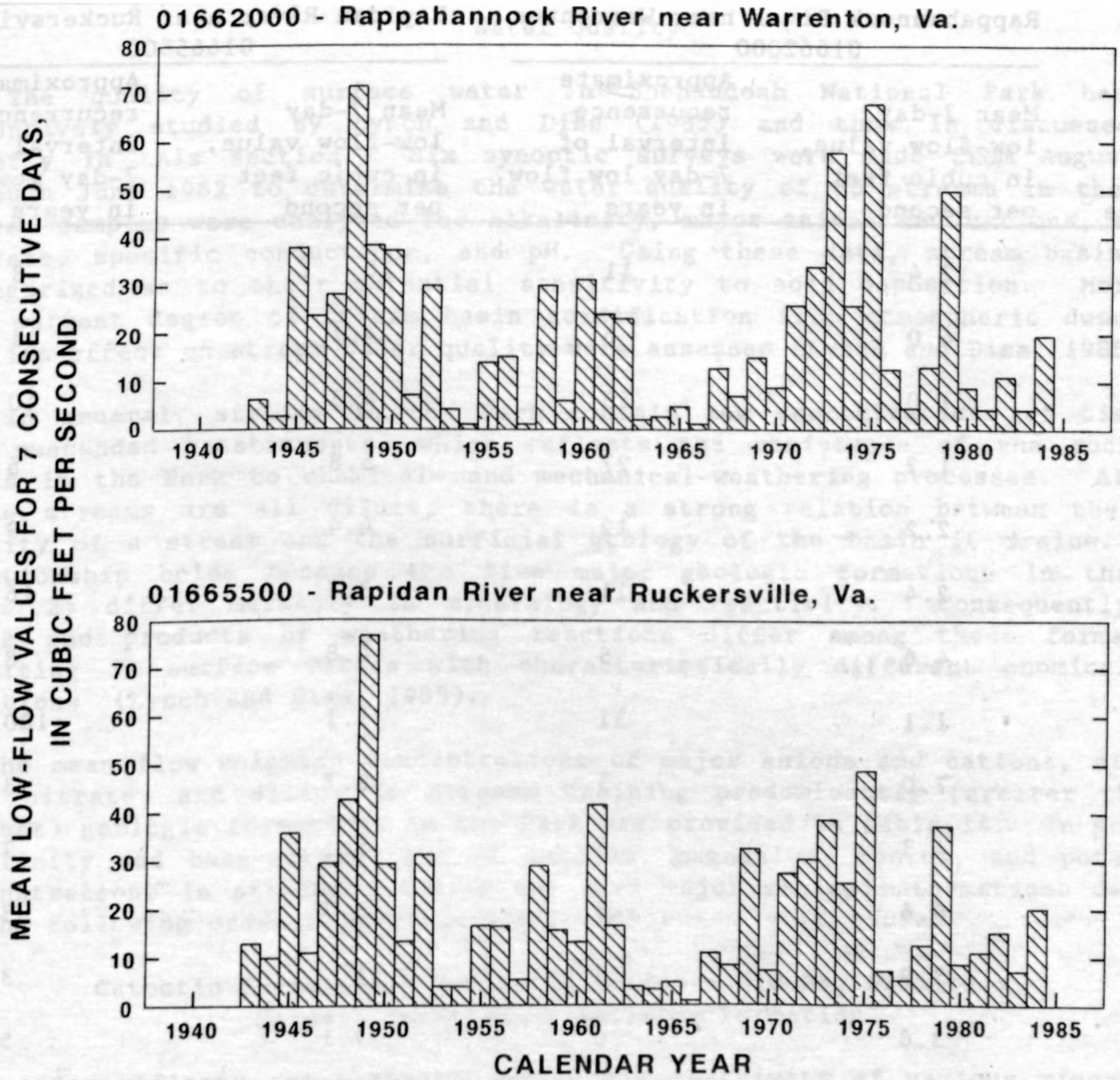


Figure 9.--Mean low-flow value for 7 consecutive days for Rappahannock River near Warrenton and Rapidan River near Ruckersville, 1943 through 1984.

Table 13.--Mean 7-day low-flow values, and their associated recurrence intervals, for the 10 lowest years from 1943 through 1979, and for the years 1980, 1981 and 1983, for Rappahannock River near Warrenton and Rapidan River near Ruckersville

Calendar year of occurrence	Rappahannock River near Warrenton 01662000: Mean 7-day low-flow value, in cubic feet per second	Rappahannock River near Warrenton 01662000: Approximate recurrence interval of 7-day low flow, in years	Rapidan River near Ruckersville 01665500: Mean 7-day low-flow value, in cubic feet per second	Rapidan River near Ruckersville 01665500: Approximate recurrence interval of 7-day low flow, in years
1944	2.4	11	10	3
1953	4.0	6	4.1	11
1954	1.0	35	4.3	10
1957	1.2	27	5.8	6
1963	2.2	12	4.4	9
1964	2.4	11	3.3	16
1965	4.6	5	4.8	8
1966	1.1	31	1.1	>100
1968	7.0	3	8.7	3
1977	4.3	5	5.1	7
1980	8.6	3	8.7	3
1981	3.9	6	11	3
1983	3.8	6	7.1	5

years (table 13), and is not as extreme as the recent record would indicate. This illustrates the necessity of evaluating many years of record in order to reach proper conclusions about the frequency distribution of hydrologic events.

Water Quality

The quality of surface water in Shenandoah National Park has been extensively studied by Lynch and Dise (1985) and thus is discussed only briefly in this section. Six synoptic surveys were made from August 1981 through June 1982 to determine the water quality of 56 streams in the Park. Stream samples were analyzed for alkalinity, major anions and cations, silica, nitrate, specific conductance, and pH. Using these data, stream basins were categorized as to their potential sensitivity to acid deposition. Moreover, the current degree of stream basin acidification from atmospheric deposition and its effect on stream-water quality were assessed (Lynch and Dise, 1985).

In general, streams in the Park contain low concentrations of dissolved and suspended constituents, which reflects the resistance of the rocks and soils in the Park to chemical- and mechanical-weathering processes. Although these streams are all dilute, there is a strong relation between the water quality of a stream and the surficial geology of the basin it drains. This relationship holds because the five major geologic formations in the Park (fig. 2) differ markedly in mineralogy and reactivity. Consequently, the rates and products of weathering reactions differ among these formations, resulting in surface waters with characteristically different chemical compositions (Lynch and Dise, 1985).

The mean flow-weighted concentrations of major anions and cations, alkalinity, nitrate, and silica in streams draining predominantly (greater than 75 percent) geologic formations in the Park are provided in table 14. In general, alkalinity and base-cation (sum of calcium, magnesium, sodium, and potassium) concentrations in streams draining the five major geologic formations decrease in the following order (Lynch and Dise, 1985):

Catoctin Formation > Pedlar Formation > Old Rag Granite >
Harpers Formation > Antietam Formation

This order reflects the quantity and/or the reactivity of various minerals in these formations. The crystalline rocks are more weatherable than the sedimentary rocks. The Catoctin Formation contains the largest quantity of moderately reactive minerals in the Park, including plagioclase and chlorite, as well as the largest quantity of highly reactive trace minerals, including calcite and actinolite, which explains why streams draining this formation are the most mineralized in the Park (table 14). Streams draining the Pedlar Formation (Allen, 1963) and the Old Rag Granite (Furcron, 1934) are less mineralized because these formations contain smaller amounts of both moderately reactive minerals and highly reactive trace minerals than the Catoctin Formation. Streams draining the metasediments of the Harpers and Antietam Formations are the least mineralized in the Park. Considerable weathering of the sediments and subsequent removal of reactive minerals prior to lithification accounts for the overall low alkalinity and base-cation concentrations in streams draining these formations. In particular, the Antietam Formation is nearly devoid of minerals capable of yielding base cations or alkalinity from

Table 14.--Water-quality characteristics of streams draining the five major geologic formations in Shenandoah National Park

[Mean constituent concentration[a], and standard deviation in parentheses, in microequivalents per liter except silica, which is in micromoles per liter]

	Catoctin Formation (n=7)	Pedlar Formation (n=12)	Old Rag Granite (n=5)	Harpers Formation (n=6)	Antietam Formation (n=3)
Alkalinity	144	88	81	11	[b]-7
	(24)	(21)	(11)	(7)	(4)
Sulfate	75	97	63	90	78
	(19)	(35)	(9)	(25)	(20)
Chloride	31	30	28	23	23
	(4)	(4)	(2)	(3)	(1)
Nitrate	21	19	3	3	1
	(15)	(12)	(2)	(2)	(1)
Calcium	109	99	57	25	19
	(15)	(27)	(5)	(3)	(10)
Magnesium	91	56	36	43	41
	(17)	(17)	(3)	(12)	(5)
Sodium	65	76	76	24	21
	(14)	(16)	(12)	(3)	(3)
Potassium	7	9	13	39	14
	(3)	(2)	(2)	(7)	(1)
Hydrogen	.11	.20	.21	1.9	10.2
	(.03)	(.06)	(.02)	(.9)	(1.2)
	pH=6.95	pH=6.70	pH=6.68	pH=5.73	pH=4.99
Silica	157	161	163	77	63
	(26)	(31)	(17)	(7)	(2)

[a] Represents a mean flow-weighted concentration of a constituent in streams draining basins dominated (≥ 75 percent) by a single surficial geologic formation. Flow weighting is based on six synoptic surveys from August 1981 through June 1982.

[b] Alkalinity of -7 micromoles per liter is equal to a mineral acidity of 7 micromoles per liter.

weathering reactions. This formation is composed of several thick (up to 200 feet), highly resistant quartzite ledges separated by thin strata of sericitic metasandstone and phyllite (Schwab, 1970; Gathright, 1976). Weathering of minerals in these thin strata yields small amounts of magnesium and potassium, but the amount of alkalinity produced is inadequate to neutralize atmospheric sources of strong mineral acids, as evidenced by an average alkalinity concentration of -7 microequivalents per liter and an average pH of 4.99 of streams draining the Antietam Formation (table 14) (Lynch and Dise, 1985).

The alkalinity of surface water is a commonly used indicator of the sensitivity of a basin to acid deposition (Hendry and others, 1980). Basins with a surface-water alkalinity of less than 200 microequivalents per liter are considered sensitive because of their small capacity to neutralize incoming acids. Using this criteria, nearly every basin in the Park is sensitive to acid deposition (table 14). To identify the most critical areas in the Park, Lynch and Dise (1985) further divided sensitive basins into three categories. Basins with a surface-water alkalinity less than 20 microequivalents are categorized as extremely sensitive to acid deposition. This includes all basins underlain by the highly resistant metasediments of the Harpers and Antietam Formations, which are primarily located in the southwestern part of the Park. Basins with a surface-water alkalinity of from 20 to 100 microequivalents per liter are categorized as highly sensitive to acid deposition. This includes basins underlain by the Old Rag Granite and the Pedlar Formation. And basins with a surface-water alkalinity of from 101 to 200 microequivalents per liter are categorized as moderately to marginally sensitive. Most basins underlain by the Catoctin Formation or a mixture of Pedlar and Catoctin Formations are included in this category.

In addition to quantifying basin sensitivity, Lynch and Dise (1985) determined the degree to which drainage basins in the Park have been acidified. A basin is considered acidified if acid deposition has decreased the alkalinity of its surface water or increased the rate of base-cation weathering from its rocks and soils. Prolonged acidification of a basin may result in a loss of biota, increased concentrations of dissolved aluminum and other toxic metals in surface water, and a significant depletion of plant nutrients in the soil (Linthurst, 1983).

Lynch and Dise (1985) determined that all basins in the Park have been similarly acidified by acid deposition, which is manifest as an increase in the base-cation concentration of surface water and/or a decrease in alkalinity. This change in surface-water chemistry, which averages 50 microequivalents per liter, has the most serious consequences in extremely sensitive areas of the Park. Even small perturbations in an extremely sensitive area can produce large changes in the chemical composition of streams draining that area, such as a large drop in pH or a large increase in dissolved aluminum concentration. Lynch and Dise (1985) suggest that acid deposition has resulted in the complete loss of alkalinity from streams draining the Antietam Formation, which now have an average pH of 4.99, and that the alkalinity concentration in streams draining the Harpers Formation also may soon be depleted.

Springs and Ground Water

Springs

Past surveys have identified hundreds of springs in Shenandoah National Park, but the majority of these are impractical for water-supply development because of their remote location, intermittant flow, and/or small discharge (DeKay, 1972). The greatest number, as well as the highest yielding and most reliable springs, are in the central section of the Park. Forty-seven springs with flows measured at greater than 100 gal/min (gallons per minute) have been identified. Big Meadows, Skyland, and Lewis Mountain Campground were each located near one of these reliable springs. In the northern and southern sections of the Park, but particularly in the southern section, springs are sparser. Only 18 springs in these sections have had flows measured in excess of 10 gal/min (DeKay, 1972). The lack of large, reliable springs has prevented the development of large lodging facilities in these areas. However, two large campgrounds--Matthews Arm Campground in the northern section and Loft Mountain Campground in the southern section--are located near two of the more accessible and reliable springs.

DeKay (1972) provides flow data for 30 major springs in the Park. Monthly flows from April through October are available for most of these springs for the period 1960 through 1970. Monthly flows for the entire year are available for four of these springs.

Controls on spring flow

The important factors controlling spring flow in the Park are (1) season of the year; (2) climate; and (3) characteristics of the spring's recharge area, which includes its size, regolith thickness, topography, and geology. The first two factors control the timing of the maximum and minimum flow of springs. Flows are often at a minimum in late summer or early fall, which corresponds to the end of a period of high evapotranspiration rates and low ground-water recharge. Flows generally reach a maximum in spring, which corresponds to the end of a period of low evapotranspiration rates and high ground-water recharge. Minimums and maximums in annual average spring flows generally follow annual precipitation patterns. For example, from 1960 through 1970, annual average spring flow was at a minimum in the mid 1960's (DeKay, 1972), coincident with a period of extreme drought; and the annual average spring flow was at a maximum in 1961, coincident with the largest annual precipitation amounts during this 11-year period.

Geology and topography largely control spring occurrence in the Park and the quantity of flow associated with different seasons and patterns of precipitation. Conditions are most suitable for large yielding springs, with reliable flows throughout the year, in areas underlain by basalt flows of the Catoctin Formation. Large ground-water catchments have developed with a thick (10 to 60 feet) regolith of partially weathered rock in many of the gently inclined basalt flows in the Park (DeKay, 1972). These catchments promote infiltration of precipitation and provide a major reservoir of ground water capable of sustaining spring flow (or base flow of streams) during dry periods. This is borne out by the 1960 through 1970 flow record for Lewis Spring near Big Meadows. This spring drains a large, gently sloping catchment in the Catoctin Formation that is overlain with a thick regolith (up to 60 feet). Flows from this spring were relatively large and uniform, ranging from 289 gal/min in March 1961, which was associated with a very wet winter, to 20 gal/min in December 1965, which was associated with a long, extreme drought (DeKay, 1972). Headquarters Spring and Lewis Mountain Spring also issue from catchments with thick regoliths developed in the basaltic terrane. Flows from both were relatively uniform in the 1960's. In particular, Headquarters Spring only varied from 4 to 28 gal/min, depending on climate and season. The ground-water catchment for the Headquarters Spring is relatively small, which partly explains why this spring has less flow than Lewis and Lewis Mountain springs.

Springs in the granitic Pedlar Formation are less common than in the Catoctin Formation. Catchments in the Pedlar Formation tend to be smaller and the regolith thinner because of steeper slopes and less weatherable bedrock. However, large springs do exist in the Pedlar Formation and several are as large as those on the basaltic terrane (Dekay, 1972). Dickey Ridge Spring and Swift Run Gap Spring drain fairly large catchments with thick regoliths in the Pedlar Formation, and both yield relatively large, reliable flows. Furnace Spring is the highest yielding and most reliable spring in the Pedlar Formation. Monthly flows varied from 8 to 139 gal/min during the period 1960 through 1970. The Furnace Spring catchment has up to 60 feet of regolith in a large, flat pass between two mountains, and is partly underlain by the Catoctin Formation.

Very few springs occur in areas underlain by the metamorphosed sandstones and siltstones of the Antietam, Harpers, and Weverton Formations. Large catchments with a thick regolith have not readily formed in these formations because of steep slopes and extremely resistant bedrock. These geologic conditions promote rapid runoff of precipitation and provide little storage of ground water to sustain the flow of springs. The few springs that do exist in these formations respond rapidly to precipitation, decline rapidly during dry periods, and are generally dry several months of the year (DeKay, 1972).

Current spring-flow conditions

Flows from six major springs in the Park were measured monthly to bimonthly from May 1983 through October 1984. Flows from two additional springs--Lewis and Furnace springs--were measured more frequently with the assistance of Park personnel. (Spring flows for 1983 and 1984 are tabulated in appendix 2.) These eight springs were developed many years ago for water supplies, and each is equipped with collection galleries, pipelines, and a spring box built into a hillslope. Each spring box (with the exception of the Swift Run Gap Spring) has a stilling pool behind a 90-degree V-notch weir for measuring flow. Staff gages were installed (or refurbished) in each stilling pool, and the theoretical rating of each weir was verified with two volumetric measurements made at different flows. The theoretical rating agreed within 10 percent of the measured flow in all cases. Consequently, during subsequent visits flows were estimated using gage height and the theoretical rating. Because the spring box at Swift Run Gap Spring is not equipped with a weir, flows were measured directly during each visit. Total spring flow equaled the flow into the distribution system (gaged by an in-line flow meter) plus the spring-box overflow (measured volumetrically).

Flows from the eight springs measured in 1983 and 1984 are shown in figure 10, along with the median and minimum monthly flows reported by DeKay (1972)

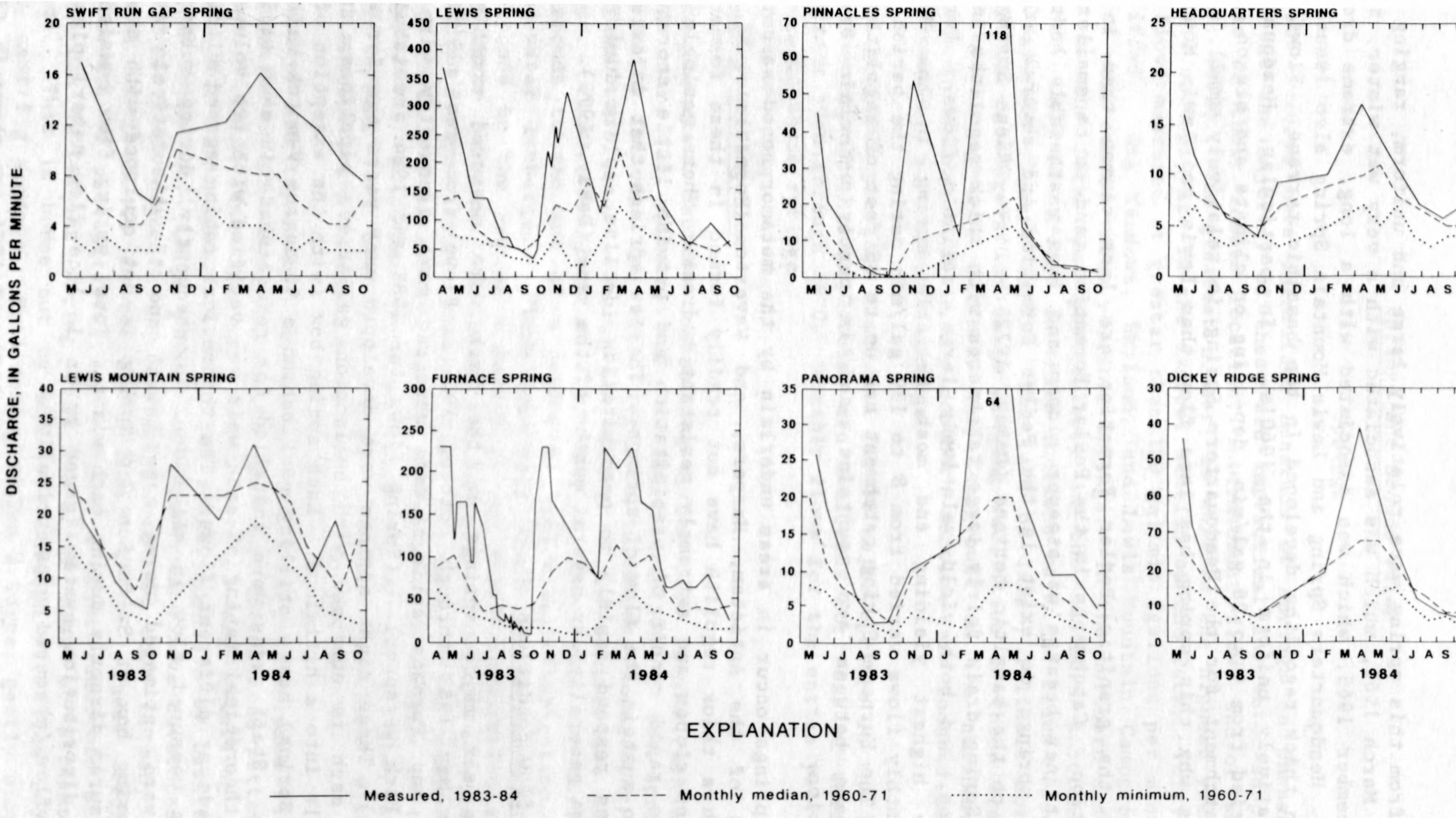


Figure 10.--Minimum and median monthly flows from springs for 1960 through 1971, and flows measured in 1983 and 1984.

for the period 1960 through 1970. The flows measured in 1983 and 1984 correlate strongly to precipitation patterns and season. Heavier than normal rains between March and May 1983 accounted for the high spring flows observed in May and June 1983. However, drier than normal conditions from July through September 1983, together with high summer rates of evapotranspiration, produced a steady decrease of flow from all eight monitored springs. Flow from Pinnacles Spring dropped from 21 gal/min in June 1983 to 0.3 gal/min in early October 1983, and flow from Panorama Spring dropped from 19 gal/min to 2.8 gal/min during this same period. Minimum flows for the year generally occurred in early October, and approached or dropped below the median October flow reported by DeKay (1972) for the period 1960 through 1970. Considering that the severe drought of the mid-1960's is included in this period, October 1983 spring flows were relatively low.

Above-normal precipitation in October through December 1983, together with the seasonal reduction in evapotranspiration, accounted for a sharp increase in most spring flows. By mid-November, flow from all monitored springs again exceeded the 1960-70 median monthly flow (fig. 10).

Dry conditions in January 1984 followed heavy fall rains, and flows declined in February at four of the eight monitored springs. This decline was reversed by greater-than-normal precipitation beginning in late February and continuing through April. By April, all spring flows were considerably greater than the 1960-70 median April flow (fig. 10). Furnace Spring flow averaged 210 gal/min from mid-February through April 1984, compared with the 1960-70 median flow for these months of 90 gal/min.

Flows began to decline by May 1984 and continued to decline through the active growing season in response to slightly less-than-normal precipitation and the seasonal increase in evapotranspiration. By October 1984, most spring flows approached the 1960-70 median flow for October.

A short lag time between precipitation events and increased flow at the monitored springs suggests that precipitation rapidly infiltrates through the unsaturated zone to the saturated zone. This lag time appears to be on the order of hours or days, regardless of the time of year. In June 1983, for example, when the evapotranspiration rate was undoubtedly high, flow from Furnace Spring increased from 92 to 165 gal/min in a single day in response to 3.2 inches of rainfall. And in October 1983, when the evapotranspiration rate was low, about 6 inches of rainfall over a period of 4 days steadily increased the Furnace Spring flow from 7.8 to 165 gal/min.

Although the lag time between rainfall and spring flow does not differ appreciably between seasons, the quantity of rain required to produce the same increase in spring flow does differ with season. During the period of vegetation inactivity in the Park (October through May), rates of evapotranspiration are low and the soil moisture content is high. As a result, a large proportion of rain reaches the water table because it is not utilized or retained in the unsaturated zone. Consequently, 1 or 2 inches of rain during this time of year can produce large increases in spring flow. In contrast, during the active growing season, a much smaller proportion of rain reaches the water table because it is lost to evapotranspiration or retained in dry soil. On many occasions during the growing season 1 or 2 inches of rain has little impact on spring flow. At Lewis Spring, for example, 1.6 inches of rain between August 9th and 11th, 1983, only stabilized flow at 69 gal/min for several days; no increase in spring flow was observed (fig. 10).

Trends in spring flow

Generally, spring flows in 1983 and 1984 were greater than or equal to the median monthly flows reported by DeKay (1972) for the period 1960 through 1970 (fig. 10). This trend is reasonable considering that precipitation averaged 25 percent above normal at the Big Meadows and Luray gages during this period. During the 7-month period of April though October 1984, when precipitation at these two gages was near-normal (National Oceanic and Atmospheric Administration, 1984b), spring flows approached the 1960 through 1970 median monthly flows (fig. 10). This pattern suggests that, except for natural variations due to climate, flows from these eight springs have not changed appreciably since the 1960's. There is no indication of long-term declines in spring flow due to collapsed or plugged collection galleries, flows bypassing the collection system, or broken pipelines.

Although spring collection systems in the Park appear rugged, some deterioration can be expected with time. To detect a decline in spring flow due to collection system deterioration, a long-term monitoring program could be established to synoptically measure flow several times a year from all water-supply springs in the Park. By comparing flows within synoptic surveys over a number of years, it would be possible to identify a spring showing a decline in flow relative to other springs. Considering that water-supply springs in the Park were developed decades ago, such a monitoring program may prove valuable.

To prevent misinterpreting spring-flow trends from the hydrographs in figure 10, three apparent anomalies need to be clarified. (1) Flows at Swift Run Gap Spring appear anomalously high in 1983 and 1984. Only at this spring were flows consistently greater than the 1960-70 median monthly flows. This higher than expected flow from Swift Run Gap Spring is probably due to a reconfiguration of the spring collection system in the 1970's, which increased its capture efficiency. (2) Flows from Furnace Spring appear anomalously low between August and mid-October 1983, and during October 1984. In September and early October 1983 flows from Furnace Spring averaged less than 15 gal/min, and were less than the 1960-70 minimum flows reported by DeKay (1972) for these 2 months. These extreme low flows were due to large ground-water withdrawals from a nearby water-supply well in the spring catchment area. This well was pumped at a rate of 24 gal/min during these periods (to offset water shortages at Skyland), which almost instantaneously reduced the flow rate of Furnace Spring by 23 gal/min. (3) Flow from Headquarters Spring in October 1983 appears anomalously low, equaling the lowest October flow observed from 1960 through 1970. This low spring flow probably resulted from a temporary build up of debris in a screen which impeded flow into the spring box. Apparently, openings created by the deterioration of collection galleries at the Headquarters Spring have provided entrance for small animals and plant matter into the system.

Ground Water

Prior to 1960, springs were the only source of water used at developments in Shenandoah National Park. Years of operational experience showed that additional, more reliable water sources were needed to meet demands in the summer and early fall and during drought periods. Moreover, larger water sources were needed to allow expansion of facilities for the increasing number of visitors. Consequently, the Virginia Department of Mines, Minerals and Energy (VDMME) was requested to evaluate the potential of obtaining supplemental water from drilled wells.

From 1961 through 1971, VDMME contracted for the drilling of 38 test holes in the Park, with the majority of these located near existing developments on the crest of the Blue Ridge along Skyline Drive. Although a ridge crest is not an ideal water-well location, VDMME selected drilling sites with topographic and structural conditions that favor high-yielding wells. As much as possible, wells were drilled on flats, gentle slopes, or draws, which have a thick regolith and are underlain by low-dipping or relatively unsheared bedrock (Dekay, 1972).

Twenty of the test holes drilled by VDMME were converted into water-supply wells, 16 of which are currently connected to water-supply systems. Many of these wells provide a primary or secondary source of water for Park developments. The remaining wells provide a back-up source when the primary and secondary sources are inadequate because of dry conditions, excessive water demands, mechanical failures, or water-quality problems. Wells at Big Meadows, Loft Mountain Campground, and Lewis Mountain Campground currently provide the primary sources of water for these developments. Although wells at Skyland and Matthews Arm Campground are not primary water sources, they do provide water needed to avert shortages during much of the year.

Of the 18 test holes not developed into water wells, all but three were cased down to bedrock. Most of these test holes were originally drilled for water wells but were never used because of poor yields, obstructions in the hole, interferences with nearby supplies, or problems with location. However, five holes were drilled expressly for the purpose of stratigraphic evaluation and water-level observations (DeKay, 1972).

Current ground-water conditions

To assess the current condition of ground water in the Park, water levels were measured monthly to bimonthly in 20 wells and continuously in another 3 wells drilled by VDMME (table 15). The depths of these wells range from 60 to 500 feet, averaging 240 feet. Typically, these wells are cased through the regolith and left open in bedrock. Casing lengths range from 20 to 70 feet, averaging 45 feet. Well locations are plotted on plate 1. Water levels were measured from January 1983 through October 1984 in most wells, and beginning in September 1982 in four wells. Eleven wells remote from the effects of ground-water withdrawals were monitored to record natural fluctuations associated with changes in climate and season. The short-term effects of withdrawals on ground-water levels were monitored at an additional 12 wells that were either pumped or were near pumped wells. These effects are superimposed on the seasonal and climatic water-level fluctuations.

Table 15.--Location and construction data of wells drilled by the Virginia Department of Mines, Minerals and Energy used in this report

U.S. Geological Survey local number	Site identification number	VDMME number[a]	Latitude	Longitude	Date of well completion	Depth of hole, in feet below land surface	Land surface elevation, in feet above sea level	Use of well[b]	Location description
41Q 4	381601078393201	W- 715	381601	0783932	09-10-1962	303	2,740	WS	Loft Mountain Campground
41Q 5	381602078393301	W- 718	381602	0783933	09-14-1962	250	2,746	OB	Loft Mountain Campground
41Q 6	381606078393501	W- 754	381606	0783935	11-27-1962	320	2,670	WS	Loft Mountain Campground
42Q 1	382145078342801	W- 865	382145	0783428	07-16-1963	60	1,475	UN	Swift Run maintenance area
42Q 2	381802078371801	W-1704	381802	0783718	07-14-1966	205	2,230	BS	Simmons Gap Ranger residence
43R 1	382622078284201	W-1072	382622	0782842	06-01-1964	300	3,390	WS	Lewis Mountain Campground
43S 1	383548078224901	W- 591	383548	0782249	06-14-1961	70	3,460	UN	Skyland
43S 2	383546078224801	W- 592	383546	0782248	06-22-1961	233	3,490	BS	Skyland
43S 3	383548078224601	W- 593	383548	0782246	06-30-1961	162	3,480	UN	Skyland
43S 4	383515078225801	W-1033	383515	0782258	05-25-1964	500	3,560	WS	Skyland
43S 5	383432078223501	W- 869	383432	0782235	08-02-1963	250	3,240	UN	South of Skyland
43S 6	383122078260901	W-1701	383122	0782609	06-27-1966	100	3,504	WS	Big Meadows
43S 7	383051078254201	W-1702	383051	0782542	07-11-1966	350	3,440	UN	Big Meadows
43S 8	383117078250201	W-1347	383117	0782502	08-20-1965	265	2,730	UN	Big Meadows
44S 1	383704078203901	W-3288	383704	0782039	10-28-1971	145	3,300	BS	Pinnacles ranger residence
44S 4	383443078221801	W- 876	383443	0782218	08-21-1963	250	3,160	UN	South of Skyland
44T 1	384417078182001	W-1703	384417	0781820	07-21-1966	363	2,570	BS	Elkwallow
44T 2	384008078221401	W- 851	384008	0782214	06-05-1963	280	1,135	BS	Park Headquarters
44T 3	384005078220901	W- 855	384005	0782209	06-14-1963	220	1,120	BS	Park Headquarters
44T 4	383930078193701	W- 948	383930	0781937	02-11-1964	333	2,050	BS	Thornton Gap
44U 1	384540078175701	W- 850	384540	0781757	06-17-1963	200	2,730	UN	Matthews Arm Campground
44U 2	384532078180201	W- 856	384532	0781802	06-10-1963	200	2,590	BS	Matthews Arm Campground
45V 1	385241078121701	W-1138	385241	0781217	07-16-1964	200	1,730	UN	Fox Hollow

[a] Numbers assigned by the Virginia Department of Mines, Minerals and Energy (DeKay, 1972) formerly the Virginia Division of Mineral Resources

[b] (WS)-Primary or secondary water supply, (OB)-Observation well, (BS)-Back-up water supply, (UN)-Unsued well.

Wells unaffected by ground-water withdrawals.--Hydrographs for the 11 wells unaffected by ground-water withdrawals are shown in figure 11. Back-up supply wells for Simmons Gap ranger station (well 42Q 2 on plate 1), Park Headquarters (44T 2 and 44T 3), and the Park Entrance Station on U.S. Highway 211 (44T 4) are included in this group of wells because they were pumped so seldom or not at all during the study period. The unaffected wells are distributed fairly evenly in the Park and provide a good indication of natural water-level fluctuations. Maximum and minimum water levels (fig. 11) occurred at the same time as the maximum and minimum spring flows (fig. 10). The lowest water levels in a year occurred in late summer or early fall, which corresponds to the end of the period of high evapotranspiration rates and low ground-water recharge. The highest water levels generally occurred in spring, which corresponds to the period of low evapotranspiration rates and maximum ground-water storage. In well 43S 7 near Big Meadows, for example, the annual maximum water levels in 1983 and 1984 occurred in April and May, and the annual minimum water levels in 1982 through 1984 occurred in September and October. Maximum water levels in the spring of 1983 and 1984 were above the land surface in wells 42Q 1, 43S 5, and 45V 1.

The lag time between a precipitation event and the resulting rise in ground-water level is on the order of hours or days, which is similar to that observed for springs. This similarity is expected because ground water is the source of spring flow and a rise in ground-water level must precede an increase in spring flow. The relationship between precipitation and a rise in ground water is most evident between October and May when evapotranspiration rates are low and a large proportion of precipitation reaches the water table. At well 43S 5, the abrupt ground-water rises in October and December 1982, February, March, and mid-October 1983, and February 1984, occurred within a day or two of major precipitation events in the area (fig. 11).

Although the annual timing of the maximum and minimum water levels in the 11 wells unaffected by withdrawals are similar, and the lag times between precipitation and ground-water response also are similar, the amplitudes of ground-water fluctuation varied widely among these 11 wells during the study period. The difference between maximum and minimum water levels from January 1983 through October 1984 ranged from 3.14 feet in well 42Q 1 to 12.17 feet in well 42Q 2. The median fluctuation was 8.6 feet (table 16). This large variability in water-level fluctuations among wells is not related to climatic heterogeneity in the Park but to the heterogeneity of ground-water catchment areas, which supports the concept that the ground-water system in the Park is effectively composed of many isolated subsystems of interconnected fractures. While each ground-water subsystem responds rapidly to climatic changes, the degree of water-level change in a well depends on regolith thickness, land slope, and the aperture size and number of connected fractures.

Precipitation between growing seasons recharged the ground-water system in the Park in 1983 and 1984, as evidenced by maximum annual water levels in the early spring of both years (fig. 11). Precipitation amounts during the October through April recharge period prior to the 1983 and 1984 water level maximums were 20 and 70 percent greater-than-normal, respectively, as determined from the seven long-term precipitation stations in and around the Park. Although the quantity of precipitation during these two recharge periods varied considerably, the maximum water levels measured in 1983 in the 11 wells unaffected by ground-water withdrawals were nearly identical to the maximum

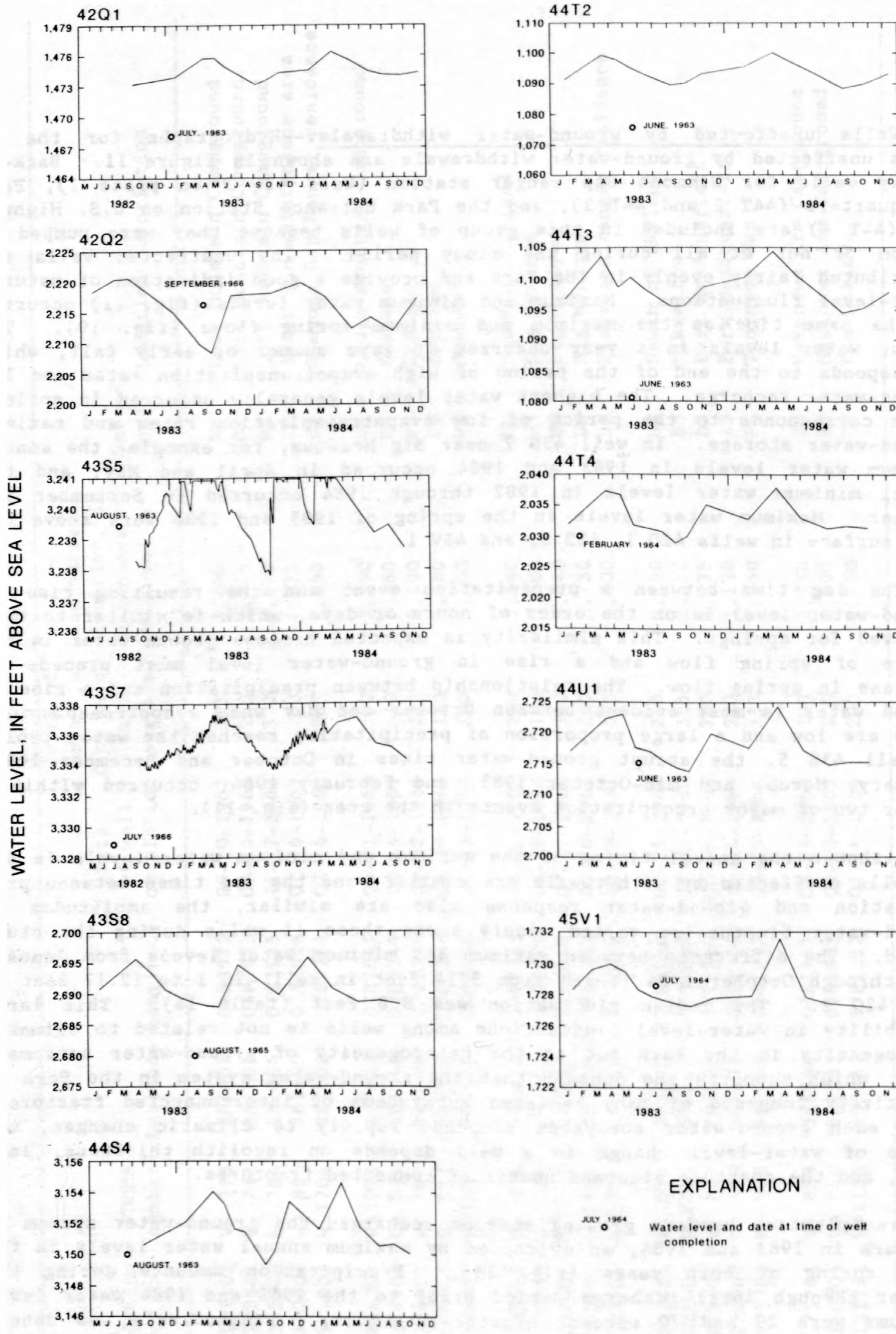


Figure 11.--Hydrographs of 11 wells in Shenandoah National Park unaffected by ground-water withdrawals.

water levels measured in 1984. The median absolute value of the difference between maximums was 0.74 feet (table 16). The similarity of water-level maximums suggests that the physical upper limit for ground-water storage in the Park was met in both years. At this upper limit, nearly all precipitation quickly runs off as streamflow and ground-water levels remain stable. Additional data presented later in the Water Budget section supports this contention and suggests that ground-water storage reaches a maximum by springtime when precipitation amounts during the recharge season are near-normal. This has two important implications. First, greater-than-normal precipitation amounts from October through April provide little benefit over normal amounts of precipitation in terms of maximizing ground-water storage by the beginning of a growing season. Consequently, a wetter-than-normal recharge period does not insure high ground-water levels in the following summer. The quantity and temporal distribution of precipitation during the growing season most strongly influence water levels at that time of year. Second, because ground-water levels fully recover during a recharge period with normal amounts of precipitation, there is little tendency for the effects of a dry year to carry over into years with near-normal precipitation amounts. In less dynamic ground-water systems, the effects of a dry period can be measured for many years. (Additional support for this concept is provided in the Water Budget section.)

Wells affected by ground-water withdrawals.--Hydrographs for the 12 wells affected by ground-water withdrawals are shown in figure 12. Water levels in these wells follow the same general pattern as in the wells unaffected by ground-water withdrawals. Minimum water levels generally occurred in late summer, and maximum water levels occurred in early spring. In addition, the lag time between precipitation events and water-level changes was short. Each abrupt water-level rise in well 41Q 5 (fig. 12) occurred within hours or days of large precipitation events. (Well 41Q 5 was continuously monitored from February through November 1983, and is located 70 feet from the primary water-supply well for Loft Mountain Campground, well 41Q 4.) For example, 4.15 inches of rainfall at Loft Mountain on April 24 and 25, 1983, resulted in a water-level rise of 2.3 feet in 24 hours.

As expected, the range of water-level fluctuations in wells affected by ground-water withdrawals was greater than fluctuations in unaffected wells. The difference between the maximum and minimum water levels observed from January 1983 through October 1984 ranged from 134.83 feet in well 43R 1, the primary water supply for Lewis Mountain Campground, to 5.60 feet in well 41Q 5, the observation well at Loft Mountain discussed above. The median water-level fluctuation in these 12 wells was 21.0 feet (table 17), which is 140 percent greater than the median fluctuation in the 11 wells unaffected by ground-water withdrawals.

Despite ground-water withdrawals, water levels in these 12 wells fully recovered by spring of 1983 and 1984 (fig. 12). As discussed above for unaffected wells, the fact that maximum water levels measured in the affected wells in 1983 were very similar to those measured in 1984 (median absolute value of the difference equals 2.56 feet), while median water-level fluctuation in these wells was 21 feet, suggests that these ground-water subsystems also approached a physical upper limit for storage both years (table 17). This is important because it indicates that recharging precipitation from October through April generally eliminates the effects of ground-water withdrawals between heavy pumping periods. Thus, ground-water withdrawals

Table 16.--Water-level fluctuations in wells unaffected by ground-water withdrawals, January 1983 through October 1984

Well local number	Observed range of water level fluctuation for the period 1/83-10/84, in feet	Differences between maximum water levels in 1983 and maximum levels in 1984, in feet
42Q 1	3.18	0.63
42Q 2	12.17	-.81
[a]43S 5	--	--
43S 7	3.75	.71
43S 8	8.10	.32
44S 4	5.30	.57
44T 2	11.77	.97
44T 3	10.15	.78
44T 4	9.05	.68
44U 1	10.38	1.27
45V 1	4.56	1.66
Median =	8.6	Median of absolute values = .74

[a] Maximum water level overtopped the well casing and could not be measured.

Table 17.--Water-level fluctuations in wells affected by ground-water withdrawals, January 1983 through October 1984

Well local number	Observed range of water level fluctuation for the period 1/83-10/84, in feet	Differences between maximum water levels in 1983 and maximum levels in 1984, in feet
41Q 4	6.96	1.69
41Q 5	5.60	-1.12
41Q 6	131.81	1.59
43R 1	134.83	-8.72
43S 1	9.16	.85
43S 2	6.70	.50
43S 3	30.44	.75
43S 4	76.19	9.63
43S 6	23.25	-.12
44S 1	18.76	1.75
44T 1	47.03	-3.88
44U 2	11.78	.14
Median =	21.0	Median of absolute values = 2.56

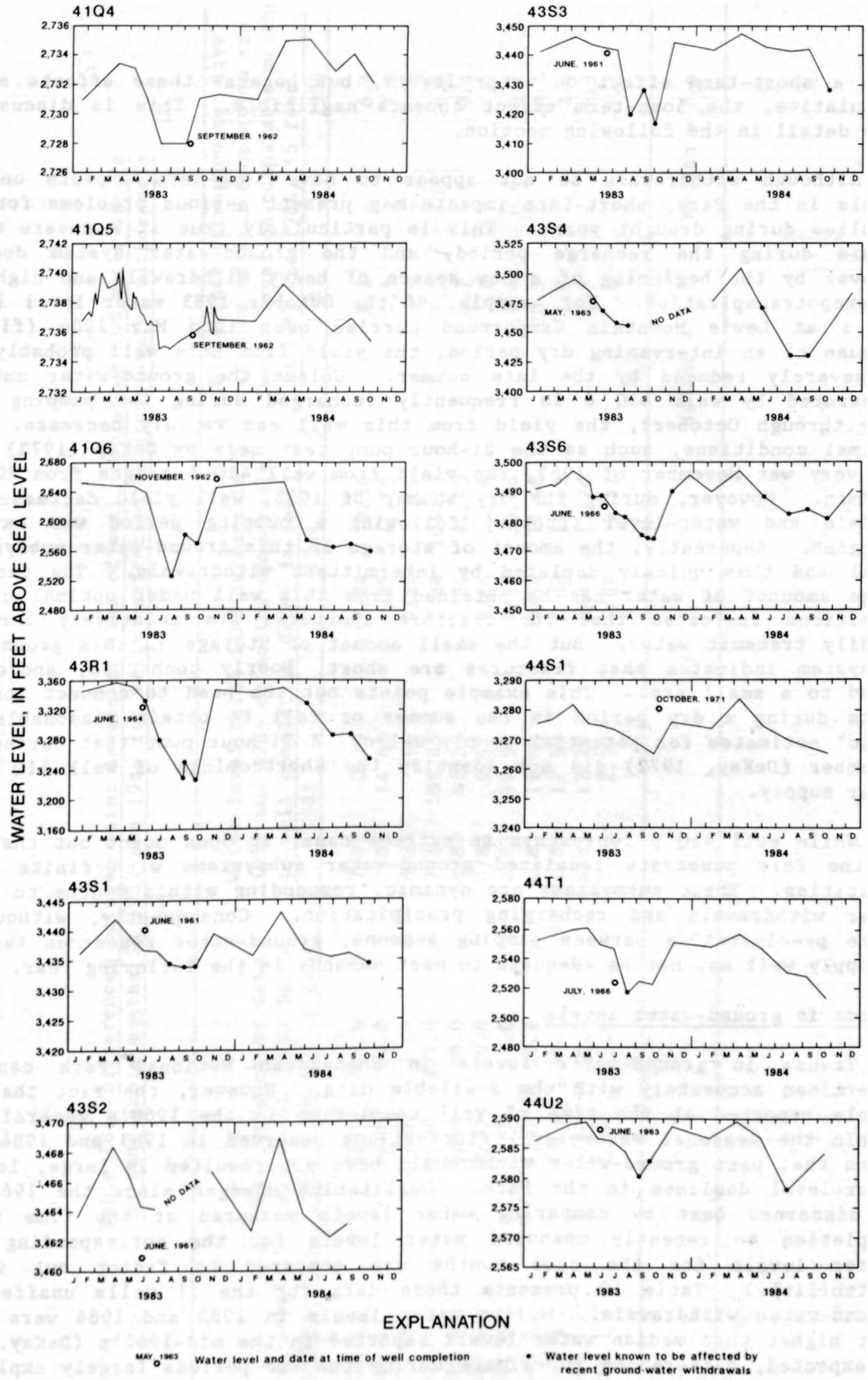


Figure 12.--Hydrographs of 12 wells in Shenandoah National Park affected by ground-water withdrawals.

have a short-term effect on water levels, but because these effects are not cummulative, the long-term effect appears negligible. This is discussed in more detail in the following section.

Although withdrawals do not appear to have long-term impacts on water levels in the Park, short-term impacts may present serious problems for water supplies during drought years. This is particularly true if a severe drought occurs during the recharge period, and the ground-water system does not recover by the beginning of a new season of heavy withdrawals and high rates of evapotranspiration. For example, if the October 1983 water level in well 43R 1 at Lewis Mountain Campground carried over into May 1984 (fig. 12) because of an intervening dry period, the yield from this well probably would be severely reduced by the late summer. Unless the ground-water subsystem penetrated by well 41Q 6 is frequently recharged during the pumping season (May through October), the yield from this well can rapidly decrease. Under optimal conditions, such as the 21-hour pump test made by DeKay (1972) during the very wet November of 1962, the yield from well 41Q 6 ranges from 20 to 30 gal/min. However, during the dry summer of 1983, well yield decreased to 2 gal/min and water-level recovery following a pumping period was extremely sluggish. Apparently, the amount of storage in this ground-water subsystem is small and thus quickly depleted by intermittent withdrawals. The fact that large amounts of water can be obtained from this well under optimal climatic conditions indicates that the fracture apertures are relatively large and readily transmit water. But the small amount of storage in this ground-water subsystem indicates that fractures are short, poorly connected, and/or confined to a small area. This example points out the need to conduct long pump tests during a dry period in the summer or fall to obtain reasonable "safe yield" estimates for potential supply wells. A 21-hour pump test during a wet November (DeKay, 1972) did not identify the shortcomings of well 41Q 6 as a water supply.

While well 41Q 6 represents an extreme case, it does point out that wells in the Park penetrate localized ground-water subsystems with finite storage capacities. These subsystems are dynamic, responding within months to ground-water withdrawals and recharging precipitation. Consequently, without adequate precipitation between pumping seasons, ground-water resources tapped by a supply well may not be adequate to meet demands in the following year.

Trends in ground-water levels

Trends in ground-water levels in Shenandoah National Park cannot be determined accurately with the available data. However, the fact that water levels reported at the time of well completion in the 1960's generally fall within the seasonal water-level fluctuations observed in 1983 and 1984, indicates that past ground-water withdrawals have not resulted in large, long-term water-level declines in the Park. Qualitative changes since the 1960's can be discerned best by comparing water levels measured at the time of well completion to recently measured water levels for the corresponding month. (Water levels for the same months are compared to factor out seasonal variability.) Table 18 presents these data for the 11 wells unaffected by ground-water withdrawals. Median water levels in 1983 and 1984 were 2 to 3 feet higher than median water levels reported in the mid-1960's (DeKay, 1972). As expected, differences in climate during the two periods largely explain the observed water-level differences. Very dry conditions in the mid-1960's

Table 18.--Differences between water levels at time of well completion and water levels on comparable months in 1983 and 1984 for wells unaffected by ground-water withdrawals

Well local number	Well completion date and water level below land surface, in feet		Water level below land surface in 1983 and 1984 on months comparable to well completion date, in feet: 1983		1984		Difference between water level at time of well completion and water level on comparable months in 1983 and 1984, in feet: 1983	1984
42Q 1	7/63	7.0	7/83	0.79	7/84	0.58	6.2	6.4
42Q 2	7/66	14.0	7/83	14.80	7/85	17.59	-.8	-3.6
43S 5	8/63	.5	8/83	.96	9/84	.62	-.5	-.1
43S 7	7/66	111.0	7/83	103.85	7/84	104.66	7.2	6.3
43S 8	8/65	50.0	8/83	41.27	9/84	40.90	8.7	9.1
44S 4	8/63	10.0	8/83	9.57	9/84	9.28	.4	.7
44T 2	6/63	59.0	6/83	39.58	6/84	38.86	19.4	20.1
44T 3	6/63	39.9	6/83	19.63	6/84	19.48	20.3	20.4
44T 4	2/64	19.7	1/83	17.90	2/84	17.25	1.8	2.4
44U 1	6/63	15.0	6/83	12.29	6/84	12.70	2.7	2.3
45V 1	7/64	1.5	7/83	2.10	7/84	2.57	-.6	-1.1
							Median = 2.7	Median = 2.4

probably resulted in ground-water levels below the long-term median levels. Moreover, greater-than-normal precipitation amounts in and around the Park in 1983 and 1984 probably resulted in ground-water levels at or above the long-term median levels.

Table 19 presents similar data for the 12 wells affected by ground-water withdrawals. Median ground-water levels in 1983 and 1984 were about 1 to 2 feet higher than median ground-water levels reported at the time of well completion (DeKay, 1972). Again, only water levels for similar months are compared to factor out seasonal variability. Most of the water-level differences seen in table 19 can be attributed to either climatic differences of the two periods being compared or to recent short-term effects of ground-water withdrawals. Consequently, the current rates of withdrawals have had a negligible long-term impact on the Park's ground-water resource. Even the most heavily pumped wells in the Park (41Q 4 at Loft Mountain Campground, 43R 1 at Lewis Mountain Campground, 43S 4 at Skyland, 43S 6 at Big Meadows, and 44U 2 at Matthews Arm Campground) show no indication of long-term water-level declines (table 19). Median water levels in 1983 and 1984 in these heavily pumped wells were about 3 feet higher than water levels for comparable months in the 1960's.

Water Budget

This section of the report, which explores the relationships between the components of the hydrologic cycle in the Park, is divided into three parts: (1) spatial variability of water budgets in the Park; (2) temporal variability of water budgets; and (3) the generalized water budget. The term "water year" in this section is defined as the 12-month period beginning October 1 and ending September 30. For instance, water year 1983 refers to the period October 1, 1982 through September 30, 1983. Water years are preferable when discussing water budgets because the break between years generally corresponds to the break between the growing season (May through October) and the season of the greatest ground-water recharge (October through April).

A water budget is derived from the equation of continuity:

$$\text{Inflow} = \text{Outflow} + \text{Change in storage.} \quad (1).$$

In a water budget, the inflow component equals precipitation on the drainage basin; the outflow component is made up of (1) runoff (surface- and ground-water discharge to streams), (2) subsurface flow (undetected by surface-water measurements), and (3) evapotranspiration (of surface and ground water); and the component "change-in-storage" equals the change in ground-water storage (Linsley and others, 1975). The continuity equation for water in a basin becomes:

Components of the hydrologic cycle

$$\text{Precipitation} = \text{Runoff} + \text{Subsurface flow} + \text{Evapotranspiration} + \text{Change in ground-water storage.} \quad (2).$$

Units of volume in this equation are expressed in depths (inches) averaged over the drainage area. As long as four of these components can be accurately measured, a water budget for any time period can be determined. However, in practice neither evapotranspiration loss nor subsurface flow nor the change in ground-water storage can be readily measured. Quantifying these components

Table 19.--Differences between water levels at time of well completion and water levels on comparable months in 1983 and 1984 for wells affected by ground-water withdrawals

Well local number	Well completion date and water level below land surface, in feet		Water level below land surface in 1983 and 1984 on months comparable to well completion, in feet: 1983		1984		Difference between water level at time of well completion and water level on comparable months in 1983 and 1984, in feet: 1983	1984
41Q 4	9/62	12.0	9/83	11.94	9/84	5.90	0.1	6.1
41Q 5	9/62	10.0	9/83	10.34	9/84	9.03	-.3	1.0
41Q 6	11/62	15.0	11/83	24.90	[a](--)	[a](--)	-9.9	[a](--)
43R 1	6/64	66.0	6/83	58.65	6/84	62.05	7.4	4.0
43S 1	6/61	19.7	6/83	22.94	5/84	23.20	-3.2	-3.5
43S 2	6/61	29.0	6/83	25.67	5/84	26.26	3.3	2.7
43S 3	6/61	38.8	6/83	37.20	5/84	36.94	1.6	1.9
43S 4	5/64	84.0	5/83	75.84	6/84	92.16	8.2	-8.2
43S 6	6/66	18.0	6/83	14.64	6/84	15.11	3.4	2.9
44S 1	10/71	19.0	11/83	24.10	10/84	34.75	-5.1	-15.8
44T 1	7/66	44.0	7/83	22.82	7/84	39.18	21.2	4.8
44U 2	6/63	1.5	6/83	3.28	6/84	3.20	-1.8	-1.7
							Median = .8	Median = 1.9

[a] No comparable water level was measured in 1984.

require extremely complex and expensive studies. Consequently, equation (2) is generally simplified by eliminating the subsurface-flow and change-in-ground-water-storage components:

$$\text{Precipitation} = \text{Runoff} + \text{Evapotranspiration}. \qquad (3).$$

This simplification is valid if (1) a water budget is calculated for a period of many years (making the change-in-ground-water-storage component inconsequential) or if it can be shown that ground-water levels in the basin (and thus ground-water storage) are similar at the beginning and end of the budget period (Linsley and others, 1975); (2) subsurface flow is negligible; and (3) ground-water withdrawals from the basin are negligible.

The water budgets calculated for various basins in Shenandoah National Park in the following sections satisfy these requirements. In each case, the drainage basins have negligible ground-water withdrawals, and the change-in-ground-water-storage component is shown to be either inconsequential or about zero. In addition, it is assumed that subsurface flow in the Park is negligible with respect to an annual water budget. In the basin with the largest suspected subsurface-flow component (White Oak Run 01628060), less than 5 percent of the annual water loss from the basin is subsurface flow (Vreeland, 1983).

Spatial Variability

Water budgets for water year 1983 were calculated for four basins in the Park in order to assess spatial variability. Two basins--Happy Creek at Front Royal (01636210) and Rush River near Washington (01662490)--are located in the northern section of the Park, and two basins--White Oak Run near Grottoes (01628060) and North Fork Moormans River near Whitehall (02031500)--are located in the southern section of the Park (pl. 1). Monthly precipitation amounts and surface-water runoff were measured for each basin, and month-end ground-water levels in nearby wells were estimated by interpolating between measured water levels. These month-end water levels are used to show relative changes in ground-water storage in a month and to verify that the net change in ground-water storage in water year 1983 was negligible. It is assumed the water-level hydrograph of well 42Q 2, located at Simmons Gap ranger residence (pl. 1), has the same relative shape as hydrographs of ground-water levels in the White Oak Run and North Fork Moormans River basins. Similarly, it is assumed that the hydrograph of water levels in well 45V 1 (pl. 1) has the same relative shape as hydrographs of ground-water levels in the Happy Creek and Rush River basins.

Surface runoff from White Oak Run and North Fork Moormans River basins was measured by continuous recording gaging stations. Daily gage-height readings, together with current stage/discharge relationships, were used to estimate daily flows at Happy Creek and Rush River. Precipitation on each basin was calculated using the isohyetal method described by Linsley and others (1975). For the North Fork Moormans River basin, precipitation stations at Sawmill Ridge Overlook, Loft Mountain, and Charlottesville (pl. 1 and fig. 4) were used. Precipitation stations at Loft Mountain and West Swift Run (pl. 1) were used for the White Oak Run basin, and precipitation stations at Panorama, Sperryville, and Front Royal (pl. 1 and fig. 4) were used for the Happy Creek and Rush River basins.

Monthly precipitation and runoff for the North Fork Moormans River and White Oak Run basins, located in the southern section of the Park, are shown in figure 13 for the 1983 water year along with the water-level hydrograph for well 42Q 2. The hydrologic response of these two basins was very similar. Beginning in October and continuing through February, precipitation recharged the ground-water system as evidenced by steadily rising water levels in well 42Q 2. Because evapotranspiration is typically low during this period, the difference between precipitation amounts and runoff approximates the increase in ground-water storage. During March, ground-water storage approached a maximum value in both basins. Runoff nearly equaled precipitation amounts, and nearby water levels did not change appreciably. Similarly, large amounts of precipitation in April (10 to 12 inches) did not significantly increase ground-water storage in the basins but quickly ran off. The discrepancy between precipitation and runoff amounts in March for North Fork Moormans River (fig. 13) is probably due to slight errors in one or both numbers.

Beginning in May and continuing through September, the large difference between precipitation amounts and runoff is attributed to high rates of evapotranspiration (fig. 13). In fact, water losses due to evapotranspiration exceeded the difference between precipitation amounts and runoff because ground-water storage dropped during this period, as evidenced by steadily declining water levels in well 42Q 2. The effects of evapotranspiration are most evident in July through September. Less than 5 percent of precipitation during these months left either the White Oak Run or North Fork Moormans River basins as surface runoff.

Because ground-water levels in well 42Q 2 were nearly identical at the beginning and end of the 1983 water year (fig. 13), it is assumed that the annual change in ground-water storage for both basins was zero. Consequently, evapotranspiration loss in water year 1983, calculated from equation (3), was about 23 inches (43 percent of total precipitation) for the North Fork Moormans River basin and about 26 inches (52 percent of total precipitation) for the White Oak Run basin.

Monthly precipitation and runoff for the Happy Creek and Rush River basins, located in the northern section of the Park, are shown in figure 14 for the 1983 water year along with the water-level hydrograph for well 45V 1. The hydrologic response of these basins was very similar to the response observed in the southern section of the Park (fig. 13). The ground-water systems in the northern basins were recharged by precipitation beginning in October; by March and April, ground-water storage approached a maximum value, as evidenced by steady water levels in well 45V 1 and runoff equaling precipitation amounts during these months. As in the southern basins, runoff in July through September averaged less than 5 percent of precipitation due to high rates of evapotranspiration.

Ground-water levels in well 45V 1 were nearly identical at the beginning and end of the 1983 water year, indicating that the annual change in ground-water storage in the Happy Creek and Rush River basins was zero. Consequently, evapotranspiration loss in the 1983 water year, calculated using equation (3), was about 21 inches (49 percent of total precipitation) for the Happy Creek basin and about 20 inches (46 percent of total precipitation) for the Rush River basin. The two northern basins probably had slightly smaller evapotranspiration losses in the 1983 water year than the southern basins because of smaller amounts of precipitation during the summer.

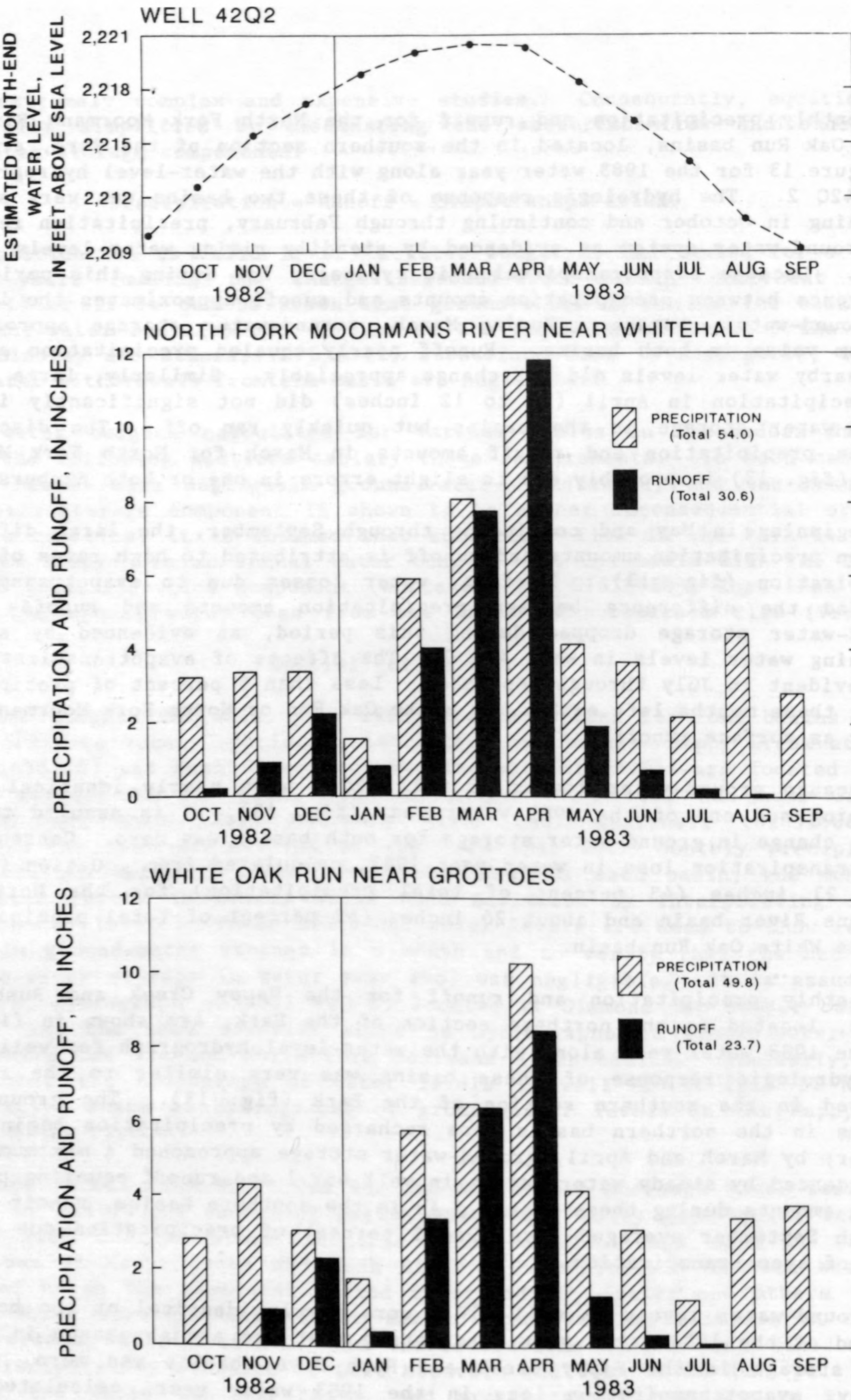


Figure 13.--Ground-water levels in the southern part of Shenandoah National Park, and monthly precipitation and runoff in the North Fork Moormans River and White Oak Run basins, October 1982 through September 1983.

Although the four basins differ widely in size, underlying rock type, and location in the Park, the water budgets for the 1983 water year (figs. 12 and 13) were similar in the quantity and seasonal distribution of precipitation, runoff, change in ground-water storage, and evapotranspiration losses. These data suggest that for similar climatic conditions most basins in the Park have similar annual water budgets. However, this does not imply that water budgets for smaller time periods are necessarily similar throughout the Park. For example, during summer months with similar climatic conditions, surface runoff from basins with different physical characteristics may vary considerably. Because summer runoff only comprises a small percentage of the annual water budget, these differences in runoff are inconsequential.

Temporal Variability

The temporal variability of water budgets in the Park is assessed by comparing water years 1980 through 1983 for White Oak Run, which was a period of widely ranging climatic conditions. White Oak Run basin was selected because surface runoff was gaged by the U.S. Geological Survey during this period and because precipitation amounts were measured at several points in the basin during water years 1980 through 1982 (J. N. Galloway, University of Virginia, Department of Environmental Sciences, written commun., 1983). The budget for water year 1983, which is the same as shown in figure 13, is based on precipitation amounts measured at Loft Mountain and West Swift Run (pl. 1). Water budgets for the four water years are given in figure 15. Precipitation amounts on the White Oak Run basin were 96, 75, 96, and 111 percent of normal for the 1980 through 1983 water years, respectively. (Normal annual precipitation in the White Oak Run basin averages 45.0 inches, as determined from pl. 1.)

Extremely dry conditions in water year 1981 resulted in only 4.3 inches of runoff from the White Oak Run basin. This is only 20 percent of the mean annual runoff measured during the other three water years shown in figure 14, and provides an indication of the variability possible in water budgets. The amount of runoff in water year 1981 was particularly small because of the seasonal distribution of precipitation. The majority of precipitation (20.4 inches) came during the growing season and was lost to evapotranspiration before reaching the stream. Only 13.4 inches of precipitation fell on the White Oak Run basin when the rate of evapotranspiration was low and the potential for surface runoff was high. If the seasonal distribution of precipitation had been reversed in the 1981 water year, runoff amounts would undoubtedly have been larger and evapotranspiration losses would have been smaller.

A comparison of water budgets for water years 1980 and 1982 further illustrates how the same amount of precipitation with a different seasonal distribution can produce different annual runoff amounts. White Oak Run basin received 43.4 inches of precipitation in both years, but the amount of runoff was 22.5 inches (52 percent of total precipitation) in water year 1980 and 16.5 inches (38 percent of total precipitation) in water year 1982 (fig. 15). This discrepency is primarily due to the fact that the majority of precipitation (62 percent) in water year 1980 fell from October through April when the potential for runoff was high because of low rates of evapotranspiration. In contrast, the majority of precipitation (52 percent) in water year 1982 fell during the growing season and was largely lost to evapotranspiration before reaching the stream channels.

In 3 out of 4 years (1980-83) it appears that ground-water storage approached an upper limit by the end of the recharge season, as evidenced by runoff amounts equaling precipitation amounts in March and/or April of these 3 years (fig. 15). Runoff amounts equaled precipitation amounts in March and/or April in years with slightly less-than-normal precipitation (water years 1980 and 1982), and in water year 1983, with greater-than-normal precipitation. In the 1981 water year, precipitation amounts were apparently insufficient to fully recharge the ground-water system, as evidenced by precipitation amounts far in excess of runoff amounts during the spring months (fig. 15). Most importantly, the slightly less-than-normal precipitation amounts in the 1982 water year were apparently sufficient to fully recharge the ground-water system in White Oak Run following the severe dry period of 1981. This rapid recovery of a ground-water system suggests that the effects of dry periods in the Park are eliminated quickly by near-normal precipitation amounts. However, 2 consecutive years like water year 1981 may have a large, short-term impact on the availability of ground water in the Park because the effects of dry periods are cummulative when precipitation amounts between growing seasons are insufficient to fully recharge the ground-water system.

Generalized Water Budget

A generalized water budget for the Park was developed to provide a baseline for future studies. This budget is based on 13 years of flow record (water years 1953 through 1963, 1983, and 1984) for North Fork Moormans River near Whitehall (02031500). During this 13-year period annual runoff averaged 20.6 inches. The mean monthly distribution is shown in figure 16. Annual precipitation amounts at the nearby Charlottesville station averaged 44.9 inches, or 98 percent of normal for this period. Consequently, it is assumed that the mean annual precipitation on the North Fork Moormans River basin was also 98 percent of normal for this period, or 45.0 inches. (Normal annual precipitation for this basin is 45.9 inches, as determined from the map on plate 1.) The mean monthly distribution of precipitation on the North Fork Moormans River basin for the 13-year period is assumed to be proportional to the distribution of precipitation at the Charlottesville station for the same period. This ensures that the monthly distribution of runoff reflects the monthly distribution of precipitation in the water budget.

Although estimates of normal-monthly precipitation and runoff in figure 16 are for the North Fork Moormans River basin, these estimates approximate normal conditions for basins throughout the Park. During a year with a normal pattern of precipitation, runoff should average about 20.6 inches (46 percent of total precipitation) and evapotranspiration loss should average 24.4 inches (54 percent of total precipitation), primarily occurring in May through September. Because the water budget is based on 13 years of hydrologic data, the net change in ground-water storage is assumed to be negligible, and the annual evapotranspiration loss for this period is calculated using equation (3). The discrepancy between precipitation and runoff amounts in March (fig. 16) probably reflects slight errors in the data or in the method of calculation. Figure 16 illustrates that during a normal year, precipitation from October through February fully recharges the ground-water system in the Park, and that precipitation during March and April does not appreciably increase ground-water storage.

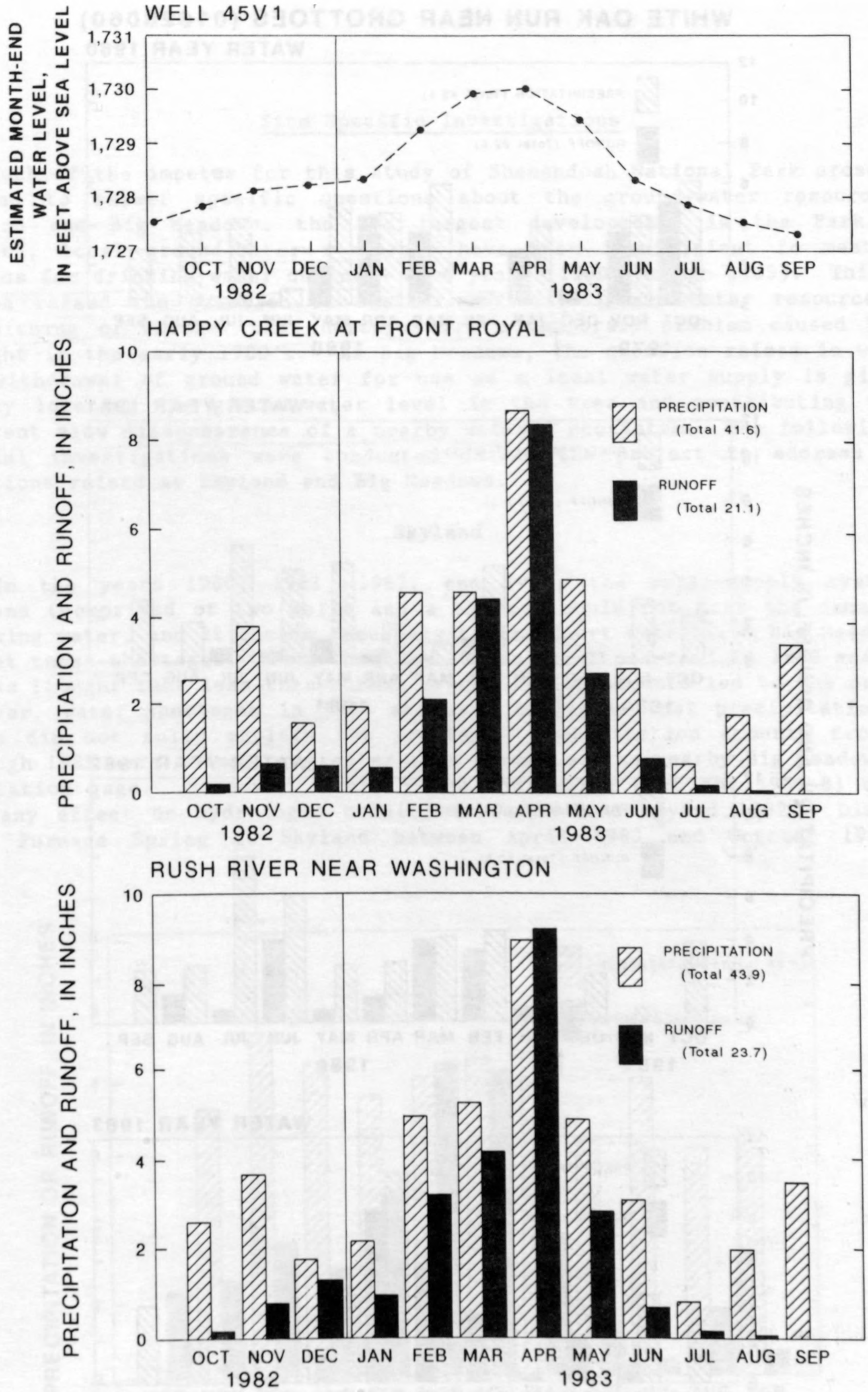


Figure 14.--Ground-water levels in the northern part of Shenandoah National Park, and monthly precipitation and runoff in the Happy Creek and Rush River basins, October 1982 through September 1983.

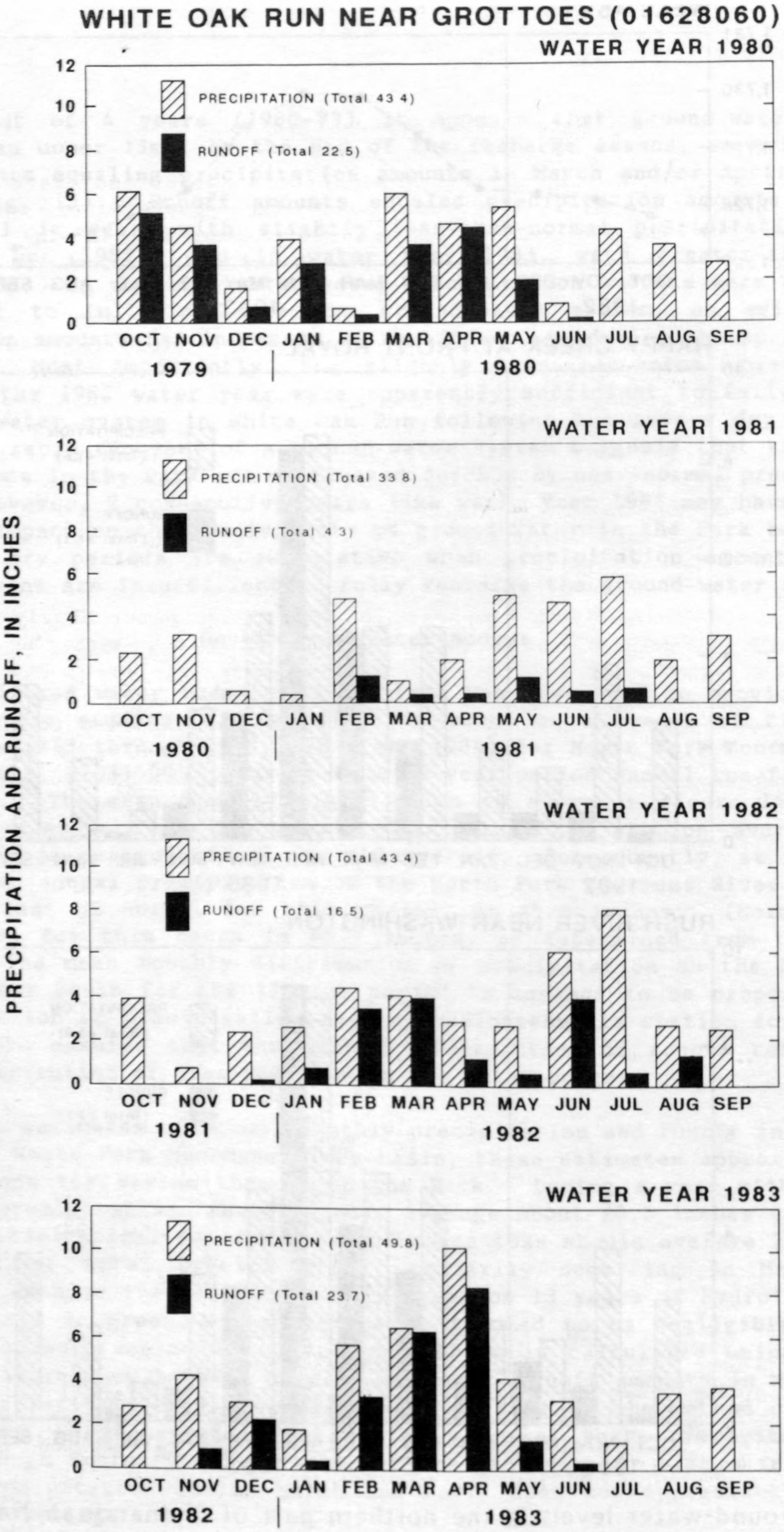


Figure 15.--Monthly precipitation and runoff in the White Oak Run basin, October 1979 through September 1983.

Site Specific Investigations

Much of the impetus for this study of Shenandoah National Park arose from a need to answer specific questions about the ground-water resources at Skyland and Big Meadows, the two largest developments in the Park. At Skyland, local ground-water resources have been insufficient to meet peak demands for drinking water during 4 of 6 years (1980 through 1985). This condition raised the question of whether Skyland's ground-water resources are diminishing or whether the shortages are a temporary problem caused by the drought in the early 1980's. At Big Meadows, the question raised is whether the withdrawal of ground water for use as a local water supply is significantly lowering the ground-water level in the area and contributing to the apparent slow disappearance of a nearby wetland ecosystem. The following two special investigations were conducted during the project to address these questions raised at Skyland and Big Meadows.

Skyland

In the years 1980, 1981, 1983, and 1985, the water-supply system at Skyland (comprised of two wells and a spring) could not meet the demand for drinking water, and it became necessary to transport water from Big Meadows to offset these shortages. When these shortages first occurred in 1980 and 1981, it was thought that less-than-normal precipitation amounts led to the problem. However, water shortages in 1983 and 1985 suggested that precipitation patterns did not fully explain the problem. Precipitation amounts from 1982 through 1985 were normal or greater than normal at the nearby Big Meadows precipitation gage. Moreover, there is no indication that the 1980-81 drought had any effect on hydrologic conditions in Skyland beyond 1982. Discharge from Furnace Spring at Skyland between April 1983 and October 1984 was

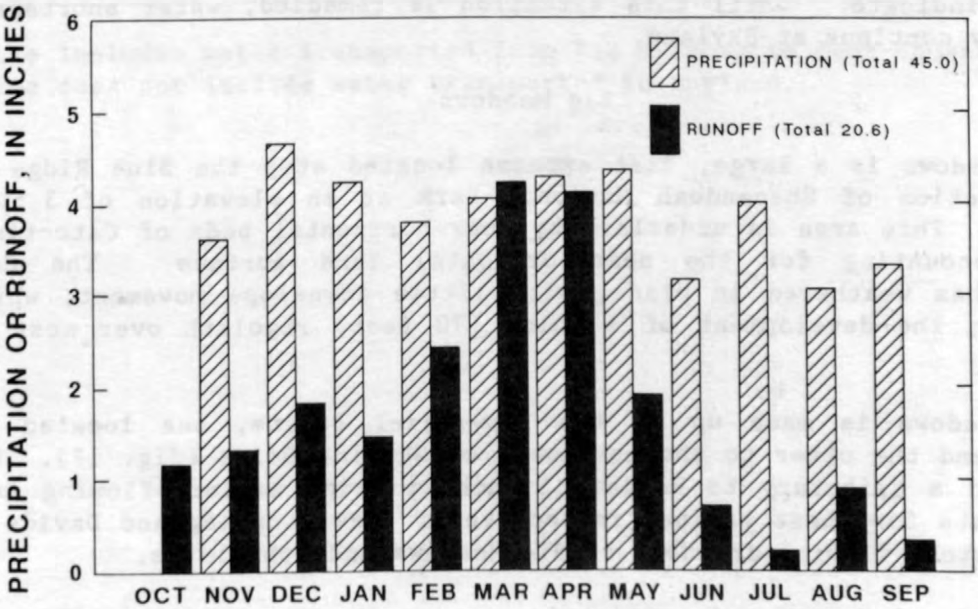


Figure 16.--Normal monthly precipitation and runoff for a typical basin in Shenandoah National Park.

generally greater than the medium discharge between 1960 and 1970 (fig. 10). (As discussed earlier, the extremely low discharges observed in August through October 1983 resulted from pumping a back-up supply well that captured water from Furnace Spring at a rate of 23 gal/min.) In addition, hydrographs of two supply wells at Skyland (43S 2 and 43S 4) suggest that the ground-water system was fully recharged by early spring of both 1983 and 1984 (fig. 12).

An examination of water-use records for Skyland and Big Meadows (table 20) reveals the most probable explanation for the water shortages at Skyland. After the facility was expanded in 1973, water use at Big Meadows followed a trend similar to Park visitation records. Use of water between the months of April and October peaked in the late 1970's when the facilities were fully occupied in the summer months. Water use declined at Big Meadows in 1979 and remained stable through 1984, which seems to reflect the reduction in Park visitation during these years. In contrast to Big Meadows, water use at Skyland does not reflect Park visitation. Rather than seeing a decline around 1979, water use during April through October rose sharply at Skyland in 1980 and continued to rise through 1984 (table 20). The April to October water use in 1979 was 10.6 million gallons compared to 17.7 million gallons in 1984, a 67 percent increase in five years.

In light of these records, it is apparent that recent water shortages at Skyland are not due to a diminishing ground-water resource but to an increased demand for water. These shortages, however, appear to be more likely and of greater severity in years when precipitation amounts prior to and during the heavy water-use period (April through October) are below normal.

Increased water use at Skyland, without an accompanying increase in the use of facilities, suggests that a large quantity of water is being lost from the water-supply distribution system. Some losses are noted in the water-use records, but it appears that recent losses are considerably larger than the notations indicate. Until this situation is remedied, water shortages will undoubtedly continue at Skyland.

Big Meadows

Big Meadows is a large, flat expanse located atop the Blue Ridge in the central section of Shenandoah National Park at an elevation of 3,500 feet (fig. 17). This area is underlain by near-horizontal beds of Catoctin metabasalt, accounting for the near-horizontal land surface. The Catoctin Formation has weathered in place, with little downslope movement, which has resulted in the development of a thick (70 feet) regolith over most of the area.

Big Meadows is made up of two low-relief basins, one located to the southeast and the other to the northwest of Skyline Drive (fig. 17). Hogcamp Branch, and a tributary to Hogcamp Branch, provide eastern-flowing surface-water outlets for these basins, respectively. Lewis Spring and Davids Spring provide western flowing drainage of Big Meadows and its flanks.

The National Park Service maintains the southeastern basin of Big Meadows as a meadow in order to reflect the land use of early inhabitants. Otherwise, this area is virtually undeveloped. The northwestern basin has been more

Table 20.--Water use at Skyland and Big Meadows, 1962 through 1984

[in millions of gallons]

	Skyland		Big Meadows	
	Annual	April-October	Annual	April-October
1962	6.1	6.0	6.8	6.2
63	5.5	5.4	6.4	5.9
64	5.1	4.8	8.0	7.3
65	5.8	5.4	7.9	7.1
66	5.8	5.6	9.0	8.1
67	5.7	5.2	8.5	7.7
68	6.4	6.1	8.3	7.5
69	7.3	7.0	10.2	9.1
1970	6.5	6.1	10.6	9.4
71	6.8	6.5	10.7	9.0
72	8.5	8.0	10.6	9.0
73	11.1	10.3	14.5	11.9
74	8.9	7.3	16.1	12.2
75	9.4	8.3	19.2	14.0
76	11.1	9.7	25.8	17.5
77	10.1	9.3	22.5	15.9
78	14.2	10.0	22.6	16.3
79	14.2	10.6	18.8	13.8
1980	[a]17.8	[a]14.5	[b]17.8	[b]13.8
81	[a]18.2	[a]14.0	[b]17.1	[b]13.0
82	18.0	14.6	17.2	13.4
83	[a]21.2	[a]16.2	[b]17.6	[b]12.9
84	21.8	17.7	19.1	13.8

[a] Value includes water transported from Big Meadows to meet demands.
[b] Value does not include water transported to Skyland.

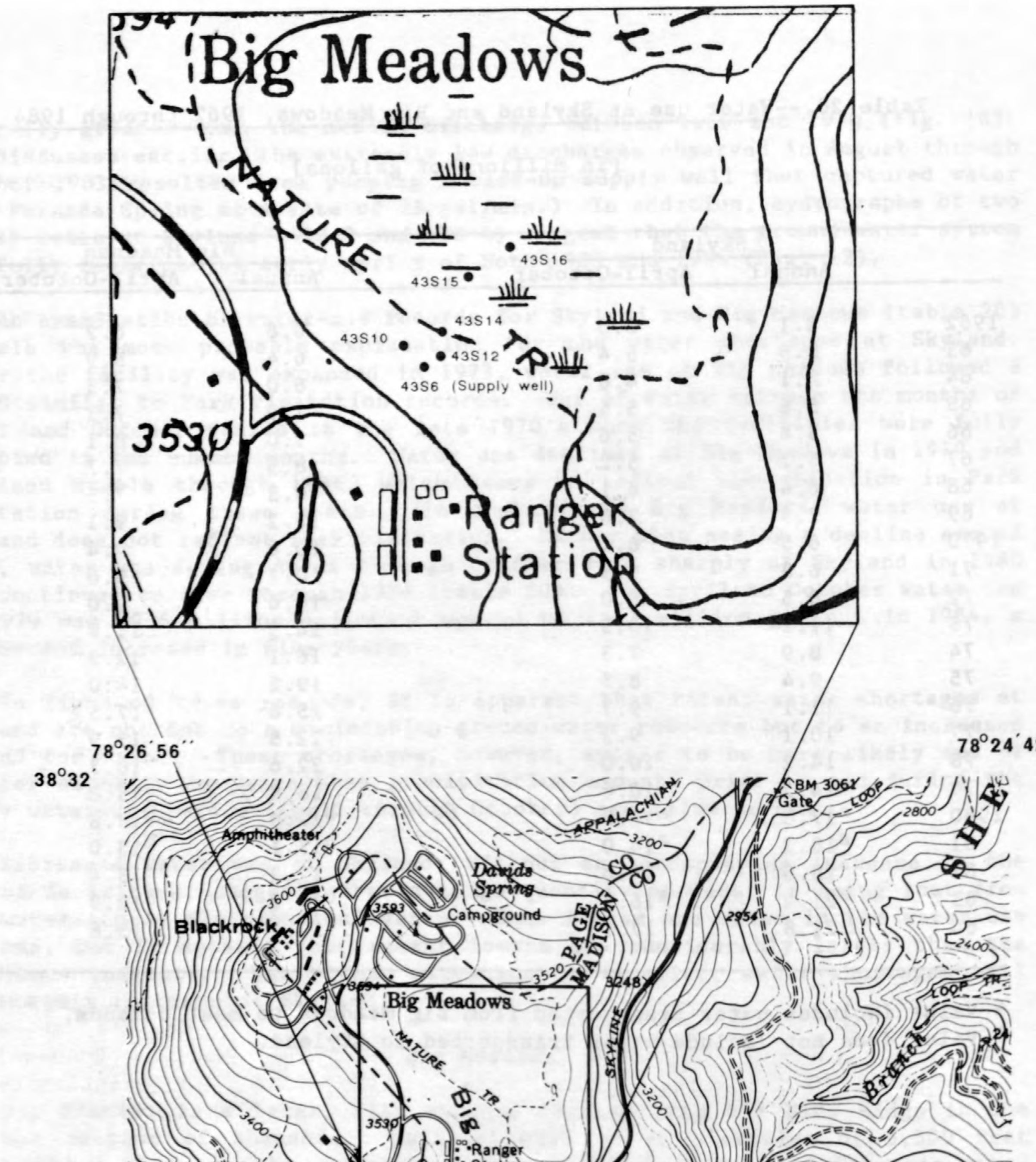


Figure 17.--Location of wells in the Big Meadows study area.

extensively developed, including the construction of lodging facilities, a campground, and a large maintenance area. Within the lower half of this basin, the National Park Service has attempted to preserve a high elevation swamp because it supports an assemblage of plants rarely found in the Park or the State of Virginia. Big Meadows swamp exists in this area because of the thick, moderately permeable regolith, the very low relief within the drainage basin, and because the underlying bedrock is impermeable except for shallow fractures (Dekay, 1972). Consequently, recharge from precipitation is effectively retained in a local ground-water system and is slowly discharged to the surface outlet through a flat, saturated area in the lowest portion of the basin. Water also may be lost from this basin through Lewis and Davids Springs, but the hydrogeologic properties of this basin are not known in sufficient detail to quantify the losses. From May through September, when vegetation is fully active in Big Meadows, a large quantity of water also is lost from this basin via evapotranspiration.

Expansion of the Big Meadows visitor facilities west of Skyline Drive required the development of an additional water supply to supplement water obtained from Lewis Spring. In 1966, a 100-foot water-supply well was drilled in the northwestern basin of Big Meadows, about 300 feet from the swamp perimeter (fig. 17). The well is cased through 68 feet of regolith and left open-hole through 32 feet of fractured bedrock. From 1983 through 1984, 11.2 million gallons per year were obtained from this well, providing 61 percent of the Big Meadows water supply. Demand varied from a low in February of 13,000 gal/d (gallons per day) to a high in August of 47,000 gal/d.

Although the thick regolith in Big Meadows stores a tremendous quantity of ground water, there is concern that pumping 40,000 to 50,000 gal/d from this well during the summer months will lower the swamp water level. The concern is for the fragile swamp ecosystem and, in particular, for the shallow rooting flora that are poorly adapted to dry soil conditions. Small water-level changes in the swamp due to nearby pumping may select for heartier, deeper rooting plants capable of crowding out the native flora. A comparison of areal photographs of the swamp, taken over a period of decades, suggests this may already be occurring (Emily Baxter, James Madison University, Department of Biology, oral commun., 1983), as evidenced by a shrinking swamp perimeter and the recent encroachment of deeper rooting plants.

Because of concern for this fragile swamp ecosystem, five observation wells were installed in the northwestern basin of Big Meadows to determine the short-term effects of local pumping on ground-water levels in and around the swamp. Figure 17 shows the location of these wells in relation to the swamp and water-supply well (43S 6). Wells 43S 10, 43S 12, and 43S 14 were augered to depths of 52, 34, and 19 feet, respectively, and fitted with screens of 4-foot length and 2-inch diameters. Each well was instrumented with an automatic water-level recorder from April 28, 1983 to December 10, 1984. Wells 43S 15 and 43S 16, located in the Big Meadows swamp, are well points that were driven manually to depths of 7.5 and 5.8 feet, respectively. Both wells have screens 4 feet in length and 2 inches in diameter. Well 43S 15 is located about 390 feet from the supply well and was instrumented for continuous water-level measurements as described above. Well 43S 16 is located in the surface-water drainage channel of the basin about 540 feet from the supply well. Water levels in this well were measured about monthly during the study period.

To obtain the exact altitude of the observation and water supply wells, levels were run from a benchmark located near the intersection of Skyline Drive and the southern access road to Big Meadows Lodge.

The combined effect of ground-water withdrawals, precipitation, evapotranspiration, and natural discharge through the surface-water outflow and springs accounts for the variations in the ground-water hydrographs of the supply well and five observation wells in Big Meadows (fig. 18). Generally, the maximum water level at these wells occurs between November and April, corresponding to a period of minimum evapotranspiration and minimum ground-water withdrawals. Between May and October water levels tend to decline, corresponding to increased evapotranspiration and ground-water withdrawals. The relationship between ground-water levels in Big Meadows and the amount of ground-water withdrawals, precipitation, and evapotranspiration can be seen more clearly in figures 19 and 20. Hydrographs for well 43S 12 (50 feet from the water-supply well) and well 43S 15 (in the swamp and 390 feet from the supply well) are plotted together in these figures to compare their responses to changing hydrologic conditions and ground-water withdrawals. Figure 19 shows the hydrographs for the 22-month period of record and figure 20 shows a 6-week period from July 28 through September 8, 1983, to better resolve details of the hydrographs during a critical time of year.

In the beginning of the study period, the Big Meadows ground-water system was recharged by heavy precipitation from February through April 1983. Within the swamp, at well 43S 15, water levels were about 3,493 feet above sea level. At this water level, the swamp was fully saturated and discharging water through its surface outlet. Adequate precipitation during May 1983 kept the swamp nearly saturated and water levels near the pumping well relatively high. By mid-June, however, water levels in both wells were declining. This decline was temporarily reversed by 3 inches of rain on June 21. A very dry July, together with increased rates of withdrawal, resulted in about a 7-foot water-level decline near the pumping well and a 3-foot water-level decline in the swamp by the end of July. About 3 inches of rain in early August 1983 raised water levels in the swamp about 2 feet, but had little effect on water levels near the pumping well other than slightly slowing the rate of water-level decline (fig. 20). Apparently the majority of precipitation near the pumping well was taken up by vegetation and/or retained in a very dry unsaturated zone before it reached the water table 25 feet below land surface. Because the water level in the swamp was only 3 feet below land surface, a much larger proportion of the precipitation in early August reached the water table. This phenomenon was also observed in early July and late September 1984 (fig. 19). Rainfall of 2 to 4 inches at these times quickly raised water levels in the swamp but only slowed the rate of water-level decline near the supply well. By early October 1983, water levels in the swamp reached a minimum, which reflects the cumulative effect of evapotranspiration throughout the summer, heavy ground-water withdrawals to meet demands, and less-than-normal precipitation amounts during the previous 4 months. By mid-December 1983, however, 2 months of heavy rains fully recharged the ground-water resource at Big Meadows, as evidenced by a fully saturated swamp and ground-water levels only 8 feet below the land surface near the supply well.

The hydrographs for 1984 are similar to those for 1983. Water-level declines in 1984 began in May, reached a minimum in October, and were approaching full recovery by December. However, normal to greater-than-normal

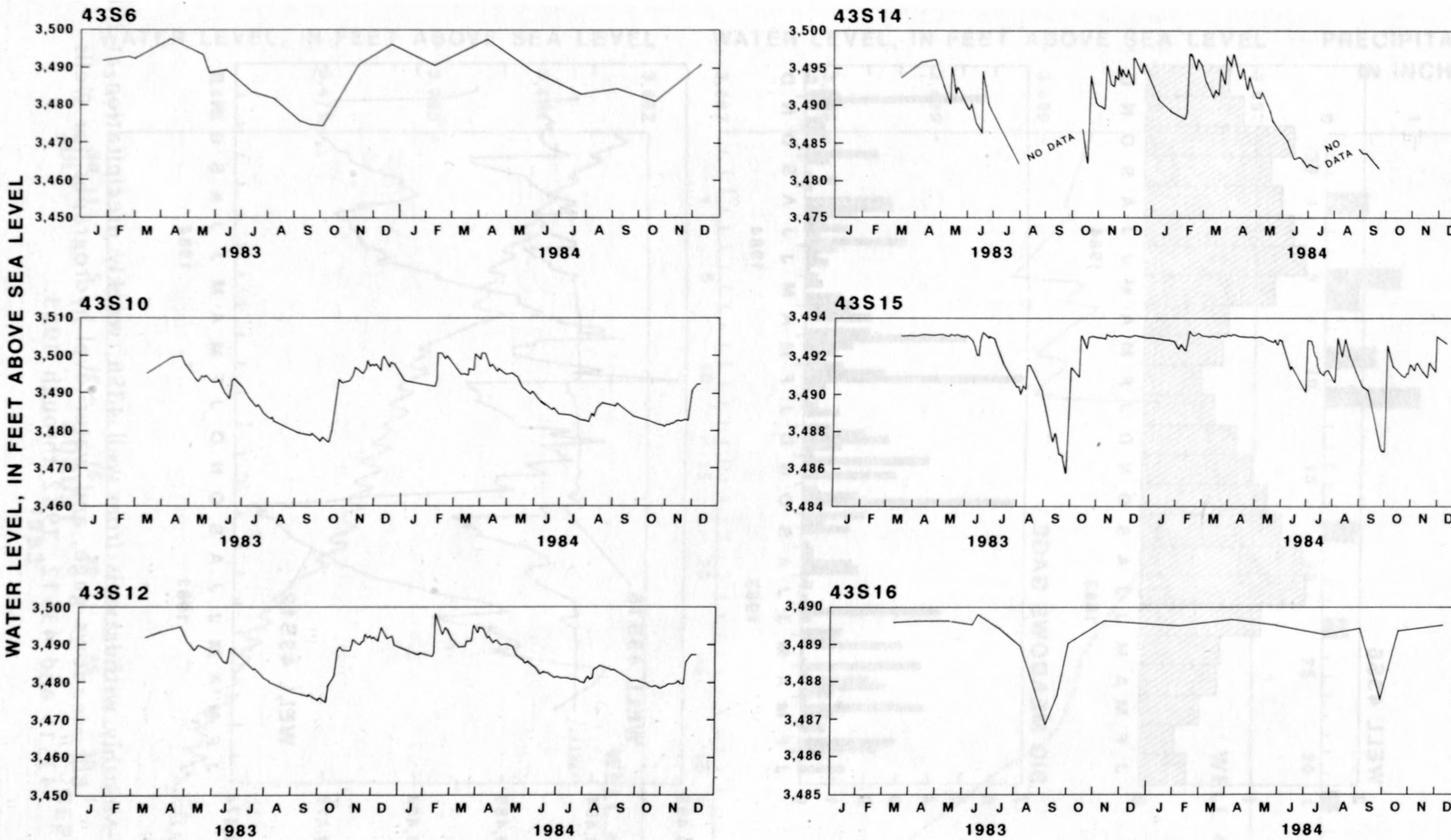


Figure 18.--Hydrographs of six wells in the Big Meadows study area.

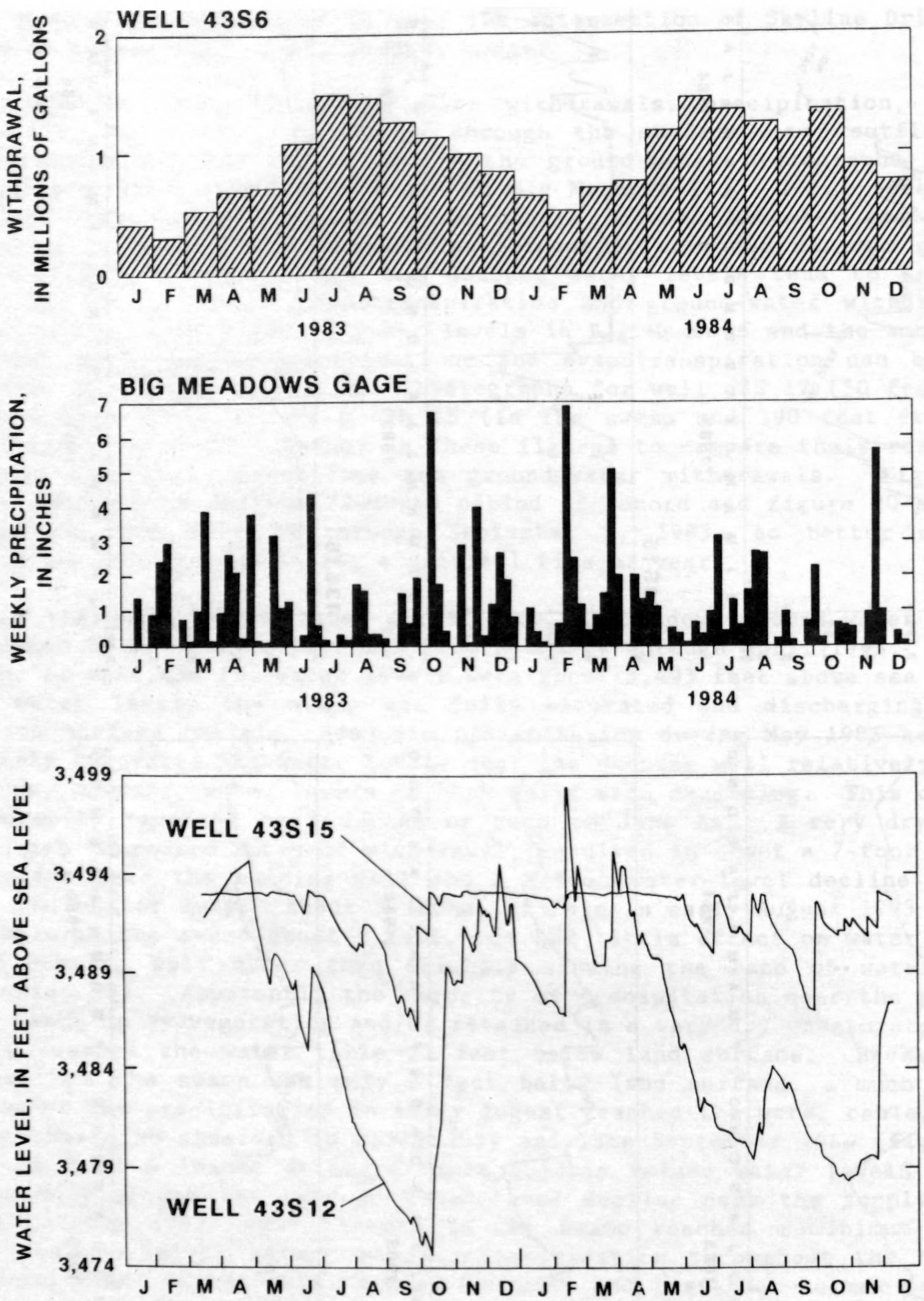


Figure 19.--Monthly withdrawals from well 43S6, weekly precipitation at the Big Meadows gage, and water-level hydrographs for wells 43S15 and 43S12, 1982 through 1983.

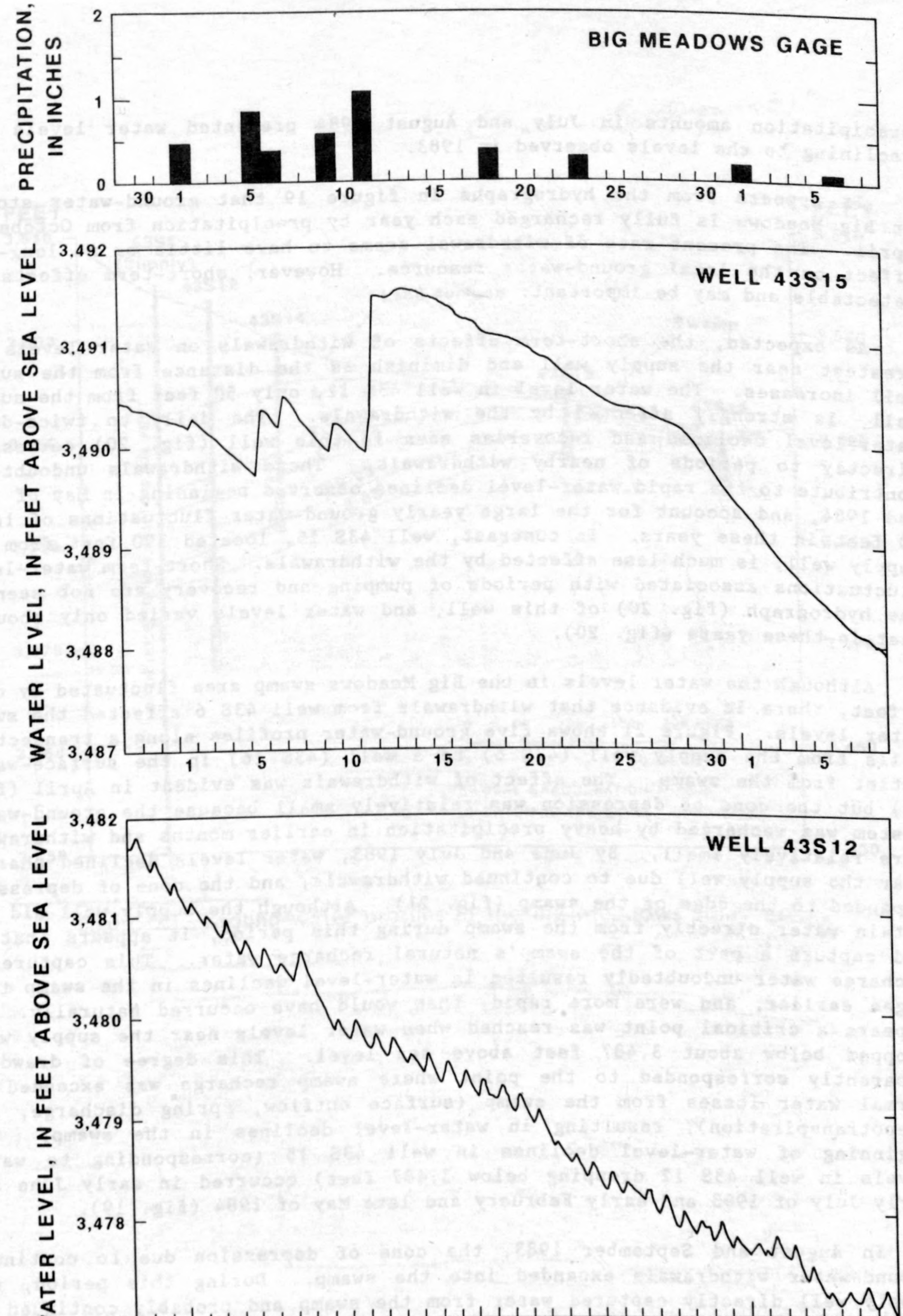


Figure 20.--Daily precipitation at the Big Meadows gage, and water-level hydrographs for wells 43S15 and 43S12, July 29 through September 8, 1983.

precipitation amounts in July and August 1984 prevented water levels from declining to the levels observed in 1983.

It appears from the hydrographs in figure 19 that ground-water storage at Big Meadows is fully recharged each year by precipitation from October to April. The present rate of withdrawal seems to have little or no long-term effect on the local ground-water resource. However, short-term effects are detectable and may be important.

As expected, the short-term effects of withdrawals on water levels are greatest near the supply well and diminish as the distance from the supply well increases. The water level in well 43S 12, only 50 feet from the supply well, is strongly affected by the withdrawals. The daily to twice-daily water-level declines and recoveries seen in this well (fig. 20) correspond directly to periods of nearby withdrawals. These withdrawals undoubtedly contribute to the rapid water-level declines observed beginning in May of 1983 and 1984, and account for the large yearly ground-water fluctuations of 16 to 20 feet in these years. In contrast, well 43S 15, located 390 feet from the supply well, is much less affected by the withdrawals. Short-term water-level fluctuations associated with periods of pumping and recovery are not seen in the hydrograph (fig. 20) of this well, and water levels varied only about 7 feet in these years (fig. 20).

Although the water levels in the Big Meadows swamp area fluctuated by only 7 feet, there is evidence that withdrawals from well 43S 6 affected the swamp water levels. Figure 21 shows five ground-water profiles along a transect of wells from the supply well (43S 6) to a well (43S 16) in the surface-water outlet from the swamp. The effect of withdrawals was evident in April (fig. 21) but the cone of depression was relatively small because the ground-water system was recharged by heavy precipitation in earlier months and withdrawals were relatively small. By June and July 1983, water levels declined sharply near the supply well due to continued withdrawals, and the cone of depression expanded to the edge of the swamp (fig. 21). Although the supply well did not obtain water directly from the swamp during this period, it appears that it did capture a part of the swamp's natural recharge water. This capture of recharge water undoubtedly resulted in water-level declines in the swamp that began earlier, and were more rapid, than would have occurred naturally. It appears a critical point was reached when water levels near the supply well dropped below about 3,487 feet above sea level. This degree of drawdown apparently corresponded to the point where swamp recharge was exceeded by normal water losses from the swamp (surface outflow, spring discharge, and evapotranspiration), resulting in water-level declines in the swamp. The beginning of water-level declines in well 43S 15 (corresponding to water levels in well 43S 12 dropping below 3,487 feet) occurred in early June and early July of 1983 and early February and late May of 1984 (fig. 19).

In August and September 1983, the cone of depression due to continued ground-water withdrawals expanded into the swamp. During this period, the supply well directly captured water from the swamp and probably continued to do so into early October 1983. This direct capture of water may explain the relatively rapid water-level declines measured in the swamp (well 43S 15) during the month of September in both 1983 and 1984 (fig. 19).

Cone of depression

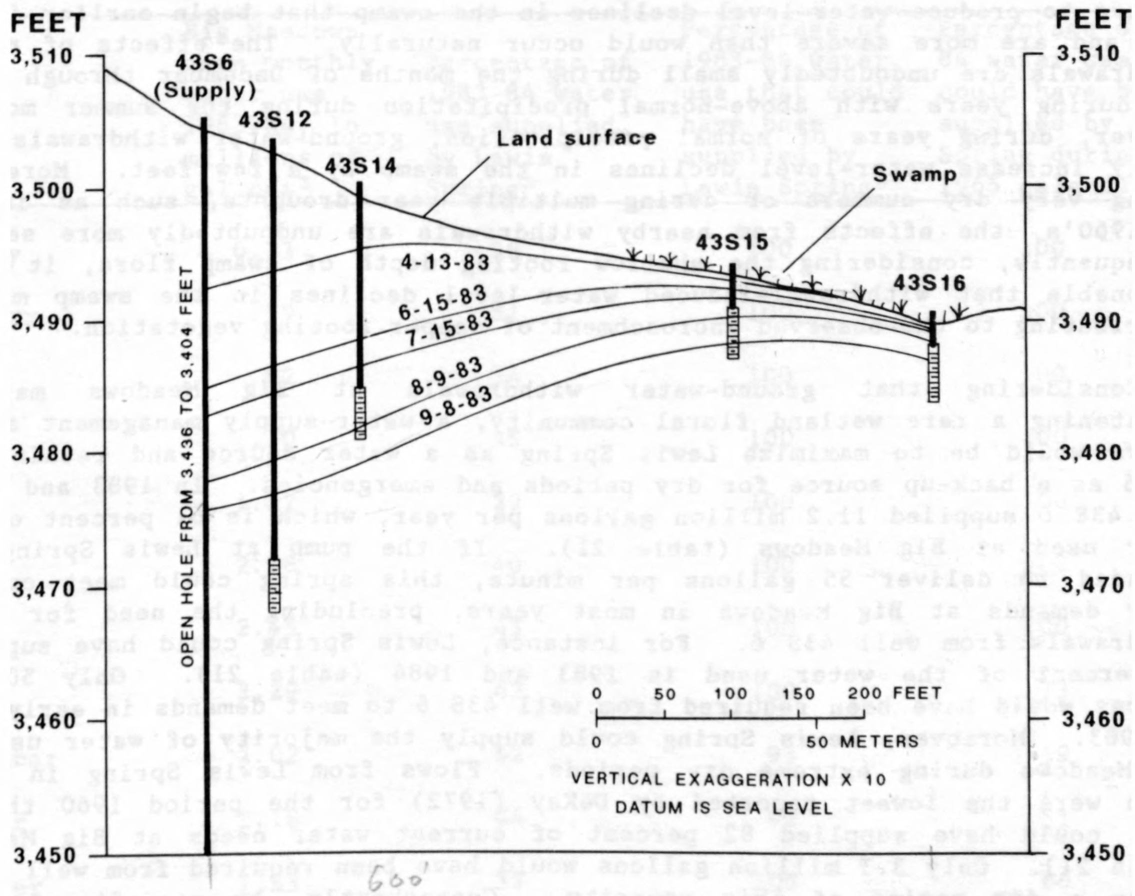


Figure 21.--Ground-water profiles in the Big Meadows study area.

Overall, the current rate of ground-water withdrawal at Big Meadows appears to produce water-level declines in the swamp that begin earlier in the year and are more severe than would occur naturally. The effects of nearby withdrawals are undoubtedly small during the months of December through April and during years with above-normal precipitation during the summer months. However, during years of normal precipitation, ground-water withdrawals most likely increase water-level declines in the swamp by a few feet. Moreover, during very dry summers or during multiple year droughts, such as in the mid-1960's, the effects from nearby withdrawals are undoubtedly more severe. Consequently, considering the shallow rooting depth of swamp flora, it seems reasonable that withdrawal-induced water-level declines in the swamp may be contributing to the observed encroachment of deeper rooting vegetation.

Considering that ground-water withdrawals at Big Meadows may be threatening a rare wetland floral community, a water-supply management alternative would be to maximize Lewis Spring as a water source and retain well 43S 6 as a back-up source for dry periods and emergencies. In 1983 and 1984, well 43S 6 supplied 11.2 million gallons per year, which is 61 percent of the water used at Big Meadows (table 21). If the pump at Lewis Spring was upgraded to deliver 55 gallons per minute, this spring could meet current water demands at Big Meadows in most years, precluding the need for daily withdrawals from well 43S 6. For instance, Lewis Spring could have supplied 98 percent of the water used in 1983 and 1984 (table 21). Only 500,000 gallons would have been required from well 43S 6 to meet demands in early fall of 1983. Moreover, Lewis Spring could supply the majority of water used at Big Meadows during extreme dry periods. Flows from Lewis Spring in 1965, which were the lowest reported by DeKay (1972) for the period 1960 through 1971, could have supplied 82 percent of current water needs at Big Meadows (table 21). Only 3.3 million gallons would have been required from well 43S 6 during a dry period of this severity. Consequently, by reconfiguring the water-supply system at Big Meadows, the effect of ground-water withdrawals on the nearby swamp could be lessened. It should be noted that using Lewis Spring as the primary water supply for Big Meadows would reduce the flow over Lewis Spring Falls, located 0.4 miles downstream. The reduction in flow would be most evident in summer months and during dry periods. Further study would be required to reliably determine the percent loss of flow over the falls during dry periods if additional water was pumped from Lewis Spring.

SUMMARY

Hydrologic conditions (1983 through 1984) and trends were studied in Shenandoah National Park to provide basic data for research and to address specific water-management questions. The study primarily focuses on (1) the amount and variability of precipitation, surface water, and ground water in the Park, and (2) short- and long-term effects of ground-water withdrawals and droughts on water resources.

Maps of estimated precipitation amounts for a normal year and for a 1-year dry period with a 10-year recurrence interval are provided. Normal annual precipitation ranges from 52 inches on the higher peaks to 38 inches in the foothills, and averages 45 inches. Annual precipitation during a 10-year drought averages 80 percent of normal. Because of "rain shadow" effects, precipitation amounts are smallest in the northeastern part of the Park and

Table 21.--Monthly water use at Big Meadows, and percentage supplied and potentially supplied, by Lewis Spring

	Big Meadows mean monthly water use 1983-84, in millions of gallons[a]	Percentage of 1983-84 water use supplied by Lewis Spring[a]	Percentage of 1983-84 water use that could have been supplied by Lewis Spring[b]	Percentage of 1983-84 water use that could have been supplied by Lewis Spring during the 1965 calendar year[c]
January	0.73	28	100	100
February	.59	31	100	100
March	.92	34	100	100
April	1.10	35	100	100
May	1.32	29	100	100
June	2.08	40	100	100
July	2.45	43	100	100
August	2.29	42	100	73
September	2.02	42	93	59
October	2.18	44	93	51
November	1.53	39	100	66
December	1.23	36	100	71
Total	18.44	39	98	82

[a] Records available at Shenandoah National Park Headquarters in Luray, Virginia.
[b] Assumes the pump at Lewis Spring can deliver 55 gallons per minute.
[c] Year of lowest flow from Lewis Spring during the period 1960-71 (DeKay, 1972).

largest in the southwestern part. Precipitation is fairly evenly distributed in a year; but the areal coverage, duration, and intensity of storms vary seasonally. Storms from October through May are characterized by wide areal coverage, low intensity, and long duration. Storms from June through September are characterized by local areal distribution, high intensity, and short duration.

In the mid-1960's and early 1980's the Park received less-than-normal precipitation. The 3-year precipitation totals at seven stations in and around the Park from 1963 through 1965 averaged 78 percent of normal, and are the lowest on record. The recurrence interval of this dry period is about 60 years. The dry period in 1980 and 1981 was much less severe. Two-year precipitation totals at the same seven stations averaged 86 percent of normal, which has a recurrence interval of about 10 years.

Surface water is primarily assessed in terms of low-flow characteristics. Seven-day, 10-year and 7-day, 2-year low-flow values are estimated for 29 sites in the Park. The variability in low flow is largely explained by drainage basin size, geology, and stream-channel characteristics. Unit 7-day, 2-year low-flow values average 0.13 and 0.032 cubic feet per second per square mile for streams that drain crystalline and sedimentary rocks, respectively; this represents a four-fold difference in low flows. Basins in sedimentary rocks generally have a thin (less than 10 feet) regolith underlain by a poorly fractured, steeply inclined bedrock, which provides little ground-water storage for sustaining flows during dry periods. In contrast, basins in crystalline rocks contain larger quantities of ground water for sustaining flows during dry periods because regoliths are thicker (10 to 60 feet) and underlying bedrock is more fractured and gently inclined. Differing amounts of subsurface flow through transmissive channel deposits may explain some of the variability in low-flow values not accounted for by drainage basin size and geology.

There is no indication that rates of withdrawals since the 1960's have had a long-term effect on ground-water resources in the Park. Static water levels in 23 wells measured in 1983 and 1984 generally were several feet higher than water levels measured in the 1960's, regardless of whether wells were heavily pumped during this period or were remote from ground-water withdrawals. Apparently, normal precipitation amounts from October through April fully recharge the many separate ground-water systems in the Park by the spring, which negates the effect of withdrawals (or a dry period) in the previous year. However, the short-term effect of ground-water withdrawals may be important because the quantity of water available in many ground-water systems in the Park is inadequate to supply needs for more than 1 year. Unless these systems are fully recharged each year, water-supply shortages may occur. A supply well at Loft Mountain (41Q 6), which penetrates a small ground-water system, provides an extreme example of this. Unless this system is frequently recharged in the summer, withdrawals nearly deplete the ground-water resource by late summer, and well yields decline to 2 gallons per minute or less.

Except for natural variations due to climate, flows from eight water-supply springs in the Park have not changed appreciably since the 1960's. There is no indication of long-term declines in flow from springs due to collapsed or plugged collection galleries or by water that bypasses the collection system.

Regardless of size, location, or geology, most drainage basins in the Park have similar annual water budgets given similar climatic conditions. During a year with a normal precipitation pattern, about 54 percent of precipitation is lost to evapotranspiration and the remainder is lost as surface runoff. Ground water is fully recharged by the end of February in a normal year, as indicated by surface runoff that equals precipitation in March and April. Stable ground-water levels during periods when surface runoff equals precipitation indicate that ground-water storage is at a maximum.

Climate largely controls variability in annual water budgets. Surface runoff from the White Oak Run basin ranged from 4.3 inches during a dry year (October 1980 through September 1981) to 23.7 inches during a wet year (October 1982 through September 1983). Even for years with the same precipitation amount, surface runoff from White Oak Run varied depending on the seasonal distribution of precipitation. Because nearly all precipitation that falls during the summer months is lost to evapotranspiration, surface runoff during a year when precipitation was concentrated in the summer months was considerably less than surface runoff during a year when precipitation was concentrated in the fall, winter, and spring.

The most important finding from the White Oak Run water budgets is that slightly less-than-normal precipitation amounts after the extreme dry conditions in 1981 were apparently sufficient to fully recharge the ground-water system by March 1982. This provides strong evidence that near-normal precipitation amounts during a recharge season prevents drought effects in the Park from carrying over into subsequent years.

Questions concerning the ground-water resources at Skyland and Big Meadows--the two largest developments in the Park--were addressed with site-specific investigations. Recent shortages of drinking water at Skyland are attributed to increased water use rather than to a diminished ground-water source brought about by past withdrawals or climatic conditions. Because water use has increased by 67 percent from 1979 to 1984 without an increase in the number of Park visitors, the water shortages probably resulted from large losses in the distribution system. At Big Meadows, withdrawals from well 43S 6, the primary water supply, are linked to the steady disappearance of a nearby wetland floral community. The water-level decline in the wetland caused by these withdrawals is probably on the order of a few feet during years with normal precipitation amounts, which may adversely affect the survival of shallow rooting plants. To lessen these effects, an alternative would be to maximize use of Lewis Spring, currently the secondary water supply for Big Meadows, and retain well 43S 6 as a back-up source for use during dry periods and emergencies.

REFERENCES CITED

Allen, R. M., Jr., 1963, Geology and mineral resources of Greene and Madison counties: Virginia Division of Mineral Resources Bulletin 78, 102 p.

----- 1967, Geology and mineral resources of Page County: Virginia Division of Mineral Resources Bulletin 81, 78 p.

Bloomer, R. O., and Werner, H. J., 1955, Geology of the Blue Ridge region in central Virginia: Geological Society of America Bulletin, v. 66 p. 579-606.

Brent, W. B., 1960, Geology and mineral resources of Rockingham County: Virginia Division of Mineral Resources Bulletin 76, 174 p.

Cushing, E. M., Kantrowitz, I. H., and Taylor, K. R., 1973, Water resources of the Delmarva Peninsula: U.S. Geological Survey Professional Paper 822, 58 p.

DeKay, R. H., 1972, Development of ground-water supplies in Shenandoah National Park, Virginia: Virginia Division of Mineral Resources, Mineral Resources Report 10, 158 p.

Furcron, A. S., 1934, Igneous rocks of the Shenandoah National Park area: Journal of Geology, v. 42, p. 400-410.

Galloway, J. N., Hornberger, G. M., and Beven, K. J., 1982, Shenandoah watershed acidification study: Three year summary report, September 1979 - September 1982: Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, 31 p., 8 appendixes.

Gathright, T. M., II, 1976, Geology of the Shenandoah National Park, Virginia: Virginia Division of Mineral Resources Bulletin 86, Charlottesville, Virginia, 93 p., 3 pls.

Gathright, T. M., II, Henika, W.S., and Sullivan, J.L., 1977, Geology of the Waynesboro East and Waynesboro West quadrangles, Virginia: Virginia Division of Mineral Resources Publication 3, Charlottesville, Virginia, 53 p., 2 pls.

Haelen, T. R., 1985, Hydrological and solution chemistry responses in a tributary of the White Oak Run watershed, Shenandoah National Park, Virginia: Master of Science thesis, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia, 279 p.

Hendry, G. R., Galloway, J. N., Norton, S. A., Schofield, C. L., Shaffer, P. W., and Burns, D. A., 1980, Geological and hydrochemical sensitivity of the eastern United States to acid precipitation: U.S. Environmental Protection Agency, EPA-600/3-80-024, 90 p.

King, P. B., 1950, Geology of the Elkton area, Virginia: U.S. Geological Survey Professional Paper 230, 82 p.

Linsley, R. K., Jr., Kohler, M. A., and Paulhus, J. L. H., 1975, Hydrology for engineers: Mcgraw-Hill, Incorporated, New York, 482 p.

Linthurst, R. A., 1983, The acid deposition phenomenon and its effects: Critical assessment review papers, v. 2, chap. E4, Effects on aquatic chemistry, U.S. Environmental Protection Agency, EPA-600/8-83-016B, p. 1-162.

Lohman, S. W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p., 9 pls.

Lynch, D. D., and Dise, N. B., 1985, Sensitivity of stream basins in Shenandoah National Park to acid deposition: U.S. Geological Survey Water-Resources Investigations Report 85-4115, 61 p.

National Oceanic and Atmospheric Administration (NOAA), 1982, Climatological data--Virginia: National Climatic Data Center, Asheville, North Carolina, v. 92, no. 7-12.

----- 1983a, Climatological data--Virginia: National Climatic Data Center, Asheville, North Carolina, v. 93, no. 1-12.

----- 1983b, Hourly data--Virginia: National Climatic Data Center, Asheville, North Carolina, v. 33, no. 4 and 6.

----- 1984a, Climatological data--Virginia: National Climatic Data Center, Asheville, North Carolina, v. 94, no. 1-12.

----- 1984b, Monthly precipitation data from files: National Climatic Data Center, Asheville, North Carolina.

Nelson, W. A., 1962, Geology and mineral resources of Albemarle County: Virginia Division of Mineral Resources Bulletin 77, 92 p.

Reed, J. C., Jr., 1955, Catoctin Formation near Luray, Virginia; Geological Society of America Bulletin, v. 66, p.871-896.

----- 1969, Ancient lavas in Shenandoah National Park near Luray, Virginia: U.S. Geological Survey Bulletin 1265, 43 p.

Riggs, H. C., 1968, Frquency curves: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chapter A2, 15 p.

----- 1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chapter B1, 18 p.

Rogers, W. B., 1884, A reprint of annual reports and other papers on the geology of the Virginias: D. Appleton and Company, New York, 832 p.

Schwab, F. L., 1970, Origin of the Antietam Formation, central Virginia: Journal of Sedimentary Petrology, v.40, p. 343-366.

----- 1971, Harpers Formation, central Virginia: a sedimentary model: Journal of Sedimentary Petrology, v. 41, p. 139-149.

Searcy, J. K., 1959, Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Vreeland, J. N., 1983, The role of shallow groundwater in the hydrogeochemical response of the White Oak Run catchment, Shenandoah National Park: Master of Science thesis, Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia.

Weibull, W., 1939, A statistical theory of the strength of materials: Ing. Vetenskapsakad. Handl. (Stockholm), v.151, p. 15.

Appendix 1.--Daily precipitation amounts in Shenandoah National Park

[in inches]

July 1982

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1			0			0			0	0.03	0.06
2			0			0			0	.02	0
3			0.08			0.09			0.41	.46	.38
4			0			0			.02	.07	.38
5			.06			.03			0	.04	.03
6			0			0			0	0	.03
7			0			0			0	0	0
8			.11			.19			.05	0	0
9			1.15			.60			0	1.19	.08
10			0			.17			0	.06	0
11			0			0			0	.06	0
12			0			.79			.38	.03	.92
13			0			0			0	0	0
14			.07			0			0	0	0
15			0			.10			0	.64	.04
16			0			0			0	.03	.01
17			0			0			0	0	0
18			0			.17			0	.29	.06
19			0			.40			0	0	0
20			.39			.08			0	0	0
21			0			0			0	0	0
22			0			0			0	0	0
23			.53			.35			.53	.88	.48
24			0			0			0	.53	.09
25			0			0			0	0	0
26			0			0			0	0	0
27			0			0			0	0	0
28			.07			.09			.04	.09	.08
29			0			0			0	0	0
30			.44			.68			.55	.26	.22
31			.43			.31			.34	.59	.38
Total			3.33			4.05			2.32	5.27	3.24

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

August 1982

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1			0			0			0	0.21	0
2			0.08			0.04			1.43	.15	0.54
3			0			0			0	0	0
4			0			0			0	0	0
5			.96			0			.13	0	.42
6			.05			0			2.80	.41	2.55
7			.08			.06			0	0	0
8			0			0			0	.01	0
9			0			0			.62	.39	.74
10			0			0			0	.01	0
11			.05			0			0	0	0
12			0			0			.03	.02	.13
13			0			0			0	.01	0
14			0			0			0	0	0
15			0			0			0	0	0
16			0			.05			0	0	0
17			.23			.21			0	.30	0
18			0			0			0	0	0
19			0			0			0	0	0
20			0			0			0	0	0
21			0			0			.39	.18	.41
22			0			0			0	0	0
23			0			0			0	.01	0
24			0			0			.03	.02	.04
25			.03			0			0	0	0
26			0			0			0	0	0
27			.03			0			.02	.09	.05
28			0			0			0	.01	0
29			0			0			0	0	0
30			0			0			0	0	0
31			0			.06			0	.00	0
Total			1.51			.42			5.45	1.82	4.88

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued.

[in inches]

September 1982

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0	0	0.04	0
2	0	0	0	0	0	0	0.47	0.72	0.73	.01	0.55
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0.02	0.03	0.02	0.03	.11	0	0	.08	0
9	0	0	0	0	0	0	0	0	0	.12	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	.01	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0.08	0	0	0	0	0	.13	.10	.15	.01	.06
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	.02
19	0	0	0	0	0	0	0	0	0	.05	.07
20	.06	.10	.25	.19	.17	.07	.29	.14	.18	.59	.42
21	0	0	0	0	0	0	0	0	0	.04	0
22	.28	.45	.46	.44	.32	.27	.75	.51	.31	.81	.22
23	0	0	0	0	0	0	0	.04	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0
26	2.05	1.92	1.48	1.37	1.75	1.08	2.31	2.32	2.33	2.05	1.60
27	0	0	.09	.13	.09	.02	.15	.18	.03	.01	.04
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	.06	0
Total	2.47	2.47	2.30	2.16	2.35	1.47	4.21	4.01	3.73	3.88	2.98

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

October 1982

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0	0	0.01	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0.10	0	0	0
5	0.24	0.16	0	0	0	0	0	0	0	0	0
6	0	0	0	0.05	0.07	0	0	.10	0.05	.13	0
7	0	0	0	0	0	0	0	0	0	.03	0
8	0	0	0	0	0	0	0	0	0	0	0
9	.23	.44	0.31	.35	.55	0.57	0.35	.30	.39	.01	0
10	.05	.07	.05	.10	.15	.06	.20	.20	.19	.30	0
11	.23	.24	0	.10	.16	.08	.10	.10	.19	.19	.11
12	0	0	0	0	0	0	0	0	0	.03	0
13	.71	.88	.46	.55	.50	.43	.85	.65	.58	.69	.55
14	0	0	0	0	0	0	0	0	0	0	0
15	0	.03	.04	.05	.04	.01	0	0	0	0	0
16	0	.02	.03	.05	.02	.02	0	0	0	.10	.10
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	.30	.10	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	.20	.08	0	0	0	0	0	0	0	0	0
21	0	.10	.02	.07	.08	.04	.15	.10	.08	.15	.07
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	.16	.05	0	0	0	0	0	0	0	0	0
25	.79	1.36	1.23	1.10	.76	.72	1.6	1.15	.95	1.51	1.17
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0
Total	2.61	3.43	2.14	2.42	2.33	1.93	3.55	2.80	2.43	3.15	2.00

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

November 1982

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pirnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	1.91	1.60	2.06	2.46	2.85	2.32	1.95	1.50	1.48	1.96	1.31
5	0	0	0	0	0	0	0	0	0	.04	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	.43	.30	.30	.32	.31	.27	.30	.20	.20	.41	.25
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	.02	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	.59	.40	.50	.34	.30	.60	.60	.36	.59	.12
20	.15	.15	.13	.10	.09	.13	.15	.11	.16	.10	.05
21	0	0	0	0	0	0	0	0	0	.03	0
22	0	0	0	0	0	0	0	0	0	.05	0
23	0	0	0	0	0	0	.07	.05	0	.04	.03
24	0	0	0	0	0	0	0	0	0	.01	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	1.10	.90	.87	1.10	1.05	1.05	1.10	.90	.87	1.10	.85
29	.50	.60	.59	.60	.58	.60	.20	.35	.38	.59	.45
30	0	0	.04	.04	.03	.02	0	0	.04	0	0
Total	4.09	4.14	4.39	5.12	5.25	4.69	4.37	3.71	3.45	4.94	3.06

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

December 1982

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0.59	0.90	0.61	0.65	0.57	0.54	0.65	0.45	0.47	0.72	0.67
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	.01
5	.22	.26	.13	.15	.11	.08	.10	.05	.05	.13	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	.35	.38	.08	.08	.11	.08	.80	.60	0.54	.80	.52
12	.62	.69	.20	.45	.30	.20	.05	.05	.05	.03	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	.63	.45	.43	.5	.53	.34	.50	.30	0.23	0	0
16	1.18	.85	.82	1.05	1.00	1.07	1.05	.55	0.60	1.32	0.78
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	.09	.17	.11	.10	.10	.10	.15	.15	.12	.12	.12
20	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	.05	.04	.04	.03	.03
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0
Total	3.68	3.70	2.38	2.98	2.72	2.41	3.35	2.19	2.10	3.15	2.13

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

January 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0	0	0	0
2	0.03	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0.05	0	0	0.05	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	.05	0	0.04	.05	0	0	0	0
6	0	0	0.04	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	.11	0.05	.09	.16	0.16	.05	.25	0.37	0.31	0.64	0.26
10	57	.85	.80	1.05	.82	.54	1.38	1.40	1.21	.77	.22
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	.01	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	.05	0	0	0	0	0	0	0	0	0
18	0	0	0	.05	0	0	.10	0	0	.03	.05
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0
22	.47	.25	.45	.50	.49	.44	.60	.50	.30	.80	0
23	.24	.65	.35	.30	.43	.27	.60	.50	.45	.16	.10
24	0	0	0	.03	0	0	0	.03	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	.03	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	.01	0
Total	1.42	1.88	1.73	2.19	1.90	1.34	3.03	3.03	2.27	2.42	.63

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

February 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0	0.05	0	.12
2	2.13	2.58	1.69	2.47	2.20	1.63	3.35	2.44	2.52	2.45	1.28
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	.50	.50	.39	.45	.40	.35	.50	.55	0	.07	0
7	.06	.05	.03	.03	.02	.02	.10	.13	.36	.40	.27
8	0	0	0	0	0	0	0	.03	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	.07	.13	0	.08	0	0	.10	.10	0	0	0
11	1.74	2.20	1.41	1.60	1.40	1.20	1.45	2.20	2.0	2.52	2.50
12	.32	.30	.21	.20	.22	.15	.40	.20	.16	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	.40	.40	.32	.37	.25	.22	.15	.15	.10	.16	0
24	0	0	0	0	0	0	0	0	0	0	0
25	.40	.85	.40	.40	.36	.19	.60	.45	.32	.67	.21
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
Total	5.62	7.01	4.45	5.60	4.85	3.76	6.65	6.25	5.51	6.27	4.38

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

March 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0.09	0.15	0.23	0.29	0.23	.19	0.2	0.25	0.20	0.13	0.07
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	.39	.48	.25	.69	.68	.45	.65	.50	.56	.47	.13
7	.24	.30	.09	.22	.21	.10	.25	.20	.15	.31	.18
8	1.40	1.42	.33	.40	.37	.32	.45	.55	.49	.23	.31
9	0	0	.03	.08	.07	.02	0	0	.02	.02	.01
10	0	0	0	.09	.11	.04	.05	.04	.03	.01	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	.06	.05	.05	.06	0	0	.04	.02	0
15	0	0	0	0	0	0	0	0	.04	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	.05	0	0	0	0
18	3.59	3.70	1.88	1.47	1.51	1.21	3.8	3.6	3.53	3.97	2.68
19	.80	1.05	.36	.55	.41	.24	.65	.30	.20	0	0
20	0	0	.06	.05	.04	.02	0	0	0	0	0
21	.4	.4	.24	.55	.48	.36	.20	.10	.09	.16	.08
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	.02	0	.04	.06	.04	.02	0	0	0	0	0
26	.05	.05	.05	.05	.04	.03	0	.05	0	0	0
27	.88	1.05	.62	.95	.80	.82	1.20	1.00	.90	.84	.60
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
31	0	0	.03	.11	.08	.08	.25	.20	.19	.14	.10
Total	7.86	8.60	4.27	5.61	5.12	3.96	7.75	6.79	6.44	6.30	4.16

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

April 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0.03	0.04	0.03	.03	0.04	0.03	0	0	0	0.04	0
2	3.0	3.25	1.77	2.0	1.81	1.65	3.25	2.10	1.94	2.25	1.69
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	.05	.05	.05	.07	.05	.05	.20	.05	.07	.06	.03
7	.20	.22	.17	.20	.16	.15	.20	.15	.15	.19	.21
8	0	0	.03	.05	.07	.04	.10	.10	.06	.19	.21
9	1.25	1.39	1.19	1.20	1.08	1.25	1.00	1.2	1.15	1.73	1.38
10	.95	1.0	.69	.60	.75	.82	.80	.95	.69	.42	.10
11	.30	.39	.28	.30	.32	.19	.25	.20	.19	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	.32	.25	.14	.20	.29	.18	.1	0	0	0	.10
16	1.11	1.36	1.18	1.30	2.05	1.73	2.13	1.43	1.68	.27	.95
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	2.04	1.69	1.19	1.30	1.03	.98	1.93	1.80	1.05	3.26	2.00
25	1.96	2.46	1.12	1.35	1.29	1.20	2.25	2.30	2.03	.55	.45
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
Total	11.21	12.46	7.84	8.60	8.94	8.27	12.21	10.28	9.01	8.96	7.12

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

May 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0.09	0.03	0.06	0.05	0.06	0.05	0.3	0.15	0.16	0.19	0.08
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	.11	.15	.08	.08	.07	.06	.10	.2	.20	.12	.20
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	.87	.10	.17	.12	.11	.08	.28	.60	.44	.23	.34
15	0	0	.25	.35	.16	.06	.30	0	.12	1.07	1.08
16	1.42	2.00	2.15	2.70	2.43	2.08	2.75	2.05	2.37	1.61	1.73
17	0	0	0	0	0	0	0	.35	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	.24	.25	.14	.20	.19	.16	.25	.2	.14	.32	.13
20	0	.1	.04	.10	.10	.11	0	0	.03	0	0
21	.48	.47	.78	.73	.75	.65	.70	.60	.47	.72	.86
22	.20	.30	.18	.20	.30	.36	.30	.30	.21	.32	.16
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	.15	.10	.11	.11	.07	.05	.13	.10	.04	.07	.01
26	0	0	0	0	0	0	.05	.20	.15	0	.20
27	0	0	0	0	0	0	0	0	0	0	0
28	.19	.10	0	0	.03	.03	.05	0	0	.34	.24
29	.17	.33	.26	.30	.27	.26	.35	.35	.31	.16	.08
30	0	.08	.04	0	.04	0	.05	.05	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0
Total	3.92	4.01	4.26	4.94	4.58	3.95	5.61	5.15	4.64	5.15	5.11

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

June 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0.09	0.08	0.13	0.06	0.03	0.05	0.05	0	.02	.04
2	0	0	0	0	0	0	0	0	0	0	0
3	0.40	.67	.54	.60	.51	.42	1.20	.45	0.46	.80	.39
4	0	0	0	0	0	0	0	0	0	.02	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	.20	.30	0.44	.01	.35
7	0	0	0	0	0	0	0	.05	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	.10	.14	.43	.10	.05	.02	.02	.66
14	.51	0	0	0	0	0	0	0	0	0	0
15	0	0	.03	.20	.15	.03	0	0	0	0	0
16	.13	.15	0	0	0	0	0	0	0	0	0
17	.05	.18	0	.07	.05	0	1.00	.15	0.26	.31	.28
18	1.3	1.65	.84	1.30	1.10	1.06	.10	.10	0.10	.80	.56
19	.10	.38	.16	.25	.25	.10	0	0	0	.17	0
20	.55	.50	.03	.08	.10	.20	0	0	0	.19	.08
21	.24	.15	.02	.12	.10	.10	2.10	1.70	1.39	3.22	1.03
22	.18	.18	0	.05	.03	.02	.05	.05	0.05	.01	0
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0
27	.09	.10	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	.08	.18	.15	.25	.28
29	.07	.10	.05	.10	.05	.05	.95	.57	.50	.32	.43
30	.06	.20	.09	.20	.21	.10	.10	.05	.05	0	0
Total	3.68	4.35	1.84	3.20	2.75	2.54	5.93	3.70	3.42	6.14	4.10

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

July 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0.55	0.60	0	0	0	0	0	0	0	0.03	0
2	0	0	0	0	0	0	0	0	0	.02	0
3	0	0	0	0	0	0	0	0	0	0	0
4	.14	.10	0	0	0	0	0.05	0.15	.10	.01	0.05
5	.16	.08	0.13	0.38	0.28	0.20	.90	.45	.40	.12	.39
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	.10	0	0	0	0
18	0	0	0	0	0	0	0	.05	0	.03	.02
19	0	0	0	0	0	0	0	0	0	0	0
20	.04	.08	.08	.15	.83	.58	.55	.30	0	.01	.87
21	.72	.80	.25	.30	.41	.37	.30	.15	.15	.32	.27
22	0	0	0	0	0	0	0	0	0	0	0
23	.10	.20	.06	.05	.11	.06	.10	.05	.06	.20	.18
24	.10	.10	.06	.04	.08	.06	.10	.12	.08	0	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0
Total	1.81	1.96	0.58	0.92	1.71	1.27	2.10	1.27	.79	0.74	1.78

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

August 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0.05	.04	0	0.08	0.1	0.05	0.47	0.20
2	0	0	0	0	0	0.40	0	0	0	0	0
3	0	0	0	0	0	0	.10	0	0	.02	0
4	0.16	0.13	0	0	0	0	.23	.2	.31	0	.11
5	.47	.60	0.61	.40	.06	.27	.75	.60	.19	.88	1.10
6	0	0	0	0	0	0	0	0	0	.35	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	1.05	0	.75	.65	.70	.67	1.23	.40	.46	.55	.66
10	0	0	0	0	0	0	0	0	0	0	0
11	.87	1.08	.83	.55	.43	.25	1.00	.85	.71	1.06	1.13
12	0	0	0	0	0	0	0	.15	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	.05	.21	.19	.15	.14	.10	.17	.15	.09	.36	.20
19	0	0	0	0	0	0	0	.15	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0
23	.76	.61	.47	.48	.48	.24	.25	.10	.09	.27	.11
24	0	0	0	0	.02	.05	.10	.10	.08	.05	0
25	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	.1	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	1.11	.89	.39	.20	.17	.15	.07	.20	.08	.03	.12
29	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0
31	0	0	.10	.15	.16	.10	0	0	0	0	0
Total	4.47	3.52	3.34	2.63	2.20	2.23	3.98	3.10	2.06	4.04	3.63

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

September 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1	0	0	0	0	0	0	0	0.10	0	0.19	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	.05	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0.05	0	0	.01	0
12	0	0.13	2.35	2.0	1.80	1.31	.45	.10	0	.10	0
13	0.40	.30	.53	.75	.69	.72	1.70	1.30	1.48	1.43	1.19
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	.10	0	0	0
20	0	0	0	0	0	0	0	0	0	.01	0
21	.75	.87	.26	.70	.74	1.22	.30	.25	.16	.64	.03
22	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	.01	0
26	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	.06	0
30	1.40	1.62	1.39	1.45	1.37	1.32	2.20	1.90	1.89	1.92	1.91
Total	2.55	2.92	4.53	4.90	4.60	4.57	4.70	3.75	3.53	4.42	3.13

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

October 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1			0		0.05	0.06	0.05	0.80	0.03	0.02	0.02
2			0		0	0	0	0	0	0	0
3			0		0	0	0	0	0	0	0
4			0		0	0	0	0	0	0	0
5			0		0	0	0	0	0	0	0
6			0		0	0	0	0	0	0	0
7			0		0	0	0	0	0	0	0
8			0		0	0	0	0	0	0	0
9			0		0	0	0	0	0	.01	0
10			0		0	0	0	0	0	.05	.18
11			0.91		.73	.66	1.6	.90	.88	1.92	2.0
12			1.26		1.97	1.44	3.1	1.95	1.90	3.40	.04
13			1.80		1.30	1.14	1.2	.65	.63	1.40	.97
14			0		0	0	0	0	0	0	0
15			0		0	0	0	0	0	0	0
16			0		0	0	0	0	0	0	0
17			0		0	0	0	0	0	0	0
18			0		0	0	0	0	0	.01	0
19			0		0	0	0	0	0	.20	.31
20			1.20		.96	1.25	1.30	1.10		1.55	.97
21			.48		.50		.65	.85		.01	.01
22			.26		.37		.30	.20		.08	1.27
23			1.32		2.01		1.85	.80		.08	.49
24			.02		0		.05	0	0	.21	.25
25			.08		.08		.25	0	0	.03	0
26			0		0		0	0	0	.02	0
27			0		0		0	0	0	0	0
28			0		0		0	0	0	0	0
29			0		0		0	0	0	0	0
30			0	0	0		0	0	0	0	0
31			0	0	0		0	0	0	0	0
Total			7.33		7.97	--	10.35	7.25	--	8.99	6.51

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

November 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1			0	0	0	0	0	0	0	0	0
2			0	0	0	0	0	0	0	0	0
3			0.03	0.08	.05	0	0.45	0.25	0.03	0.01	0
4			.04	0	0	0	0	0	.09	.16	.21
5			.18	.17	.19	0.08	.05		0	0	0
6			0	0	0	0	0		.07	.10	.01
7			0	0	0	0	0		0	0	0
8			0	0	0	0	0		0	0	0
9			0	0	0	0	0		0	.74	0
10			1.75	1.83	1.91	1.90	2.02		1.45	2.10	1.03
11			.07	.12	.19	.08	.40		.30	0	.29
12			0	0	0	0	0		0	0	0
13			0	0	0	0	0		0	0	0
14			0	0	0	0	0		0	0	0
15			.36	.36	.39	.36	.40		.40	.10	.07
16			0	0	0	0	0		0	0	0
17			0	0	0	0	0		0	0	0
18			0	0	0	0	0		0	0	0
19			0	0	0	0	0		0	0	0
20			.86	1.40	1.04	.97	1.25		.98	1.30	.82
21			0	0	0	0	0		0	0	0
22			0	0	0	0	0		0	0	0
23			0	.1	0	.15	.10		0	.31	.31
24			.73	.78	1.25	1.71	1.95		1.16	2.45	1.54
25			1.18	.95	.37	.05	.65		.78	0	0
26			.05	0	0	0	0		.07	0	0
27			0	0	0	0	.10		.11	.20	.27
28			.17	.15	.14	.12	.40		.33	.10	.04
29			0	0	0	0	0		0	0	0
30			0	0	0	0	0		0	0	0
Total			5.42	5.94	5.53	5.42	7.77	--	5.77	7.57	4.59

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

December 1983

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1							0			0	0
2							0.07			0	0
3							.20			0.04	0.05
4							.90			.92	.95
5							0			0	0
6				0.20			.25			.15	.23
7				0			0			0	0
8				0			0			0	0
9				0			.05			.12	.04
10				0			0			0	0
11				.05			.05			1.41	.90
12				2.15			2.40			1.23	.92
13				.15			.50			.08	.03
14			0	0	0	0	0			0	0
15			0	0	0	0	0			0	0
16			0	0	0	0	0			0	0
17			0	0	0	0	0			0	0
18			0	0	0	0	0			0	0
19			0	0	0	0	0			0	0
20			0	0	0	0	0			0	0
21			0	0	0	0	.30			0	0
22			1.38	1.60	1.45	1.40	1.73			1.85	1.38
23			0	0	0	0	0			.05	0
24			.04	0	0	0	0			0	0
25			0	0	0	0	0			0	0
26			0	0	0	0	0			0	0
27			0	0	0	0	0			0	.08
28			.91	1.10	.64	.54	1.23			.86	.95
29			0	.10	.10	.09	0			0	0
30			0	0	0	0	0			0	0
31			0	0	0	0	0			0	0
Total			--	--	--	--	7.68			6.71	5.53

Appendix 1.--Daily precipitation amounts in Shenandoah National Park--Continued

[in inches]

January 1984

	Sawmill Ridge Overlook	Loft Mountain	Swift Run West	Swift Run Gap	Swift Run East	Lydia	Pinnacles ranger residence	Thornton Gap	Sperry-ville	Big Meadows	Luray
1									0.07	0	0
2									0	0	0
3									0	0	0
4									.04	0.07	0
5									0	0	0
6									0	0	0
7									0	0	0
8									0	0	0
9									0	0	0
10									.45	1.13	0.18
11									0	0	0
12									0	0	0
13									0	0	0
14									.23	.11	.09
15									0	0	0
16									0	0	0
17									0	0	0
18									0	.03	0
19									.29	.29	.28
20									0	0	0
21									0	0	0
22									0	0	0
23									.06	0	0
24									.27	.12	.17
25									0	0	0
26									0	0	0
27									0	0	0
28									0	0	0
29									0	0	0
30									0	0	0
31									0	.04	.04
Total									1.41	1.79	.76

Appendix 2.--Flows from selected springs in Shenandoah National Park

NAME: SWIFT RUN GAP SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2480
LATITUDE: 382119 LONGITUDE: 0783256 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

MAY 27, 1983	17	OCT 05, 1983	5.7	JUL 25, 1984	11
JUN 14, 1983	15	NOV 14, 1983	11	SEP 04, 1984	8.8
JUL 15, 1983	12	FEB 08, 1984	12	OCT 19, 1984	7.4
AUG 10, 1983	9.0	APR 09, 1984	16		
SEP 07, 1983	6.5	MAY 31, 1984	13		

NAME: LEWIS MOUNTAIN SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3030
LATITUDE: 382603 LONGITUDE: 0782859 USE OF SITE: BACK-UP SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

MAY 27, 1983	25	OCT 04, 1983	5.2	JUL 25, 1984	11
JUN 14, 1983	19	NOV 14, 1983	28	SEP 04, 1984	19
JUL 15, 1983	15	FEB 08, 1984	19	OCT 19, 1984	8.5
AUG 09, 1983	9.3	APR 09, 1984	31		
SEP 07, 1983	6.4	MAY 31, 1984	21		

NAME: LEWIS SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3320
LATITUDE: 383109 LONGITUDE: 0782638 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

APR 13, 1983	369	AUG 12, 1983	69	NOV 19, 1983	231
MAY 27, 1983	210	AUG 18, 1983	69	DEC 05, 1983	328
JUN 04, 1983	172	AUG 28, 1983	52	FEB 08, 1984	112
JUN 14, 1983	138	SEP 09, 1983	48	APR 09, 1984	384
JUL 09, 1983	138	OCT 04, 1983	32	MAY 31, 1984	138
JUL 21, 1983	108	OCT 12, 1983	48	JUL 25, 1984	56
JUL 27, 1983	95	OCT 30, 1983	221	SEP 04, 1984	95
AUG 07, 1983	69	NOV 07, 1983	190	OCT 19, 1984	52
AUG 09, 1983	69	NOV 14, 1983	265		

NAME: FURNACE SPRINGS
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3630
LATITUDE: 383549 LONGITUDE: 0782248 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

APR 15, 1983	230	AUG 31, 1983	19*	APR 09, 1984	230
MAY 04, 1983	230	SEP 01, 1983	31*	APR 19, 1984	205
MAY 15, 1983	119	SEP 06, 1983	13*	APR 28, 1984	165
MAY 19, 1983	165	SEP 07, 1983	25*	MAY 20, 1984	155
JUN 07, 1983	165	SEP 19, 1983	11*	MAY 26, 1984	125
JUN 17, 1983	92	SEP 20, 1983	19*	JUN 07, 1984	86
JUN 21, 1983	92	SEP 27, 1983	9.3*	JUN 18, 1984	64
JUN 22, 1983	165	OCT 11, 1983	7.8*	JUN 26, 1984	64
JUL 08, 1983	134	OCT 14, 1983	165	JUL 19, 1984	74
JUL 21, 1983	86	OCT 24, 1983	230	JUL 29, 1984	64
JUL 30, 1983	54	NOV 04, 1983	230	AUG 11, 1984	64
AUG 06, 1983	54	NOV 14, 1983	165	SEP 04, 1984	80
AUG 07, 1983	31*	FEB 10, 1984	74	OCT 19, 1984	25*
AUG 22, 1983	22*	FEB 17, 1984	230		
AUG 23, 1983	34*	MAR 15, 1984	205		

* Flow influenced by withdrawals from a nearby well.

NAME: PINNACLES SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3480
LATITUDE: 383733 LONGITUDE: 0781941 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

MAY 27, 1983	45	OCT 04, 1983	0.3	JUL 26, 1984	3.3
JUN 13, 1983	21	NOV 14, 1983	54	SEP 05, 1984	2.8
JUL 13, 1983	14	FEB 08, 1984	11	OCT 18, 1984	1.3
AUG 10, 1983	3.7	APR 10, 1984	118		
SEP 09, 1983	0.8	JUN 01, 1984	14		

NAME: PANORAMA SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2470
LATITUDE: 383957 LONGITUDE: 0781914 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

MAY 26, 1983	26	OCT 05, 1983	2.8	JUL 26, 1984	9.3
JUN 13, 1983	19	NOV 14, 1983	10	SEP 05, 1984	9.3
JUL 13, 1983	12	FEB 09, 1984	14	OCT 18, 1984	4.7
AUG 11, 1983	5.8	APR 10, 1984	64		
SEP 09, 1983	2.8	JUN 01, 1984	21		

NAME: HEADQUARTERS SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 1300
LATITUDE: 383936 LONGITUDE: 0782117 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

MAY 26, 1983	16	OCT 05, 1983	4.0	JUL 26, 1984	7.1
JUN 13, 1983	12	NOV 14, 1983	9.3	SEP 05, 1984	5.8
JUL 13, 1983	8.5	FEB 08, 1984	10	OCT 18, 1984	7.1
AUG 11, 1983	5.8	APR 10, 1984	17		
SEP 09, 1983	5.2	JUN 01, 1984	12		

NAME: DICKEY RIDGE SPRING
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2330
LATITUDE: 384959 LONGITUDE: 0781033 USE OF SITE: WATER SUPPLY

DISCHARGE, IN GALLONS PER MINUTE

MAY 26, 1983	56	OCT 05, 1983	7.1	JUL 26, 1984	12
JUN 13, 1983	32	NOV 21, 1983	12	SEP 04, 1984	7.8
JUL 13, 1983	19	FEB 09, 1984	19	OCT 18, 1984	6.4
AUG 11, 1983	12	APR 10, 1984	59		
SEP 09, 1983	8.5	JUN 01, 1984	32		

LOCAL NUMBER: 41Q 4 SITE IDENTIFICATION NUMBER: 381601078393201
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2740
LATITUDE: 381601 LONGITUDE: 0783932 WELL DEPTH, IN FEET: 303
DATE OF WELL COMPLETION: 09-10-1962 USE OF SITE: WATER SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
SEP 10, 1962	12.	JUL 14, 1983	12.00	APR 09, 1984	5.04
JAN 25, 1983	8.98	SEP 07, 1983	11.94	MAY 31, 1984	4.94
APR 13, 1983	6.63	OCT 05, 1983	8.98	JUL 27, 1984	7.07
MAY 18, 1983	6.93	NOV 14, 1983	8.67	SEP 05, 1984	5.90
JUN 14, 1983	9.03	FEB 08, 1984	9.02	OCT 19, 1984	7.85

LOCAL NUMBER: 41Q 5 SITE IDENTIFICATION NUMBER: 381602078393301
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2746
LATITUDE: 381602 LONGITUDE: 0783933 WELL DEPTH, IN FEET: 250
DATE OF WELL COMPLETION: 09-14-1962 USE OF SITE: OBSERVATION

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
SEP 14, 1962	10.	MAY 15, 1983	8.56	SEP 13, 1983	10.34
JAN 25, 1983	9.30	MAY 17, 1983	7.54	SEP 24, 1983	10.13
FEB 02, 1983	8.97	MAY 18, 1983	7.30	OCT 01, 1983	9.91
FEB 10, 1983	8.65	MAY 21, 1983	7.89	OCT 21, 1983	9.48
FEB 16, 1983	8.98	MAY 23, 1983	7.65	OCT 26, 1983	8.19
FEB 24, 1983	7.30	MAY 27, 1983	7.91	NOV 04, 1983	10.05
MAR 01, 1983	8.19	JUN 02, 1983	8.72	NOV 09, 1983	10.14
MAR 07, 1983	6.36	JUN 07, 1983	8.80	NOV 10, 1983	8.52
MAR 09, 1983	5.95	JUN 11, 1983	9.02	NOV 11, 1983	8.21
MAR 20, 1983	6.75	JUN 14, 1983	9.24	NOV 14, 1983	8.90
MAR 23, 1983	7.05	JUN 18, 1983	9.60	NOV 15, 1983	9.04
APR 13, 1983	6.72	JUN 24, 1983	9.22	NOV 19, 1983	9.17
APR 16, 1983	5.88	JUN 30, 1983	9.54	FEB 08, 1984	9.25
APR 23, 1983	7.81	JUL 09, 1983	9.56	APR 09, 1984	6.73
APR 24, 1983	5.61	JUL 14, 1983	11.21	MAY 31, 1984	8.30
APR 29, 1983	7.01	JUL 22, 1983	11.00	JUL 27, 1984	9.93
MAY 05, 1983	8.08	AUG 05, 1983	11.20	SEP 05, 1984	9.03
MAY 08, 1983	8.26	AUG 29, 1983	10.60	OCT 19, 1984	10.65

LOCAL NUMBER: 41Q 6 SITE IDENTIFICATION NUMBER: 381606078393501
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2670
LATITUDE: 381606 LONGITUDE: 0783935 WELL DEPTH, IN FEET: 320
DATE OF WELL COMPLETION: 11-27-1962 USE OF SITE: WATER SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
NOV 27, 1962	15.	AUG 10, 1983	148.20	APR 09, 1984	16.39
JAN 25, 1983	17.98	SEP 07, 1983	89.18	MAY 31, 1984	96.90
APR 13, 1983	22.06	OCT 05, 1983	102.52	JUL 27, 1984	105.40
MAY 18, 1983	22.90	NOV 14, 1983	24.90	SEP 05, 1984	100.30
JUN 14, 1983	30.90	FEB 08, 1984	18.66	OCT 19, 1984	111.06

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 42Q 1 SITE IDENTIFICATION NUMBER: 382145078342801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 1475
LATITUDE: 382145 LONGITUDE: 0783428 WELL DEPTH, IN FEET: 60.0
DATE OF WELL COMPLETION: 07-16-1963 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE ("+" INDICATES ABOVE LAND SURFACE)

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUL 16, 1963	7.	JUL 15, 1983	0.79	APR 09, 1984	+1.40
SEP 29, 1982	1.78	AUG 10, 1983	1.27	MAY 31, 1984	+0.54
JAN 25, 1983	1.13	SEP 07, 1983	1.78	JUL 25, 1984	0.58
APR 13, 1983	+0.75	OCT 05, 1983	1.47	SEP 04, 1984	0.92
MAY 17, 1983	+0.77	NOV 14, 1983	0.63	OCT 19, 1984	1.00
JUN 14, 1983	0.08	FEB 08, 1984	0.40	DEC 10, 1984	0.60

LOCAL NUMBER: 42Q 2 SITE IDENTIFICATION NUMBER: 381802078371801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2230
LATITUDE: 381802 LONGITUDE: 0783718 WELL DEPTH, IN FEET: 205
DATE OF WELL COMPLETION: 07-14-1966 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUL 14, 1966	14.	JUN 14, 1983	12.93	APR 09, 1984	10.20
SEP 29, 1982	20.02	JUL 14, 1983	14.80	MAY 31, 1984	12.53
NOV 24, 1982	15.04	AUG 10, 1983	17.25	JUL 25, 1984	17.59
JAN 25, 1983	11.82	SEP 07, 1983	20.10	SEP 04, 1984	15.86
MAR 08, 1983	9.80	OCT 05, 1983	21.56	OCT 19, 1984	18.13
APR 13, 1983	9.39	NOV 14, 1983	12.22	DEC 10, 1984	13.00
MAY 17, 1983	11.36	FEB 08, 1984	11.80		

LOCAL NUMBER: 43R 1 SITE IDENTIFICATION NUMBER: 382622078284201
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3390
LATITUDE: 382622 LONGITUDE: 0782842 WELL DEPTH, IN FEET: 300
DATE OF WELL COMPLETION: 06-01-1964 USE OF SITE: WATER SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 01, 1964	66.	JUL 15, 1983	109.80	APR 10, 1984	41.64
JAN 25, 1983	44.86	SEP 07, 1983	163.30	JUN 01, 1984	62.05
APR 13, 1983	32.92	SEP 08, 1983	139.22	JUL 26, 1984	105.70
MAY 17, 1983	38.58	OCT 04, 1983	167.75	SEP 05, 1984	103.40
JUN 15, 1983	58.65	NOV 14, 1983	44.13	OCT 19, 1984	138.98
JUL 13, 1983	109.70	FEB 08, 1984	47.95		

LOCAL NUMBER: 43S 1 SITE IDENTIFICATION NUMBER: 383548078224901
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3460
LATITUDE: 383548 LONGITUDE: 0782249 WELL DEPTH, IN FEET: 70.0
DATE OF WELL COMPLETION: 06-14-1961 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 14, 1961	19.7	AUG 09, 1983	25.30	MAY 31, 1984	23.20
JAN 26, 1983	23.45	SEP 09, 1983	25.97	JUL 26, 1984	24.50
APR 13, 1983	17.66	OCT 04, 1983	25.80	SEP 04, 1984	23.76
MAY 17, 1983	20.79	NOV 14, 1983	20.29	OCT 19, 1984	25.58
JUN 13, 1983	22.94	FEB 08, 1984	24.03		
JUL 13, 1983	23.08	APR 09, 1984	16.81		

LOCAL NUMBER: 43S 2 SITE IDENTIFICATION NUMBER: 383546078224801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3490
LATITUDE: 383546 LONGITUDE: 0782248 WELL DEPTH, IN FEET: 233
DATE OF WELL COMPLETION: 06-22-1961 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 22, 1961	29.	JUN 13, 1983	25.67	APR 09, 1984	21.15
JAN 26, 1983	26.33	JUL 13, 1983	25.85	MAY 31, 1984	26.26
APR 13, 1983	21.65	NOV 14, 1983	23.40	JUL 26, 1984	27.85
MAY 17, 1983	23.55	FEB 08, 1984	27.32	SEP 04, 1984	27.00

LOCAL NUMBER: 43S 3 SITE IDENTIFICATION NUMBER: 383548078224601
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3480
LATITUDE: 383548 LONGITUDE: 0782246 WELL DEPTH, IN FEET: 162
DATE OF WELL COMPLETION: 06-30-1961 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 30, 1961	38.8	AUG 09, 1983	60.72	MAY 31, 1984	36.94
JAN 26, 1983	38.36	SEP 09, 1983	51.65	JUL 26, 1984	38.62
APR 13, 1983	33.35	OCT 04, 1983	63.04	SEP 04, 1984	38.02
MAY 17, 1983	36.08	NOV 14, 1983	35.43	OCT 19, 1984	52.37
JUN 13, 1983	37.20	FEB 08, 1984	38.15		
JUL 13, 1983	38.00	APR 09, 1984	32.60		

LOCAL NUMBER: 43S 4 SITE IDENTIFICATION NUMBER: 383515078225801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3560
LATITUDE: 383515 LONGITUDE: 0782258 WELL DEPTH, IN FEET: 500
DATE OF WELL COMPLETION: 05-25-1964 USE OF SITE: WATER SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAY 25, 1964	84.	JUN 15, 1983	92.20	JUN 01, 1984	92.16
JAN 26, 1983	82.15	JUL 13, 1983	102.51	JUL 27, 1984	129.97
FEB 24, 1983	75.35	AUG 09, 1983	104.80	SEP 05, 1984	130.90
APR 14, 1983	64.34	FEB 08, 1984	83.28	DEC 10, 1984	76.30
MAY 19, 1983	75.84	APR 10, 1984	54.71		

LOCAL NUMBER: 43S 5 SITE IDENTIFICATION NUMBER: 383432078223501
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3240
LATITUDE: 383432 LONGITUDE: 0782235 WELL DEPTH, IN FEET: 250
DATE OF WELL COMPLETION: 08-02-1963 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE ("+" INDICATES ABOVE LAND SURFACE)

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
AUG 02, 1963	0.5	MAY 12, 1983	+0.97*	OCT 12, 1983	0.83
SEP 28, 1982	1.55	MAY 17, 1983	+0.66	OCT 13, 1983	+0.41
OCT 03, 1982	1.73	MAY 21, 1983	+0.57	OCT 15, 1983	0.13
OCT 08, 1982	1.85	MAY 26, 1983	+0.89	OCT 18, 1983	0.49
OCT 13, 1982	1.78	MAY 31, 1983	+0.95	OCT 20, 1983	0.45
OCT 18, 1982	1.85	JUN 05, 1983	+0.66	OCT 23, 1983	+0.97*
OCT 23, 1982	1.89	JUN 10, 1983	+0.29	NOV 14, 1983	+0.97*
OCT 25, 1982	0.94	JUN 14, 1983	+0.07	NOV 19, 1983	+0.84
OCT 28, 1982	0.97	JUN 19, 1983	0.15	NOV 21, 1983	+0.97*
NOV 02, 1982	1.28	JUN 20, 1983	0.19	JAN 06, 1984	+0.97*
NOV 04, 1982	0.80	JUN 24, 1983	+0.02	JAN 11, 1984	+0.59
NOV 07, 1982	0.79	JUN 29, 1983	0.10	JAN 16, 1984	+0.11
NOV 12, 1982	0.80	JUL 04, 1983	0.10	JAN 21, 1984	0.05
NOV 17, 1982	0.67	JUL 09, 1983	0.20	JAN 26, 1984	0.24
NOV 21, 1982	0.54	JUL 13, 1983	0.31	JAN 30, 1984	0.38
NOV 26, 1982	0.53	JUL 18, 1983	0.43	FEB 04, 1984	0.39
NOV 29, 1982	0.29	JUL 23, 1983	0.56	FEB 08, 1984	0.52
DEC 01, 1982	0.26	JUL 28, 1983	0.67	FEB 09, 1984	0.51
DEC 06, 1982	0.16	AUG 02, 1983	0.75	FEB 10, 1984	0.52
DEC 11, 1982	0.01	AUG 07, 1983	0.83	FEB 11, 1984	0.39
DEC 15, 1982	+0.04	AUG 11, 1983	0.86	FEB 12, 1984	0.37
DEC 16, 1982	+0.48	AUG 16, 1983	0.96	FEB 13, 1984	+0.05
DEC 21, 1982	+0.45	AUG 21, 1983	1.04	FEB 14, 1984	+0.98*
DEC 26, 1982	+0.58	AUG 26, 1983	1.16	MAR 14, 1984	+0.99*
DEC 31, 1982	+0.44	AUG 31, 1983	1.32	MAR 15, 1984	+0.95
JAN 04, 1983	+0.22	SEP 05, 1983	1.49	MAR 16, 1984	+0.84
JAN 26, 1983	0.20	SEP 09, 1983	1.66	MAR 17, 1984	+0.81
JAN 31, 1983	0.29	SEP 12, 1983	1.75	MAR 18, 1984	+0.77
FEB 02, 1983	0.01	SEP 13, 1983	1.57	MAR 19, 1984	+0.70
FEB 04, 1983	+0.93	SEP 14, 1983	1.64	MAR 20, 1984	+0.64
FEB 09, 1983	+0.93	SEP 19, 1983	1.82	MAR 21, 1984	+0.97*
FEB 14, 1983	+0.98*	SEP 24, 1983	1.94	APR 09, 1984	+0.97*
FEB 19, 1983	+0.68	SEP 29, 1983	2.07	MAY 31, 1984	+0.10
FEB 24, 1983	+0.27	OCT 04, 1983	2.00	JUL 26, 1984	0.85
MAR 01, 1983	+0.01	OCT 08, 1983	2.13	SEP 04, 1984	0.62
MAR 04, 1983	+0.06	OCT 10, 1983	2.18	OCT 19, 1984	1.30
MAR 07, 1983	+0.97*	OCT 11, 1983	1.94		

LOCAL NUMBER: 43S 6 SITE IDENTIFICATION NUMBER: 383122078260901
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3504.01
LATITUDE: 383122 LONGITUDE: 0782609 WELL DEPTH, IN FEET: 100
DATE OF WELL COMPLETION: 06-27-1966 USE OF SITE: WATER SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 27, 1966	18.	MAY 27, 1983	15.36	DEC 22, 1983	7.83
JAN 25, 1983	12.01	JUN 15, 1983	14.64	FEB 08, 1984	13.55
FEB 24, 1983	10.90	JUL 15, 1983	20.52	APR 09, 1984	6.40
MAR 02, 1983	11.64	AUG 09, 1983	22.28	JUN 01, 1984	15.11
MAR 03, 1983	11.44	SEP 08, 1983	28.42	JUL 26, 1984	21.20
MAR 15, 1983	9.83	SEP 21, 1983	29.25	SEP 04, 1984	19.55
APR 12, 1983	6.28	OCT 04, 1983	29.53	OCT 19, 1984	22.93
MAY 19, 1983	10.34	NOV 14, 1983	13.32	DEC 10, 1984	13.10

* Indicates water flowing over top of casing, actual water level is higher than the value shown.

LOCAL NUMBER: 43S 7 SITE IDENTIFICATION NUMBER: 383051078254201
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3440
LATITUDE: 383051 LONGITUDE: 0782542 WELL DEPTH, IN FEET: 350
DATE OF WELL COMPLETION: 07-11-1966 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUL 11, 1966	111.	MAR 26, 1983	104.53	OCT 10, 1983	106.39
SEP 28, 1982	105.88	MAR 27, 1983	103.97	OCT 13, 1983	105.90
SEP 30, 1982	105.95	MAR 30, 1983	104.24	OCT 16, 1983	106.28
OCT 03, 1982	105.82	MAR 31, 1983	103.98	OCT 19, 1983	106.20
OCT 07, 1982	106.01	APR 03, 1983	103.65	OCT 21, 1983	106.35
OCT 09, 1982	105.86	APR 05, 1983	104.12	OCT 27, 1983	105.67
OCT 12, 1982	106.02	APR 11, 1983	103.50	OCT 29, 1983	105.87
OCT 16, 1982	105.69	APR 13, 1983	103.93	NOV 01, 1983	106.20
OCT 19, 1982	106.34	APR 20, 1983	102.96	NOV 05, 1983	105.52
OCT 22, 1982	106.21	APR 22, 1983	103.35	NOV 09, 1983	105.69
OCT 24, 1982	106.32	APR 23, 1983	102.98	NOV 10, 1983	105.14
OCT 25, 1982	106.03	APR 25, 1983	102.64	NOV 11, 1983	104.97
OCT 27, 1982	106.30	APR 30, 1983	103.23	NOV 14, 1983	105.42
OCT 31, 1982	106.22	MAY 04, 1983	102.68	NOV 17, 1983	104.99
NOV 05, 1982	105.83	MAY 06, 1983	103.09	NOV 19, 1983	105.45
NOV 10, 1982	106.23	MAY 08, 1983	102.91	NOV 21, 1983	105.04
NOV 12, 1982	105.69	MAY 11, 1983	103.28	NOV 22, 1983	105.34
NOV 15, 1982	105.89	MAY 16, 1983	102.89	NOV 25, 1983	104.80
NOV 16, 1982	106.10	MAY 18, 1983	103.31	NOV 27, 1983	105.14
NOV 19, 1982	106.19	MAY 24, 1983	102.92	NOV 29, 1983	104.79
NOV 24, 1982	105.60	MAY 28, 1983	103.11	DEC 01, 1983	105.03
NOV 25, 1982	106.00	MAY 31, 1983	102.84	DEC 04, 1983	104.56
NOV 29, 1982	105.50	JUN 02, 1983	103.07	DEC 05, 1983	104.81
DEC 02, 1982	105.88	JUN 04, 1983	102.94	DEC 06, 1983	104.18
DEC 06, 1982	105.46	JUN 08, 1983	103.06	DEC 10, 1983	104.94
DEC 08, 1982	105.86	JUN 12, 1983	103.52	DEC 14, 1983	104.13
DEC 12, 1982	105.28	JUN 14, 1983	103.49	DEC 17, 1983	104.71
DEC 14, 1982	105.66	JUN 16, 1983	103.43	DEC 21, 1983	104.61
DEC 15, 1982	105.46	JUN 17, 1983	103.52	DEC 22, 1983	104.20
DEC 20, 1982	104.95	JUN 21, 1983	103.54	DEC 24, 1983	103.80
DEC 23, 1982	105.50	JUN 23, 1983	103.57	DEC 27, 1983	104.22
DEC 26, 1982	105.41	JUN 25, 1983	103.41	DEC 28, 1983	103.81
DEC 29, 1982	105.14	JUN 28, 1983	103.47	DEC 31, 1983	104.55
JAN 01, 1983	105.34	JUL 03, 1983	103.73	JAN 06, 1984	103.67
JAN 03, 1983	105.17	JUL 06, 1983	103.61	JAN 09, 1984	104.15
JAN 04, 1983	105.39	JUL 08, 1983	103.91	JAN 11, 1984	103.92
JAN 07, 1983	105.00	JUL 10, 1983	103.75	JAN 13, 1984	104.40
JAN 09, 1983	105.35	JUL 14, 1983	103.94	JAN 19, 1984	104.02
JAN 10, 1983	104.91	JUL 16, 1983	103.85	JAN 23, 1984	104.45
JAN 12, 1983	104.77	JUL 20, 1983	104.03	JAN 25, 1984	104.04
JAN 26, 1983	105.21	JUL 24, 1983	103.88	JAN 31, 1984	103.85
JAN 30, 1983	104.94	JUL 29, 1983	104.46	FEB 02, 1984	104.34
FEB 01, 1983	105.15	AUG 02, 1983	104.42	FEB 05, 1984	103.82
FEB 03, 1983	104.46	AUG 05, 1983	104.51	FEB 08, 1984	104.47
FEB 05, 1983	104.99	AUG 09, 1983	104.48	FEB 10, 1984	104.60
FEB 08, 1983	104.78	AUG 12, 1983	104.36	FEB 15, 1984	104.15
FEB 10, 1983	105.04	AUG 16, 1983	104.83	FEB 20, 1984	103.90
FEB 12, 1983	104.97	AUG 18, 1983	104.75	FEB 25, 1984	103.51
FEB 13, 1983	105.18	AUG 21, 1983	104.87	FEB 26, 1984	103.77
FEB 15, 1983	104.83	AUG 25, 1983	105.20	FEB 29, 1984	103.06
FEB 21, 1983	105.18	AUG 29, 1983	105.00	MAR 04, 1984	103.95
FEB 25, 1983	104.56	SEP 05, 1983	105.29	MAR 05, 1984	103.67
FEB 27, 1983	105.13	SEP 08, 1983	105.39	MAR 10, 1984	103.69
MAR 02, 1983	104.63	SEP 09, 1983	105.52	MAR 11, 1984	103.98
MAR 05, 1983	104.95	SEP 13, 1983	105.45	MAR 20, 1984	103.70
MAR 11, 1983	104.17	SEP 19, 1983	105.77	APR 09, 1984	103.28
MAR 16, 1983	104.57	SEP 21, 1983	105.51	MAY 31, 1984	102.96
MAR 19, 1983	103.89	SEP 25, 1983	106.12	JUL 25, 1984	104.66
MAR 21, 1983	103.69	SEP 29, 1983	106.08	SEP 04, 1984	104.90
MAR 23, 1983	104.22	OCT 05, 1983	105.86	OCT 19, 1984	105.75

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 43S 8 SITE IDENTIFICATION NUMBER: 383117078250201
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2730
LATITUDE: 383117 LONGITUDE: 0782502 WELL DEPTH, IN FEET: 265
DATE OF WELL COMPLETION: 08-20-1965 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
AUG 20, 1965	50.	AUG 09, 1983	41.27	MAY 31, 1984	39.23
JAN 26, 1983	39.26	SEP 08, 1983	41.80	JUL 25, 1984	41.28
APR 13, 1983	34.32	OCT 04, 1983	42.10	SEP 04, 1984	40.90
MAY 17, 1983	36.66	NOV 14, 1983	35.29	OCT 19, 1984	41.55
JUN 13, 1983	39.23	FEB 08, 1984	40.15		
JUL 15, 1983	40.54	APR 09, 1984	34.00		

LOCAL NUMBER: 43S 10 SITE IDENTIFICATION NUMBER: 383123078261101
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL:DEPTH, IN FEET: 51.5
LATITUDE: 383123 LONGITUDE: 0782611
DATE OF WELL COMPLETION: 03-15-1983 USE OF SITE: OBSERVATION

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAR 16, 1983	9.37	OCT 16, 1983	21.80	MAY 19, 1984	12.72
APR 12, 1983	5.27	OCT 23, 1983	10.60	MAY 24, 1984	13.74
APR 27, 1983	4.19	OCT 27, 1983	11.60	MAY 25, 1984	13.64
MAY 01, 1983	6.59	NOV 04, 1983	11.20	MAY 29, 1984	15.08
MAY 05, 1983	7.79	NOV 09, 1983	9.50	JUN 01, 1984	14.20
MAY 10, 1983	9.53	NOV 11, 1983	7.50	JUN 09, 1984	16.58
MAY 15, 1983	11.33	NOV 15, 1983	8.04	JUN 19, 1984	18.30
MAY 19, 1983	9.66	NOV 20, 1983	9.14	JUN 23, 1984	18.98
MAY 20, 1983	9.46	NOV 22, 1983	8.19	JUN 25, 1984	18.40
MAY 21, 1983	9.86	NOV 24, 1983	7.93	JUL 01, 1984	20.08
MAY 24, 1983	9.34	NOV 25, 1983	5.60	JUL 03, 1984	19.95
MAY 25, 1983	9.62	NOV 28, 1983	7.25	JUL 08, 1984	20.08
MAY 30, 1983	11.04	NOV 30, 1983	6.70	JUL 13, 1984	20.25
JUN 03, 1983	11.50	DEC 03, 1983	7.20	JUL 18, 1984	20.69
JUN 04, 1983	11.38	DEC 05, 1983	6.41	JUL 23, 1984	21.30
JUN 06, 1983	11.40	DEC 11, 1983	8.34	JUL 30, 1984	21.60
JUN 08, 1983	10.65	DEC 12, 1983	5.52	AUG 04, 1984	22.14
JUN 14, 1983	14.06	DEC 14, 1983	4.48	AUG 08, 1984	19.45
JUN 20, 1983	15.89	DEC 21, 1983	7.52	AUG 10, 1984	20.71
JUN 21, 1983	12.54	DEC 22, 1983	6.20	AUG 14, 1984	18.14
JUN 23, 1983	10.81	DEC 26, 1983	6.58	AUG 20, 1984	17.00
JUN 25, 1983	10.26	JAN 05, 1984	10.62	SEP 01, 1984	17.80
JUN 29, 1983	11.32	JAN 10, 1984	11.29	SEP 04, 1984	18.08
JUL 05, 1983	12.71	FEB 08, 1984	12.60	SEP 05, 1984	17.15
JUL 11, 1983	15.06	FEB 11, 1984	12.57	SEP 11, 1984	18.32
JUL 15, 1983	16.31	FEB 13, 1984	11.01	SEP 18, 1984	19.46
JUL 21, 1983	17.66	FEB 14, 1984	3.77	SEP 24, 1984	20.64
JUL 22, 1983	17.13	FEB 18, 1984	3.75	SEP 30, 1984	21.00
JUL 27, 1983	19.17	FEB 23, 1984	5.25	OCT 04, 1984	21.00
AUG 01, 1983	20.36	FEB 24, 1984	4.13	OCT 08, 1984	21.79
AUG 06, 1983	21.02	FEB 27, 1984	5.07	OCT 13, 1984	22.01
AUG 07, 1983	20.72	FEB 28, 1984	5.06	OCT 18, 1984	22.46
AUG 09, 1983	21.82	MAR 05, 1984	7.62	OCT 22, 1984	23.12
AUG 10, 1983	21.73	MAR 12, 1984	9.57	OCT 26, 1984	22.77
AUG 11, 1983	21.90	MAR 16, 1984	9.26	OCT 29, 1984	23.30
AUG 12, 1983	21.91	MAR 20, 1984	9.60	OCT 31, 1984	23.10
AUG 16, 1983	22.34	MAR 21, 1984	7.74	NOV 02, 1984	22.75
AUG 21, 1983	23.21	MAR 27, 1984	8.04	NOV 04, 1984	22.90
AUG 26, 1983	23.63	MAR 28, 1984	3.92	NOV 09, 1984	22.16
AUG 31, 1983	24.15	APR 03, 1984	5.63	NOV 13, 1984	21.84
SEP 05, 1983	24.79	APR 04, 1984	3.76	NOV 18, 1984	21.90
SEP 12, 1983	25.20	APR 08, 1984	3.81	NOV 21, 1984	21.59
SEP 16, 1983	25.25	APR 14, 1984	7.32	NOV 26, 1984	22.00
SEP 21, 1983	25.73	APR 16, 1984	6.66	NOV 28, 1984	18.91
SEP 22, 1983	25.18	APR 22, 1984	8.63	NOV 29, 1984	15.46
SEP 26, 1983	26.04	APR 23, 1984	7.84	DEC 01, 1984	13.58
OCT 02, 1983	27.14	MAY 02, 1984	9.54	DEC 05, 1984	12.28
OCT 04, 1983	26.03	MAY 03, 1984	9.05	DEC 06, 1984	12.03
OCT 11, 1983	27.57	MAY 08, 1984	9.13	DEC 10, 1984	11.99
OCT 12, 1983	26.23	MAY 14, 1984	10.16		

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 43S 12 SITE IDENTIFICATION NUMBER: 383122078260801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3502.62
LATITUDE: 383122 LONGITUDE: 0782603 WELL DEPTH, IN FEET: 33.9
DATE OF WELL COMPLETION: 03-15-1983 USE OF SITE: OBSERVATION

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAR 16, 1983	10.79	OCT 27, 1983	13.36	MAY 02, 1984	12.90
APR 12, 1983	8.51	OCT 31, 1983	14.28	MAY 03, 1984	12.73
APR 27, 1983	7.80	NOV 04, 1983	14.07	MAY 08, 1984	12.86
APR 28, 1983	8.52	NOV 09, 1983	14.24	MAY 14, 1984	13.45
MAY 01, 1983	10.00	NOV 10, 1983	12.05	MAY 19, 1984	15.50
MAY 05, 1983	11.30	NOV 11, 1983	11.21	MAY 24, 1984	16.42
MAY 10, 1983	12.88	NOV 14, 1983	11.58	MAY 25, 1984	16.45
MAY 15, 1983	14.26	NOV 20, 1983	12.63	MAY 29, 1984	17.57
MAY 16, 1983	13.30	NOV 22, 1983	11.82	JUN 01, 1984	17.24
MAY 19, 1983	12.54	NOV 24, 1983	11.73	JUN 09, 1984	18.65
MAY 21, 1983	12.91	NOV 25, 1983	9.85	JUN 15, 1984	20.65
MAY 27, 1983	13.32	NOV 28, 1983	10.83	JUN 18, 1984	19.96
MAY 30, 1983	13.90	NOV 30, 1983	10.28	JUN 19, 1984	20.09
JUN 03, 1983	14.36	DEC 03, 1983	10.82	JUN 23, 1984	20.39
JUN 04, 1983	14.40	DEC 05, 1983	10.51	JUN 25, 1984	20.36
JUN 06, 1983	14.60	DEC 11, 1983	11.91	JUL 01, 1984	21.62
JUN 08, 1983	14.08	DEC 12, 1983	9.71	JUL 09, 1984	21.70
JUN 14, 1983	16.49	DEC 14, 1983	8.02	JUL 13, 1984	21.73
JUN 20, 1983	17.86	DEC 21, 1983	11.22	JUL 18, 1984	22.08
JUN 21, 1983	15.77	DEC 22, 1983	10.47	JUL 26, 1984	22.16
JUN 23, 1983	13.62	DEC 24, 1983	10.13	AUG 04, 1984	23.21
JUN 25, 1983	13.37	DEC 26, 1983	10.28	AUG 08, 1984	21.31
JUN 29, 1983	14.33	DEC 29, 1983	12.96	AUG 10, 1984	21.95
JUL 05, 1983	15.49	JAN 01, 1984	13.00	AUG 13, 1984	21.38
JUL 11, 1983	17.21	JAN 05, 1984	13.19	AUG 14, 1984	19.59
JUL 15, 1983	18.16	JAN 10, 1984	13.76	AUG 21, 1984	18.40
JUL 21, 1983	19.20	JAN 17, 1984	14.45	AUG 26, 1984	18.85
JUL 22, 1983	19.09	JAN 24, 1984	15.27	SEP 01, 1984	19.32
JUL 27, 1983	20.41	JAN 28, 1984	15.01	SEP 04, 1984	19.59
AUG 01, 1983	21.48	JAN 31, 1984	15.13	SEP 05, 1984	19.27
AUG 06, 1983	22.09	FEB 04, 1984	15.40	SEP 11, 1984	19.98
AUG 07, 1983	21.99	FEB 08, 1984	15.78	SEP 18, 1984	21.03
AUG 09, 1983	22.70	FEB 11, 1984	15.76	SEP 24, 1984	21.99
AUG 10, 1983	22.66	FEB 13, 1984	14.49	SEP 30, 1984	22.36
AUG 11, 1983	22.80	FEB 14, 1984	4.15	OCT 04, 1984	22.36
AUG 12, 1983	22.83	FEB 18, 1984	6.89	OCT 08, 1984	22.99
AUG 16, 1983	23.18	FEB 23, 1984	9.99	OCT 13, 1984	23.21
AUG 21, 1983	23.86	FEB 25, 1984	8.15	OCT 18, 1984	23.63
AUG 26, 1983	24.34	FEB 28, 1984	8.89	OCT 22, 1984	24.05
AUG 31, 1983	24.83	MAR 05, 1984	11.40	OCT 26, 1984	23.86
SEP 05, 1983	25.37	MAR 12, 1984	13.23	OCT 29, 1984	24.23
SEP 12, 1983	25.72	MAR 16, 1984	13.17	OCT 31, 1984	24.13
SEP 16, 1983	25.89	MAR 20, 1984	13.24	NOV 02, 1984	23.88
SEP 21, 1983	26.34	MAR 21, 1984	11.88	NOV 04, 1984	23.97
SEP 22, 1983	25.96	MAR 27, 1984	11.78	NOV 09, 1984	23.35
SEP 26, 1983	26.62	MAR 28, 1984	8.49	NOV 13, 1984	23.10
OCT 02, 1983	27.54	MAR 29, 1984	7.37	NOV 18, 1984	23.08
OCT 04, 1983	26.74	APR 03, 1984	9.56	NOV 21, 1984	22.89
OCT 11, 1983	28.02	APR 04, 1984	8.05	NOV 26, 1984	23.15
OCT 12, 1983	27.10	APR 09, 1984	8.41	NOV 28, 1984	18.32
OCT 14, 1983	23.63	APR 14, 1984	10.84	NOV 29, 1984	17.19
OCT 16, 1983	22.66	APR 17, 1984	10.47	DEC 01, 1984	16.21
OCT 21, 1983	20.82	APR 22, 1984	12.20	DEC 05, 1984	15.39
OCT 23, 1983	17.41	APR 23, 1984	11.77	DEC 06, 1984	15.21
OCT 25, 1983	13.95	APR 25, 1984	11.54	DEC 10, 1984	15.19

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 43S 14 SITE IDENTIFICATION NUMBER: 383124078260801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3499.09
LATITUDE: 383124 LONGITUDE: 0782608 WELL DEPTH, IN FEET: 18.8
DATE OF WELL COMPLETION: 03-15-1983 USE OF SITE: OBSERVATION

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAR 16, 1983	5.60	NOV 10, 1983	3.56	APR 04, 1984	2.06
APR 12, 1983	3.26	NOV 15, 1983	6.20	APR 09, 1984	3.49
APR 27, 1983	2.85	NOV 19, 1983	6.66	APR 14, 1984	5.65
MAY 02, 1983	4.87	NOV 21, 1983	4.78	APR 15, 1984	4.31
MAY 12, 1983	8.09	NOV 23, 1983	5.84	APR 16, 1984	3.93
MAY 15, 1983	9.05	NOV 25, 1983	3.55	APR 22, 1984	7.06
MAY 16, 1983	3.85	NOV 27, 1983	5.13	APR 23, 1984	5.10
MAY 21, 1983	7.64	NOV 29, 1983	3.92	APR 28, 1984	7.05
MAY 23, 1983	6.49	DEC 03, 1983	5.14	MAY 02, 1984	8.02
MAY 28, 1983	8.29	DEC 05, 1983	3.90	MAY 06, 1984	8.14
JUN 02, 1983	9.26	DEC 11, 1983	6.31	MAY 08, 1984	7.15
JUN 05, 1983	9.55	DEC 12, 1983	2.62	MAY 10, 1984	7.96
JUN 08, 1983	8.88	DEC 13, 1983	2.47	MAY 15, 1984	8.99
JUN 13, 1983	11.36	DEC 21, 1983	4.82	MAY 20, 1984	10.98
JUN 17, 1983	12.10	DEC 22, 1983	3.04	MAY 25, 1984	11.83
JUN 20, 1983	12.89	DEC 25, 1983	4.34	MAY 31, 1984	12.83
JUN 21, 1983	4.08	JAN 10, 1984	8.40	JUN 01, 1984	12.69
JUN 23, 1983	6.66	JAN 25, 1984	10.00	JUN 06, 1984	13.61
JUN 28, 1983	9.25	FEB 09, 1984	10.94	JUN 11, 1984	14.98
JUL 03, 1983	10.08	FEB 12, 1984	9.90	JUN 15, 1984	16.27
JUL 08, 1983	11.45	FEB 13, 1984	6.08	JUN 19, 1984	16.07
JUL 13, 1983	12.69	FEB 14, 1984	2.08	JUN 22, 1984	16.11
JUL 18, 1983	13.86	FEB 17, 1984	2.13	JUN 26, 1984	16.53
JUL 23, 1983	14.70	FEB 22, 1984	4.44	JUN 30, 1984	17.34
JUL 28, 1983	15.99	FEB 23, 1984	3.07	JUL 03, 1984	16.87
AUG 02, 1983	16.94	FEB 24, 1984	2.73	JUL 08, 1984	17.18
AUG 09, 1983	17.00	FEB 29, 1984	3.79	JUL 13, 1984	17.49
SEP 08, 1983	DRY	MAR 05, 1984	5.96	AUG 28, 1984	14.74
OCT 10, 1983	DRY	MAR 10, 1984	7.20	SEP 04, 1984	15.46
OCT 13, 1983	12.73	MAR 13, 1984	8.00	SEP 06, 1984	15.34
OCT 14, 1983	12.15	MAR 16, 1984	6.85	SEP 08, 1984	15.50
OCT 20, 1983	17.03	MAR 20, 1984	7.71	SEP 13, 1984	16.19
OCT 21, 1983	11.29	MAR 21, 1984	3.90	SEP 18, 1984	16.96
OCT 24, 1983	4.85	MAR 25, 1984	6.33	SEP 23, 1984	17.56
OCT 29, 1983	8.61	MAR 27, 1984	6.02	OCT 19, 1984	DRY
NOV 02, 1983	9.18	MAR 28, 1984	2.25	DEC 10, 1984	10.38
NOV 06, 1983	9.23	APR 02, 1984	4.02		
NOV 09, 1983	9.60	APR 03, 1984	3.91		

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 43S 15 SITE IDENTIFICATION NUMBER: 383125078260501
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3493.24
LATITUDE: 383125 LONGITUDE: 0782605 WELL DEPTH, IN FEET: 7.50
DATE OF WELL COMPLETION: 03-01-1983 USE OF SITE: OBSERVATION

WATER LEVELS IN FEET BELOW LAND SURFACE ("+" INDICATES ABOVE LAND SURFACE)

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
MAR 16, 1983	0.20	OCT 16, 1983	0.34	JUN 16, 1984	2.21
APR 13, 1983	0.14	OCT 19, 1983	0.88	JUN 20, 1984	2.42
APR 27, 1983	0.17	OCT 20, 1983	0.32	JUN 26, 1984	2.88
APR 28, 1983	0.14	OCT 24, 1983	0.16	JUN 29, 1984	3.21
MAY 07, 1983	0.15	OCT 31, 1983	0.28	JUN 30, 1984	0.81
MAY 13, 1983	0.23	NOV 04, 1983	0.32	JUL 01, 1984	0.39
MAY 16, 1983	0.09	NOV 09, 1983	0.37	JUL 03, 1984	0.41
MAY 19, 1983	0.17	NOV 10, 1983	0.08	JUL 06, 1984	0.55
MAY 20, 1983	0.17	NOV 14, 1983	0.21	JUL 10, 1984	1.30
MAY 23, 1983	0.13	NOV 19, 1983	0.23	JUL 11, 1984	1.34
MAY 28, 1983	0.22	NOV 20, 1983	0.15	JUL 16, 1984	2.17
MAY 30, 1983	0.18	NOV 23, 1983	0.21	JUL 17, 1984	2.11
JUN 02, 1983	0.27	NOV 24, 1983	0.12	JUL 20, 1984	2.26
JUN 03, 1983	0.16	DEC 03, 1983	0.18	JUL 23, 1984	1.99
JUN 08, 1983	0.35	DEC 11, 1983	0.19	JUL 25, 1984	2.01
JUN 13, 1983	0.91	DEC 12, 1983	0.12	JUL 28, 1984	2.24
JUN 15, 1983	1.24	DEC 16, 1983	0.16	AUG 02, 1984	2.63
JUN 17, 1983	1.25	JAN 24, 1984	0.44	AUG 04, 1984	0.28
JUN 18, 1983	0.42	JAN 28, 1984	0.48	AUG 06, 1984	0.35
JUN 21, 1983	0.00	FEB 02, 1984	0.90	AUG 10, 1984	1.29
JUN 24, 1983	0.17	FEB 04, 1984	0.63	AUG 11, 1984	1.01
JUN 28, 1983	0.32	FEB 08, 1984	0.88	AUG 13, 1984	0.30
JUN 29, 1983	0.22	FEB 10, 1984	0.96	AUG 15, 1984	0.34
JUL 04, 1983	0.36	FEB 12, 1984	0.45	AUG 20, 1984	1.39
JUL 09, 1983	0.94	FEB 14, 1984	+0.14	AUG 29, 1984	2.34
JUL 14, 1983	1.58	FEB 16, 1984	0.12	SEP 04, 1984	2.91
JUL 15, 1983	1.70	FEB 22, 1984	0.17	SEP 05, 1984	2.85
JUL 19, 1983	2.03	FEB 23, 1984	0.10	SEP 10, 1984	3.14
JUL 24, 1983	2.39	MAR 01, 1984	0.16	SEP 15, 1984	4.13
JUL 29, 1983	2.79	MAR 08, 1984	0.19	SEP 21, 1984	5.27
JUL 31, 1983	2.95	MAR 12, 1984	0.25	SEP 26, 1984	6.20
AUG 01, 1983	2.92	MAR 13, 1984	0.20	SEP 28, 1984	6.20
AUG 04, 1983	3.29	MAR 20, 1984	0.27	SEP 30, 1984	6.35
AUG 07, 1983	2.74	MAR 21, 1984	0.16	OCT 01, 1984	0.85
AUG 09, 1983	3.00	MAR 27, 1984	0.22	OCT 02, 1984	0.65
AUG 10, 1983	3.04	MAR 28, 1984	0.12	OCT 03, 1984	0.65
AUG 11, 1983	1.74	APR 03, 1984	0.18	OCT 06, 1984	1.39
AUG 14, 1983	1.70	APR 04, 1984	0.10	OCT 09, 1984	1.80
AUG 19, 1983	2.17	APR 08, 1984	0.16	OCT 13, 1984	2.00
AUG 24, 1983	2.71	APR 13, 1984	0.20	OCT 18, 1984	2.24
AUG 29, 1983	3.09	APR 17, 1984	0.19	OCT 23, 1984	2.36
SEP 03, 1983	4.30	APR 22, 1984	0.24	OCT 24, 1984	2.08
SEP 08, 1983	5.25	APR 23, 1984	0.21	OCT 27, 1984	2.09
SEP 11, 1983	5.80	MAY 02, 1984	0.28	OCT 29, 1984	1.60
SEP 12, 1983	5.30	MAY 03, 1984	0.22	NOV 03, 1984	1.99
SEP 14, 1983	5.33	MAY 11, 1984	0.30	NOV 05, 1984	1.52
SEP 19, 1983	6.40	MAY 17, 1984	0.36	NOV 07, 1984	1.63
SEP 20, 1983	6.50	MAY 22, 1984	0.52	NOV 12, 1984	2.07
SEP 22, 1983	6.00	MAY 23, 1984	0.37	NOV 18, 1984	2.37
SEP 29, 1983	7.40	MAY 27, 1984	0.68	NOV 19, 1984	1.48
SEP 30, 1983	1.83	MAY 29, 1984	0.34	NOV 23, 1984	1.83
OCT 04, 1983	1.99	JUN 01, 1984	0.44	NOV 27, 1984	2.11
OCT 10, 1983	2.38	JUN 05, 1984	1.08	NOV 28, 1984	0.15
OCT 11, 1983	0.30	JUN 11, 1984	1.98	DEC 03, 1984	0.37
OCT 12, 1983	0.12	JUN 12, 1984	1.80	DEC 10, 1984	0.55

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 43S 16 SITE IDENTIFICATION NUMBER: 383126078260201
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3489.48
LATITUDE: 383126 LONGITUDE: 0782602 WELL DEPTH, IN FEET: 5.80
DATE OF WELL COMPLETION: 03-02-1983 USE OF SITE: OBSERVATION

WATER LEVELS IN FEET BELOW LAND SURFACE ("+" INDICATES ABOVE LAND SURFACE)

MAR 16, 1983	+0.13	SEP 08, 1983	2.61	JUL 25, 1984	0.20
APR 13, 1983	+0.17	SEP 21, 1983	1.87	SEP 04, 1984	0.03
MAY 19, 1983	+0.16	OCT 04, 1983	0.42	SEP 28, 1984	1.97
JUN 15, 1983	+0.06	NOV 14, 1983	+0.17	OCT 19, 1984	0.10
JUN 21, 1983	+0.34	FEB 08, 1984	+0.03	DEC 10, 1984	+0.05
JUL 15, 1983	0.02	APR 09, 1984	+0.20		
AUG 10, 1983	0.54	MAY 31, 1984	+0.04		

LOCAL NUMBER: 44S 1 SITE IDENTIFICATION NUMBER: 383704078203901
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3300
LATITUDE: 383704 LONGITUDE: 0782039 WELL DEPTH, IN FEET: 145
DATE OF WELL COMPLETION: 10-28-1971 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 28, 1971	19.	JUL 13, 1983	26.56	JUN 01, 1984	25.76
JAN 26, 1983	24.31	AUG 10, 1983	28.85	JUL 26, 1984	30.40
FEB 24, 1983	23.30	OCT 04, 1983	35.08	SEP 05, 1984	32.64
APR 13, 1983	18.07	NOV 14, 1983	24.10	OCT 18, 1984	34.75
MAY 17, 1983	24.56	FEB 08, 1984	26.35		
JUN 13, 1983	25.18	APR 10, 1984	16.32		

LOCAL NUMBER: 44S 4 SITE IDENTIFICATION NUMBER: 383443078221801
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 3160
LATITUDE: 383443 LONGITUDE: 0782218 WELL DEPTH, IN FEET: 250
DATE OF WELL COMPLETION: 08-21-1963 USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
AUG 21, 1963	10.	JUL 13, 1983	8.50	APR 09, 1984	5.36
SEP 29, 1982	9.35	AUG 10, 1983	9.57	MAY 31, 1984	8.21
JAN 26, 1983	7.90	SEP 09, 1983	10.66	JUL 26, 1984	9.42
APR 14, 1983	5.93	OCT 04, 1983	9.79	SEP 04, 1984	9.28
MAY 17, 1983	6.74	NOV 14, 1983	6.56	OCT 19, 1984	9.90
JUN 13, 1983	8.35	FEB 08, 1984	8.35		

LOCAL NUMBER: 44T 1 SITE IDENTIFICATION NUMBER: 384417078182001
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2570
LATITUDE: 384417 LONGITUDE: 0781820 WELL DEPTH, IN FEET: 363
DATE OF WELL COMPLETION: 07-21-1966 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUL 21, 1966	44.	AUG 11, 1983	53.25	JUN 01, 1984	23.11
JAN 27, 1983	17.95	SEP 09, 1983	45.42	JUL 26, 1984	39.18
APR 14, 1983	10.85	OCT 05, 1983	47.05	SEP 04, 1984	41.40
MAY 18, 1983	9.26	NOV 21, 1983	18.46	OCT 18, 1984	56.29
JUN 13, 1983	20.54	FEB 09, 1984	21.46		
JUL 13, 1983	22.82	APR 10, 1984	13.14		

LOCAL NUMBER: 44T 2 SITE IDENTIFICATION NUMBER: 384008078221401
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 1135
LATITUDE: 384008 LONGITUDE: 0782214 WELL DEPTH, IN FEET: 280
DATE OF WELL COMPLETION: 06-05-1963 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 05, 1963	59.	SEP 09, 1983	45.44	JUL 26, 1984	42.96
JAN 27, 1983	43.50	OCT 05, 1983	45.04	SEP 04, 1984	46.50
APR 14, 1983	35.70	NOV 14, 1983	41.50	OCT 18, 1984	45.18
MAY 18, 1983	37.16	FEB 09, 1984	39.38	DEC 10, 1984	41.67
JUN 13, 1983	39.58	APR 10, 1984	34.73		
JUL 13, 1983	41.80	JUN 01, 1984	38.86		

LOCAL NUMBER: 44T 3 SITE IDENTIFICATION NUMBER: 384005078220901
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 1120
LATITUDE: 384005 LONGITUDE: 0782209 WELL DEPTH, IN FEET: 220
DATE OF WELL COMPLETION: 06-14-1963 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 14, 1963	39.90	SEP 09, 1983	24.31	JUL 26, 1984	22.72
JAN 27, 1983	23.21	OCT 05, 1983	24.23	SEP 05, 1984	25.42
APR 14, 1983	16.05	NOV 14, 1983	21.14	OCT 18, 1984	24.65
MAY 18, 1983	21.26	FEB 09, 1984	19.57	DEC 10, 1984	22.02
JUN 13, 1983	19.63	APR 10, 1984	15.27		
JUL 13, 1983	21.45	JUN 01, 1984	19.48		

LOCAL NUMBER: 44T 4 SITE IDENTIFICATION NUMBER: 383930078193701
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2050
LATITUDE: 383930 LONGITUDE: 0781937 WELL DEPTH, IN FEET: 333
DATE OF WELL COMPLETION: 02-11-1964 USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
FEB 11, 1964	19.7	AUG 11, 1983	19.12	JUN 01, 1984	17.00
JAN 26, 1983	17.90	SEP 09, 1983	21.01	JUL 26, 1984	18.53
APR 14, 1983	12.64	OCT 05, 1983	20.00	SEP 05, 1984	18.24
MAY 17, 1983	13.19	NOV 14, 1983	14.75	OCT 19, 1984	18.52
JUN 13, 1983	18.09	FEB 09, 1984	17.25		
JUL 13, 1983	18.50	APR 10, 1984	11.96		

Appendix 3.--Water levels at selected wells in Shenandoah National Park--Continued

LOCAL NUMBER: 44U 1   SITE IDENTIFICATION NUMBER: 384540078175701
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2730
LATITUDE: 384540   LONGITUDE: 0781757   WELL DEPTH, IN FEET: 200
DATE OF WELL COMPLETION: 06-17-1963   USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 17, 1963	15.	AUG 11, 1983	14.23	JUN 01, 1984	12.70
JAN 27, 1983	12.89	SEP 09, 1983	15.48	JUL 26, 1984	14.87
APR 14, 1983	7.58	OCT 05, 1983	15.93	SEP 05, 1984	14.52
MAY 18, 1983	6.82	NOV 21, 1983	10.00	OCT 18, 1984	14.54
JUN 13, 1983	12.29	FEB 09, 1984	12.18		
JUL 13, 1983	12.85	APR 10, 1984	5.55		

LOCAL NUMBER: 44U 2   SITE IDENTIFICATION NUMBER: 384532078180201
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 2590
LATITUDE: 384532   LONGITUDE: 0781802   WELL DEPTH, IN FEET: 200
DATE OF WELL COMPLETION: 06-10-1963   USE OF SITE: BACK-UP SUPPLY

WATER LEVELS IN FEET BELOW LAND SURFACE

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUN 10, 1963	1.5	JUL 13, 1983	3.64	FEB 09, 1984	3.18
JAN 27, 1983	3.72	AUG 11, 1983	5.47	APR 10, 1984	0.30
APR 14, 1983	0.83	SEP 09, 1983	9.76	JUN 01, 1984	3.20
MAY 18, 1983	0.44	OCT 04, 1983	7.09	JUL 26, 1984	12.08
JUN 13, 1983	3.28	NOV 21, 1983	1.16	OCT 18, 1984	5.86

LOCAL NUMBER: 45V 1   SITE IDENTIFICATION NUMBER: 385241078121701
LAND SURFACE ELEVATION, IN FEET ABOVE SEA LEVEL: 1730
LATITUDE: 385241   LONGITUDE: 0781217   WELL DEPTH, IN FEET: 200
DATE OF WELL COMPLETION: 07-16-1964   USE OF SITE: UNUSED

WATER LEVELS IN FEET BELOW LAND SURFACE ("+" INDICATES ABOVE LAND SURFACE)

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
JUL 16, 1964	1.5	JUN 13, 1983	1.65	APR 10, 1984	+1.70
SEP 29, 1982	2.5	JUL 13, 1983	2.10	JUN 01, 1984	2.18
NOV 24, 1982	2.0	AUG 11, 1983	2.34	JUL 16, 1984	2.57
JAN 27, 1983	1.72	SEP 09, 1983	2.62	SEP 04, 1984	2.73
MAR 08, 1983	0.35	OCT 04, 1983	2.73	OCT 18, 1984	2.86
APR 14, 1983	+0.04	NOV 21, 1983	2.20		
MAY 18, 1983	0.45	FEB 09, 1984	2.10		

49
51
Table 16
54 Words on depletion of Ground water levels
56 Water Budget
65 & Words Local Groundwater insufficient
86
74 ~~Fig~~ Cone of Depression
79 Conclusion & Cone of Depression
62 Note Balance of Water Supply